Progress in Essential Oils

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Lemon Oil

A steam-distilled oil produced from the peels of *Citrus limon* grown in the Republic of Benin, West Africa, was analyzed by Ayedoun et al. (1996) using GC on two columns of different polarity and GC/MS. The composition of the oil was found to be as follows:

α-thujene (0.3 percent)
α-pinene (1.8 percent)
camphene (0.1 percent)
sabinene (t)
β-pinene (4.2 percent)
octanal (0.1 percent)
myrcene (1.8 percent)
α-phellandrene (0.1 percent)
α-terpinene (0.3 percent)
p-cymene (0.4 percent)
1,8-cineole (3.3 percent)
limonene (70.4 percent)
(Z)-β-ocimene (0.2 percent)
(E)-β-ocimene (0.3 percent)
γ-terpinene (11.8 percent)
terpinolene (0.8 percent)
linalool (0.1 percent)
α-fenchol (t)
cis-β-terpineol (0.1 percent)
borneol (t)
terpinen-4-ol (0.7 percent)
α-terpineol (1.4 percent)
decanal (t)
citronellol (t)
neral (t)
geranial (t)
β-caryophyllene (0.3 percent)
trans-α-bergamotene (0.3 percent)
α-humulene (t)
germacrene D (0.2 percent)
(E,E)-α-farnesene (0.2 percent)
β-bisabolene (0.5 percent)
δ-cadinene (0.1 percent)

t = trace (< 0.6 percent)

Haggag et al. (1998) determined that an oil produced by cold-pressing lemon peels obtained from fruit grown in Egypt contained the following major components:

α-pinene (26.90 percent)
camphene (0.87 percent)
β-pinene (18.29 percent)
limonene (9.58 percent)
p-cymene (0.60 percent)
citronellal (0.60 percent)
linalool (1.19 percent)
nerol (2.67 percent)
α-terpineol (1.27 percent)
citronellol (7.00 percent)
geraniol (3.55 percent)
thymol (2.66 percent)
carvacrol (1.33 percent)
eugenol (8.55 percent)

It should be pointed out that this is a very atypical lemon oil composition.

Cold-pressed lemon oils produced from fruit grown at an experimental station in Japan were the subject of analysis by Sawamura et al. (1998). The range in composition of the oils was as follows:

α-pinene (2.3-2.6 percent)
β-pinene (10.5-14.0 percent)
myrcene (1.4-1.6 percent)
α-terpinene (t)
limonene (64.6-69.7 percent)
γ-terpinene (8.2-10.3 percent)
p-cymene (t)
terpinolene (0.3-0.4 percent)
octanal (t-0.1 percent)
citronellal (t-0.1 percent)
decanal (t)
linalool (0.2 percent)
terpinen-4-ol (0-t)
neral (0.6-1.1 percent)
α-terpineol (0.2-0.3 percent)
geranial (1.0-1.1 percent)
geranyl acetate (0.2 percent)

decanol (0-t)
citronellol (t)
nerol (t)
geraniol (t-0.1 percent)

t = trace (< 0.1 percent)

Wright (1999) reported that the typical quantitative levels of the major and important constituents of lemon oil were:

β-pinene (12.0 percent)
limonene (63.0 percent)
γ-terpinene (9.0 percent)
geranial (1.5 percent)
neral (1.0 percent)
neryl acetate (0.5 percent)
geranyl acetate (0.4 percent)
citronellal (0.2 percent)
linalool (0.2 percent)
nonanal (0.1 percent)

Verzera et al. (2001) examined the influence of lemon cultivars on the composition of lemon oil produced from cultivars grown in Sicily (Italy). A summary of these analyses can be seen in T-1. The results reveal some interesting variations in the various cultivar oils. In particular, the odor strength of 'Feminello incappucciato' oil would be higher than the others, based on the level of carbonyl compounds.

Vekiari et al. (2002) examined the variation of lemon peel oil volatiles obtained from the 'Zambetakis' cultivar harvested at different times in Crete (Greece). They found that the peel oil harvested in December 1996, March 1997, May 1997, June 1997, November 1997 and April 1998 varied as follows:

α-thujene (2.1-3.6)[a]
α-pinene (8.6-16.6)
camphene (0-0.6)
β-pinene (57.8-138.0)
myrcene (10.5-18.9)
δ-3-carene (0-2.5)
p-cymene (0-1.6)
limonene (220.3-315.5)
(Z)-β-ocimene (0-1.6)
(E)-β-ocimene (1.8-4.0)
γ-terpinene (66.8-90.2)
terpinolene (3.4-5.2)
linalool (3.4-5.2)
neral (0.5-1.8)
citronellal (0.9-2.9)
cis-isoneral (0-0.8)
trans-isogeranial (2.7-5.0)
terpinen-4-ol (0.8-1.5)
α-terpineol (5.6-11.9)
decanal (0-1.1)
neral (30.3-45.5)
geranial (42.3-65.4)
citronellyl acetate (0-0.7)
neryl acetate (3.6-12.3)
geranyl acetate (3.7-24.9)
dodecanal (0-4.5)
β-caryophyllene (2.9-6.0)
bergamotene* (0-0.7)
α-humulene (1.0-7.9)
neryl propionate (0-6.6)
geranyl propionate (0-5.4)
farnesene* (0.4-1.7)

[a] = mg/kg oil; *correct isomer not identified

It was of interest to note that the peel oil harvested in April 1998 was richest in oxygenated constituents.

