

CHARACTERISATION OF MALAYSIA
AGARWOOD OIL (*AQUILARIA SP.*) AND
COMPARISON WITH DIFFERENT ORIGINS
BASED ON SENSORY STUDIES

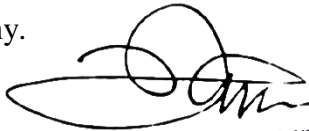
ERNY HASLINA BINTI ABD LATIB

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that We have checked this thesis and, in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.



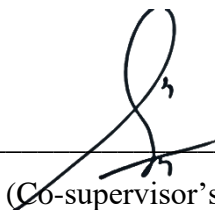
PROF MADYA DR SAIFUL NIZAM BIN TAJUDDIN
PENGARAH
PUSAT KECEMERLANGAN PENYELIDIKAN BIO AROMATIK
UNIVERSITI MALAYSIA PAHANG
LEBUHRAYA TUN RAZAK, 26300 GAMBANG,
KUANTAN, PAHANG
TEL : 09-549 2332 FAX : 09-549 2706
EMAIL : saifulnizam@ump.edu.my

(Supervisor's Signature)

Full Name : ASSOC. PROF. DR. SAIFUL NIZAM TAJUDDIN

Position : Lecturer, Faculty of Industrial Science and Technology, UMP.

Date : 27/03/2023



(Co-supervisor's Signature)

Full Name : ASSOC. PROF. DR. MOHD. SHARFI BIN NAJIB

Position : Lecturer, Faculty of Electrical and Engineering, UMP.

Date : 27/03/2023



STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

A handwritten signature in black ink, appearing to be 'ERNY HASLINA BINTI ABD LATIB', is written over a horizontal line.

(Student's Signature)

Full Name : ERNY HASLINA BINTI ABD LATIB

ID Number : PKD14001

Date : 27/03/2023

CHARACTERISATION OF MALAYSIA AGARWOOD OIL (*AQUILARIA SP.*)
AND COMPARISON WITH DIFFERENT ORIGINS BASED ON SENSORY
STUDIES

ERNY HASLINA BINTI ABD LATIB

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Industrial Science and Technology
UNIVERSITI MALAYSIA PAHANG

APRIL 2023

ACKNOWLEDGEMENTS

First of all, I am grateful to Allah SWT, the Almighty God, the source of my life, for allowing me to complete the research and finish this thesis. I would like to pay my sincere gratitude to my supervisor, Assoc. Prof. Dr. Saiful Nizam Tajuddin for his continuous guidance that steered me to complete my research work patiently. His kind support during my research activities is a great source of encouragement for me.

I am highly thankful to my co-supervisor, Assoc. Prof. Dr. Mohd. Sharfi Najib for his thoughtful input and guidance for me to complete this research. Special thanks to Dr. Seema for helping me with chemical structures. May Allah bless you always. I thank profusely the Faculty of Industrial Science and Technology, Universiti Malaysia Pahang (UMP) and Bio Aromatic Research Centre of Excellence (BIOAROMATIC) laboratory and the team for their laboratory facilities and the great opportunity for me to operate high technology equipment. This will be a great knowledge for me and a precious experience. My appreciation also goes to the Ministry of Higher Education (KPT) Malaysia for the financial support via MyBrain and the Ministry of Science, Technology, and Innovation (MOSTI) for the research grant for me to complete the research.

Lastly, it is my privilege to express my sincere gratefulness to all my friends, especially Asma, Huda, Amalina, Rofiza, Sufihana, Syafiq, Che Aizal, Fitrah; my family members, especially both my beloved parents, Abd. Latib bin Othman and Rajemah binti Ab. Latif; my niece, Erny Qistina Izzara binti Ermy Hasrulnizam; my uncle and aunty, my cousin, and my supportive husband, Faizzat Bin Mustafa for their prayers, understanding, continuous support, and moral inspiration throughout the journey of this thesis. They will always be close to my heart.

