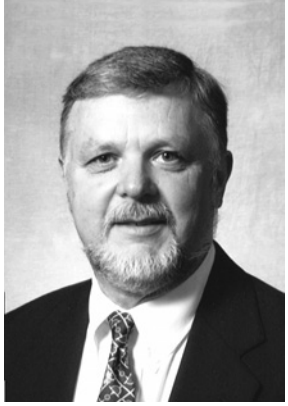

Progress in Essential Oils

by Brian M. Lawrence, R.J. Reynolds Tobacco Company

Geranium Oil

In 1996, Zang et al. analyzed geranium oil of Chinese origin. Although they found that some of the major constituents were citronellol (24.73%), geraniol (8.79%) and linalool (4.16%), the authors misidentified many of the other constituents; however, it is included in this review for completeness.

Möllenbeck et al. (1997) analyzed a sample of geranium oil produced in Madagascar. The oil composition was found to be as follows:

α-pinene (0.7%)
β-pinene (t)
cis-rose oxide (0.7%)
trans-rose oxide (0.2%)
cis-linalool oxide† (0.3%)
menthone (3.4%)
isomenthone (6.6%)
linalool (10.9%)
terpinen-4-ol (6.0%)
citronellyl formate (8.6%)
neral (t)
geranyl formate (6.4%)
geranial (1.4%)
citronellol (22.5%)
nerol (1.2%)
geraniol (18.2%)
geranyl tiglate (1.0%)
geranic acid (t)

† furanoid form
t = trace (<0.1%)

In addition, the authors examined the oil using chiral GC of some of the major constituents of the oil. They found the following enantiomeric distribution:

(3R)-(-)-linalool (51%) : (3S)-(+)-linalool (49%)
(4R)-(-)-terpinen-4-ol (67%) : (4S)-(+)-terpinen-4-ol (33%)
(3R)-(+)-citronellol (26%) : (3S)-(-)-citronellol (74%)

Also in 1997, Rao et al. studied the effect of plant growth regulators on oil yield and composition of geranium grown in southern India. Although they found that the use of plant growth regulators significantly increased plant growth (both height and number of branches per plant) biomass production and oil yield, the oil composition was not found to be that different to the oil of a control sample. The major constituents of the control geranium oil were as follows:

isomenthone (3.4%)
geraniol (22.7%)
linalool (4.2%)
citronellol (24.9%)
citronellyl formate (6.8%)
geranyl formate (4.9%)

Similarly, the amounts of the same constituents of the oils of geranium plants treated with different growth regulators only ranged as follows:

isomenthone (3.7-5.0%)
linalool (4.9-6.3%)
citronellol (25.3-26.4%)
geraniol (23.8-25.0%)
citronellyl formate (4.3-5.1%)
geranyl formate (3.1-3.6%)

The following year, Kaul et al. (1998) compared the major component composition of the oil of rose-scented geranium as the plant matured. From a field planting of geranium in India, the authors harvested entire plants monthly (in triplicate) over a 12-month period. They found that for the plants harvested 9-10 months after the rooted cuttings were planted, the oil yield reached a maximum of 1.15-1.16%. The oil composition (major components) ranged as can be seen in T-1. The composition of oil produced from plants harvested 10 months after planting did not differ from oil produced from plants harvested after 12 months; however, at 12 months the oil yield had dropped to 0.77%.

The Bourbon cultivar of geranium grown in southern India was harvested during the hot, dry summer on four separate occasions and the oils produced were compared with each other and a representative oil produced from plants harvested during the rainy autumn, winter and spring seasons. Kaul et al. analyzed these oils (1998) and their variation in major component compositions can be seen in T-2. It would appear from these results that the ideal time for harvesting geranium in India is during the cooler rainy season and not during the hot summer.

Major components of geranium oil produced from plants of differing ages **T-1**

Compound	Oil produced from plants harvested after 2 months	4 months	6 months	10 months	12 months
linalool	6.5	4.4	4.3	11.8	11.3
cis-and *trans*-rose oxide	0.8	1.1	1.0	0.4	0.6
menthone	0.3	0.9	1.4	0.5	0.3
isomenthone	6.4	11.9	13.0	7.7	7.7
citronellol	28.3	34.5	36.0	22.2	23.0
geraniol	26.2	10.5	7.9	24.9	24.2
citronellyl formate	4.7	5.7	5.5	4.7	3.0
geranyl formate	2.8	1.4	1.4	3.9	4.2
10-epi-γ-eudesmol	7.7	4.5	2.0	5.5	4.0

Percentage composition of major constituents of the Bourbon cultivar harvested at different times **T-2**

Compound	1	2	3	4	5
linalool	0.97	0.77	1.60	2.80	9.49
menthone	38.63	47.16	0.30	0.70	0.32
isomenthone	2.07	0.52	0.70	12.00	7.19
citronellol	16.02	8.02	13.50	36.30	25.38
geraniol	18.56	20.92	10.20	7.90	23.53
citronellyl formate	1.84	0.67	5.20	8.00	6.90
geranyl formate	0.42	0.19	1.00	1.50	5.78
10-epi-γ-eudesmol	1.69	1.42	22.00	7.10	5.38

Samples 1-4 were all harvested during the summer heat (42∞C night); sample 5 was harvested during the rainy season

Also in 1998, Kulkarni et al. compared the composition of the oil of the Bourbon cultivar of geranium with oils of two variants (clones 53 and 79) obtained from leaf cuttings of the parent cultivar. The results of this comparative study can be seen in T-3. The composition of geranium oil was found by Kaul and Rajeswara Rao (1999) to differ if it was produced from mature expanded leaves versus young expanding leaves. The authors compared this phenomenon between three Indian cultivars, and the results of this study can be seen in T-4.

Also in 1999, Rao et al. examined the effect of raw material comminution on oil yield and composition of shoots and leaves of rose-scented geranium grown in India. The results of this study can be seen in T-5. In addition to the fact that the oil obtained from un-chopped plants was richer in the oxygenated constituents, the authors found that the oil yield of chopped plants was 0.24% as against 0.15% for un-chopped plants. The same authors (Rao et al., 1999), compared the composition of oils produced from healthy and diseased geranium plants infected with wilt disease of two cultivars grown in India. The results are shown in T-6.

Doimo et al. (1999) obtained numerous samples of commercially available geranium oils of different geographic origins and subjected them to chiral GC analysis. The results of this study can be seen in T-7. In addition, the authors also determined the amounts of the same chiral constituents in geranium hybrid oils produced in Australia over a number of seasons. The chiral components characterized were as follows:

(+)-*cis*-rose oxide (0.3-2.3%)
(-)-*cis*-rose oxide (0-0.2%)
(-)-*trans*-rose oxide (0.1-0.6%)
(+)-*trans*-rose oxide (0.1-0.9%)
(-)-linalool (0.9-6.69%)
(+)-linalool (0%)
(-)-menthone (0%)
(+)-menthone (0.1-0.3%)
(+)-isomenthone (0%)
(-)-isomenthone (3.3-8.4%)
(-)-citronellol (1.0-11.6%)
(+)-citronellol (19.7-36.2%)
(+)-β-caryophyllene (0.2-0.5%)
(-)-β-caryophyllene (0.6-1.6%)

The same authors (Doimo et al., 1999) examined the ester composition of 41 oil samples of Australian grown rose-scented geranium. They found that these oils contained the following esters:

2-phenethyl formate (t)
citronellyl formate (13.9%)
neryl formate (0.1%)
geranyl formate (5.7%)
2-phenethyl acetate (t)
citronellyl acetate (0.3%)
geranyl propionate (1.2%)
citronellyl butyrate (0.7%)
neryl butyrate (0.1%)
geranyl butyrate (0.8%)
citronellyl valerate (0.1%)
geranyl valerate (0.1%)

Comparative percentage composition of the oils of the Bourbon cultivar and two isomenthone-rich variants (clone 53 and 79) T-3

Compound	Bourbon Oil	Clone 53 Oil	Clone 79 Oil	Compound	Bourbon Oil	Clone 53 Oil	Clone 79 Oil
(Z)-3-hexenol	0.1	t	0.1	geranial	0.5	0.2	-
α-pinene	0.3	1.1	8.5	citronellyl formate	8.2	0.3	0.2
camphene	t	t	0.1	neryl formate	0.1	0.3	0.1
sabinene	0.1	t	0.1	geranyl formate	3.1	-	t
β-pinene	-	t	0.1	citronellyl acetate	0.2	t	-
myrcene	0.7	0.4	0.7	α-cubebene	t	0.1	0.1
α-phellandrene	0.1	0.3	0.6	geranyl acetate	0.3	0.1	-
p-cymene	0.1	0.3	0.6	α-copaene	0.1	0.2	0.2
limonene	0.3	1.0	1.9	β-bourbonene	0.5	0.8	0.6
(Z)-β-ocimene	0.2	0.3	0.5	β-caryophyllene	0.5	1.2	1.0
(E)-β-ocimene	0.3	0.1	0.1	guaia-6,9-diene	0.1	t	0.1
cis-linalool oxide†	0.1	0.1	0.1	geranyl propionate	0.5	0.2	0.1
trans-linalool oxide †	t	0.1	0.1	α-humulene	0.1	0.4	0.3
terpinolene	t	0.1	0.1	germacrene D	0.9	2.0	1.4
linalool	6.7	0.3	0.2	calamenene*	0.2	0.1	0.3
cis-rose oxide	0.4	-	-	geranyl butyrate	0.2	-	0.1
trans-rose oxide	0.2	-	-	2-phenethyl tiglate	0.9	2.0	1.4
menthone	0.1	1.7	1.2	furopelargone B	0.1	0.1	0.1
isomenthone	7.9	67.6	64.4	geranyl isovalerate	0.3	0.8	0.5
terpinen-4-ol	-	0.1	0.1	10-epi-γ-eudesmol	7.6	8.4	6.8
α-terpineol	0.3	0.3	0.2	geranyl valerate	0.1	0.2	0.2
citronellol + nerol	26.7	0.5	0.3	citronellyl tiglate	1.5	1.7	1.4
piperitone	-	0.2	0.2	geranyl tiglate	1.6	-	-
geraniol	24.1	0.2	0.1				

* correct isomer not identified
† furanoid form
t=trace (<0.1%)

Comparative percentage composition of oils produced from mature and young leaves of three geranium cultivars T-4