The composition of the cold-pressed peel oils of a number of lemon cultivars was the subject of analysis by Lota et al. (2002). A summary of the results of the analysis of the 'Eureka,' 'Fino,' 'Berna,' 'Santa Teresa,' 'Lisbon,' 'Corpacia,' 'Lapithou,' 'Menton' and 'Panaché' cultivar oils can be seen in T-2.

The oil of one cultivar, 'Barum,' possessed a dissimilar peel oil composition. It was found to possess the following components:

α-thujene (t)
α-pinene (0.2 percent)
β-pinene (0.1 percent)
sabinene (0.1 percent)
myrcene (1.1 percent)
α-phellandrene (t)
α-terpinene (t)
limonene (52.5 percent)
β-phellandrene (0.2 percent)
(Z)-β-ocimene (0.1 percent)
γ-terpinene (1.0 percent)
(E)-β-ocimene (0.4 percent)
p-cymene (0.1 percent)
terpinolene (t)
nonanal (t)
p-cymenene (t)
linalool (16.0 percent)
linalyl acetate (23.3 percent)
trans-α-bergamotene (0.3 percent)
β-caryophyllene (0.1 percent)
neral (0.1 percent)
α-terpineol (0.1 percent)
β-bisabolene (0.5 percent)
neryl acetate (0.1 percent)
geranial (0.2 percent)
geranyl acetate (0.1 percent)
nerol (t)
(E)-nerolidol (t)

t = trace (< 0.1 percent)

The distilled peel oil of lemons of Venezuelan origin was analyzed by Gonzalez de et al. (2002). The oil was found to contain:

α-thujene (0.56 percent)
α-pinene (2.04 percent)
sabinene (4.77 percent)
β-pinene (1.16 percent)

Comparative percentage composition of lemon oil produced from different cultivars **T-1**

Compound	1	2	3	4	5	6	7	8	9
tricyclene	0.03	t	t	t	t	t	t	t	t
α-thujene	0.32	0.33	0.28	0.29	0.27	0.26	0.39	0.33	0.29
α-pinene	1.38	1.50	1.18	1.21	1.12	1.13	1.51	1.41	1.44
camphene	0.04	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.04
sabinene + β-pinene†	8.48	8.49	8.50	8.52	6.66	8.33	9.77	8.44	10.81
6-methyl-5-hepten-2-one	t	t	t	t	t	t	t	t	t
myrcene	1.72	1.75	1.54	1.62	1.65	1.45	1.52	1.54	1.60
octanal	0.04	0.03	0.03	0.04	0.03	0.04	0.04	0.03	0.03
α-phellandrene	0.06	0.06	0.12	0.04	0.07	0.10	0.09	0.03	0.11
δ-3-carene	t	t	t	t	t	0.01	t	t	t
α-terpinene	0.19	0.16	0.19	0.17	0.17	0.19	0.23	0.20	0.15
p-cymene	0.04	0.02	0.04	0.06	0.05	0.08	0.04	0.04	0.06
limonene	72.23	75.99	69.58	72.38	74.34	65.96	67.01	70.20	70.95
(Z)-β-ocimene	0.06	0.04	0.05	0.03	0.04	0.04	0.07	0.20	0.03
(E)-β-ocimene	0.12	0.08	0.11	0.07	0.08	0.10	0.13	0.29	0.07
γ-terpinene	9.27	7.42	9.43	8.70	8.55	9.82	11.11	9.61	7.16
cis-sabinene hydrate	0.07	0.05	0.07	0.07	0.06	0.08	0.08	0.06	0.07
octanol	t	t	t	t	-	t	-	-	-
terpinolene	0.42	0.32	0.42	0.39	0.39	0.46	0.48	0.42	0.31
trans-sabinene hydrate	0.07	0.04	0.10	0.06	0.07	0.09	0.10	0.05	0.06
linalool	0.17	0.13	0.20	0.18	0.18	0.22	0.14	0.13	0.15
nonanal	0.06	0.05	0.11	0.05	0.06	0.11	0.12	0.01	0.09
heptyl acetate	t	t	t	t	t	t	t	t	t
cis-limonene oxide	t	t	t	t	t	t	t	t	t
trans-limonene oxide	t	t	t	t	t	0.01	t	t	t
camphor	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	t
citronellal	0.15	0.08	0.18	0.21	0.17	0.33	0.10	0.07	0.19
borneol	0.01	0.01	0.03	0.02	0.02	0.03	0.02	0.01	0.02
terpinen-4-ol	0.03	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.02
α-terpineol	0.26	0.16	0.32	0.26	0.26	0.37	0.31	0.21	0.24
decanal	0.04	0.04	0.06	0.04	0.05	0.08	0.22	0.02	0.05
octyl acetate	t	t	t	t	t	t	t	t	t
nerol† + citronellol	0.03	0.02	0.07	0.05	0.04	0.07	0.03	0.01	0.03
neral† + carvone	0.92	0.48	1.72	1.06	1.05	2.47	1.44	0.41	1.34
piperitone	t	t	t	t	t	t	t	t	t
geraniol	0.02	0.01	0.04	0.03	0.02	0.05	0.05	0.01	0.03
geranial† + perillaldehyde	1.51	0.78	2.86	1.76	1.74	4.16	2.42	0.68	2.20
bornyl acetate	t	0.01	0.01	0.01	0.01	0.01	0.01	0.02	t
undecanal	0.01	0.01	0.02	0.02	0.02	0.04	0.02	0.01	0.02
nonyl acetate	t	t	t	t	t	t	t	t	t
methyl geranate	0.01	0.01	0.01	0.01	0.01	0.01	t	0.02	t
citronellyl acetate	0.04	0.03	0.03	0.06	0.05	0.06	0.02	0.06	0.04
neryl acetate	0.30	0.31	0.46	0.53	0.42	0.60	0.39	0.38	0.40
geranyl acetate	0.22	0.17	0.31	0.35	0.34	0.45	0.54	0.49	0.31
dodecanal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
decyl acetate	0.03	0.02	0.03	0.02	0.03	0.04	0.03	0.04	0.03
β-caryophyllene	0.22	0.16	0.23	0.31	0.25	0.44	0.28	0.35	0.17
trans-α-bergamotene	0.40	0.32	0.48	0.31	0.45	0.62	0.42	0.61	0.38
α-humulene	0.02	0.02	0.02	0.03	0.02	0.04	0.03	0.03	0.02
(E)-β-farnesene	0.04	0.03	0.04	0.03	0.04	0.06	0.04	0.05	0.03
β-santalene	0.02	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.01
γ-muurolene	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
germacrene D	0.01	0.01	0.01	0.01	0.01	0.01	0.01	t	0.02
valencene	0.02	0.01	0.02	0.02	0.01	0.06	0.01	0.03	0.01

