



Progress in Essential Oils

Brian M. Lawrence, Consultant

56

Cajuput Oil

Melaleuca cajuputi Powell (syn. *M. minor* Smith) is a Myrtaceae tree, which is true source of cajuput oil not *M. leacodendron*. This earlier nomenclatural confusion stems from the fact that the trees of both *Melaleuca* species are known in Indonesia and Malaysia as gelam. *Melaleuca cajuputi* trees are found in northern Australia, Papua New Guinea, Indonesia, Malaysia, Thailand and Vietnam. The oil produced by stem distillation of the leaves of *M. cajuputi* and its commercial value is judged on its 1,8-cineole content. Lawrence (1992) analyzed a number of commercial samples of cajuput oil of Indonesian origin and found that the 1,8-cineole content ranged from 55.6–69.1%.

A commercial sample of cajuput oil was subjected to analysis using GC and GC/MS by Reichling et al. (1999). The constituents identified in this oil were as follows:

α -pinene (5.4%)
 camphene (0.2%)
 β -pinene (0.4%)
 myrcene (0.3%)
 α -phellandrene (0.4%)
 α -terpinene (1.7%)
 p-cymene (0.6%)
 1,8-cineole (61.2%)
 γ -terpinene (0.7%)
 terpinolene (1.9%)
 terpinen-4-ol (0.2%)
 α -terpineol (10.6%)
 γ -terpineol (3.2%)
 longifolene (0.4%)
 β -caryophyllene (0.1%)

A commercial sample of cajuput oil that was purchased in Hungary was

determined by Hethelyi et al. to possess the following main components:

α -pinene (3.2–5.3%)
 β -pinene (1.5–4.4%)
 α -terpinene (0–11.1%)
 1,8-cineole (56.4–61.9%)
 γ -terpinene (0.1–2.9%)
 linalool (0.1–3.7%)
 α -terpineol (0.9–9.1%)
 terpinen-4-ol (0.1–1.3%)
 β -caryophyllene (0.1–5.4%)

Christoph et al. (2000) determined that a commercial sample of cajuput possessed the following composition:

α -pinene (5.5%)
 α -thujene (0.7%)
 β -pinene (3.2%)
 myrcene + α -phellandrene (1.1%)
 α -terpinene (0.4%)
 limonene (7.0%)
 1,8-cineole (53.5%)
 γ -terpinene (1.9%)
 p-cymene (2.2%)
 terpinolene (1.1%)
 linalool (0.4%)
 β -caryophyllene (3.9%)
 terpinen-4-ol (0.7%)
 aromadendrene (0.2%)
 α -humulene (1.8%)
 α -terpineol (8.5%)
 β -selinene (1.6%)
 α -selinene (1.3%)

Sakasegawa et al. (2003) collected leaves of *M. cajuputi* from three different locations in Indonesia. The first was from an experimental garden near the Gashing River, the second was on the roadside near Yogyakarta and the third was from a factory that produces cajuput oil in Sukum, Ponoroga. Oils produced from these

leaves were separately analyzed using GC/MS as their only method of analysis. The lab-distilled oils and one commercial oil were found to range in composition as follows:

(E)- β -ocimene[†] (0–5.8%)
 α -pinene (0–1.8%)
 camphene (0–0.1%)
 β -pinene (0.7–3.6%)
 myrcene (0.6–1.6%)
 α -terpinene (0–0.2%)
 limonene (1.4–2.6%)
 1,8-cineole (31.8–69.4%)
 γ -terpinene (0–1.5%)
 o-cymene (0–0.3%)
 terpinolene (0–1.0%)
 β -caryophyllene (0–9.1%)
 α -humulene (0.9–4.6%)
 isocaryophyllene (0–4.9%)
 α -guaiene (0–1.3%)
 allo-aromadendrene (0–4.4%)
 α -bulnesene (0–2.7%)
 terpinen-4-ol (0–0.4%)
 linalyl propionate^a (0–8.8%)
 α -terpineol (0–16.6%)
 β -selinene (0–0.3%)
 δ -cadinene (0–0.1%)
 aromadendrene[†] (0–1.1%)
 caryophyllene oxide (0–0.8%)
 globulol (0–10.4%)
 ledol (0–0.7%)
 ledene[†] (0–4.9%)
 α -muurolol (0–1.0%)
 spathulenol (0–0.2%)
 α -copaene[†] (0–1.2%)
 aromadendrene[†] (0–1.5%)

