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## RESEARCH ARTICLE

### Study on the recovered essential oil obtained from hydrosol of *Yulania denudata* fresh flowers

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This study focused on the recovered essential oil of *Yulania denudata* fresh flowers obtained from hydrosol, the main by-product of *Y. denudata* essential oil production. The yield percentage and chemical profile of the recovered oil (extracted from the hydrosol by adsorption and solvent extraction, respectively) were investigated and compared with those of the decanted oil (obtained directly by field distillation of fresh flowers). Decanted oil accounted for 91.3–92.1% and recovered oil 7.9–8.7% of the total oil yield. The decanted oil was rich in hydrocarbons (78.2%), whereas the recovered oil was rich in organoleptically important oxygenated compounds (99.1–99.5%). For the recovery of dissolved essential oil from *Y. denudata* hydrosol, adsorption using activated carbon was preferred over diethyl ether extraction due to higher efficiency and lower solvent consumption. The recovered oil is a rich source of eucalyptol, which finds uses in the fragrance and pharmaceutical industries.

**Keywords:** *Yulania denudata*; hydrosol; recovered oil; essential oil composition; eucalyptol;  $\alpha$ -terpineol

#### Introduction

Essential oils are, by definition, important natural products conventionally produced by the hydrodistillation or steam distillation of aromatic plants (1). During the distillation process, the water-soluble fraction of the essential oil dissolves in the distillation water or hydrosol, which leads to an oil loss as the hydrosol is discarded (2, 3). The recovery of dissolved essential oils from hydrosols, the main by-products of essential oil production, becomes necessary because the recovered oils are rich in organoleptically important oxygenated components (4). Unfortunately, limited reports are available on this aspect. The Pangarkar research group focused on synthetic polymeric adsorbents (5–7) while Rajeswara Rao et al. (4, 8–10) employed organic solvents. Although activated carbon is widely used for the recovery or removal of dissolved organics from aqueous solutions (11–13), its application in essential oil isolation is still scarce (14).

Until now, only a few aromatic plants have been investigated with regard to recovered oils. These plants include *Rosa damascena* Mill. (15), *Ocimum basilicum* (7), *Eucalyptus citriodora* Hook. (8), *Tagetes minuta* L. (10), and several species of the genus *Mentha* (7, 14), the genus *Pelargonium* (4, 5) and the genus *Cymbopogon* (9, 14), etc. The recovered oils of other aromatic plants, especially those native to China, remain to be studied in terms of chemical composition.

*Yulania denudata* (formerly named *Magnolia denudata*) is a small deciduous tree that belongs to the Magnoliaceae family (16). It is known as an ornamental and medicinal plant native to eastern and southern China. The essential oil isolated from flowers or buds of the species is widely used in the fragrance and pharmaceutical industries in China. Despite the extensive use of *Y. denudata* decanted oil, the utilization of recovered oil or hydrosol has long been neglected. To the best of our knowledge, the composition of the recovered oil or hydrosol of *Y. denudata* fresh flowers has not been investigated before.

The aim of this study is to examine the recovered essential oil of *Y. denudata* fresh flowers for the first time. For this purpose, the recovered oil was obtained from the hydrosol of *Y. denudata* through adsorption or solvent extraction. The yield percentage was evaluated and the chemical profile investigated. Furthermore, activated carbon adsorption and diethyl ether extraction were compared with regard to yields and chemical profiles of the recovered oils obtained.

#### Experimental

##### Plant materials and chemicals

Fresh flowers of *Y. denudata* were collected before sunrise in early March, on the Zijingang Campus of Zhejiang University (7 m altitude, 30°18'N latitude and

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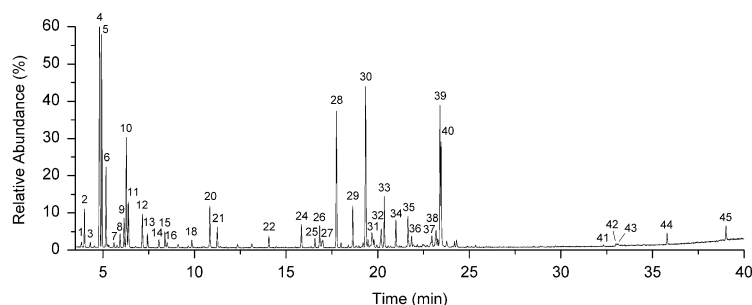


Figure 1. Gas chromatogram of Clevenger distilled oil of *Yulania denudata* fresh flowers.