ABSTRAK

Gaharu mempunyai aplikasi yang luas untuk perubatan, aromaterapi, minyak wangi, kosmetik, dan setangi. Salah satu isu utama dalam industri perdagangan gaharu adalah sukar untuk mengenal pasti gred dan kualiti dengan tepat kerana tiada rujukan standard. Oleh itu, tujuan kajian ini adalah untuk menganalisis dan membandingkan profil kimia minyak gaharu daripada negara yang berbeza (Malaysia, India, Kemboja, dan Thailand) menggunakan analisis kromatografi gas. Pengenalpastian dan pengesahan sebatian penanda terpilih berdasarkan taburan jujuk kimia di kalangan sampel telah dijalankan menggunakan kromatografi gas persediaan (Prep-GC). Penilaian profil bau daripada hidung elektronik yang direka (E-nose) telah dijalankan untuk gred minyak gaharu yang berbeza sebagai penilaian awal. Pengekstrakan telah dijalankan menggunakan kaedah Taguchi sebagai reka bentuk eksperimen untuk penyulingan hidro yang telah difabrikasi. Keputusan menunjukkan bahawa hasil tertinggi dicapai daripada sampel EX8 dengan 1.05 g minyak gaharu. Pengekstrakan EX8 dijalankan pada 14 hari masa rendaman, 16 jam masa pengekstrakan, dan nisbah rendaman 1:8 (sampel: air). Secara keseluruhan, sebatian seskuiterpenoid dikenal pasti sebagai sebatian utama dalam sampel gred tinggi, yang bercanggah dengan minyak kayu gaharu gred rendah. Sebatian seskuiterpenoid utama yang dikenal pasti dalam sampel ialah norketoagarofuran, asid selina-4,11-dien-14-oik, epi- α -kadinol, kusunol, agarospirol, 10-epi- γ -eudesmol, α -agarofuran, guaia-1(10), 11-dien-15-ol, α -eudesmol, bulnesol, guaiol, 9,11-eremophiladien-8-on, rotundon, dan selina-3,11-dien-9-on. Agarospirol dan asid n-heksadekanolik telah dipilih sebagai sebatian penanda dan selanjutnya diasingkan menggunakan Prep-GC. Akhirnya, profil bau sampel minyak gaharu gred tinggi dan gred rendah yang dihasilkan oleh E-nose berjaya dibangunkan. Kajian ini memberi rujukan kepada minyak gaharu dari negara yang berbeza, khususnya dari Malaysia, India, Kemboja, dan Thailand berdasarkan taburan jujuk kimia ke arah penyeragaman gred dan kualiti. Di samping itu, kajian mengenai tindak balas profil bau daripada E-nose yang direka memberikan rujukan asas untuk pembangunan instrumen sistematik untuk penilaian gred dan kualiti minyak gaharu dalam industri gaharu.

ABSTRACT

Agarwood has wide applications for medicine, aromatherapy, perfume, cosmetics, and incense. One of the primary issues in the agarwood trading industry is difficult to identify the grade and quality accurately as there is no standard reference. Therefore, this study aims to analyze and compare the chemical profile of agarwood oil from different origins (Malaysia, India, Cambodia, and Thailand) using gas chromatography analysis. The identification and validation of the selected marker compounds based on the distribution of chemical constituents among the samples were carried out using preparative gas chromatography (Prep-GC). The evaluation of the odor profile from the fabricated electronic nose (E-nose) was conducted for different grades of agarwood oil as a preliminary assessment. The extraction was carried out using the Taguchi method as the design of experiment for fabricated hydrodistillation. The results show that highest yield was achieved from sample EX8 with 1.05 g of agarwood oil. The extraction of EX8 was conducted at 14 days of soaking time, 16 h of extraction time, and a soaking ratio of 1:8 (sample:water). Overall, sesquiterpenoid compounds were identified as the major compound in a high-grade sample, which contradicted low-grade agarwood oil. The major sesquiterpenoid compounds identified in the samples were norketoagarofuran, selina-4,11-dien-14-oic acid, epi- α -cadinol, kusunol, agarospirol, 10-epi- γ -eudesmol, α -agarofuran, guaia-1(10),11-dien-15-ol, α -eudesmol, bulnesol, guaiol, 9,11-eremophiladien-8-one, rotundone, and selina-3,11-dien-9-one. Agarospirol and n-hexadecanoic acid were selected as the marker compounds and further isolated using Prep-GC. Finally, the odor profiles of agarwood oil samples were successfully developed by the E-nose based on sensory studies. This study provides a reference for agarwood oil from different origins, specifically from Malaysia, India, Cambodia, and Thailand based on the distribution of chemical constituents toward standardizing the grade and quality. In addition, a study on odor profile response from the fabricated E-nose provides fundamental results for the development of a systematic instrument for the assessment of the grade and quality of agarwood oil in the agarwood industry.