^acorrect isomer not identified

[†]incorrect identification based on GC elution order

^afound only in a commercial cajuput oil

Oils produced from leaves of *M. cajuputi* from other collection sites were found to be rich in sesquiterpenes, devoid of 1,8-cineole and of little value as a source of cajuput oil.

Milchard et al. (2004) examined a commercial oil of cajuput of Vietnamese origin. The components identified in this oil were as follows:

α -pinene (2.1%)
 β -pinene (1.5%)
 myrcene (2.0%)
 p-cymene (0.7%)
 1,8-cineole (70.8%)
 limonene (3.8%)
 γ -terpinene (1.2%)
 p-mentha-2,4(8)-diene (0.9%)
 linalool (2.7%)
 terpinen-4-ol (0.6%)
 α -terpineol (6.5%)
 β -caryophyllene (0.7%)
 α -humulene (0.5%)

Silva et al. (2007) analyzed a lab-distilled oil of *M. cajuputi* subsp. *cajuputi* that was obtained from an arboretum in Viçosa (Minas Geras, Brazil). Using a combination of GC-FID and GC/MS the oil was found to contain the following constituents:

α -pinene (2.8%)
 β -pinene (0.9%)
 1,8-cineole (43.7%)
 γ -terpinene (0.5%)
 terpinen-4-ol (1.0%)
 α -terpineol (22.6%)
 β -caryophyllene (0.8%)
 ledol (0.6%)
 globulol (7.6%)
 viridiflorol (13.4%)
 T-cadinol (0.6%)

Jajaei et al. (2010) collected leaves of *M. cajuputi* Trengganu (Malaysia) and subjected them to supercritical fluid CO₂ extraction. The extracts produced were analyzed using GC-FID and GC/MS. They were found to be rich sesquiterpenoid compounds; the major ones being β -caryophyllene, humulene epoxide and bulnesol and were therefore an example of a chemotype of cajuput that has not achieved commercial importance.

B.M. Lawrence, unpublished data (1992).

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

E. Hethelyi, G. Takacs, M. Palfine Ledniczky and J. Domokos, *Gas chromatographic investigation of the biologically active components of Melaleuca species and of natural cosmetic components containing tea tree oil*. Olaj. Szappan Kozmet., **49**(1), 25–37 (2000).

F. Christoph, E. Stahl-Biskup and P.-M. Kaulfers, *Death kinetics of Staphylococcus aureus exposed to commercial tea tree oils s.l.* J. Essent. Oil Res., **13**, 98–102 (2001).

M. Sakasegawa, K. Hori and M. Yatagai, Composition and antitermitic activities of essential oils from *Melaleuca* species. J. Wood Sci., **49**, 181–187 (2003).

M.J. Milchard, R. Clery, N. DaCosta, M. Flowerdew, L. Gates, N. Moss, D.A. Moyler, A. Sherlock, B. Stair, J. Webb, J. Wootten and J.J. Wilson, *Application of Gas-Liquid Chromatography to the analysis of essential oils. Fingerprints of 12 essential oils*. Perfum. Flavor., **29**(5), 28–36 (2004).

C.J. Silva, L.C.A. Barbosa, C.R.A. Maltha, A.L. Pinheiro and F.D. Ismail, *Comparative study of the essential oils of seven Melaleuca (Myrtaceae) species grown in Brazil*. Flav. Fragr. J., **22**, 474–478 (2007).

S.M. Jajaei, W.R.W. David, M. Markom, Z. Zakaria, M. Lo Presti, R. Costa, L. Mondello and L. Santi, Extraction of *Melaleuca cajuputi* using supercritical fluid extraction and solvent extraction. J. Essent. Oil Res., **22**, 205–210 (2010).