120°05'E longitude), Hangzhou, China. The species was identified by Associate Professor Juanhua Xu of Zhejiang University. A voucher specimen (HZU60040413) was deposited at the Herbarium of Zhejiang University. The coconut shell-based granular activated carbon was supplied by Shuangyuan Activated Carbon Co., Ltd., China. The physical properties of the carbon were given in Table 1 (17). A standard solution of *n*-alkanes ( $C_7$ – $C_{30}$ ) was purchased from Supelco Analytical (Bellefonte, PA, USA). Other chemicals were of analytical grade.

#### Clevenger distillation

Fresh flowers (1000 g) soaked in an aqueous sodium chloride solution for 4 hours, were hydrodistilled in a Clevenger-type apparatus (18) for 2 hours. The essential oil collected was dried over anhydrous sodium sulfate, weighed and recorded as 'Clevenger distilled oil'. The yield was calculated as a w/w percentage on a fresh weight basis.

#### Field distillation

Fresh flowers (20,000 g) were soaked in an aqueous sodium chloride solution and hydrodistilled in a field distillation unit (Zhejiang Wenxiong Machine Valve Co., Ltd., China). The essential oil decanted from the receiver was collected and dried over anhydrous sodium sulfate, weighed and recorded as 'decanted oil'.

Table 1. Physical properties of the granular activated carbon.

Parameter	Value
Particle size (mm)	0.9–2.0 <sup>a</sup>
Bulk density (g/cm <sup>3</sup> )	0.62 <sup>a</sup>
BET surface area (m <sup>2</sup> /g)	912 <sup>b</sup>
Micropore surface area (m <sup>2</sup> /g)	707 <sup>b</sup>
Total pore volume (cm <sup>3</sup> /g)	0.45 <sup>b</sup>
Micropore volume (cm <sup>3</sup> /g)	0.33 <sup>b</sup>
Average pore diameter (nm)	2.0 <sup>b</sup>

Notes: <sup>a</sup>Data determined. <sup>b</sup>Data from the literature (17).

The yield was calculated in the same way as in the case of the Clevenger distilled oil. The hydrosol (10 dm<sup>3</sup>) was collected from the distillation unit after decanting the oil. It was then divided evenly into two subsamples (each 5 dm<sup>3</sup>).

#### Recovery of dissolved essential oil from hydrosol by activated carbon adsorption

The granular activated carbon was thoroughly washed with ethanol and deionized water, and dried overnight at 105°C in an air oven. The carbon (20 g) was packed into a glass column (150 cm × 1.2 cm i.d.). The carbon bed occupied a height of 32 cm inside the column. The hydrosol (5 dm<sup>3</sup>) was then passed through the column at a flow rate of 5 cm<sup>3</sup>/minute controlled by a peristaltic pump (LongerPump, China).

The carbon was removed from the column, air-dried at room temperature for 1 hour and packed into the column again with diethyl ether. The carbon bed was then eluted with diethyl ether at a flow rate of 2 cm<sup>3</sup>/minute. A total of 160 cm<sup>3</sup> (5 BV) solvent was used. The eluate was collected, dried over anhydrous sodium sulfate and distilled in a rotary evaporator to yield the 'recovered oil by adsorption'. The yield was calculated in the same way as mentioned above.

#### Recovery of dissolved essential oil from hydrosol by diethyl ether extraction

The hydrosol (5 dm<sup>3</sup>) was extracted with diethyl ether (600 cm<sup>3</sup>, 500 cm<sup>3</sup> × 2) in presence of sodium chloride, using a mechanical shaker. The organic layer was collected and dried over anhydrous sodium sulfate. The solvent was removed to yield the 'recovered oil by extraction'. The yield was calculated.