Compound	"Algerian" M	"Algerian" Y	"Bourbon" M	"Bourbon" Y	"Kelkar" M	"Kelkar" Y
linalool	0.1	0.2	0.2	0.7	0.3	0.8
cis-rose oxide	2.9	0.8	8.6	6.0	13.2	2.7
trans-rose oxide	1.0	0.1	0.9	0.1	0.2	0.1
menthone	0.4	0.1	0.3	0.1	0.1	0.1
isomenthone	8.0	4.0	7.8	6.5	8.9	2.9
citronellol	45.0	58.2	25.0	26.3	5.4	19.4
geraniol	13.2	6.7	22.8	33.2	42.1	42.0
citronellyl formate	7.9	8.8	4.2	4.8	0.1	0.9
geranyl formate	1.5	0.6	3.3	2.8	0.3	1.3
10-epi-γ-eudesmol	4.9	4.8	7.4	7.9	5.4	8.7
oil yield (%)	0.08	0.21	0.15	0.66	0.26	0.83

M = oil produced from mature leaves; Y = oil produced from young leaves

Comparative percentage composition of leaf and shoot oils of geranium produced from whole and chopped plant material **T-5**

Compound	Whole Shoot Oil	Chopped Shoot Oil	Whole Leaf Oil	Chopped Leaf Oil	Compound	Whole Shoot Oil	Chopped Shoot Oil	Whole Leaf Oil	Chopped Leaf Oil
(E)-2-hexenal	0.2	-	t	0.1	citronellyl acetate	0.4	2.4	0.4	0.4
(Z)-3-hexenol	1.6	0.4	0.5	1.0	neryl acetate	-	0.1	0.1	t
α-pinene	0.5	-	0.2	0.3	α-cubebene	-	0.3	-	-
camphene	-	-	t	-	geranyl acetate	0.4	0.3	0.3	0.3
β-pinene	0.2	0.1	0.2	0.3	α-ylangene	-	0.1	t	t
myrcene	0.3	0.1	0.1	0.2	α-copaene	0.3	0.1	0.2	0.2
α-phellandrene	-	-	t	0.1	β-bourbonene	0.9	0.6	0.6	0.4
p-cymene	0.2	0.1	0.1	0.1	2-phenethyl butyrate	-	-	0.1	0.1
limonene	0.5	0.3	0.5	0.6	β-caryophyllene	0.7	0.1	0.4	0.4
(Z)-β-ocimene	-	-	0.1	0.1	citronellyl propionate	-	0.1	0.1	t
(E)-β-ocimene	0.1	-	0.1	0.2	guaia-6,9-diene	0.1	-	0.1	0.1
cis-linalool oxide†	0.5	0.6	0.4	0.5	α-humulene	-	-	0.1	0.1
trans-linalool oxide†	0.3	0.4	0.2	0.3	germacrene D	0.3	0.2	0.2	0.2
terpinolene	-	-	0.1	0.1	α-selinene	-	0.1	0.2	0.2
linalool	9.5	7.5	9.3	12.2	geranyl isobutyrate	0.5	-	0.6	0.5
cis-rose oxide	1.0	0.4	0.5	0.6	α-muurolene	0.8	0.1	0.8	0.6
trans-rose oxide	0.5	0.2	0.3	0.3	citronellyl butyrate	-	-	0.1	0.1
2-phenethyl alcohol	-	-	t	t	γ-cadinene	-	-	0.1	0.1
menthone	0.9	0.8	0.9	0.8	calamenene*	0.8	-	0.4	0.4
isomenthone	8.6	6.2	6.4	6.2	geranyl butyrate	0.4	0.8	0.4	0.4
terpinen-4-ol	-	0.1	0.2	0.2	2-phenethyl tiglate	0.5	1.1	0.7	0.8
α-terpineol	0.6	0.5	0.8	1.2	furopelargone B	-	0.4	0.1	0.1
citronellol	29.3	26.0	25.9	25.5	geranyl isovalerate	-	0.4	0.2	0.2
neral	-	0.1	-	t	10-epi-γ-eudesmol	3.4	4.2	5.2	4.8
geraniol	21.8	18.5	26.9	25.3	geranyl valerate	-	0.2	0.1	0.1
geranial	0.3	4.3	0.7	0.6	β-eudesmol	-	0.1	0.1	0.1
citronellyl formate	5.4	4.5	4.2	3.8	citronellyl tiglate	0.6	2.4	1.4	1.3
neryl formate	-	0.1	t	t	geranyl tiglate	1.2	2.2	1.5	1.4
geranyl formate	4.1	3.8	3.5	3.0					

t = trace (<0.1%)
† - furanoid form
correct isomer not identified

neryl acetate (0.1%) 2-phenethyl tiglate (0.9%)
geranyl acetate (0.4%) citronellyl tiglate (0.8%)
2-phenethyl propionate (t) geranyl tiglate (2.3%)
citronellyl propionate (0.7%) neryl propionate (0.6%)

t = trace (<0.1%)

In addition, the authors also identified 2-phenethyl iso-esters (0.1%), citronellyl iso-esters (0.4%), neryl iso-esters (0.1%), geranyl iso-esters (0.7%) and one other equally less defined normal ester such as a citronellyl ester (0.1%).

Chisowa et al. (1999) compared the composition of geranium oil produced from plants propagated by tissue culture and those raised from cuttings in Zambia. T-8 shows the results of this study.

Wüst et al. (1999) examined the enantiomeric distribution of nerol oxide and found that it was as follows:

(R)-(+)-nerol oxide (48.5-50.6%) : (S)-(-)-nerol oxide (49.4-51.5%)

This shows that nerol oxide occurs in geranium oil as a racemate.

A commercial sample of geranium oil of unknown geographic origin was analyzed by Reichling et al. (1999). The components that were characterized in the oil were as follows:

α-pinene (0.39%) citronellol (15.13%)
2-phenethyl alcohol (15.26%) neryl acetate (4.00%)
linalool (3.23%) geranyl acetate (9.11%)
menthol (2.23%) geranyl acetate (9.11%)
geranial (0.23%) β-caryophyllene (0.48%)

This oil bears little resemblance to a true oil of

Influence of wilt disease on the composition of the oils produced from two geranium cultivars

T-6

Compound	Cultivar 1 Healthy Plant Oil	Cultivar 1 Diseased Plant Oil	Cultivar 2 Healthy Plant Oil	Cultivar 2 Diseased Plant Oil	Compound	Cultivar 1 Healthy Plant Oil	Cultivar 1 Diseased Plant Oil	Cultivar 2 Healthy Plant Oil	Cultivar 2 Diseased Plant Oil
sabinene	-	-	0.2	-	geranyl acetate	1.2	0.7	0.5	1.4
myrcene	0.5	0.4	0.4	-	α-ylangene	-	-	0.1	-
p-cymene	0.2	-	0.3	-	α-copaene	0.2	0.2	0.3	-
limonene	0.1	0.3	0.1	-	β-bourbonene	0.6	0.9	1.1	1.1
(Z)-β-ocimene	0.1	0.2	0.1	-	β-caryophyllene	0.3	0.5	0.6	2.3
(E)-β-ocimene	0.4	0.1	0.2	-	citronellyl propionate	-	-	0.1	-
terpinolene	0.3	0.1	0.2	-	guaia-6,9-diene	-	-	0.1	0.1
linalool	9.3	1.8	3.2	0.3	α-humulene	-	-	0.2	-
cis-rose oxide	0.4	0.6	0.8	1.9	germacrene D	0.2	0.3	0.3	0.3
trans-rose oxide	0.2	0.4	0.3	1.0	geranyl isobutyrate	0.3	0.8	0.7	0.3
menthone	0.7	0.3	0.8	0.8	citronellyl butyrate	-	t	0.2	-
isomenthone	6.4	6.7	9.4	11.3	geranyl butyrate	0.1	-	0.2	0.3
terpinen-4-ol	0.2	0.2	0.3	0.5	2-phenethyl tiglate	0.9	1.2	0.7	0.7
α-terpineol	0.7	0.2	0.6	0.3	furopelargone B	-	0.1	0.1	-
citronellol	28.7	32.0	39.7	43.5	geranyl isovalerate	0.6	0.8	0.5	0.3
piperitone	0.3	0.2	0.1	-	10-epi-γ-eudesmol	5.6	7.3	4.6	2.1
geraniol	21.5	19.2	14.9	0.5	geranyl valerate	0.2	0.3	0.2	0.2
geranial	0.8	0.7	0.5	-	β-eudesmol	0.3	0.5	0.2	0.2
citronellyl formate	4.8	6.7	6.7	14.5	citronellyl tiglate	2.1	3.3	1.1	-
neryl formate	-	0.1	0.1	-	geranyl tiglate	1.4	2.0	1.2	0.3
geranyl formate	3.8	4.2	3.4	-	geranyl hexanoate	0.2	0.3	-	0.3
citronellyl acetate	0.4	0.2	0.1	1.4	geranyl heptanoate	0.4	0.2	0.1	0.3
neryl acetate	0.2	0.4	0.2	0.4	geranyl octanoate	-	0.1	0.1	0.4
α-cubebene	-	0.1	-	-					

t = trace (<0.1%)

Percentage composition of chiral constituents of geranium oils of different origin

T-7

Chiral Compound	Chinese	Reunion	Moroccan	Egyptian	Australian
(+)-*cis*-rose oxide	1.2	0.6-1.3	0.4-1.4	0.7-1.4	0.6-1.2
(-)-*cis*-rose oxide	0	0-0.2	0-0.1	0-0.1	0
(-)-*trans*-rose oxide	0.1	0-0.2	0-0.1	0-0.2	0
(+)-*trans*-rose oxide	0.5	0.2-0.5	0.1-0.5	0.3-0.5	0.2-0.5
(-)-linalool	3.8	7.2-9.7	5.3-11.3	3.5-9.2	2.6-4.6
(+)-linalool	0	0	0	0	0
(-)-menthone	0	0	0	0	0
(+)-menthone	2.1	0.8-2.9	1.7-1.9	0.5-2.4	0.1-0.4
(+)-isomenthone	0	0-0.1	0-0.2	0-2.8	0-0.2
(-)-isomenthone	5.0	2.0-6.7	1.6-4.4	1.0-5.2	6.0-8.1
(-)-citronellol	1.5	1.3-5.3	3.6-4.0	0.6-4.4	0-1.8
(+)-citronellol	36.9	17.0-34.7	24.6-25.7	24.4-40.3	33.7-38.1
(+)-β-caryophyllene	0.3	0.1-0.4	0.1-0.2	0-0.2	0.2-0.3
(-)-β-caryophyllene	1.2	0.4-1.2	0.3-1.0	0.7-1.2	0.2-1.8

geranium. As a result, the analysis is only included for completeness of the review. Rao et al. (2000) examined the effect of little leaf disease on the oil composition of geranium grown in India. The results of the comparison in oil composition produced from healthy and diseased plants are presented in T-9. These same authors (Rao et al., 2000) compared the composition of the flower oils produced from "Algerian", "Bourbon" and "Kelkar" cultivars of geranium grown in the Bangalore region of India. The comparative compositional data obtained from the analysis can be found in T-10.