Cassia Oil

Oils produced from the bark of *Cinnamomum cassia* Presl. that was collected from trees growing in Xijang and Fangcheng counties (Guangxi, China) were the subject of analysis by Xu et al. (2001a). The range in composition of the oils was as follows:

benzaldehyde (0.3–1.5%)
 salicylaldehyde (0–0.4%)
 hydrocinnamaldehyde (0.1–0.7)
 borneol (0–0.4%)
 (Z)-cinnamaldehyde (0.7–1.1%)
 anisaldehyde[†] (0–t)
 2-phenethyl acetate (0–t)
 (E)-cinnamaldehyde (88.1–93.5%)
 α -cubebene (0–1.1%)
 (E)-cinnamyl acetate (0.3–7.6%)
 γ -muurolene (0–1.0%)
 γ -cadinene (0–0.5%)
 o-methoxy-cinnamaldehyde (0.1–0.5%)
 β -bisabolol (0–0.1%)
 T-muurolol (0–0.2%)

[†]probably incorrect identification
 t = trace (<0.05%)

Xu et al. (2001b) examined the lab-distilled oil of dried twigs of *C. cassia* using HPLC and GC/MS. According to the authors, although 47 constituents were identified in the oil, there appeared to be numerous other compounds that had hitherto never been reported as cassia oil constituents. Because their identifications are incorrect, they are not included in this review. As a result, the following

components that are normally characterized in the oil were determined to be as follows:

benzaldehyde (2.9%)
 camphene (0.3%)
 myrcene (0.1%)
 limonene (0.2%)
 2-phenethyl alcohol (t)
 hydrocinnamaldehyde (0.9%)
 α -terpineol (0.2%)
 α -copaene (0.9%)
 (E)-cinnamaldehyde (50.4%)
 coumarin (0.4%)
 t = trace (<0.1%)

He et al. (2005) examined the oils of 15 samples of cassia bark collected in China. They found that the four important components ranged as follows:

(E)-cinnamaldehyde (9.4–93.8)*
 (E)-cinnamic acid (0.2–1.9)
 (E)-cinnamyl alcohol (0–1.8)
 coumarin (0–12.2)
 * = mg/g

An oil of cassia that was screened for its fungicidal properties by Powar and Thaker (2007), was determined to contain the following constituents:

linalool (9.2%)
 (E)-cinnamaldehyde (66.4%)
 eugenol (7.7%)
 (E)-cinnamyl acetate (4.0%)
 eugenyl acetate (0.5%)
 benzyl benzoate (10.2%)
 benzaldehyde (0.2%)
 benzyl alcohol (0.2%)

Based on the above composition the authors of this study should have realized that their oil was adulterated with eugenyl and benzyl derivatives.

As part of an antibacterial screening program of essential oils Rossi et al. (2007) determined that the main constituents of a commercially available sample of cassia oil were as follows:

α -pinene (1.5%)
 p-cymene (3.2%)
 limonene (1.0%)
 β -phellandrene (2.2%)
 linalool (4.9%)
 terpinen-4-ol (1.0%)
 α -terpineol (1.0%)
 (E)-cinnamaldehyde (64.6%)

eugenol (1.6%)
 α -copaene (1.2%)
 (E)-cinnamyl acetate (3.0%)
 β -caryophyllene (2.9%)
 caryophyllene oxide (1.5%)

As this oil was found to contain eugenol (which is not a normal constituent of cassia oil) it is suggested that the oil that was screened was not 100% natural.

Koroch et al. (2007) determined that a commercial sample of cassia oil contained the following major components:

α -pinene (0.2%)
 (E)-cinnamaldehyde (92.3%)
 (E)-cinnamyl acetate (1.1%)

Using a stable isotope dilution assay based on liquid chromatography-tandem mass spectrometry Rychlik (2008) determined that cassia contained 1380 mg/kg of coumarin.