#### Gas chromatography and gas chromatography–mass spectrometry

Gas chromatographic (GC) analysis was carried out using an Agilent 6890N gas chromatograph equipped

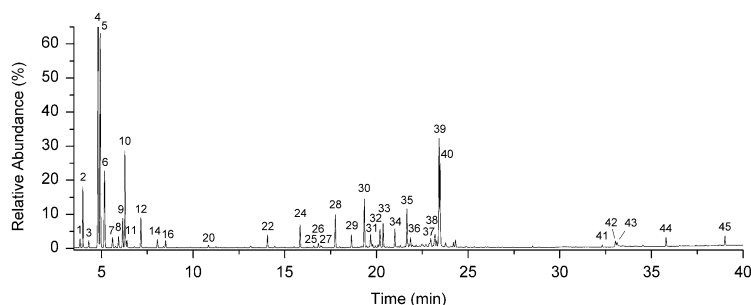


Figure 2. Gas chromatogram of decanted oil of *Yulania denudata* fresh flowers.

with a flame ionization detector (FID). A HP-5ms capillary column (30 m  $\times$  0.25 mm i.d., 0.25  $\mu$ m film thickness; Agilent technologies, USA) was used. The oven temperature was held at 80°C for 5 minutes, raised to 250°C at 5°C/minute and then held at 250°C for 15 minutes. Temperatures of the injector and the detector were 250°C and 280°C, respectively. The injection volume of *n*-alkanes standard and essential oil samples (all diluted with hexane) was 1.0  $\mu$ L, and the split ratio was 20:1. The carrier gas was helium at a flow rate of 1 cm<sup>3</sup>/minute.

GC–mass spectrometry (GC–MS) was performed using an Agilent 6890N GC coupled with an Agilent 5975I mass spectrometer and fitted with a HP-5ms capillary column (30 m  $\times$  0.25 mm i.d., 0.25  $\mu$ m film thickness; Agilent, USA). The oven temperature program was the same as that in the GC analysis. The temperatures of the injector and the transfer line were 250° and 280°C, respectively. The injection volume of *n*-alkanes standard and essential oil samples (all diluted with hexane) was 1.0  $\mu$ L (split ratio, 20:1). Helium was used as the carrier gas (flow rate, 1 cm<sup>3</sup>/minute). MS scan conditions were as follows: ion source temperature: 230°C; electron energy: 70 eV; mass scan range: 30–550 amu.

#### Identification of essential oil components

The essential oil components were identified based on their mass spectra and retention indices (RIs) (19). Computer matching of the mass spectra with those in the NIST 05a library was performed. RIs calculated relative to C<sub>7</sub>–C<sub>30</sub> *n*-alkanes by linear interpolation (20) were compared with those in the literature (21–23). The relative percentage amounts of individual components were calculated based on GC peak areas without using correction factors.

### Results and discussion

#### Extraction efficiency of field distillation

Extraction efficiency of field distillation was evaluated relative to Clevenger distillation, which served as the

reference method. The yields of essential oils obtained by field distillation and Clevenger distillation were 0.210% and 0.290% (both based on weight of fresh flowers), respectively. Therefore, the efficiency of field distillation was 72.4% relative to Clevenger distillation, which was due to a loss of dissolved essential oil in the field distillation process and continuous cohobation of distillation water in the Clevenger distillation method (9).

#### Yields of decanted and recovered essential oils

The yield of decanted (field-distilled) oil was 0.210%. The yields of recovered oil obtained by activated carbon adsorption and diethyl ether extraction were 0.020% and 0.018%, respectively (all based on the weight of fresh flowers). Consequently, field distillation produced 91.3–92.1% of the total oil yield, while adsorption or solvent extraction of the hydrosol produced 7.9–8.7% of the total oil yield. The recovery efficiency of adsorption was a little higher than that of solvent extraction. Unless recovered, the oil dissolved in the hydrosol would be lost. The results confirmed that recovery of dissolved essential oil from *Y. denudata* hydrosol is necessary.

#### Chemical profiles of Clevenger distilled, decanted and recovered essential oils

Chemical compositions of Clevenger distilled, decanted and recovered essential oils were listed in Table 2 and gas chromatograms of those samples were shown in Figures 1–4. The chemical composition of recovered oil was significantly different from that of Clevenger distilled and decanted oils. The major components of the Clevenger distilled and decanted oils were  $\beta$ -thujene (15.8% and 23.8%, respectively) and  $\beta$ -pinene (11.1% and 16.4%, respectively), while those of the recovered oil were eucalyptol (67.3–70.6%) and  $\alpha$ -terpineol (14.5–16.1%). Recovered oils obtained by adsorption and solvent extraction respectively showed similar chemical profiles (Figures 3 and 4). In contrast to the