TABLE OF CONTENT

DECLARATION	
TITLE PAGE	
ACKNOWLEDGEMENTS	ii
ABSTRAK	iii
ABSTRACT	iv
TABLE OF CONTENT	v
LIST OF TABLES	ix
LIST OF FIGURES	xi
LIST OF SYMBOLS	xiii
LIST OF ABBREVIATIONS	xiv
CHAPTER 1 INTRODUCTION	1
1.1 Research Background	1
1.2 Problem Statement	3
1.3 Objectives of the Study	5
1.4 Scope of the Study	5
1.5 Significance and Novelty of the Study	6
1.6 Thesis Outline	7
CHAPTER 2 LITERATURE REVIEW	8
2.1 Introduction to Agarwood	8
2.1.1 Overview of Agarwood	8
2.1.2 Application of Agarwood	10

2.1.3	An Overview of the Agarwood Industry	12
2.2	Method of Extraction	14
2.2.1	Hydrodistillation	14
2.2.2	Microwave-assisted Extraction	16
2.2.3	Supercritical Fluid Extraction	18
2.2.4	Accelerated Soxhlet Extraction	20
2.2.5	Ultrasound-assisted Extraction	21
2.2.6	An Overview of the Method of Extraction	22
2.3	Design of Experiment: Taguchi Method	24
2.3.1	Taguchi Method	24
2.3.2	Signal-to-noise (S/N) Ratio Analysis	25
2.4	Quality Control and Grading Analysis	27
2.4.1	Method of Analysis (Traditional)	27
2.4.2	Method of Analysis (Modern)	33
2.5	Agarwood Oil	41
2.6	Electronic Nose	44
2.7	Research Gap	46
CHAPTER 3 METHODOLOGY		48
3.1	Outline of Methodology	48
3.2	Materials	50
3.2.1	Chemicals and Solvent	50
3.2.2	Plant Materials	50
3.2.3	Sample Sourcing	50
3.2.4	Gases	52
3.3	Extraction	52

3.3.1	Hydrodistillation (HD)	52
3.2.3	Design of Experiment: Taguchi Method	55
3.2.4	Scanning Electron Microscopy	57
3.2.5	Thermogravimetric Analysis	57
3.3	Analysis of Oil for Chemical Profiling	58
3.3.1	Gas Chromatography-Mass Spectrometry	58
3.3.2	Gas Chromatography-Flame Ionization Detector	58
3.3.3	Identification of Compounds	59
3.3.4	Comprehensive Gas Chromatography Quadrupole Time-of-Flight	60
3.4	Isolation and Characterization of Compounds	61
3.4.1	Preparative Gas Chromatography	61
3.5	Development of E-Nose Odor Profile	61
3.5.1	E-Nose and Data Collection Measurement	62
3.5.2	Normalization	64
3.5.3	Box Plot	65
CHAPTER 4 RESULTS AND DISCUSSION		67
4.1	Introduction	67
4.2	Agarwood Oil Extraction	68
4.2.1	Hydrodistillation of Agarwood Chips by the Taguchi Method	68
4.2.2	Agarwood Chip Morphology via Scanning Electron Microscopy	72
4.2.3	Agarwood Chip Thermal Study via Thermogravimetric Analysis	75
4.3	Analysis of Chemical Constituents of Agarwood Oil	76
4.3.1	Chemical Constituents of Extracted Agarwood Oil	76
4.3.2	Chemical Constituents of Agarwood Oil from Malaysia	80
4.3.3	Chemical Constituents of Agarwood Oil from India	84

4.3.4	Chemical Constituents of Agarwood Oil from Cambodia	87
4.3.5	Chemical Constituents of Agarwood Oil from Thailand	90
4.3.6	Summary of the Chemical Constituent Distribution from Different Origins	93
4.4	Identification and Validation of the Selected Marker Compounds	96
4.4.1	Identification of Selected Marker Compounds	96
4.4.2	Validation of Agarospirol	98
4.4.3	Validation of n-Hexadecanoic Acid	101
4.5	Odor Profile Evaluation by E-Nose	104
4.5.1	Agarwood Oil Sample Selection	104
4.5.2	Odor Profile Evaluation	106
	CHAPTER 5 CONCLUSIONS	110
5.1	Conclusions	110
5.2	Recommendations	111
	REFERENCES	113
	APPENDIX A	128
	APPENDIX B	130
	APPENDIX C	131
	APPENDIX D	132
	APPENDIX E	146
	APPENDIX F	149