continued **T-1**

Compound	1	2	3	4	5	6	7	8	9
bicyclogermacrene	0.07	0.04	0.05	0.09	0.05	0.11	0.02	0.02	0.05
(Z)-α-bisabolene	0.04	0.04	0.05	0.03	0.05	0.07	0.05	0.06	0.04
β-bisabolene	0.58	0.47	0.71	0.46	0.67	0.91	0.63	0.88	0.54
(E)-α-bisabolene	0.02	0.01	0.02	0.01	0.02	0.03	0.02	0.03	0.02
tetradecanal	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.05	0.01
2,3-dimethyl-3-(4-methyl-3-pentenyl)-2-norbornanol	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.02
campherenol	0.03	0.02	0.03	0.02	0.03	0.04	0.03	0.04	0.02
α-bisabolol	0.03	0.02	0.03	0.02	0.03	0.05	0.03	0.04	0.02
nootkatone	t	t	t	t	t	0.01	t	t	t

t = trace (< 0.01 percent); †major component of mixture; cultivars: 1. 'Feminello siracusano,' 2. 'Feminello continella,' 3. 'Feminello S. Teresa,' 4. 'Feminello fior d'arancio,' 5. 'Feminello Dosaco,' 6. 'Feminello incappucciato,' 7. 'Monachello,' 8. 'Interdonato,' 9. 'Fino'

myrcene (2.17 percent)
p-cymene (1.46 percent)
limonene (75.73 percent)
γ-terpinene (9.19 percent)
methyl thymol (2.28 percent)

It is unusual to see a lemon oil that is rich in methyl thymol and devoid of the carbonyl aroma-characteristic compounds.

A commercial sample of lemon oil of unknown origin was analyzed by Kubeczka and Formacek (2002) using GC and ^{13}C-NMR. The composition of the oil was reported to be as follows:

α-pinene (2.06 percent)
camphene (0.06 percent)
β-pinene (12.27 percent)