**Table 2.** Composition (%) of Clevenger distilled, decanted and recovered oils of *Yulania denudata* fresh flowers.

No. <sup>a</sup>	Components <sup>b</sup>	RI <sub>exp</sub> <sup>c</sup>	RI <sub>liter</sub> <sup>d</sup>	Clevenger distilled oil	Decanted oil	Recovered oil by adsorption	Recovered oil by extraction
1	$\alpha$ -Thujene	926	928	0.3	0.6	—	—
2	$\alpha$ -Pinene	932	934	1.4	3.3	—	—
3	Camphene	949	951	0.3	0.5	—	—
4	$\beta$ -Thujene	978	978	15.8	23.8	—	—
5	$\beta$ -Pinene	980	979	11.1	16.4	—	—
6	$\beta$ -Myrcene	990	991	4.9	6.5	—	—
7	$\alpha$ -Phellandrene	1003	1005	0.3	0.7	—	—
8	$\alpha$ -Terpinene	1014	1016	0.6	0.7	—	—
9	o-Cymene	1022	1022	1.2	1.7	—	—
10	Limonene	1027	1030	6.6	8.3	—	—
11	Eucalyptol	1031	1033	2.4	0.5	70.6	67.3
12	$\gamma$ -Terpinene	1058	1059	1.6	2.0	—	—
13	cis-Sabinene hydrate	1067	1068	0.9	—	1.7	1.7
14	Terpinolene	1085	1088	0.5	0.6	—	—
15	trans-Sabinene hydrate	1095	1097	1.2	—	2.1	2.1
16	Nonanal	1103	1102	0.5	0.8	—	—
17	Phenylethyl alcohol	1113	1114	—	—	0.8	1.7
18	Camphor	1144	1147	0.5	—	—	—
19	$\delta$ -Terpineol	1166	1162	—	—	1.0	1.2
20	Terpinen-4-ol	1177	1176	2.4	tr <sup>e</sup>	2.7	2.8
21	$\alpha$ -Terpineol	1190	1189	1.0	—	14.5	16.1
22	Bornyl acetate	1283	1285	0.5	0.8	tr	tr
23	exo-2-Hydroxycineole acetate	1344	1343	—	—	0.6	0.6
24	$\alpha$ -Terpinyl acetate	1351	1351	1.0	1.4	tr	tr
25	$\alpha$ -Copaene	1376	1375	0.4	tr	—	—
26	$\beta$ -Bourbonene	1384	1380	1.0	tr	—	—
27	$\beta$ -Cubebene	1388	1388	0.3	tr	—	—
28	Caryophyllene	1418	1418	6.5	2.1	—	—
29	$\alpha$ -Caryophyllene	1452	1450	2.1	0.8	—	—
30	Germacrene D	1472	1478	8.0	3.1	—	—
31	$\gamma$ -Selinene	1477	1479	1.1	0.8	—	—
32	$\alpha$ -Murolene	1499	1499	1.1	1.2	—	—
33	$\delta$ -Cadinene	1521	1524	2.3	1.5	—	—
34	Elemol	1542	1550	1.3	1.1	tr	tr
35	Germacrene B <sup>f</sup>	1558	1556	1.8	2.7	—	—
36	Caryophyllene oxide	1583	1581	0.5	0.6	—	—
37	$\gamma$ -Eudesmol	1630	1632	1.0	0.9	—	—
38	$\tau$ -Cadinol	1635	1640	1.2	1.0	—	—
39	$\beta$ -Eudesmol	1649	1650	7.2	7.9	3.2	3.5
40	$\alpha$ -Eudesmol	1652	1652	6.0	5.7	1.9	2.5
41	Heneicosane	2100	2100	tr	tr	—	—
42	Oleic acid	2141	2141	tr	tr	—	—
43	(Z)-6-Octadecenoic acid	2147	—	tr	tr	—	—
44	Tricosane	2300	2300	0.4	0.4	—	—
45	Pentacosane	2500	2500	0.6	0.5	—	—
Total identified				97.8	98.9	99.1	99.5

Notes: <sup>a</sup>In order of elution on a HP-5ms column. <sup>b</sup>Components identified based on mass spectra and retention indices. <sup>c</sup>RI<sub>exp</sub>, retention indices determined experimentally on HP-5ms using C<sub>7</sub>–C<sub>30</sub> n-alkanes. <sup>d</sup>RI<sub>liter</sub>, retention indices from the literature (21–23). <sup>e</sup>tr, trace (<0.05%). <sup>f</sup>Tentatively identified; —, not detected.

high concentration of eucalyptol in recovered oil, its content in Clevenger distilled and decanted oils was much lower (2.4% and 0.5%, respectively), which was attributed to the relatively high aqueous solubility of eucalyptol (24). The results are consistent with the earlier findings that recovered oils contain entirely different major components relative to decanted oils, as reported

by Rajeswara Rao et al. in the cases of *Eucalyptus citriodora* Hook. (8) and *Tagetes minuta* L. (10).