As part of a screening study for the antioxidant activity of essential oils and certain oil constituents, Dorman et al. (2000) analyzed a sample of geranium oil produced from dried geranium leaves and found that it contained:

α-pinene (0.54%)
myrcene (0.17%)
p-cymene (0.15%)
limonene (0.21%)
β-ocimene* (0.13%)
linalool oxide* (0.45%)
linalool (6.62%)
menthone (1.75%)
isomenthone (5.83%)
α-terpineol (0.57%)
citronellal (32.90%)
geraniol (12.60%)
citronellyl formate (7.55%)
citronellyl acetate (0.33%)
α-cubebene (0.20%)
geranyl acetate (0.44%)
α-copaene (0.51%)
aromadendrene (0.41%)
α-humulene (0.25%)
allo-aromadendrene (0.16%)
β-selinene (0.12%)
bicyclogermacrene (0.65%)
α-muurolene (0.21%)
calamenene* (0.34%)
δ-cadinene (0.20%)
geranyl tiglate (1.12%)

*correct isomer not identified

It should be noted that this oil is not very similar to the normally encountered geranium oil of commerce particularly as it was found to be rich in citronellal not citronellol.

Aggarwal et al. (2000) studied the antimicrobial activity of geranium oil. The oil they examined possessed the following major constituents:

α-pinene (0.56%)
menthone (3.85%)
isomenthone (6.92%)
linalool (8.38%)
citronellyl formate (6.12%)
geranyl formate (1.22%)
(-)-citronellol (35.21%)
geraniol (24.88%)

Over the past decade (the 1990s), the quantity of geranium oil imported into India has grown to in excess of 90 tonnes. As a result, there has been an increased interest in producing a commercial quality of oil in India for domestic consumption. Singh et al. (2000) reported an evaluation of commercial production of geranium oil in the Kannauj region of Uttar Pradesh (India). The oil produced in Kannauj was found to have the following composition:

cis-rose oxide (0.72%)
trans-rose oxide (0.28%)
isomenthone (7.69%)
linalool (4.49%)
β-caryophyllene (0.70%)
citronellyl formate (6.90%)
geranyl formate (1.58%)
citronellol (34.36%)
nerol (0.71%)
geraniol (23.45%)
10-epi-γ-eudesmol (6.22%)
geranyl tiglate (1.62%)

Jain et al. (2001) compared the composition of the oils obtained from the Bourbon cultivar of geranium grown in Kodiakanal (southern India) and Lucknow (northern India). A summary of the comparative oil compositions can be seen in T-11.

Percentage composition of geranium oil produced from plants propagated both by tissue culture and cuttings **T-8**

Compound	1	2
α-pinene	0.4	0.4
sabinene	0.1	0.2
limonene	0.3	0.2
β-phellandrene	0.1	-
1-octene	0.4	0.1
cis-rose oxide	4.6	1.9
trans-rose oxide	1.7	0.8
(Z)-3-hexenol	0.8	-
cis-linalool oxide†	0.6	0.3
menthone	0.5	0.3
trans-linalool oxide†	0.4	0.3
citronellal	-	0.1
isomenthone	9.9	7.1
α-copaene	0.5	0.3
β-bourbonene	0.9	0.9
linalool	3.7	2.6
β-caryophyllene	1.1	0.8
α-gurjunene	3.9	5.0
citronellyl formate	8.3	11.5
β-cadinene	0.5	-
longifolene	0.6	-
viridiflorene	1.1	1.1
β-cedrene	2.9	3.5
citronellyl isobutyrate	0.6	0.7
citronellyl propionate	1.0	0.9
δ-cadinene	1.2	1.0
citronellol	36.1	42.8
citronellyl butyrate	1.1	1.1
geranyl isobutyrate	0.2	0.2
geranyl propionate	0.6	0.6
geraniol	9.2	9.1
geranyl butyrate	1.0	0.9
citronellyl tiglate	0.6	0.6
cubenol	0.3	0.3
geranyl tiglate	1.6	1.6
2-phenethyl tiglate	1.0	0.9

† furanoid form
1.oil produced from plants propagated from tissue culture
2.oil produced from plants propagated from cuttings

Influence of little leaf disease on the oil composition of rose-scented geranium grown in India

T-9

Compound	Oil from Healthy Plants	Oil from Diseased Plants	Compound	Oil from Healthy Plants	Oil from Diseased Plants
α-pinene	0.2	0.3	citronellyl formate	5.0	6.2
β-pinene	0.2	0.4	geranyl formate	2.1	1.9
limonene	0.5	0.6	citronellyl acetate	0.1	0.2
(Z)-β-ocimene	0.1	0.1	geranyl acetate	0.3	0.3
(E)-β-ocimene	0.2	0.2	β-bourbonene	0.5	0.8
cis-linalool oxide†	0.5	0.5	β-caryophyllene	0.4	0.5
trans-linalool oxide†	0.2	0.3	guaia-6,9-diene	0.1	0.1
linalool	10.5	9.5	germacrene D	0.2	0.2
cis-rose oxide	0.5	0.8	citronellyl butyrate	0.1	0.4
2-phenethyl alcohol	t	t	geranyl butyrate	0.4	0.6
trans-rose oxide	0.4	0.5	2-phenethyl tiglate	0.9	1.4
menthone	0.8	0.9	10-epi-γ-eudesmol	5.7	8.2
isomenthone	7.7	8.9	citronellyl tiglate	1.3	3.9
citronellol	28.5	31.4	geranyl tiglate	1.2	3.0
geraniol	24.3	12.4			

t = trace (<0.1%)

Percentage composition of the flower oils of three cultivars of geranium

T-10

Compound	Algerian	Bourbon	Kelkar	Compound	Algerian	Bourbon	Kelkar
α-pinene	1.7	0.6	0.1	geranyl formate	0.3	3.6	0.4
sabinene	-	0.1	0.1	citronellyl acetate	1.0	0.2	-
myrcene	0.2	0.2	0.2	geranyl acetate + geranic acid	0.1	0.6	5.2
α-phellandrene	0.4	0.1	0.3	α-ylangene	-	0.1	0.2
p-cymene	0.2	0.1	0.1	α-copaene	0.1	0.3	0.2
limonene	0.3	0.2	0.2	β-bourbonene	0.4	1.2	0.3
(Z)-β-ocimene	0.2	0.1	0.1	2-phenethyl butyrate	-	-	4.6
(E)-β-ocimene	0.1	0.1	0.1	β-caryophyllene	2.6	0.9	0.7
cis-linalool oxide†	-	0.3	0.1	guaia-6,9-diene	1.5	0.1	2.3
trans-linalool oxide†	-	0.1	0.1	α-humulene	0.4	0.6	1.5
linalool	1.1	5.5	7.6	germacrene D	0.2	0.3	0.1
cis-rose oxide	1.3	0.6	0.2	α-selinene	0.1	0.2	-
trans-rose oxide	0.6	0.3	0.1	α-muurolene	0.4	1.3	0.6
menthone	0.1	0.1	0.2	citronellyl butyrate	2.1	0.4	0.2
isomenthone	6.8	4.6	5.3	geranyl butyrate	0.2	0.2	0.5
terpinen-4-ol	-	1.3	-	2-phenethyl tiglate	0.7	0.7	0.5
α-terpineol	0.3	0.3	0.3	geranyl isovalerate	0.1	0.9	0.3
citronellol	43.8	27.5	15.2	10-epi-γ-eudesmol	2.0	4.6	2.5
geraniol	1.7	22.7	38.6	geranyl valerate	0.2	0.2	0.6
geranial	0.7	0.8	0.4	citronellyl tiglate	1.9	0.2	1.1
citronellyl formate	20.4	9.9	0.6	geranyl tiglate	0.2	2.9	2.6

† furanoid form

Rao et al. (2001) examined the effect of time of harvest on oil yield and composition of Bourbon cultivar of rose-scented geranium. They found that the oil yield varied from 0.18% (midnight) to 0.27% (noon); however, the major constituents of the oil only varied as follows:

linalool (7.1-8.4%)
isomenthone (7.0-8.1%)
geraniol (20.6-25.2%)
citronellyl formate (4.9-5.5%)
geranyl formate (3.8-4.7%)
citronellol (22.2-23.3%)
10-epi-γ-eudesmol (5.0-7.4%)

According to Gupta et al. (2001), there are three cultivars of geranium that are available for cultivation for oil production in India. They are "Bipuli" (an intermedi-

ate between the Bourbon and the Egyptian types), "Hemanti" (similar to the Chinese type) and "Kunti" (whose oil is rich in geraniol and poor in citronellol). The authors also reported that a somoclonal mutant (IRPG) obtained from a regenerant induced in a callus culture, which was initiated with a leaf explant of "Kunti", was found to produce an oil which was rich in isomenthone. A comparison between this oil and that if its parent "Kunti" can be seen in T-12.

Pino et al. (2002) analyzed an oil of geranium produced in Cuba. The composition of this oil was found to be as follows:

linalool (0.1%)	cubebol (0.6%)
cis-rose oxide (5.5%)	*cis*-calamenene (0.2%)
trans-rose oxide (4.5%)	δ-cadinene (2.6%)
isomenthone (0.3%)	α-calacorene (0.3%)
borneol (0.1%)	β-calacorene (0.1%)
terpinen-4-ol (0.4%)	geranyl butyrate (0.1%)
α-terpineol (0.2%)	spathulenol (2.0%)
citronellol (25.6%)	caryophyllene oxide (14.7%)
geraniol (1.9%)	gleenol (0.1%)
citronellyl formate (2.5%)	humulene epoxide II (1.8%)
thymol (0.1%)	
citronellyl acetate (0.1%)	*trans*-sesquilavandulol (0.4%)
α-cubebene (0.1%)	
α-copaene (0.2%)	T-muurolol (0.4%)
β-bourbonene (0.8%)	cubenol (0.6%)
β-elemene (0.7%)	xselin-11-en-4α-ol (0.4%)
longifolene (0.1%)	α-cadinol (0.2%)
β-caryophyllene (3.2%)	14-hydroxy-9-epi-β-caryophyllene (0.5%)
α-guaiene (7.2%)	
(Z)-β-farnesene (3.0%)	cadalene (1.0%)
α-humulene (0.7%)	(Z)-nerolidyl acetate (0.9%)
α-patchoulene (0.6%)	(Z,E)-farnesol (0.4%)
geranyl propionate (0.3%)	(E)-nerolidyl acetate (0.4%)
γ-muurolene (0.1%)	
germacrene D (1.8%)	(E,E)-farnesol (0.2%)
β-selinene (0.3%)	(Z,E)-farnesyl acetate (0.4%)
cis-β-guaiene (0.2%)	
α-bulnesene (2.4%)	ethyl hexadecanoate (0.8%)
γ-cadinene (0.1%)	

P. Zang, J. Qing and Q. Lu, *A study on the chemical constituents of geranium oil.* Guizhou Gongxueyuan Xuebo, *25(1)*, 82-85 (1996).