Percentage composition of the peel oils of some lemon cultivars **T-2**

Compound	1	2	3	4	5	6	7	8	9
α-thujene	0.2	0.2	0.3	0.3	0.4	0.3	0.3	0.3	0.4
α-pinene	1.6	1.6	1.7	1.7	1.4	1.6	2.0	2.2	2.3
camphene	t	-	0.1	t	0.1	t	0.1	0.1	0.1
β-pinene	11.7	11.2	13.6	12.3	14.2	11.6	15.4	15.8	15.5
sabinene	2.0	1.7	1.9	1.8	2.2	1.7	2.2	2.0	1.9
δ-3-carene	-	-	t	-	-	t	-	t	t
myrcene	1.5	1.2	1.2	1.1	1.4	1.1	1.1	1.1	1.1
α-phellandrene	t	-	t	-	t	-	-	-	t
α-terpinene	0.1	-	-	-	0.2	-	-	-	0.1
limonene	70.5	65.7	63.3	63.0	62.6	61.9	58.3	48.6	
β-phellandrene	0.3	0.4	0.4	0.3	0.4	0.3	0.5	0.5	0.6
(Z)-β-ocimene	t	t	t	t	t	t	t	t	t
γ-terpinene	6.3	2.3	3.0	3.2	11.1	2.4	3.4	1.3	6.8
(E)-β-ocimene	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
p-cymene	0.9	5.9	5.4	6.0	0.1	7.1	6.8	7.8	2.2
terpinolene	0.3	0.1	0.1	0.1	0.5	0.1	0.1	t	0.3
octanal	t	0.1	0.1	0.1	t	0.1	-	0.1	0.1
6-methyl-5-hepten-2-one	-	t	t	t	-	t	t	t	t
nonanal	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.3
α-p-dimethylstyrene	-	-	t	-	-	-	-	-	-
cis-limonene oxide	t	0.3	0.1	0.5	-	0.4	0.2	0.1	t
trans-limonene oxide	-	0.5	0.2	0.5	-	0.6	0.4	0.5	t
trans-sabinene hydrate	t	0.1	t	0.1	0.1	0.1	0.1	0.1	0.1
trans-linalool oxide†	-	-	t	-	-	t	-	-	-
octyl acetate	-	-	-	-	-	-	-	-	t
citronellal	t	0.1	0.1	0.1	0.1	t	t	0.1	0.2
decanal	-	t	-	-	t	-	-	t	t
linalool	0.2	0.3	0.3	0.3	0.2	0.3	0.2	0.3	0.4
cis-p-menth-2-en-1-ol	-	-	-	-	-	-	-	0.1	-
bornyl acetate	-	-	-	-	-	-	t	-	-
trans-α-bergamotene	0.3	0.5	0.5	0.4	0.3	0.6	0.3	0.6	1.3
β-caryophyllene	0.2	t	0.1	t	0.2	t	0.1	-	0.7
terpinen-4-ol	t	t	0.1	t	t	t	t	t	t
trans-p-menth-2-en-1-ol	-	-	-	t	-	0.1	t	0.1	-
citronellyl acetate	t	t	-	-	t	-	-	t	0.2
(E)-β-farnesene	t	t	t	t	t	t	t	t	0.2
α-humulene	-	-	t	t	t	-	t	-	-
neral	0.6	1.0	1.1	1.3	0.7	1.3	0.5	0.5	1.5
α-terpineol	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3
germacrene D	-	-	-	-	t	-	-	-	-
β-bisabolene	0.4	0.8	0.7	0.6	0.5	0.9	0.5	0.9	2.0
α-bisabolene*	-	-	-	-	-	-	-	0.2	-
neryl acetate	0.4	0.6	0.5	0.5	0.5	0.5	0.4	0.6	3.9
geranial	1.3	1.9	2.0	2.5	1.3	2.6	1.0	1.1	2.9
geranyl acetate	0.4	0.8	0.8	0.6	0.8	1.0	0.5	0.7	3.2
citronellol	-	-	t	-	t	-	-	-	t
nerol	-	-	t	-	t	-	-	-	0.1
geraniol	-	t	t	t	0.1	t	-	-	0.1
caryophyllene oxide	-	0.2	0.1	0.1	-	0.2	0.3	0.2	t
spathulenol	-	-	-	-	-	-	-	0.1	-
thymol	-	-	-	t	-	-	-	-	-

*correct isomer not identified; †furanoid form; t = trace (< 0.1 percent); cultivars: 1. 'Eureka,' 2. 'Fino,' 3. 'Berna,' 4. 'Santa Teresa,' 5. 'Lisbon,' 6. 'Corpacia,' 7. 'Lapithou,' 8. 'Menton,' 9. 'Panaché'

Comparison between the percentage composition of lemon oil by conventional and fast GC analysis **T-3**