Eucalyptol (also named 1,8-cineole) is an important aroma chemical mainly found in eucalyptus (*Eucalyptus globulus* Lab.) leaf oil (25). Other sources include essential oils of rosemary (*Rosmarinus officinalis* L.) and sage (*Salvia officinalis* L.) (25). Eucalyptol is

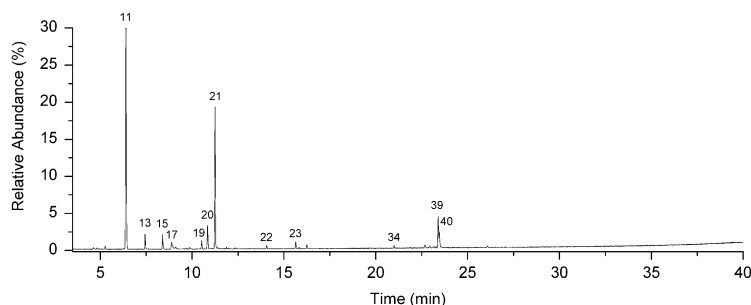


Figure 3. Gas chromatogram of recovered oil of *Yulania denudata* fresh flowers obtained by activated carbon adsorption.

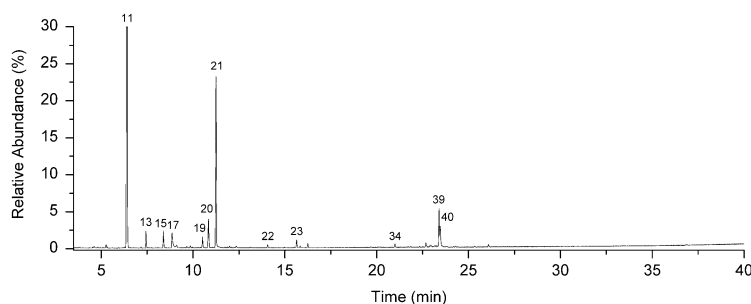


Figure 4. Gas chromatogram of recovered oil of *Yulania denudata* fresh flowers obtained by diethyl ether extraction.

Table 3. Class composition (%) of Clevenger distilled, decanted and recovered oils of *Yulania denudata* fresh flowers.

Chemical classes	Clevenger distilled oil	Decanted oil	Recovered oil by adsorption	Recovered oil by extraction
Hydrocarbon monoterpenes	44.6	65.1	—	—
Hydrocarbon sesquiterpenes	24.6	12.2	—	—
Hydrocarbon non-terpenes	1.0	0.9	—	—
Oxygenated monoterpenes	9.9	2.7	93.2	91.8
Oxygenated sesquiterpenes	17.2	17.2	5.1	6.0
Oxygenated non-terpenes	0.5	0.8	0.8	1.7
Total hydrocarbons	70.2	78.2	—	—
Total oxygenated compounds	27.6	20.7	99.1	99.5

widely used in fragrance and pharmaceutical industries, and its high content in recovered oil of *Y. denudata* makes it a new source for eucalyptol isolation.

The class composition of different oils was shown in Table 3. Clevenger distilled and decanted oils were rich in hydrocarbons (70.2% and 78.2%, respectively), whereas the recovered oil was rich in oxygenated compounds (99.1–99.5%). Specifically, the content of oxygenated monoterpenes in recovered oil (91.8–93.2%) was much higher than that in decanted oil (2.7%), which was due to the relatively high solubility of oxygenated monoterpenes in water (24, 26) and incomplete recovery of these components through field distillation. It was also found that Clevenger distilled oil contained

a higher percentage of oxygenated monoterpenes than decanted oil (9.9% versus 2.7%), which can be explained by the fact that Clevenger distillation represents one of the recovery methods of part of the dissolved oil from the hydrosol through cohobation (9). Besides, hydrocarbons were absent in the recovered oil.