S. Möllenbeck, T. König, P. Schreier, W. Schwab, J. Rajaonarivony and L. Ranarivelo, *Chemical composition and analyses of enantiomers of essential oils from Madagascar.* Flav. Fragr. J., *12*, 63-69 (1997).

B. R. Rajeswara Rao, A. K. Bhattacharya, K. Singh, P. N. Kaul and C. P. Singh, *Growth, biomass production and essential oil profile of rose-scented geranium (Pelargonium sp.) as influenced by plant growth regulators.* PAFAI (Oct./Nov.), 11-15 (1997).

P. N. Kaul, B. R. Rajeswara Rao, A. K. Bhattacharya and K. Singh, *Relationship between crop age, essential oil concentration and its composition in rose-scented geranium (Pelargonium species).* J. Essent. Oil Bear. Plants, *1*, 88-92 (1998).

P. N. Kaul, B. R. Rajeswara Rao and G. R. Mallavarapu, *Aberrations in the composition of the herb oil of rose-scented geranium (Pelargonium species).* J. Essent. Oil Res., *10*, 439-441 (1998).

R. N. Kulkarni, G. R. Mallavarapu, K. Baskaran, S. Ramesh and S. Kumar, *Composition of the essential oils of two isomenthone-rich variants of geranium (Pelargonium sp.).* Flav. Fragr. J., *13*, 389-392 (1998).

P. N. Kaul and B. R. Rajeswara Rao, *Quality variations of the essential oils of young and old leaves of three varieties of rose-scented geranium (Pelargonium species).* PAFAI, *1(1)*, 35-37 (1999).

B. R. Rajeswara Rao, P. N. Kaul, G. R. Mallavarapu and S. Ramesh, *Combination of plant material and its effect on the quality of rose-scented geranium (Pelargonium species) oil.* J. Essent. Oil. Res., *11*, 589-592 (1999).

B. R. Rajeswara Rao, A. K. Bhattacharya, H. B. Singh and G. R. Mallavarapu, *The impact of wilt disease on oil yield and quality of two cultivars of rose-scented geranium (Pelargonium species).* J. Essent. Oil Res., *11*, 769-775 (1999).

L. Doimo, R. J. Fletcher and B. R. D'Arcy, *Chiral excess: measuring the chirality of geographically and seasonally different geranium oils.* J. Essent. Oil Res., *11*, 291-299 (1999).

L. Doimo, R. J. Fletcher and B. R. D'Arcy, *Esters in Australian geranium oil (Pelargonium hybrid).* J. Essent. Oil. Res., *11*, 611-614 (1999).

E. H. Chisowa, W. K. Chisimba, D. R. Hall and D. I. Farman, *A comparison of the oils of rose-scented geranium (Pelargonium sp.) propagated by tissue culture and cuttings.* J. Essent. Oil Res., *11*, 461-464 (1999).

M. Wüst, J. Reindl., S. Fuchs, T. Beck and A. Mosandl, *Structure elucidation enantioselective analysis and biogenesis of nerol oxide in Pelargonium species.* J. Agric. Food Chem., *47*, 3145-3150 (1999).

J. Reichling, M. Harkenthal and R. Saller, *Wirkung ausgewählter ätherischer Öle.* Erfahrungsheilkunde, *6*, 357-366 (1999).

B. R. Rajeswara Rao, P. N. Kaul, G. R. Mallavarapu and S. Ramesh, *First observation of little leaf disease and its impact on the yield and composition of the essential oil of rose-scented geranium (Pelargonium species).* Flav. Fragr, J., *15*, 137-140 (2000).

H. J. D. Dorman, P. Surai and S. G. Deans, *In vitro antioxidant activity of a number of plant essential oils and phytoconstituents.* J. Essent. Oil Res., *12*, 241-248 (2000).

B. R. Rajeswara Rao, K. P. Sastry, S. M. Saleem, E. V. S. Prakasa Rao and K. V. Syamasunder, *Volatile flower oils of three genotypes of rose-scented geranium (Pelargonium sp.).* Flav. Fragr. J., *15*, 105-107 (2000).

K. K. Aggarwal, A. Ahmad, T. R. S. Kumar, N. Jain, V. K. Gupta, S. Kumar and S. P. S. Khanuja, *Antimicrobial activity spectra of Pelargonium gravolens L. and Cymbopogon winterianus Jowitt. oil constituents and acyl derivatives.* J. Med. Arom. Plant Sci., *22*, 544-548 (2000).

S. R. Singh, R. P. Mohod and N. Kumar, *Study of geranium (Pelargonium graveolens L'Heritt.) cultivated in North Indian plains.* J. Essent. Oil Bear. Plants, *4(1)*, 33-36 (2001).

N. Jain, K. L. Aggarwal, K. V. Syamasundar, S, K. Srivastava and S. Kumar, *Essential oil composition of geranium (Pelargonium sp.) from the planes of Northern India.* Flav. Fragr. J., *16*, 44-46 (2001).

B. R. Rajeswara Rao, A. Bhattacharya, P. Kaul and S. Ramesh, *Yield and chemical composition of rose-scented geranium (Pelargonium species) oil at different times of harvesting.* J. Essent. Oil. Res., *13*, 456-459 (2001).

R. Gupta, G. R. Mallavarapu, S. Banerjee and S. Kumar, *Characteristics of an isomenthone-rich somoclonal mutant isolated in a geraniol-rich rose-scented geranium accession of Pelargonium graveolens.* Flav. Fragr. J., *16*, 319-324 (2001).

Percentage composition of geranium oil produced from the same cultivar in two regions of India **T-11**

Compound	N. Indian Oil	S. Indian Oil	Compound	N. Indian Oil	S. Indian Oil
(Z)-3-hexenol	t	0.1	α-ylangene	0.1	-
2-heptanone	t	-	α-copaene	0.3	0.1
2-heptanol	t	-	β-bourbonene	0.8	0.5
α-pinene	0.3	0.3	α-cedrene	t	-
camphene	-	t	β-caryophyllene	0.8	0.5
sabinene	t	0.1	citronellyl propionate	0.1	-
β-pinene	t	-	α-cadinene‡	0.1	-
myrcene	0.1	0.7	guaia-6,9-diene	0.1	0.1
α-phellandrene	t	0.1	geranyl propionate	0.4	0.5
p-cymene	0.1	0.1	α-humulene	0.1	0.1
limonene	0.1	0.3	(E)-β-farnesene	0.2	-
1,8-cineole	0.1	-	allo-aromadendrene	0.3	-
(Z)-β-ocimene	t	0.2	germacrene D	0.1	0.9
(E)-β-ocimene	0.1	0.3	α-muurolene	0.1	-
cis-linalool oxide†	0.1	0.1	geranyl isobutyrate	0.1	-
trans-linalool oxide†	0.1	t	γ-elemene	0.1	-
terpinolene	-	t	citronellyl butyrate	0.2	-
linalool	5.3	6.7	γ-cadinene	0.1	-
cis-rose oxide	0.8	0.4	calamenene*	0.3	0.2
trans-rose oxide	0.3	0.2	δ-cadinene	t	-
photocitral A	0.1	-	geranyl butyrate	0.2	0.2
menthone	4.8	0.1	(E)-nerolidol	0.1	-
isomenthone	3.1	7.9	2-phenethyl tiglate	1.0	0.9
terpinen-4-ol	0.1	-	furopelargone B	0.1	0.1
menthol	0.1	-	geranyl isovalerate	0.7	0.3
α-terpineol	0.3	0.3	citronellyl valerate	0.2	-
citronellol + nerol	33.6	26.7	10-epi-γ-eudesmol	5.6	7.6
geraniol	20.2	24.1	T-cadinol	0.1	-
geranial	0.7	0.5	geranyl valerate	0.2	0.1
citronellyl formate	6.6	8.2	β-eudesmol	0.1	0.1
neryl formate	0.1	0.1	α-cadinol	0.1	-
geranyl formate	4.5	3.1	citronellyl tiglate	0.9	1.5
linalyl propionate	0.1	-	geranyl tiglate	1.8	1.6
citronellyl acetate	0.3	0.2	geranyl hexanoate	0.1	-
α-cubebene	-	t	geranyl heptanoate	0.1	-
geranyl acetate	0.3	0.3	geranyl octanoate	t	-

t = trace (<0.1%)
* correct isomer not identified
† furanoid form
‡ incorrect identify based on elution order

J. A. Pino, A. Rosado and V. Fuentes, *Essential oil of rose-scented geranium (Pelargonium sp.) from Cuba.* J. Essent. Oil Res., *13*, 21-22 (2001).