Compound	Conventional GC analysis	Fast GC analysis	Compound	Conventional GC analysis	Fast GC analysis
tricyclene	0.01	0.01	nerol	0.04	0.03
α-thujene	0.42	0.43	neral	0.77	0.77
α-pinene	1.89	1.89	geraniol	0.03	0.03
camphene	0.06	0.06	geranial	1.29	1.30
sabinene	1.97	1.90	perillaldehyde	0.02	0.02
β-pinene	12.56	12.40	undecanal	0.03	0.04
myrcene	1.47	1.51	nonyl acetate	0.01	0.01
octanal + α-phellandrene	0.12	0.12	methyl geranate	0.01	0.02
α-terpinene	0.16	0.17	citronellyl acetate	0.03	0.04
p-cymene	0.35		neryl acetate	0.44	0.46
limonene	66.05	}66.57	linalyl isobutyrate	0.01	0.01
(Z)-β-ocimene	0.08	0.09	geranyl acetate	0.35	0.36
(E)-β-ocimene	0.12	0.13	sesquithujene	0.02	0.03
γ-terpinene	9.16	8.94	β-caryophyllene	0.21	0.20
cis-sabinene hydrate	0.03	0.03	*trans*-α-bergamotene	0.38	0.40
terpinolene	0.35	0.36	α-humulene	0.05	0.04
linalool	0.12	0.13	β-santalene	0.01	0.02
nonanal	0.12	0.12	germacrene D	0.02	0.03
cis-limonene oxide	t	0.01	valencane	0.05	0.05
trans-limonene oxide	t	0.01	bicyclogermacrene	0.04	0.05
camphor	0.01	0.01	β-bisabolene	0.57	0.58
citronellal	0.10	0.11	γ-bisabolene*	0.02	0.02
borneol	0.01	0.01	2,3-dimethyl-3-(4-methyl-3-pentenyl)-2-norbornanol	0.02	0.02
terpinen-4-ol	0.05	0.06	campherenol	0.02	0.03
p-cymen-8-ol	0.01	0.01	α-bisabolol	0.03	0.03
α-terpineol	0.17	0.17	nootkatone	0.01	0.01
decanal	0.05	0.05			
octyl acetate	t	0.01			
citronellol	0.02	0.04			

t = trace (< 0.01 percent); *correct isomer not identified

sabinene (1.92 percent)
δ-3-carene (0.02 percent)
myrcene (1.39 percent)
α-phellandrene (0.03 percent)
α-terpinene (0.10 percent)
limonene (68.36 percent)
β-phellandrene (0.48 percent)
(Z)-β-ocimene (0.07 percent)
γ-terpinene (7.39 percent)
(E)-β-ocimene (0.13 percent)
p-cymene (0.98 percent)
terpinolene (0.27 percent)
octanal (0.04 percent)
6-methyl-5-hepten-2-one (0.04 percent)
nonanal (0.05 percent)
cis-limonene oxide (0.03 percent)
trans-limonene oxide (0.04 percent)
citronellal (0.04 percent)
decanal (0.03 percent)
linalool (0.21 percent)
trans-α-bergamotene (0.24 percent)
β-caryophyllene + terpinen-4-ol (0.24 percent)
neral (0.46 percent)
α-terpineol (0.21 percent)
neryl acetate (0.35 percent)
β-bisabolene (0.40 percent)
geranial (0.85 percent)
carvone (0.03 percent)
geranyl acetate (0.44 percent)
nerol (0.05 percent)
geraniol (0.05 percent)

A lemon peel oil that was produced by hydrodistillation from fresh fruit grown in India of an unknown cultivar was analyzed using GC and GC/MS by Mahalwal and Ali (2003). The oil composition was found to be as follows:

camphene (12.3 percent)
sabinene (1.9 percent)
α-phellandrene (6.5 percent)
δ-3-carene (1.8 percent)
p-cymene (0.7 percent)
limonene (37.2 percent)
undecane (0.1 percent)
trans-pinocarveol (0.2 percent)
terpinen-4-ol (6.4 percent)
α-terpineol (11.2 percent)

verbenone (0.4 percent)
terpinolene (2.3 percent)
sabina ketone (0.5 percent)
β-elemene (0.6 percent)
β-caryophyllene (1.0 percent)
valencene (2.1 percent)
β-selinene (0.4 percent)
α-selinene (3.0 percent)
δ-cadinene (0.4 percent)
(Z)-α-bisabolene (0.6 percent)
ledol (0.3 percent)
caryophyllene oxide (2.5 percent)
(E)-nerolidol (2.4 percent)
nerolidol* (1.8 percent)
viridiflorol (0.4 percent)
T-muurolol (0.3 percent)

*correct isomer not identified

It should be pointed out that the authors reported that L-limonene was found, although they did not even comment on this. Also, it is worth noting that the authors erroneously identified 4-ethyl-1,2-dimethyl-benzene, 2-methyl-1,1-methyl-ethyl propionate and 2-ethylhexyl phthalate (a plasticizer) in the oil. Finally, in comparison with other lemon oils, the composition of this one is peculiar, to say the least; nevertheless, it is included for completeness.

A comparison between fast and conventional GC analyses of lemon oil was reported by Mondello et al. (2003). The authors used a 30 m x .25 mm x 0.25 µm film thickness polar capillary column for conventional GC and a 10 m x 0.1 mm x 0.10 µm film thickness polar capillary column for fast GC. Similar separations were achieved with either column. However, it took 46 min for the conventional analysis, while it took only 9 min for the fast analysis. A summary of the quantitative results of these analyses is presented in T-3.

Verzera et al. (2004) compared the composition of lemon oils produced from organically grown trees and trees grown under standard (normal) agricultural practices in Sicily (Italy). The average results from 10 analyses can be seen in T-4. In addition, the authors analyzed the oils for organo-phosphorus pesticide residues. The results of these analyses are presented in T-5.