Typical oxygenated compounds found in the recovered oil include eucalyptol,  $\alpha$ -terpineol,  $\beta$ -eudesmol, terpinen-4-ol,  $\alpha$ -eudesmol, *trans*-sabinene hydrate and *cis*-sabinene hydrate. Because oxygenated components make important contribution to the aroma of an essential oil (2, 4), the recovered oil rich in those components is highly valued and may find uses in the fragrance industry.



### Comparison of activated carbon adsorption and diethyl ether extraction for recovery of dissolved essential oils

GC and GC–MS analysis confirmed the similarity in chemical profiles between recovered oils obtained by adsorption and solvent extraction respectively (Table 2, Figures 3 and 4). Furthermore, the adsorption method produced a slightly higher recovered oil yield than solvent extraction (0.020% versus 0.018%), which may be due to higher efficiency of adsorption, lower concentration of dissolved essential oil and oil losses during the solvent removal process in solvent extraction. It should be stressed that adsorption is superior to solvent extraction when the concentration of dissolved organics is lower (generally  $<10^4$  ppm) (12, 27, 28). Moreover, adsorption using activated carbon proved to be efficient for recovering the dissolved essential oil, as revealed by GC–MS of the hydrosol stripped of dissolved oil through adsorption onto carbon. In addition, the adsorption procedure consumed less solvent (10% relative to solvent extraction in this study), which makes it a relatively safe and clean process suitable for industrial production. All of these make adsorption using activated carbon a preferred method over diethyl ether extraction.

### Conclusion

Recovered essential oils are organoleptically important products extracted from hydrosols, main by-products of essential oil production. Studies concerning recovered oils are restricted to just a few aromatic plants. In this work, the first study on the recovered oil of *Y. denudata* fresh flowers was carried out. Adsorption using activated carbon as an adsorbent proved efficient for recovery of the dissolved essential oil from the hydrosol of *Y. denudata*. The recovered oil is a rich source of eucalyptol, an important fragrance compound. It is also valued for its high organoleptic qualities. This study will promote the utilization of the recovered oil and hydrosol of *Y. denudata* in fragrance and pharmaceutical industries.

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### References

1. P. Rubiolo, B. Sgorbini, E. Liberto, C. Cordero and C. Bicchi, *Essential oils and volatiles: Sample preparation and analysis. A review*. *Flavour Fragr. J.*, **25**, 282–290 (2010).
2. A. Fleisher and Z. Fleisher, *Water-soluble fractions of the essential oils*. *Perfum. Flavor.*, **16**, 37–41 (1991).
3. C.L. Queiroga, J.K. Bastos, J.P. de Sousa and P.M. de Magalhaes, *Comparison of the chemical composition of the essential oil and the water soluble oil of Baccharis dracunculifolia DC. (Asteraceae)*. *J. Essent. Oil Res.*, **20**, 111–114 (2008).
4. B.R. Rajeswara Rao, P.N. Kaul, K.V. Syamasundar and S. Ramesh, *Water soluble fractions of rose-scented geranium (Pelargonium species) essential oil*. *Bioresour. Technol.*, **84**, 243–246 (2002).
5. L.P. Amin, V.G. Pangarkar and A.A. Beenackers, *Recovery of valuable perfumery compounds from a geranium steam distillation condensate using polymeric adsorbents*. *Sep. Sci. Technol.*, **36**, 3639–3655 (2001).
6. D.A. Jogdeo, K. Niranjana and V.G. Pangarkar, *Recovery of allyl isothiocyanate from steam distillation condensate using adsorption*. *J. Chem. Technol. Biotechnol.*, **75**, 673–680 (2000).
7. K.W. Machale, K. Niranjana and V.G. Pangarkar, *Recovery of dissolved essential oils from condensate waters of basil and Mentha arvensis distillation*. *J. Chem. Technol. Biotechnol.*, **69**, 362–366 (1997).
8. B.R. Rajeswara Rao, P.N. Kaul, K.V. Syamasundar and S. Ramesh, *Comparative composition of decanted and recovered essential oils of Eucalyptus citriodora Hook*. *Flavour Fragr. J.*, **18**, 133–135 (2003).
9. B.R. Rajeswara Rao, P.N. Kaul, K.V. Syamasundar and S. Ramesh, *Chemical profiles of primary and secondary essential oils of palmarosa (Cymbopogon martinii (Roxb.) Wats var. motia Burk.)*. *Ind. Crops Prod.*, **21**, 121–127 (2005).
10. B.R. Rajeswara Rao, P.N. Kaul, A.K. Bhattacharya, D.K. Rajput, K.V. Syamasundar and S. Ramesh, *Comparative chemical composition of steam distilled and water soluble essential oils of South American marigold (Tagetes minuta L.)*. *J. Essent. Oil Res.*, **18**, 622–626 (2006).
11. D. Chatzopoulos, A. Varma and R.L. Irvine, *Activated carbon adsorption and desorption of toluene in the aqueous phase*. *AIChE J.*, **39**, 2027–2041 (1993).
12. S. Mukherjee, S. Kumar, A.K. Misra and M. Fan, *Removal of phenols from water environment by activated carbon, bagasse ash and wood charcoal*. *Chem. Eng. J.*, **129**, 133–142 (2007).
13. D.R. Zuim, D. Carpiné, G.A.R. Distler and A. de Paula Scheer, L. Igarashi-Mafra and M.R. Mafra, *Adsorption of two coffee aromas from synthetic aqueous solution onto granular activated carbon derived from coconut husks*. *J. Food Eng.*, **104**, 284–292 (2011).
14. A.E. Edris, B.S. Girgis and H.H. Fadel, *Recovery of volatile aroma components from aqueous waste streams using an activated carbon column*. *Food Chem.*, **82**, 195–202 (2003).
15. K.G. Babu, B. Singh, V.P. Joshi and V. Singh, *Essential oil composition of Damask rose (Rosa damascena Mill.) distilled under different pressures and temperatures*. *Flavour Fragr. J.*, **17**, 136–140 (2002).
16. N. Xia, Y. Liu and H.P. Nooteboom, *Magnoliaceae*. In: *Flora of China*. Edits., Z. Wu and P.H. Raven. Vol. 7,