Wang et al. (2009) found that an oil of the leaves of *C. cassia* contained:

(E)-cinnamaldehyde (30.4%)
 o-methoxycinnamaldehyde (25.4%)
 coumarin (6.4%)

Y. Xu, B-Q. Chen, J-K. Ding, Z. Yu, C-M. He, Y-H. Huang, Z-H. Chen and J-N. Zheng, *Cultivation of Cinnamomum cassia Pres. and analysis of its essential oil*. Xiangliao Xiangjing Huazhuangpin, (4), 4-9 (2001a).

C-J. Xu, Y-Z. Liang, Y-Q. Song and J-G Li, *Resolution of the essential constituents of Ramulus cinnamomi by an evolving chemometric approach*. Fres. J. Anal. Chem., **371**, 331-336 (2001b).

Z-D. He, C-F. Qiao, Q-B. Han, C-L. Cheng, H-X. Xu, R-W. Jiang, P-P-H. But and P-C. Shaw, *Authentication and Quantitative analysis on the chemical profile of cassia bark (cortex cinnamomi) by high-pressure Liquid chromatography*. J. Agric. Food Chem., **53**, 2424-2428 (2005).

V.C. Pawar and V.S. Thaker, *Evaluation of the anti-Fusarium oxysporum f. sp. cicer and anti-Alternaria porri effects of some essential oils*. World J. Microbiol. Biotechnol., **23**, 1099-1106 (2007).

P-G. Rossi, L. Berti, J. Panighi, A. Luciani, J. Maury, A. Muselli, D. de Rocca Serra, M. Gonny and J-M. Bolla, *Antibacterial action of essential oils from Corsica*. J. Essent. Oil Res., **19**, 176-182 (2007).

A. Koroch, L. Ranarivelo, O. Behra, H.R. Juliani and J.E. Simon, *Quality attributes of Ginger and cinnamon essential oils from Madagascar*. In: *Issues in New Crops and New uses*. Edits., J. Janick and A. Whipkey, pp. 338-341, ASHS Press, Alexandria, VA (2007).

M. Rychlik, *Quantification of free coumarin and its liberation from glucosylated precursors by stable isotope dilution assays based on liquid chromatography-tandem mass spectrometric detector*. J. Agric. Food Chem., **56**, 796-801 (2008).

R. Wang, R-J. Wang and B. Yang, *Extraction of essential oils from five cinnamon leaves and identification of their volatile compositions*. Innov. Food Sci. Emerging Technol., **10**, 289-292 (2009).

Tea Tree Oil

It is estimated that the current production of tea tree oil is ca. 540-580

metric tonnes with greater than 95% being produced in Australia.

Southwell et al. (1993) examined the antimicrobial activity of tea tree oil (ex *Melaleuca alternifolia* Cheel) to determine whether the 1,8-cineole level had any effect on the oils activity. They found that higher concentrations of 1,8-cineole were not inhibitory to the activity but if the terpinen-4-ol level fell below 30% then the activity decreased. The main constituents of the oils they examined were:

α -pinene (2.5–2.8%)
 α -terpinene (7.6–8.8%)
 1,8-cineole (4.1–5.3%)
 γ -terpinene (18.4–18.9%)
 terpinen-4-ol (39.0–42.0%)
 α -terpineol (3.3–3.5%)
 sesquiterpenes (<5.0%)

Christoph et al. (2001) analyzed a commercial oil of tea tree and determined that it possessed the following composition:

α -pinene (2.1%)
 α -thujene (0.7%)
 β -pinene (0.6%)
 sabinene (0.6%)
 myrcene + α -phellandrene (2.0%)
 α -terpinene (11.7%)
 limonene (2.6%)
 β -phellandrene (0.5%)
 1,8-cineole (3.2%)
 γ -terpinene (17.9%)
 p-cymene (4.6%)
 terpinolene (3.7%)
 terpinen-4-ol (36.1%)
 aromadendrene (1.0%)
 allo-aromadendrene (0.5%)
 viridiflorene (1.2%)
 α -terpineol (3.0%)
 bicyclogermacrene (0.7%)
 δ -cadinene (1.4%)