Citronella Oil

An oil of Ceylon-type citronella produced from *Cymbopogon nardus* (L.) Rendle in Guangdong (China) was the subject of analysis by Zhu et al. (1993). The composition of this oil was found to be:

α-pinene (4.78%)
camphene (0.10%)
β-pinene (0.39%)
limonene (2.81%)
eugenol (0.85%)
geranyl acetate (3.20%)
β-bourbonene (0.13%)
β-elemene (0.97%)
linalool (0.63%)
isopulegol (0.89%)
citronellal (38.47%)
citronellol (14.19%)
neral (0.23%)
geraniol (16.83%)
geranial (0.24%)
citronellyl acetate (3.88%)
β-caryophyllene (0.15%)
γ-cadinene† (0.19%)
β-cubebene† (1.21%)
α-muurolene (0.41%)
γ-muurolene (0.39%)
δ-cadinene (1.60%)
guaiene† (1.85%)

† incorrect identification based on elution order

Buchbauer et al. (1997) examined the headspace of Java citronella oil; it was found to contain the following constituents:

limonene (20.3%)
isopulegol (t)
citronellal (61.3%)
citronellol (9.2%)
geraniol (9.2%)

t = trace (<0.1%)

For comparison purposes, the authors found that the original oil possessed the following composition:

limonene (2.31%)
linalool (0.81%)
isopulegol (1.64%)
citronellal (32.5%)
citronellol (12.1%)
geraniol (22.9%)
geranial (0.75%)
citronellyl acetate (4.36%)
eugenol (5.30%)
geranyl acetate (4.60%)
elemene* (0.62%)
germacrene D (0.98%)
γ-cadinene (0.96%)
δ-cadinene (0.80%)

* correct isomer not identified

Kaul et al. (1997) examined the composition of Java citronella oil produced in Andhra Pradesh (India) and found that it possessed the following composition:

α-pinene (0.03%)
6-methyl-5-hepten-2-one (0.09%)
myrcene (0.52%)
α-phellandrene (0.04%)
p-cymene (0.04%)
limonene (6.07%)
(Z)-β-ocimene (0.20%)
(E)-β-ocimene (0.11%)
terpinolene (0.09%)
linalool (1.04%)
nonanal† (0.17%)
citronellal (50.93%)
isopulegol (0.54%)
borneol (0.12%)
terpinen-4-ol (0.07%)
α-terpineol (0.07%)
decanal† (0.11%)
citronellal (6.06%)
geraniol (16.47%)
linalyl acetate (0.29%)
terpinen-4-yl acetate (0.14%)
citronellyl acetate (3.89%)
geranyl acetate (4.94%)
β-bourbonene (0.05%)
β-elemene (0.72%)
β-caryophyllene (0.18%)
trans-α-bergamotene (0.08%)
α-guaiene† (0.04%)
α-humulene (0.07%)
germacrene D (0.04%)
β-selinene (0.04%)†
selinene* (1.40%)
γ-elemene‡ (0.31%)
β-bisabolene (0.33%)
γ-cadinene (1.06%)
elemol (1.15%)
caryophyllene oxide (1.15%)
viridiflorol† (0.08%)
α-muurolol (0.39%)
α-cadinol (0.60%)

* correct isomer not identified
† tentative identification
‡ incorrect identity based on elution order

Tyagi et al. (1998) evaluated a number of oils of *Cymbopogon* species for their repellent activities against three different mosquito species (*Anopheles stephensi, Culex quinquefasciatus,* and *Aedes aegypti*). Amongst the oils screened and analyzed was a sample of *C. nardus.* Unfortunately, the authors were not very careful about their quantitative data because the total percentage of identified constituents totaled 156.08%. As a result, the identified constituents will not be included in this review.

Comparative percentage composition of the oils of "Kunti" geranium and a somocolonal variant **T-12**

Compound	Kunti Oil	Variant Oil
α-pinene	-	0.3
sabinene	t	0.2
myrcene	0.1	0.4
p-cymene	-	0.8
limonene	t	1.4
(Z)-β-ocimene	-	0.3
(E)-β-ocimene	0.1	0.1
cis-linalool oxide†	0.2	0.2
trans-linalool oxide†	0.2	t
linalool	5.1	1.2
cis-rose oxide	0.2	0.2
trans-rose oxide	0.1	t
menthone	0.2	1.8
isomenthone	8.2	71.0
borneol + neomenthol	-	0.3
menthol	-	0.2
terpinen-4-ol	t	0.1
neoisomenthol	0.6	0.5
α-terpineol	0.3	0.4
isomenthol	-	0.1
citronellol	13.0	6.1
piperitone	0.1	0.6
geraniol	31.9	3.1
geranial	3.0	0.7
citronellyl formate	0.1	1.4
bornyl acetate	-	0.2
geranyl formate	0.3	0.5
citronellic acid	0.2	0.1
2-phenethyl propionate	0.9	0.1
citronellyl acetate	1.0	0.1
α-cubebene	0.2	0.5
geranyl acetate	0.6	0.1
decanoic acid	2.4	0.1
α-copaene	0.3	0.1
β-bourbonene	0.4	0.2
isoundecanoic acid	0.6	0.1
β-caryophyllene	0.5	0.2
citronellyl propionate	0.1	0.1
guaia-6,9-diene	1.4	0.7
geranyl propionate	2.3	0.1
α-humulene	0.1	0.1
allo-aromadendrene	0.1	t
γ-muurolene	0.1	-
germacrene D	0.1	0.2

t = trace (<0.1%)
† furanoid form

This same year, Rao et al. (1998) found that an oil produced from Java citronella grown above 900 m in Viskahapatam district, Andhra Pradesh contained the following components:

6-methyl-5-hepten-2-one (0.22%)
myrcene (0.13%)
terpinen-4-yl acetate (0.11%)
citronellyl acetate (1.65%)

p-cymene (0.10%)
limonene (5.52%)
terpinolene (0.09%)
linalool (1.10%)
citronellal (42.75%)
isopulegol (0.39%)
terpinen-4-ol (0.05%)
α-terpineol (0.09%)
citronellol (9.73%)
geraniol (23.99%)
geranyl acetate (2.85%)
β-elemene (1.91%)
β-caryophyllene (0.11%)
α-humulene (0.16%)
β-bisabolene (0.32%)
δ-cadinene (1.09%)
elemol (2.01%)
caryophyllene oxide (0.98%)
T-cadinol (0.24%)
α-cadinol (0.41%)

As part of an antifungal screening study, Delespaul et al. (2000) examined the composition of an oil of citronella ex. *C. nardus.* In addition to finding that the vapor of *C. nardus* was an effective fumigant, they found that the major constituents of the oil were as follows:

limonene (1.0%)
linalool (0.5%)
citronellal (26.3%)
citronellol (15.3%)
geraniol (30.7%)
citronellyl acetate (4.3%)
geranyl acetate (5.3%)
elemene* (3.9%)
α-muurolene (0.8%)
germacrene D (0.8%)
δ-cadinene (2.3%)
elemol (5.1%)
germacrene D-4-ol (0.3%)
α-cadinol (0.9%)

* correct isomer not identified

Although Java citronella is not normally grown in Orissa, Rao et al. (2000) examined an oil produced from plants grown in an experimental garden in coastal Orissa. The authors subjected this oil to analysis and found that it contained:

myrcene (0.17%)
limonene (3.40%)
β-ocimene * (0.03%)
melonal† (0.13%)
linalool (0.70%)
isopulegol (0.05%)
citronellol (45.80%)
isomenthone† (0.04%)
α-terpineol (0.06%)
decenal*† (0.10%)
citronellol (9.10%)
neral (0.60%)
geraniol (18.50%)
geranial (0.65%)
perillaldehyde (0.02%)
δ-elemene (0.11%)
citronellyl acetate (2.54%)
eugenol (0.35%)
β-bourbonene (2.90%)
geranyl acetate (3.40%)
β-caryophyllene (0.10%)
β-gurjunene (0.02%)
aromadendrene (0.10%)
germacrene D (1.50%)
γ-muurolene (0.42%)
γ-amorphene (0.70%)
γ-cadinene (0.32%)
δ-cadinene (1.25%)
elemol (4.25%)
cedrol† (0.19%)
γ-eudesmol (0.26%)
β-eudesmol (0.38%)
α-eudesmol (0.92%)
β-bisabolol (0.03%)
(E,E)-farnesol (0.10%)

* correct isomer not identified
† incorrect identifications

Java citronella was grown on an experimental basis over three consecutive years in Zimbabwe. According to Chagonda et al. (2000), the oils, which were analyzed by a combination of GC and GC/MS, were found to contain the following constituents:

myrcene (0.1-0.4%)
limonene (2.9-5.7%)
1,8-cineole (t-0.2%)
p-cymene (0.1%)
3-octanone (t-0.1%)
citronellal (33.4-41.6%)
linalool + linalyl acetate (0.9-2.4%)
β-caryophyllene (0.2-1.4%)
α-terpineol (2.1-2.9%)
germacrene D (1.5-2.4%)
bicyclogermacrene (0.4-1.8%)
δ-cadinene (0.6-1.9%)
citronellyl acetate (3.2-3.9%)
citronellol (9.1-12.8%)
nerol (0.2%)
geraniol (23.4-25.1%)
elemol (1.8-2.8%)
isocaryophyllene oxide (0.7-1.5%)
eugenol (0.6-1.2%)

t = trace (<0.1%)

This same year, Lorenzo et al. (2000) reported the results of an analysis of an oil of *C. winterianus* produced from plants in an experimental area in Rio Grande do Sul (Brazil). They found that the composition of this oil was as follows:

myrcene (0.1%)
limonene (3.0%)
β-phellandrene (0.1%)
terpinolene (0.1%)
linalool (0.6%)
isopulegol (0.1%)
citronellal (36.1%)
terpinen-4-ol (t)
α-terpineol (t)
decanal (0.1%)
citronellol (9.9%)
nerol (0.3%)
neral (0.4%)
geraniol (19.9%)
geranial (0.6%)
citronellyl acetate (3.5%)
geranyl acetate (3.8%)
β-bourbonene (0.2%)
β-elemene (1.6%)
β-caryophyllene (0.1%)
α-humulene (0.1%)
germacrene D (2.6%)
α-muurolene (0.4%)
γ-cadinene (0.4%)
δ-cadinene (1.9%)
elemol (5.8%)
germacrene D-4-ol(1.7%)
10-epi-γ-eudesmol (0.2%)
T-muurolol (1.0%)
α-eudesmol (1.6%)
farnesol* (0.2%)

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

In addition, Lorenzo et al. used multi-dimensional GC to heart cut specific components so that their enantiomeric distribution could be determined using chiral GC. The enantiomeric distribution of four important components of citronella oil was found to be as follows:

(4R)-(+)-limonene (13.0%) : (4S)-(-)-limonene (87.0%)
(3R)-(-)-linalool (38.7%) : (3S)-(+)-linalool (61.3%)
(3R)-(+)-citronellal (91.2%) : (3S)-(-)-citronellal (8.8%)
(3R)-(+)-citronellol (84.7%) : (3S)-(-)-citronellol (15.3%)

Lal et al. (2001) examined the genetic variability of 33 accessions of Java citronella grown throughout India and one from Sri Lanka. In addition to measuring the morphological traits and oil yields of these accessions, the authors determined the relative amounts of seven selected constituents. The results of these analyses can be seen in T-13. As can be seen, the oils have been categorized based on their citronellal content. It should be noted that the oil from the Sri Lankan accession possessed the lowest level of citronellal (5.5%) of any of the citronella oils.