- pp. 48–91, Science Press and Missouri Botanical Garden Press, Beijing and St. Louis (2008).
17. C. Xu, B. Zhang, J. Yuan, H. Lu, Y. Chen and Z. Ge, *Support effect on the Meerwein-Ponndorf-Verley reduction of acetophenone over supported magnesium oxide catalysts*. *Acta Chim. Sin. (Chin. Ed.)*, **69**, 368–374 (2011).
  18. J.F. Clevenger, *Apparatus for the determination of volatile oil*. *J. Am. Pharm. Assoc.*, **17**, 345–349 (1928).
  19. E.S. Kovats, *Gas chromatographic characterization of organic substances in the retention index system*. *Adv. Chromatogr.*, **1**, 229–247 (1965).
  20. H. Van den Dool and P.D. Kratz, *A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography*. *J. Chromatogr. A*, **11**, 463–471 (1963).
  21. National Institute of Standards and Technology (NIST), *NIST Chemistry WebBook*. U.S. Secretary of Commerce, <http://webbook.nist.gov/chemistry> (10 August 2013).
  22. T. Miyazaki, A. Plotto, K. Goodner and F.G. Gmitter, *Distribution of aroma volatile compounds in tangerine hybrids and proposed inheritance*. *J. Sci. Food Agric.*, **91**, 449–460 (2011).
  23. W.N. Setzer, J.A. Noletto, R.O. Lawton and W.A. Haber, *Leaf essential oil composition of five Zanthoxylum species from Monteverde, Costa Rica*. *Mol. Diversity*, **9**, 3–13 (2005).
  24. K. Cal, *Aqueous solubility of liquid monoterpenes at 293 K and relationship with calculated log P value*. *Yakugaku Zasshi*, **126**, 307–309 (2006).
  25. M. De Vincenzi, M. Silano, A. De Vincenzi, F. Maialetti and B. Scazzocchio, *Constituents of aromatic plants: Eucalyptol*. *Fitoterapia*, **73**, 269–275 (2002).
  26. I. Fichan, C. Larroche and J.B. Gros, *Water solubility, vapor pressure, and activity coefficients of terpenes and terpenoids*. *J. Chem. Eng. Data*, **44**, 56–62 (1999).
  27. S.P. Deosarkar and V.G. Pangarkar, *Adsorptive separation and recovery of organics from PHBA and SA plant effluents*. *Sep. Purif. Technol.*, **38**, 241–254 (2004).
  28. R.E. Treybal, *Mass-Transfer Operations*, 3rd edn. McGraw-Hill Kogakusha Ltd., Tokyo (1980).