Wyllie et al. (2001) used gas chromatographic atomic emission detection (GC-AED) and gas chromatographic olfactometry (GC-O) techniques combined with solid phase microextraction (SPME) to examine the presence of trace odor active constituents of tea tree oil, conventional analysis of four commercial samples of tea tree oil using GC-FID revealed that the oil compositions varied as follows:

α -pinene (2.2–2.6%)
 sabinene (0.3–0.7%)
 α -terpinene (8.4–10.2%)
 p-cymene (1.7–4.4%)
 limonene (0.9–1.1%)
 1,8-cineole (2.2–3.9%)
 γ -terpinene (18.9–20.7%)
 terpinolene (3.3–3.7%)
 terpinen-4-ol (37.5–41.1%)
 α -terpineol (2.7–3.2%)
 aromadendrene (1.1–1.5%)
 δ -cadinene (1.0–1.5%)
 globulol (0.4–0.6%)
 viridiflorol (0.3–0.5%)

Headspace analysis of the few oils revealed the additional charac-

terization of α -thujene, myrcene, α -phellandrene and β -phellandrene. A GC/MS analysis of the non-terpenoid fraction of a typical tea tree oil headspace revealed the further tentative characterization by GC/MS and retention times of ethanol, acetone, isobutanol, 2-butanone, ethyl acetate, 2-methylbutanal, 2-pentanone, ethylfuran, toluene, octane, hexanal, (Z)-3-hexenol and dimethyl disulphide. The authors further noted that 2-methylbutanal, dimethyl disulphide and hexanal could have an effect on the overall odor character of tea tree oil.

Russell and Southwell (2003) determined that when screening tea tree seedlings for potential as rootstock for essential oil production analysis of the leaves is best done at 16–20 weeks of age which is just prior to transplanting. At that time analysis of the lab-distilled oil produced results from which rootstock selection could be used to predict the oil composition of the plants.

A commercial sample of tea tree oil was examined for its antimicrobial characteristics by Jirovetz et al. (2005). The composition of this oil was determined to be as follows:

(Z)-3-hexenol (0.1%)
 α -thujene (0.5%)
 α -pinene (2.3%)
 camphene (0.1%)
 sabinene (0.1%)
 β -pinene (1.1%)
 myrcene (0.9%)
 α -phellandrene (0.4%)
 α -terpinene (9.0%)
 p-cymene (5.3%)
 limonene (1.3%)
 β -phellandrene (0.2%)
 1,8-cineole (4.4%)
 γ -terpinene (23.0%)
 cis-sabinene hydrate (0.1%)
 terpinolene (3.6%)
 trans-sabinene hydrate (0.1%)
 linalool (0.2%)
 p-cymenene (0.1%)
 cis-p-menth-2-en-1-ol (0.1%)
 trans-p-menth-2-en-1-ol (0.1%)
 terpinen-4-ol (38.1%)
 α -terpineol (2.9%)
 trans-piperitol (0.1%)
 methyl eugenol (0.1%)
 α -guirjunene (0.5%)
 β -caryophyllene (0.4%)
 aromadendrene (1.2%)
 allo-aromadendrene (0.5%)

viridiflorene (0.9%)
 δ -cadinene (0.9%)
 ledol (0.1%)
 spathulenol (0.1%)
 viridiflorol (0.4%)
 α -eudesmol (0.3%)

In addition, trace amounts (<0.1%) of 1,4-cineole, *trans*-pinocarveol, camphor, δ -terpineol, borneol, α -humulene, caryophyllene oxide and globulol were also characterized in this oil.

An oil of tea tree that was obtained from a commercial source in Italy was screened for its antimutagenic activity by Evandri et al. (2005). The composition of the oil that was screened by the reverse mutation assay was as follows:

α -thujene (0.9%)
 α -pinene (2.6%)
 sabinene (0.3%)
 β -pinene (0.7%)
 myrcene (0.9%)
 octanal (0.3%)
 α -terpinene (9.2%)
 p-cymene (3.3%)
 limonene (1.9%)
 1,8-cineole (4.1%)
 γ -terpinene (20.4%)
 terpinolene (3.5%)
 α -fenchyl alcohol (0.2%)
 terpinen-4-ol (39.1%)
 α -terpineol (3.0%)
 aromadendrene (0.2%)

The authors found that the oil did not possess any mutagenic activity nor any antimutagenic activity.