A.M. Ayedoun, P.V. Sossou, M. Mandarowicz and P.A. Leclercq, *Volatile constituents of the peel and leaf oils of* Citrus limon *L. Burm. f. from Benin.* J. Essent. Oil Res., **8**, 441-444 (1996).

E.G. Haggag, S.M.A. Wahab, S.M. El-Zalabany, E.A.A. Moustafa, E.M. El-Kherasy and T.J. Mabry, *Volatile oils and pectins from* Citrus aurantifolia *(lime) and* Citrus limonia *(lemon).* Asian J. Chem., **10**, 828-833 (1998).

M. Sawamura, S.H. Sun, K. Ozaki, J. Ishikawa and H. Ukeda, *Inhibitory effects of citrus essential oils and their components on the formation of N-nitrosodimethylamine.* J. Agric. Food Chem., **47**, 4668-4672 (1999).

J. Wright, *Essential Oils.* In: *Food Flavorings*. 3rd Edn. Edit, P.R. Ashurst, 24-25, Aspen Publ., Gaithersburg, MD (1999).

Average percentage composition of cold-pressed lemon oils produced under different agricultural practices **T-4**

Compound	Organic oils	Standard oils	Compound	Organic oils	Standard oils
tricyclene	0.01	0.01	nerol + citronellol	0.03	0.03
α-thujene	0.47	0.44	neral	1.03	0.84
α-pinene	2.07	1.86	piperitone	t	t
camphene	0.06	0.05	geraniol	0.04	0.03
sabinene + β-pinene	12.97	11.18	geranial	1.74	1.43
6-methyl-5-hepten-2-one	0.01	t	perillaldehyde	t	t
myrcene	1.70	1.67	bornyl acetate	0.01	t
octanal	0.07	0.06	undecanal	0.02	0.02
α-phellandrene	0.05	0.04	nonyl acetate	t	t
δ-3-carene	0.01	t	methyl geranate	t	t
α-terpinene	0.21	0.19	citronellyl acetate	0.03	0.03
p-cymene	0.08	0.07	neryl acetate	0.44	0.41
limonene	65.59	69.64	geranyl acetate	0.39	0.33
(Z)-β-ocimene	0.07	0.06	dodecanal	0.01	0.01
(E)-β-ocimene	0.13	0.12	decyl acetate	0.03	0.03
γ-terpinene	9.88	9.01	β-caryophyllene	0.22	0.23
cis-sabinene hydrate	0.03	0.03	*trans*-α-bergamotene	0.40	0.37
octanol	t	t	α-humulene	0.02	0.03
terpinolene	0.41	0.38	(Z)-β-farnesene	0.04	0.03
trans-sabinene hydrate	0.02	0.02	(Z)-β-santalene	0.02	0.01
linalool	0.11	0.11	γ-muurolene	0.01	0.01
nonanal	0.09	0.07	germacrene D	0.01	0.01
cis-limonene oxide	t	t	valencene	0.02	0.02
trans-limonene oxide	t	t	bicyclogermacrene	0.06	0.05
camphor	0.01	0.01	β-bisabolene	0.57	0.53
citronellal	0.13	0.14	γ-elemene[†]	0.02	0.02
borneol	0.01	0.01	tetradecanal	0.01	0.01
terpinen-4-ol	0.03	0.03	norbonanol	0.02	0.01
α-terpineol	0.14	0.13	campherenol	0.02	0.02
decanal	0.05	0.04	α-bisabolol	0.02	0.02
octyl acetate	t	t	nootkatone	t	t

[†]incorrect identification based on GC elution order; t = trace (< 0.01 percent)

A. Verzera, C. Russo, G. La Rosa, I. Bonaccorsi and A. Cotroneo, *Influence of cultivar on lemon oil composition.* J. Essent. Oil Res., **13**, 343-347 (2001).

S.A. Vekiari, E.E. Protopapadakis, P. Papadopoulou, D. Papanicolaou, C. Panou and M. Vamvakias, *Compositional and seasonal variation of the essential oil from leaves and peel of a Cretan lemon variety.* J. Agric. Food Chem., **50**, 147-153 (2002).

M-L. Lota, D. De Rocca Serra, F. Tomi, C. Jacquemond and J. Casanova, *Volatile components of peel and leaf oils of lemon and lime species.* J. Agric. Food Chem., **50**, 796-805 (2002).

C.N. Gonzalez de, F. Sanchez and A. Quintero, *Chemotaxonomic value of essential oil compounds in* Citrus *species.* Acta Hort., **576**, 49-51 (2002).

K-H. Kubeczka and V. Formacek, *Essential oils analysis by capillary gas chromatography and carbon - 13NMR spectroscopy.* 2nd Edn., 167-172, J. Wiley & Sons, NY (2002).

Organo-phosphorus pesticide residues in lemon oils produced in Sicily (Italy) **T-5**

Pesticide	Amount found in ppm	
	Organic oils	Standard oils
methyl parathion	0.17-0.30	1.40-1.46
ethyl parathion	0-0.15	0.65-0.70
quinalphos	-	0.13-0.20
methidithion	0-0.29	0.82-0.86
methyl chloropyriphos	-	0.04-0.10
ethyl azinphos	-	0.48-0.53

V.S. Mahalwal and M. Ali, *Volatile constituents of the fruit peels of* Citrus limon *(Linn.) Burm. f.* J. Essent. Oil Bear. Plants, **6**(1), 31-35 (2003).