Sarma et al. (2001) noted that, although a citronella plantation normally has a life span of five years in India, the three major constituents of the oil

did not vary that much in oils produced from each harvest of the plantations, e.g.,

citronellal (41.9-46.3%)
citronellol (17.6-20.3%)
geraniol (24.0-25.7%)

More recently, Naqvi et al. (2002) separately water distilled a batch of homogenized citronella plants using 1L of 1.0% solutions of NaCl, Na_2CO_3, $CaCl_2$ and $CaCO_3$ to determine whether the addition of salts to the distillation water on oil yield and composition. They found that the oil yield ranged from 1.4-1.5% while the oil composition ranged as follows:

limonene (1.9-3.2%)
citronellal (27.8-30.8%)
linalool (0.5-0.9%)
linalyl acetate (0.3-0.4%)
β-caryophyllene (0.9-1.7%)
citronellyl acetate (3.2-4.5%)
geranyl formate (1.1-1.6%)
geranyl acetate (4.5-6.9%)
citronellol (8.9-9.8%)
nerol (0.3-0.4%)
geraniol (17.2-20.4%)
elemol (7.9-12.3%)

The authors concluded that the yield and quality of the oil could be improved if $CaCO_3$ was incorporated in the distillation water.

L-F. Zhu, Y-H. Li, B-L. Li, B-Y. Lu and N-H. Xia, *Aromatic plants and essential constituents*. p. 112, South China Institute of Botany, Chinese Academy of Sciences, Hai Feng Publish. Co. distributed by Peace Book Co., Ltd., Hong Kong (1993).

G. Buchbauer, L. Jirovetz and A. Nikiforov, *Use of GC-FID, GC-FTIR-MS and olfactory characterization in the analyses of essential oils and plant extracts.*

In: *Modern methods of plant analysis*. Vol. 19, *Plant volatile analysis*. Edits., H-F. Linskens and J. F. Jackson, 97-117, Springer Verlag, Berlin (1997).

P. N. Kaul, A. K. Bhattacharya, K. Singh and B. R. Rajeswara Rao, *Chemical composition of the essential oil of Java citronella (Cymbopogon winterianus Jowitt) grown in Andhra Pradesh.* PAFAI, *19(3)*, 29-33 (1997).

B. K. Tyagi, A. K. Shahi and B. L.Kaul, *Evaluations of repellent activities of Cymbopogon essential oils against mosquito vectors of malaria, filariasis and dengue fever in India.* Phytomedicine, *5*, 324-329 (1998).

B. R. Rajeswara Rao, P.N. Kaul and A. K. Bhattacharya, *Java citronella (Cymbopogon winterianus Jowitt) cultivation in a tribal area of Andhra Pradesh.* J. Essent. Oil Bear. Plants, *1(2/3)*, 114-118 (1998).

Q. Delespaul. V. G. de Billerbeck, C. G. Roques, G. Michel, C. Marquier-Vinaules and J-M. Bessière, *The antifungal activity of essential oils as determined by different screening methods.* J. Essent. Oil Res., *12*, 256-266 (2000).

Y. R. Rao, P. K. Rout, K. S. Jena and S. B. Sahu, *Composition of essential oil of citronella (Cymbopogon winterianus Jowitt) grown in coastal Orissa.* FAFAI, *2(4)*, 29-31 (2000).

L. S. Chagonda, C. Makanda and J-C. Chalchat, *Essential oils of cultivated Cymbopogon winterianus (Jowitt) and of C. citratus (DC) Stapf. from Zimbabwe.* J. Essent. Oil Res., *12*, 478-480 (2000).

Comparative percentage composition of seven selected constituents of the oils of 34 citronella accessions **T-13**

Compound	1(2)	2(4)	3(7)	4(19)	5(1)	6(1)
citronellal	5.5-9.6	10.3-17.9	24.2-28.9	31.0-39.0	42.7	38.1
citronellol	2.0-7.7	9.7-12.5	5.7-14.0	5.7-15.3	14.4	13.7
geraniol	18.2-19.3	16.3-18.1	16.3-19.6	16.3-20.4	21.9	50.1
citronellyl acetate	4.8-5.2	4.6-6.8	3.1-6.4	2.3-6.8	6.3	3.4
geranyl acetate	5.7-7.2	2.2-7.5	3.4-7.5	2.6-7.6	8.3	7.0
limonene	1.5-2.7	1.8-3.1	2.6-3.2	2.2-3.6	2.8	2.4
elemol	1.4-8.6	8.3-17.2	0.8-16.4	0.6-13.4	1.3	4.0

1. oils with citronellal <10.0%
2. oils with citronellal 10-20%
3. oils with citronellal 20-30%
4. oils with citronellal 30-40%
5. oils with citronellal > 40%
6. geraniol-rich oils

D. Lorenzo, E. Dellacassa, L. Atti-Serafini, A. C. Santos, C. Frizzo, N. Paroul, P. Moyna, L. Mondello and G. Dugo, *Composition and stereoanalysis of Cymbopogon winterianus Jowitt oil from southern Brazil.* Flav. Fragr. J., *15*, 177-181 (2000).

R. K. Lal, J. R. Sharma, H. O. Sharma, S. Sharma and A. A. Naqvi, *Genetic variability and relationship in quantitative and qualitative traits of Java citronella (Cymbopogon winterianus Jowitt).* J. Essent. Oil Res., *13*, 158-162 (2001).

T. C. Sarma, R. K. Sharma, R. K. Adhikara and B. N. Saha, *Effect of altitude and age on herb yield, oil and its major constituents of Java citronella (Cymbopogon winterianus Jowitt).* J. Essent. Oil Bear. Plants, *4(2/3)*, 77-81 (2001).

A. A. Naqvi, S. Mandal, A. Chattopadhyay and A. Prasad, *Salt effect on the quality and recovery of essential oil citronella (Cymbopogon winterianus Jowitt).* Flav. Fragr. J., *17*, 109-110 (2002).

Olibanum Oil

Several species of *Boswellia* can be found as items of commerce depending upon the country from which the oleo-gum-resin is obtained. For example, *Boswellia carterii* Birdwood is obtained from Somalia, Ethiopia, Yemen and Oman, whereas *B. frereana* Birdwood is only obtained from Somalia. The olibanum oils of commerce can originate from the oleo-gum-resins of either of the aforementioned species.

In 1982, Strappaghetti et al. found that an oil produced from the oleo-gum-resin of *B. frereana* of Somali origin was found to be rich in the following compounds:

- α-pinene
- sabinene
- myrcene
- α-terpinene
- limonene
- p-cymene
- α-cubebene
- terpinen-4-ol
- cembrene
- isocembrene

Although the authors did not present any quantitative data, they noted that p-cymene was the major constituent.

In 1990, Kreis et al. used enantiomeric separation on a chiral capillary GC column to determine that the enantiomeric ratios of α-pinene, β-pinene and limonene in olibanum oil were found to be:

(1S,5S)-(-)-α-pinene (94-97%) : (1R,5R)-(+)-α-pinene (3-6%)
(1S,5S)-(-)-β-pinene (67-76%) : (1R,5R)-(+)-β-pinene (24.33%)
(4S)-(-)-limonene (93-94%) : (4R)-(+)-limonene (6.7%)

The following year, Chiavari et al. (1991) compared the oils produced from the oleo-gum-resin of *B. carterii* and *B. frereana.* The results of this study are shown in T-14.

Using retention indices on a polar and a non-polar SCOT capillary column and component identity confirmation with GC/MS, a Somalian olibanum oil was found (Anon 1993) to contain the following constituents:

- α-pinene + α-thujene (4.5%)
- camphene (1.1%)
- sabinene (5.1%)
- myrcene (1.7%)
- limonene (11.0%)
- γ-terpinene (0.8%)
- p-cymene (7.3%)
- β-thujone (0.4%)
- α-copaene (0.5%)
- β-bourbonene (0.3%)
- terpinen-4-ol (1.7%)
- β-caryophyllene (1.5%)
- δ-cadinene (1.5%)
- caryophyllene oxide (1.5%)
- viridiflorol (0.5%)
- δ-cadinol (0.8%)

This above analysis contains the components that were identified on the polar column. Analysis on the non-polar column revealed some additional compounds such as: β-pinene (trace), α-phellandrene (0.6%), verbenone (0.6%). α-cubebene (0.2%), β-elemene (0.5%) and α-humulene (0.3%).

Four years later, Moyler and Clery (1997) examined the major component composition of the oils of a number of aromatic resins. Within this study, they analyzed a sample of olibanum oil using GC/MS. The results of this analysis can be summarized as follows:

α-pinene (27.0%)
α-thujene (13.5%)
camphene (0.5%)
β-pinene (1.0%)
sabinene (4.1%)
δ-3-carene (0.8%)
myrcene (8.7%)
α-phellandrene (1.7%)
limonene (16.0%)
α-terpinene* (0.6%)
γ-terpinene (0.5%)
p-cymene (0.5%)
β-thujone (1.2%)
β-caryophyllene (4.2%)
terpinen-4-ol (1.2%)
δ-cadinene (1.6%)
incensole (0.5%)

*incorrect identification based on elution order

In addition, the authors stated that the oil contained a further 132 constituents (12.8% of the oil); however, none was identified.

A commercial oil of olibanum was subjected to a screening evaluation for its antimicrobial and antioxidant properties by Barata et al. (1998). The oil used in this study was found to contain the following constituents:

tricyclene (t)
α-thujene (5.8%)
α-pinene (41.2%)
camphene (0.8%)
sabinene (4.4%)
β-pinene (2.0%)
myrcene (4.9%)
α-phellandrene (0.9%)
δ-3-carene (3.2%)
α-terpinene (0.9%)
p-cymene (5.6%)
β-phellandrene (0.7%)
limonene (16.7%)
(Z)-β-ocimene (0.2%)
(E)-β-ocimene (t)
γ-terpinene (0.3%)
trans-sabinene hydrate (t)
α-p-dimethylstyrene (0.1%)
terpinolene (0.1%)
cis-sabinene hydrate (10.8%)
α-thujone (0.2%)
linalool (0.2%)
isoamyl isovalerate (0.1%)
β-thujone (0.1%)
campholenic aldehyde (0.3%)
trans-pinocarveol (0.6%)
cis-verbenol (0.3%)
trans-verbenol (0.9%)
pinocamphone (0.2%)
terpinen-4-ol (0.8%)
α-terpineol (0.2%)
verbenone (0.6%)
carvone (0.2%)
bornyl acetate (0.2%)
α-terpinyl acetate (t)
α-cubebene (0.2%)
α-copaene (0.5%)
β-bourbonene (t)
β-elemene (0.4%)
α-gurjunene (t)
β-caryophyllene (1.2%)
α-humulene (0.3%)
allo-aromadendrene (0.1%)
γ-muurolene (0.2%)
germacrene D (t)
β-selinene (0.2%)
α-selinene (0.1%)
α-muurolene (t)
δ-cadinene (0.4%)
caryophyllene oxide (0.5%)
T-cadinol (0.2%)
α-muurolol (t)

t = trace (<0.1%)