Tea tree oil that was produced in South Africa at an experimental plantation at Cramond (KwaZulu-Natal) was the subject of analysis by Figueiredo (2006). Using GC-FID and retention indices, the author determined that the main constituents of the oils produced between February and December ranged as follows:

α -pinene (1.5–2.7%)
 α -terpinene (7.5–10.9%)
 limonene (0.5–0.9%)
 1,8-cineole (2.1–4.0%)
 γ -terpinene (19.1–22.8%)
 p-cymene (0.6–2.7%)
 terpinen-4-ol (37.9–49.3%)
 α -terpineol (2.8–3.9%)

An oil of tea tree which was produced from freshly cut leaves and

branches of shrubs grown in southern India was analyzed using only GC/MS by Ansari et al. (2006). The components characterized in this oil were as follows:

α -thujene (1.2%)
myrcene (0.6%)
p-cymene (7.3%)
1,8-cineole (5.3%)
(Z)- β -ocimene (0.2%)
terpinen-4-ol (47.7%)
 β -caryophyllene (3.1%)
germacrene D (0.4%)
 γ -elemene (0.7%)
globulol (3.1%)
viridiflorol (0.4%)
spathulenol (1.3%)

In addition, the authors misidentified or tentatively incorrectly identified more than 15 more compounds in this oil.

The main constituents of a commercial sample of tea tree oil that was screened for its acetylcholinesterase activity by Miyazawa and Yamafuji (2006) were:

α -terpinene (8.3%)
1,8-cineole (4.4%)
 γ -terpinene (19.5%)
p-cymene (7.2%)
terpinen-4-ol (35.6%)

As tea tree oil is favored by aromatherapists and those producers of over the counter products that purport to possess antimicrobial properties, a review of the toxicity of the oil by Hammer et al. (2006) is recommended for updating the published biological activity data known. This review is a useful update on the earlier reviews on the antimicrobial activity and toxicity of the oil by Markham (1999) and Russell (1999), respectively.

The composition of oils produced from the stems and leaves of *M. alternifolia* that were harvested from 10 year-old plantations growing in Viçosa (Minas Gerais, Brazil) were analyzed by Silva et al. (2007). The leaf oil was found to contain the following components:

α -terpinene (7.6%)
p-cymene (3.7%)
 γ -terpinene (18.9%)
terpinolene (3.0%)

terpinen-4-ol (53.7%)
 α -terpineol (3.7%)
globulol (2.0%)
viridiflorol (1.6%)

In contrast, the stem oil contained:

terpinen-4-ol (24.2%)
 α -terpineol (2.2%)
tetradecane (5.3%)
(Z)- β -farnesene (10.2%)
(E)- β -farnesene (3.6%)
viridiflorene (5.4%)
 δ -cadinene (4.5%)
ledol (2.2%)
spathulenol (2.0%)
globulol (14.2%)
viridiflorol (7.5%)

Williams (2008) reported that tea tree oil contained the following components:

α -thujene (0.8%)
 α -pinene (2.5%)
 β -pinene (0.6%)
myrcene (0.7%)
 α -phellandrene (0.3%)
 α -terpinene (8.9%)
p-cymene (2.5%)
1,8-cineole (3.4%)
limonene (0.9%)
 γ -terpinene (19.8%)
terpinoline (3.0%)
terpinen-4-ol (39.1%)
 α -terpineol (2.9%)
 α -gurjunene (0.3%)
 β -caryophyllene (0.5%)
aromadendrene (1.5%)
allo-aromadendrene (0.5%)
cadin-1(6),4-diene (0.3%)
bicyclogermacrene (0.6%)
ledene[†] (1.0%)
 δ -cadinene (1.5%)
globulol (0.5%)

[†]misidentification of viridiflorene

p-Cymenene, α -cubebene, α -copaene, camphene, β -phellandrene, α -humulene, bicyclosesquiphellandrene, γ -cadinene, a calamenene isomer, zonarene, cadina-1,4-diene, (Z)-3-hexenol, *cis*-sabinene hydrate, *trans*-sabinene hydrate, linalool, cuminyl alcohol, epi-globulol, ledol (probably viridiflorol) and methyl eugenol were also reported as trace components of this oil.