L. Mondello, A. Casilli, P.Q. Tranchida, L. Cicero, P. Dugo and G. Dugo, *Comparison of fast and conventional GC analysis for citrus oils.* J. Agric. Food Chem., **51**, 5602-5606 (2003).

A. Verzera, A. Trozzi, G. Dugo, G. Di Bella and A. Cotroneo, *Biological lemon and sweet orange essential oil composition.* Flav. Fragr. J., **19**, 544-548 (2004).

Chirality

Using chiral GC analysis, Hara et al. (1999) determined that the enantiomeric distribution of some selected compounds in a sample of lemon oil was as follows:

(1R,5R)-(+)-α-pinene (35.3 percent):(1S,5S)-(-)-α-pinene (64.7 percent)
(1R,5R)-(+)-β-pinene (7.7 percent):(1S,5S)-(-)-β-pinene (92.3 percent)
(4R)-(+)-limonene (98.3 percent):(4S)-(-)-limonene (1.7 percent)
(3S)-(+)-linalool (46.5 percent):(3R)-(-)-linalool (53.5 percent)
(4R)-(+)-α-terpineol (25.3 percent):(4S)-(-)-α-terpineol (74.7 percent)
(3R)-(+)-citronellal (11.9 percent):(3S)-(-)-citronellal (88.1 percent)

The cold-pressed oils of the 'Eureka,' 'Monachero' and 'Feminello' cultivars of lemons grown in Japan were analyzed using chiral GC by Mitiku et al. (2001). The enantiomeric distribution of the four major monoterpene hydrocarbons was determined to be as follows:

(4R)-(+)-limonene (98.46-98.88 percent):(4S)-(-)-limonene (1.12-1.54 percent)
(1R,5R)-(+)-α-pinene (24.39-48.34 percent):(1S,5S)-(-)-α-pinene (53.66-75.61 percent)
(1R,5R)-(+)-sabinene (13.56-23.33 percent):(1S,5S)-(-)-sabinene (76.67-86.44 percent)
(1R,5R)-(+)-β-pinene (3.42-10.39 percent):(1S,5S)-(-)-β-pinene (89.61-96.58 percent)

Lorenzo et al. (2002) determined that the enantiomeric distribution of some selected compounds of lemon oil was as follows:

(1R,5R)-(+)-α-pinene (30.2 percent):(1S,5S)-(-)-α-pinene (69.8 percent)
(1R,5R)-(+)-sabinene (14.2 percent):(1S,5S)-(-)-sabinene (85.8 percent)
(1R,5R)-(+)-β-pinene (5.5 percent):(1S,5S)-(-)-β-pinene (94.5 percent)
(4R)-(+)-limonene (98.4 percent):(4S)-(-)-limonene (1.6 percent)
(3S)-(+)-linalool (41.8 percent):(3R)-(-)-linalool (58.2 percent)
(4S)-(+)-terpinen-4-ol (21.9 percent):(4R)-(-)-terpinen-4-ol (78.1 percent)
(4R)-(+)-α-terpineol (20.1 percent):(4S)-(-)-α-terpineol (79.9 percent)

F. Hara, S. Shinohara, T. Toyoda and T. Kanisawa, *The analysis of some chiral components in Citrus volatile compounds.* Proceedings 43rd TEAC Meeting, Oita, Japan, 360-362 (1999).

S.B. Mitiku, H. Ukeda and M. Sawamura, *Enantiomeric distribution of α-pinene, β-pinene, sabinene and limonene in various citrus essential oils.* In: *Food Flavors and Chemistry. Advances of the New Millennium.* Edits., A.M. Spanier, F. Shahidi, T.H. Parliment, C. Mussinan, C-T. Ho and E. Tratras Contis, 216-231, Royal Soc. Chem. Cambridge (2001).

D. Lorenzo, D. Paz, I. Loayza, R. Vila, S. Canigueral and E. Dellacassa, *Enantiomeric analysis in the characterization and evaluation of aromatic plants.* Ing. Cienc. Quim., **21**(2), 14-19 (2002).

Jamrosa oil

Jamrosa oil is available in India and, to a lesser extent, outside of India. It is obtained from a grass; a hybrid strain of *Cymbopogon nardus* var. *confertiflorus* x *C. jwarancusa*. Six harvests of the grass can be obtained annually to provide a yield of ca 240 kg/ha with a total geraniol content of 80.3-81.6 percent [Chandra et al. (1992)]. Although jamrosa oil was introduced as a substitute for palmarosa oil, the presence of citral (neral/geranial) in amounts of 6-8 percent made it less desirable as a source of geraniol.