Also in 1998, Hayashi et al. analyzed oils produced from the gum-oleo-resin of *B. carterii* of Omani origin and *B. frereana* of Turkish and Israeli origins. The oil of *B. carterii* was found to contain:

α-thujene (0.1%)
isoamyl acetate (0.1%)
α-pinene (56.6%)
camphene (2.1%)
3-methyl-2-butenol (t)
β-pinene (1.0%)
sabinene (0.5%)

Comparative percentage composition of the olibanum oils produced from *Boswellia carterii* and *B. frereana*

T-14

Compound	*B. carterii*	*B. frereana*
α-thujene	19.23	10.14
α-pinene	7.16	0.73
sabinene	9.44	3.14
α-phellandrene	0.56	1.00
p-cymene	3.53	4.28
limonene	7.82	3.44
1, 8-cineole	-	1.18
β-bourbonene	1.00	1.63
β-caryophyllene	4.91	0.40
α-muurolene	6.68	0.60
caryophyllene oxide	3.29	0.21

δ-3-carene (1.7%)
myrcene (0.1%)
α-phellandrene (0.1%)
limonene (1.0%)
1,8-cineole + β-phellandrene (0.3%)
γ-terpinene (0.1%)
hexyl acetate (t)
p-cymene (1.5%)
terpinolene (0.1%)
isoamyl 2-methylbutyrate (t)
3-octyl acetate (t)
1-(2-furanyl)-1,2-propanedione (0.1%)
2-methyl-2-penten-6-one (0.1%)
3-octen-2-one (0.1%)
2-methyl-5-ethylfuran (0.1%)
p-cresyl methyl ether (0.1%)
β-thujone (0.1%)
α-cubebene (t)
acetic acid (0.1%)
linalool oxide-furanoid (t)
α-ylangene (0.6%)
2-acetylfuran (t)
2-ethylfuran (t)
camphor (0.1%)
bourbonene* (0.5%)
benzaldehyde (t)
linalool (t)
sabinene hydrate* (0.1%)
isobutyric acid (0.1%)
pinocamphone (t)
pinocarvone (0.4%)
nopinone (0.3%)
bornyl acetate (0.5%)
β-elemene (1.0%)
2,3,5-trimethyl-2-cyclopenten-1-one (t)
methyl carvacrol (t)
β-caryophyllene (0.1%)
terpinen-4-ol (0.4%)
myrtenal (0.7%)
myrtenyl acetate (0.2%)
pinocarveol* (3.5%)
p-mentha-1,3-dien-8-ol (1.2%)
α-humulene (t)

selina-4,11-diene (0.2%)
verbenone (4.5%)
α-amorphene (0.1%)
3-methyl-2-(2-methylpropyl)furan (0.1%)
α-terpineol (0.3%)
α-terpinyl acetate (0.1%)
borneol (t)
p-cresyl acetate (0.3%)
verbenol* (2.5%)
β-selinene (3.7%)
γ-selinene (0.3%)
carvone (0.2%)
δ-cadinene (0.1%)
safranal (t)
γ-cadinene (0.1%)
p-methoxyacetophenone (t)
cuminaldehyde (t)
myrtenol (0.6%)
calamenene* (0.1%)
sabinol* (t)
1-butenyl anisole (0.1%)
2-acetyl-5-methylfuran (t)
carveol* (0.7%)
p-cymen-8-ol (0.8%)
1,5-dimethoxy-3-methylbenzene (t)
γ-calacorene (0.1%)
piperitenone (t)
β-ionol (t)
caryophyllene oxide (0.2%)
geranyl acetone (t)
humulene epoxide* (0.1%)
elemol (0.1%)
cuminyl alcohol (0.1%)
γ-eudesmol (t)
eugenol (t)
globulol (t)
carvacrol (0.1%)
β-eudesmol (0.1%)

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

In contrast, the oils of *B. frereana* were found to contain:

α-pinene (0.2-2.9%)
camphene (0-0.1%)
β-pinene (0-0.2%)
δ-3-carene (0-0.2%)
myrcene (0.1-0.3%)
2,3-dihydro-1,8-cineole (0-0.1%)
limonene (0-3.2%)
(Z)-β-ocimene (0.1-1.0%)
(E)-β-ocimene (0.1-0.6%)
p-cymene (0-0.1%)
octanol (0.1-1.1%)
perillene (0-0.5%)
α-cubebene (t-0.1%)
α-copaene (0-0.1%)
δ-elemene (0-0.2%)
octyl acetate (28.5-68.5%)
linalool (0.6-1.0%)
octanol (10.1-11.1%)
pinocamphone (t)
β-elemene (t)
allo-aromadendrene (0-0.1%)
α-guaiene (0-0.1%)
2,6-dimethyl-2-octene (0-0.2%)
γ-muurolene (0-0.2%)
eremophilene (0-0.1%)
pinocarveol* (0.2%)
verbenone (0.3-0.5%)
α-muurolene (0-0.1%)
verbenol* (0.1-0.3%)
β-selinene (0-t)
δ-cadinene (0-0.1%)
β-cadinene (0-t)
myrtenol (0-t)
calamenene* (0-0.1%)
cubenol (0-0.1%)
α-copaenol (0-0.1%)
carveol* (0.1-0.3%)
p-cymen-8-ol (0-0.1%)
γ-calacorene (t)
piperitenone (0-t)
caryophyllene oxide (0.2-0.9%)
humulene epoxide* (0-t)
elemol (0-t)
cuminyl alcohol (0-0.5%)

terpinen-4-ol (0-0.1%)
myrtenal (0.1-0.3%)
γ-eudesmol (0-0.6%)
viridiflorol (0.7-3.8%)

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

More recently, Baser et al. (2001) analyzed a sample of *B. carterii* olibanum oil and found that it contained:

(+)-α-thujene
(-)-α-pinene
camphene
sabinene
β-pinene
myrcene
δ-3-carene
p-cymene
(-)-limonene
1,8-cineole
(E)-β-ocimene
octanol
(-)-linalool
α-terpineol
octyl acetate
3,5-dimethoxytoluene
(-)-bornyl acetate
neryl acetate
geranyl acetate
(-)-(E)-nerolidol
cembra-3,7,11,15-tetraene
cembra-1,3,7,11-tetraene
incensole
incensole acetate
verticilla-4(20),7,11-triene

No quantitative data was reported in this study.

G. Strappaghetti, S. Corsano, A. Craveiro and G. Proetti, *Constituents of essential oils of Boswellia frereana*. Phytochemistry, *21*, 2114-2115 (1982).

P. Kreis, U. Hener and A. Mosandl, *Chirale Inhaltstoffe ätherischer Öle. III. Stereodifferenzierung von !a-pinen, !b-pinen and limonen in ätherischer Ölen, Drogen und Fertigarzneimitteln.* Deut. Apoth. Ztg., *130*, 985-988 (1990).

G. Chiavari, G. C. Galletti, R. Picaglia and M. A. Mohamud, *Differentiation between resins Boswellia carterii and Boswellia frereana (Frankincense) of Somali origin.* J. Essent. Oil Res., *3*, 185-186 (1991).

Anon, *Analytical methods committee application of gas-liquid chromatography to the analysis of essential oils. Part IVI. Monographs for five essential oils.* Analyst, *118*, 1089-1098 (1993).

D. A. Moyler and R. A. Clery, *The aromatic resins: Their chemistry and uses.* In: *Flavours and Fragrances*, Edit., K. A. D. Swift, pp. 96-115, Royal Soc. Chem., Cambridge, UK (1997).

M. T. Barata, H. J. D. Dorman, S. G. Deans, A. C. Figueiredo, J. G. Barroso and G. Ruberto, *Antimicrobial and antioxidant properties of some commercial essential oils.* Flav. Fragr. J., *13*, 235-244 (1998).

S. Hayashi, H. Amemori, H. Kameoka, M. Hanafusa and K. Furukawa, *Comparison of volatile compounds from olibanum from various countries.* J. Essent. Oil Res., *10*, 25-30 (1998).

S. Baser, A. Koch and W. A. König, *A verticillane-type diterpene from Boswellia carterii essential oil*. Flav. Fragr. J., *16*, 315-318 (2001).

Asafoetida Oil

Although there are some taxonomic problems associated with the actual botanical origin of the oleo-gum-resin of asafoetida, it is generally believed that it is obtained primarily from Ferula assa-foetida L. (syn. F. scorodesma Benth. et Trim.) or T. foetida (Bunge) Rogel. It is native to central Asia where it can be found growing in Turkey, Iran, Afghanistan, Pakistan, India, etc. The gum-resin is an exudate which is obtained after making an incision on the lower part of the stem and root. The gum has a very powerful odor and, as a result, it is often adulterated with other inexpensive gums. According to Noleau et al. (1991), it is quite difficult to obtain an authentic sample of asafoetida oleo-gum-resin. Because of its powerful odor, asafoetida is used as a spice in central Asian foods.

In 1989, Kajimoto examined a methanolic extract of asafoetida. In addition to characterizing some unusual umbelliferone, sesquiterpenoid, coumarinoid compounds, they also characterized a new disulphide asadisulphide in the extract. Furthermore, they found that the non-volatile asadisulphide was a derivative of one of the isomeric forms of 2-butyl propenyl disulphide.