Milchard et al. (2010) reported the results of a collaborative analysis of a commercial sample of Australian tea tree oil. The composition of this oil was found to be as follows:

α -thujene (0.8%)
 α -pinene (2.3%)
sabinene (0.2%)
 β -pinene (0.7%)
myrcene (0.8%)
 α -phellandrene (0.4%)
 α -terpinene (9.3%)
p-cymene (2.4%)
 β -phellandrene (0.7%)
limonene (0.9%)
1,8-cineole (2.4%)
 γ -terpinene (20.3%)
terpinolene (3.4%)
terpinen-4-ol (41.5%)
 α -terpineol (3.0%)
 β -caryophyllene (0.4%)
aromadendrene (1.2%)
viridiflorene (1.5%)
 δ -cadinene (1.1%)

Tranchida et al. (2010) used comprehensive two-dimensional gas chromatography (GC $\times$ GC) in combination with a rapid-scanning quadrupole mass spectrometer to compare the characterization of components in both fresh and aged oils of tea tree.

Examination of the results using nonpolar retention indices to interpret the data revealed that the fresh oil contained (Z)-3-hexenol, α -thujene, α -pinene, camphene, sabinene, β -pinene, myrcene, (Z)-3-hexenyl acetate, α -phellandrene α -terpinene, p-cymene, limonene, 1,8-cineole, (E)- β -ocimene, γ -terpinene, *cis*-sabinene hydrate, terpinolene, p-cymenene, linalool, *trans*-sabinene hydrate, α -fenchyl alcohol, *cis*-p-menth-2-en-1-ol, terpinen-1-ol, *trans*-p-menth-2-en-1-ol, camphene hydrate, borneol, terpinen-4-ol, α -terpineol, *trans*-piperitol, α -cubebene, isodene, α -copaene, β -elemene, methyl eugenol, α -gurjunene, β -caryophyllene, aromadendrene, 9-epi- β -caryophyllene, α -humulene, allo-aromadendrene, γ -gurjunene, viridiflorene, bicyclogermacrene, γ -cadinene, zonarene, *trans*-cadin-1(2),4-diene, viridiflorol, palustrol, isospathulenol, globulol, 1-epi-cubenol, spathulenol and cubenol. Additional compounds were listed in the results; however, their existence in tea tree oil is far from being unequivocal; hence, they are not included in this review. Many of the same components found in fresh tea tree oil were also found in aged tea tree oil. It was

surprising that p-menthane-1,2,4-triol (a known oxidized product of terpinen-4-ol) was not found in the aged oil (c.f. Southwell, 1988).

- I. Southwell, Australian tea tree: oil of Melaleuca terpinen-4-ol type. *Chemistry in Australia* (11), 400–402 (1988).
- I.A. Southwell, A.J. Hayes, J. Markham and D.N. Leach, *The search for optimally bioactive Australian tea tree oil*. In: *International Symposium on Medicinal and Aromatic Plants*. Edits., D. Palevitch and E. Putievsky, pp. 256–265, I.S.H.S & A.R.O., Tiberias, Israel (1993).
- M. Russell, *Toxicology of tea tree oil*. In: *Tea tree. The genus Melaleuca*. Edits., I. Southwell and R. Lowe, pp. 191–201, Harwood Academic Publishers, Amsterdam, The Netherlands (1999).
- J.L. Markham, *Biological Activity of tea tree oil*. In: *Tea tree. The genus Melaleuca*. Edits., I. Southwell and R. Lowe, pp. 169–190, Harwood Academic Publishers, Amsterdam, The Netherlands (1999).
- F. Christoph, E. Stahl-Biskup and P.-M. Kaulfers, *Death kinetics of Staphylococcus aureus exposed to commercial tea tree oils s.l.* *J. Essent. Oil Res.*, **13**, 98–102 (2001).
- S.G. Wyllie, K.-A. Merry and D.N. Leach, *SPME and GC-AED-olfactometry for the detection of trace odorants in essential oils*. In: *Gas Chromatography-olfactometry. The state*