Kak et al. used gamma rays to select genotypes that were deficient in citral, with levels of 1.4 percent and 2.5 percent in the oils of two selections. Chand et al. (1996) determined that an oil yield of ca 540 L (490 kg)/ha could be attained with jamrosa (RRL-82) grown in the Hyderabad region of India. The main constituents of this oil were geraniol (66.2-71.5 percent), geranyl acetate (7.8-16.1 percent) and linalool (1.3-2.8 percent). The authors did not comment on the citral content of the oil.

An oil of jamrosa that was screened against mosquito vectors of malaria, filariasis and dengue fever was subjected to analysis by Tyagi et al. (1998). The components that were characterized in this oil were:

α-pinene (6.28 percent)
camphene (8.12 percent)
β-pinene (0.12 percent)
sabinene (0.25 percent)
myrcene (12.74 percent)
limonene (5.96 percent)
1,8-cineole (0.35 percent)
(Z)-β-ocimene (1.11 percent)
(E)-β-ocimene (0.81 percent)
p-cymene (0.08 percent)
terpinolene (0.39 percent)
camphor (0.35 percent)
linalool (0.76 percent)
β-caryophyllene (2.14 percent)
trans-α-bergamotene (0.16 percent)
gymnomitrene‡ (0.14 percent)
δ-terpineol (1.10 percent)
borneol + α-terpineol (7.23 percent)
β-selinene (1.64 percent)
zingiberene (2.82 percent)
cuparene (1.04 percent)
p-cymen-8-ol (7.47 percent)
caryophyllene oxide (0.26 percent)
methyl eugenol (3.76 percent)
methyl isoeugenol* (1.46 percent)
neointermedeol 5 (0.20 percent)
cadinol* (< 0.01 percent)
elemicin (22.95 percent)
(Z)-asarone (0.17 percent)

(E)-isoasarone† (3.42 percent)
3,4,5-trimethoxybenzaldehyde (0.04 percent)

*correct isomer not identified; †also known as (E)-asarone or α-asarone; ‡also known as β-barbatene

The fact that this oil (a) does not contain geraniol as the main constituent; and (b) elemicin and myrcene were characterized as the main constituents, it would appear that the authors analyzed an oil that was either not jamrosa or was a chemotypic form.

An oil of jamrosa was reported (2004) to possess the following composition:

m-cymene† (0.53 percent)
δ-3-carene (0.40 percent)
limonene (0.23 percent)
(Z)-β-ocimene (0.28 percent)
(E)-β-ocimene (3.78 percent)
linalool (1.71 percent)
(E,E)-allo-ocimene (0.19 percent)
citronellal (1.01 percent)
citrathal‡ (0.28 percent)
α-terpineol (0.14 percent)
methyl chavicol (0.25 percent)
citronellol (0.62 percent)
geraniol (52.16 percent)
piperitone (3.23 percent)
geranial (0.20 percent)
citronellyl acetate (0.25 percent)
eugenol (0.34 percent)
geranyl acetate (20.71 percent)
β-elemene (0.21 percent)
β-caryophyllene (0.96 percent)
cis-α-bergamotene (0.34 percent)
(E)-isoeugenol (0.14 percent)
α-humulene (0.15 percent)
germacrene D (0.46 percent)
α-muurolene (0.17 percent)
γ-cadinene (0.16 percent)
δ-cadinene (0.42 percent)
geranyl butyrate (0.66 percent)
geranyl hexanoate (0.59 percent)

†incorrect identification based on GC elution order; ‡this reviewer does not know what the structure of this compound is

In addition, compounds found in amounts less than 0.10 percent, such as α-pinene, camphene, 6-methyl-5-hepten-2-one, β-pinene, myrcene, α-phellandrene, α-terpinene, p-cymene, 1,8-cineole, 2,6-dimethyl-5-heptenal, γ-terpinene, octanol, terpinolene, rosefuran, terpinen-1-ol, an allo-ocimene isomer, isopulegol, rosefuran epoxide, decanal, nerol, neral, citronellyl formate, α-cubebene, β-bourbonene, (Z)-isoeugenol, β-sesquiphellandrene, dihydroagarofuran, α-parnasinsene, cadina-1,4-diene, elemol, caryophyllene oxide, γ-eudesmol and T-muurolol, also were reported as constituents of jamrosa oil.

S. Chandra, A.K. Shahi and A. Singh, *Harvest management practices on jamrosa grass (RRL-82).* Indian Perfum., **36**(2), 88-92 (1992).

S.N. Kak, R.L. Jolly and B.L. Kaul, *Introduction and isolation of citral deficient genotypes of jamrosa (*Cymbopogon *sp.).* Indian Perfum., **37**(3), 218-220 (1993).

S. Chand, P.N. Kaul, A.K. Bhattacharya, K. Singh and B.B. Rajeswara Rao, *Response of jamrosa (*Cymbopogon *sp.) to spacings, FYM, nitrogen, phosphorus and zinc.* Indian Perfum., **40**(2), 41-46 (1996).

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

Anon, *GC/MS Report. Jamrosa oil.* Indian Perfum., **48**(4), 405 (2004).

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