Noleau et al. (1991) extracted two samples (one from Pakistan and one from Iran) of asafoetida after which they were triple distilled to remove the solvent. The resultant extracts were subjected to GC and GC/MS analyses. The compounds found in the volatile concentrate of the Pakistani sample were as follows:

acetaldehyde (0.10%)
isobutanol (7.65%)
cyclopentane (t)
ethyl acetate (t)
isovaleraldehyde (t)
2-butanethiol (t)
acetaldehyde diethyl acetal (t)
dimethyl disulphide (t)
isoamyl alcohol (t)
hexanal (t)
4-methyl-2-pentanone (t)
4-methyl-2-pentanol (t)
furfural (t)
3,4-dimethylthiophene (0.23%)
methyl (Z)-1-propenyl disulphide (0.88%)
α-pinene (t)
methyl (E)-1-propenyl disulphide (1.69%)
dimethyl trisulphide (1.10%)
β-pinene (0.21%)
2-pentylfuran (t)
decane (t)
ethoxypropoxyethane†* (0.17%)
δ-3-carene (t)
2,3,4-trimethylthiophene (t)
ethoxypropoxyethane†* (0.17%)
limonene (t)
undecatriene* (t)
undecane (t)
nonanal (t)
dipropyl disulphide (0.11%)
propyl 1-propenyl disulphide* (0.31%)
di-1-propenyl disulphide* (t)
pinocarveol* (t)
methyl propyl trisulphide (0.23%)
methyl (Z)-1-propenyl trisulphide (1.29%)

methyl (E)-1-propenyl trisulphide (2.55%)
2-butyl (E)-1-propenyl disulphide (11.17%)
dodecane (0.13%)
butyl methyl trisulphide† (0.41%)
dibutyl disulphide (t)
dimethyl tetrasulphide (0.19%)
α-fenchyl acetate (1.24%)
butyl butenyl disulphide* (t)
methyl carvacrol (0.28%)
butyl butenyl disulphide* (t)
butyl butenyl disulphide* (t)
(E)-2-decenal (t)
butyl butenyl disulphide* (0.22%)
4-ethyl guaicol (0.41%)
bornyl acetate (t)
pinocarvyl acetate* (0.25%)
4-vinyl guaiacol (0.44%)
dipropyl trisulphide (t)
propyl 1-propenyl trisulphide* (0.78%)
propyl 1-propenyl trisulphide* (0.68%)
eugenol (0.74%)
isoeugenol* (0.27%)
3,4-dimethoxystyrene (t)
decanoic acid (0.47%)
butyl propenyl trisulphide*† (t)
dibutyl trisulphide (1.82%)
1-(methylthio)propyl (Z)-1-propenyl disulphide (18.46%)
1-(methylthio)propyl (E)-1-propenyl disulphide (37.93%)
guaiene* (t)
guaiene* (t)
2-butyl 3-(methylthio)propyl disulphide† (0.22%)
bisabolene* (0.68%)
(Z)-asarone (t)
hexadecanoic acid (0.18%)
methyl 2-methylhexadecanoate (0.10%)
ethyl octadecadienoate* (0.16%)
ethyl octadecenoate* (t)

* correct isomer not identified
† tentative identification
t = trace (<0.10%)

In contrast, the volatiles found in the Iranian sample were as follows:

sulphur dioxide (t)
allyl acetate (t)
3-methyl-3-butenol (t)
3-methylpropene (t)
propanethiol (t)
3,4-dimethylthiophene (t)
α-thujene (0.05%)
methyl (Z)-1-propenyl disulphide (t)
α-pinene (11.88%)
camphene (0.14%)
2,4(10)-thujadiene (t)
methyl (E)-1-propenyl disulphide (t)
dimethyl trisulphide (t)
sabinene (t)
β-pinene (7.06%)
myrcene (0.93%)
α-phellandrene (0.11%)
2,3,4-trimethylthiophene (0.21%)
α-terpinene (t)
p-cymene (t)

limonene (0.47%)
(Z)-β-ocimene (6.14%)
(E)-β-ocimene (3.63%)
γ-terpinene (t)
trans-sabinene hydrate (t)
terpinolene (t)
linalool (t)
dipropyl disulphide (t)
α-fenchyl alcohol (t)
3,4-diethylthiophene* (0.07%)
allo-ocimene* (0.08%)
pinocarveol* (0.10%)
allo-ocimene* (t)
2-butyl propyl disulphide (0.48%)
2-butyl (Z)-1-propenyl disulphide (11.09%)
2-butyl (E)-1-propenyl disulphide (22.75%)
α-terpineol (t)
myrtenal (t)
dibutyl disulphide (0.17%)
dimethyl tetrasulphide (t)
α-fenchyl acetate (t)
butyl butenyl disulphide* (t)
butyl butenyl disulphide* (0.11%)
butyl butenyl disulphide* (0.11%)
butyl butenyl disulphide* (0.10%)
bornyl acetate (0.09%)
pinocarvyl acetate* (0.14%)
4-vinylguaiacol (0.04%)
di-1-propenyl trisulphide* (t)
di-1-propenyl trisulphide* (t)
α-copaene (0.09%)
α-cubebene (t)
tetradecane (0.05%)
methyl eugenol (0.16%)
guaiene* (0.48%)
dibutyl trisulphide (0.19%)
1-(methylthio)propyl (Z)-1-propenyl disulphide (2.62%)
1-(methylthio)propyl (E)-1-propenyl disulphide (2.65%)
guaiene* (0.49%)
α-humulene (0.17%)
selinene* (0.08%)
β-selinene (0.48%)
cadinene* (0.31%)
(Z)-asarone (0.71%)
farnesol* (0.14%)

* correct isomer not identified
t = trace (<0.10%)

Based on the data reported above it would appear that the Iranian sample was adulterated with an aromatic gum resin because the level of sulphides was less than normally encountered.

Sefidkon et al. (1998) analyzed a lab-distilled oil of *F. assa-foetida* gum-oleo-resin collected from central Iran (Kerman province). The oil was found to contain:

α-pinene (2.1%)
sabinene (1.0%)
β-pinene (5.0%)
myrcene (1.0%)
α-phellandrene (2.4%)
β-phellandrene (2.5%)
(Z)-β-ocimene (11.5%)
(E)-β-ocimene (9.0%)
2-butyl 1-propyl disulphide (0.6%)
2-butyl (Z)-1-propenyl disulphide (3.9%)
2-butyl (E)-1-propenyl disulphide (58.9%)
di-1-methylpropyl disulphide (0.3%)
di-1-methylpropenyl disulphide* (1.2%)

* correct isomer not identified

More recently, Takeoka (2001) determined the headspace of a stirred mixture of powdered asafoetida (80 g) in purified water (400 mL) by bubbling recirculated nitrogen (6L/min for 3 h) through the mixture and collecting it in a Tenax trap (10 g). After the 3-h period, the Tenax trap was eluted with freshly distilled diethyl ether (50 mL), after which the solvent was carefully removed. The headspace was then determined using GC/MS. It was found to contain the following components:

2-methyl-2-propanethiol† (0.040%)
2,3-dimethyllthirane† (0.044%)
propyl acetate (0.038%)
1-methylthio-(Z)-1-propene (0.028%)
1-methylthio-(E)-1-propene (0.064%)
dimethyl disulphide (0.113%)
toluene (0.013%)
amyl alcohol (0.196%)
S-methyl propanethioate (0.071%)
hexanol (0.247%)
2-(methylthio)-butane† (0.197%)
2-methyl-2-pentenal (0.107%)
3-methyl-2-hexanone† (0.026%)
(E)-2-hexenol (0.070%)
hexanal (0.242%)
2-heptanone (0.039%)
3,4-dimethylthiophene (0.043%)
methyl (Z)-1-propenyl disulphide (0.092%)
2-methyl-3,5-hexadien-2-ol† + methyl (E)-1-propenyl disulphide (0.309%)
2-ethylpentanol (0.034%)
α-thujene (0.043%)
benzaldehyde (0.097%)
α-pinene (2.888%)
dimethyl trisulphide (0.010%)
camphene (0.061%)
(E)-2-heptenol (0.047%)
6-methyl-5-hepten-2-one + sabinene + β-pinene (4.341%)
2-butyl methyl disulphide† (0.054%)
myrcene (0.284%)
2,3,4-trimethylthiophene (0.058%)
2-isopropylfuran† (0.449%)
p-cymene (0.089%)
limonene + 1,8-cineole (1.696%)
(Z)-β-ocimene (0.269%)
2-butyl vinyl disulphide (0.066%)
(E)-β-ocimene (0.552%)
γ-terpinene (0.040%)
trans-sabinene hydrate (0.039%)
2-butyl ethyl disulphide (0.038%)
trans-linalool oxide-furanoid (0.034%)
cis-linalool oxide-furanoid (0.029%)
2-phenethyl alcohol (0.124%)
linalool (0.072%)

dipropyl disulphide (0.226%)
pinocarveol* (0.073%)
trans-verbenol (0.095%)
pinocarvone (0.190%)
2-butyl propyl disulphide† + 2-butyl-(Z)-1-propenyl disulphide (20.488%)
2-butyl-(E)-1-propenyl disulphide (17.445%)
terpinen-4-ol (0.298%)
α-terpineol (0.241%)
4-vinylphenol (0.079%)
di-2-butyl disulphide (0.321%)
methyl 1-(methylthio)ethyl disulphide (0.033%)
α-fenchyl acetate (0.083%)
4-methoxybenzaldehyde + subst. phenol† (0.151%)
methyl thymol or methyl carvacrol (0.084%)
methyl 1-(methylthio)propyl disulphide (0.084%)
4-ethylguaiacol (0.046%)
(E)-anethole (0.039%)
bornyl acetate (0.236%)
4-vinyl guaiacol (0.233%)
eugenol (0.089%)
neryl acetate (0.110%)
α-longipinene (0.023%)
methyl eugenol (0.047%)
α-copaene (0.042%)
1-(methylthio)propyl propyl disulphide + 1-(methylthio)propyl-(Z)-1-propenyl disulphide (31.687%)
1-(methylthio)propyl-(E)-1-propenyl disulphide (5.097%)
methyl isoeugenol*† (0.230%)
β-selinene (0.094%)
myristicin (0.086%)
valencene (0.064%)
α-selinene (0.071%)
1,2,2-trimethyl(p-tolyl)-cyclopentane (0.037%)
β-bisabolene (0.138%)
α-muurolol‡ (0.065%)
7-epi-α-selinene + δ-cadinene (0.097%)
(E)-γ-bisabolene (0.104%)
epi-ligulyl oxide† (0.257%)
guaiol† (0.025%)
10-epi-γ-eudesmol (0.046%)
2-pentadecanone (0.034%)
farnesyl acetate†‡ (0.032%)
2-hexadecanone (0.016%)
2-heptadecanone† (0.010%)

* correct isomer not identified
† tentative identification
‡ incorrect identity based on elution order

T. Kajimoto, K. Yahiro and T. Nohara, *Sesquiterpenoid and disulphide derivatives from Ferula assa-foetida.* Phytochemistry, *28*, 1761-1763 (1989).

I. Noleau, H. Richard and A-S. Peyroux, *Volatile compounds in leek and asafoetida*. J. Essent. Oil Res., *3*, 241-256 (1991).

F. Sefidkon, F. Askari and M. Mizra, *Essential oil composition of Ferula assa-foetida L. from Iran.* J. Essen. Oil Res., *10*, 687-687 (1998).

G. Takeoka, *Volatile constituents of asafoetida.* In: *Aroma active compounds in foods.* Edits., G. R. Takeoka, M. Güntert and K-H. Engel, ACS Series 794, 33-44, Amer. Chem. Soc., Washington, DC (2001). ■