of the Art. Edits., J.V. Leland, P. Schieberle, A. Büttner and T.E. Acree, ACS Symposium Series No. 782, pp. 88–99, American Chemical Society, Washington, DC (2001).

- M.F. Russell and I. Southwell, *Preferred age for assessment of qualitative and quantitative characteristics of the essential oil of tea tree (Melaleuca alternifolia) seedlings prior to plantation establishment*. *J. Agric. Food Chem.*, **51**, 4254–4257 (2003).
- L. Jirovetz, G. Buchbauer, Z. Denkova, A. Stoyanova, I. Murgov, E. Schmidt and M. Geissler, *Antimicrobial testings and gas chromatographic analysis of pure oxygenated monoterpene 1,8-cineole, α -terpineol, terpinen-4-ol and camphor as well as target compounds in essential oils of pine (Pinus pinaster), rosemary (Rosmarinus officinalis), tea tree (Melaleuca alternifolia)*. *Sci. Pharm.*, **73**, 27–39 (2005).
- M.G. Evandri, L. Battinelli, C. Daniele, S. Mastrang, P. Bolle and G. Mazzanti, *The antimutagenic activity of Lavandula angustifolia (lavender) essential oil in the bacterial reverse mutation assay*. *Food Chem. Toxicol.*, **43**, 1381–1387 (2005).
- M. de Figueiredo, *Chemical composition and oil concentration of tea tree leaf oil grown in South Africa during a one vegetative cycle*. *J. Essent. Oil Res.*, **18**(Spec. Edn.), 52–53 (2006).
- S.H. Ansari, H.M. Mukhtar, S.R. Mir, M.Z. Abidin and P. Singh, *Analysis of Indian tea tree (Melaleuca alternifolia) essential oil*

a vital aromatherapy oil. *J. Essent. Oil Bear. Plants*, **9**, 70–74 (2006).

- M. Miyazawa and C. Yamafuji, *Inhibition of acetylcholinesterase activity by tea tree oil and constituent terpenoids*. *Flav. Fragr. J.*, **21**, 198–201 (2006).
- K.A. Hammer, C.F. Carson, T.V. Riley and J.B. Nielsen, *A review of the toxicity of Melaleuca alternifolia (tea tree) oil*. *Food Chem. Toxicol.*, **44**, 616–625 (2006).
- C.J. Silva, L.C.A. Barbosa, C.R.A. Maltha, A.L. Pinheiro and F.D. Ismail, *Comparative study of the essential oils of seven Melaleuca (Myrtaceae) species grown in Brazil*. *Flav. Fragr. J.*, **22**, 474–478 (2007).
- D.G. Williams, *The Chemistry of essential oils*. 2nd Edn., pp. 206–207, Micelle Press, Port Washington, NY (2008).
- M.J. Milchard, R. Clery, R. Esdale, L. Gates, F. Judge, N. Moss, D.A. Moyler, A. Sherlock, B. Starr, J. Webb and E.J. Newman, *Application of Gas-Liquid chromatography to the analysis of essential oils*. *Perfum. Flavor.*, **35**(5), 34–42 (2010).
- P.Q. Tranchida, R.A. Shellie, G. Purcaro, L.S. Conte, P. Dugo, G. Dugo and L. Mondello, *Analysis of fresh and aged tea tree essential oils by using GC $\times$ GC – qMS*. *J. Chrom. Sci.*, **48**, 262–266 (2010).

To purchase a copy of this article or others, visit www.PerfumerFlavorist.com/magazine. 