REFERENCES

- A. Barden, N. . A. T. M. and M. S. (2000). *Heart of the Matter: Agarwood Use and Trade and Cites Implementation for Aquilaria Malaccensis*. TRAFFIC International, Cambridge, UK.
- Abhari, K., & Mousavi Khaneghah, A. (2020). Alternative extraction techniques to obtain, isolate and purify proteins and bioactive from aquaculture and by-products. *Advances in Food and Nutrition Research*, 92, 35–52. <https://doi.org/10.1016/BS.AFNR.2019.12.004>
- Adam, F., Tajuddin, S. N., Johari, J., & Yusoff, M. M. (2012). *Rahsia dan Keunikan Gaharu*. <http://umpir.ump.edu.my/id/eprint/8410/>
- Ahmaed, D. T., & Kulkarni, A. D. (2017). Sesquiterpenes and chromones of agarwood : A review. *Malaysian Journal of Chemistry*, 19(1), 33–58.
- Akter, N. (2008). *Agarwood Plantation at BRAC Tea Estate : Introduction , Environmental Factors and Financial Analysis* (Vol. 7, Issue July).
- Akter, S., Islam, M. T., Zulkefeli, M., & Khan, S. I. (2013). Agarwood Production - A Multidisciplinary Field to be Explored in Bangladesh. *International Journal of Pharmaceutical and Life Sciences*, 2(1), 22–32. <https://doi.org/10.3329/ijpls.v2i1.15132>
- Ali, N. A. M., Jin, C. B., & Jamil, M. (2016). Agarwood (*Aquilaria malaccensis*) oils. In *Essential Oils in Food Preservation, Flavor and Safety*. Elsevier Inc. <https://doi.org/10.1016/B978-0-12-416641-7.00018-3>
- Alkhatlan, H. Z., Al-Hazimi, H. M., Al-Dhalaan, F. S., & Mousa, A. A. (2005). Three 2-(2-phenylethyl) chromones and two terpenes from agarwood. *Natural Product Research*, 19(4), 367–372. <https://doi.org/10.1080/14786410412331280122>
- Antonopoulou, M., Compton, J., Perry, L. S., & Al-Mubarak, R. (2010). The Trade and Use of Agarwood (*Oudh*) in The United Arab Emirates. In *TRAFFIC Southeast Asia*. https://www.trafficj.org/publication/10_Trade_Use_Agarwood.pdf
- Antony, J. (2003). 2 - Fundamentals of Design of Experiments. In J. Antony (Ed.), *Design of Experiments for Engineers and Scientists* (pp. 6–16). Butterworth-Heinemann. <https://doi.org/https://doi.org/10.1016/B978-075064709-0/50003-X>
- Asia-Taipei, T. E., & Asia, T. S. (2005). *The Trade and Use of Agarwood in Taiwan , Province of China* (Vol. 7).
- Atikah, N., Yusoff, M., Tajuddin, S. N., Hisyam, A., Adila, N., & Omar, M. (2015). Agarwood Essential Oil: Study on Optimum Parameter and Chemical Compounds of Hydrodistillation Extraction. *Journal of Applied Science and Agriculture J. Appl. Sci. & Agric*, 10(105), 1–5. www.aensiweb.com/JASA
- Athreya, S., & Venkatesh, Y. D. (2012). Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation. *International Refereed Journal of Engineering and Science*, 1(3), 13–19. <https://doi.org/2319-1821>

- Azah, M., Ismail, N., Mailina, J., Taib, M. N., Rahiman, M. H. F., & Zainal, M. H. (2015). Identification of odor components of agarwood Chemometric Study Of Selected Agarwood Oils By. *Journal of Tropical Forest Science* 26, 26(March 2016), 382–388. <https://doi.org/10.11113/jt.v77.5986>
- Azah, N., & Ali, M. (2012). Analysis of Agarwood Oil (Aquilaria Malaccensis) Based on GC-MS Data. *2012 IEEE 8th International Colloquium on Signal Processing and Its Applications Analysis*, 470–473.
- Baharum, S. N., Bunawan, H., Ghani, M. A., Wan Aida Wan Mustapha, & Noor, N. M. (2010). Analysis of the chemical composition of the essential oil of Polygonum minus Huds. Using two-dimensional gas chromatography-time-of-flight mass spectrometry (GC-TOF MS). *Molecules*, 15(10), 7006–7015. <https://doi.org/10.3390/molecules15107006>
- Ball, G. I., Xu, L., McNichol, A. P., & Aluwihare, L. I. (2012). A two-dimensional, heart-cutting preparative gas chromatograph facilitates highly resolved single-compound isolations with utility towards compound-specific natural abundance radiocarbon (¹⁴C) analyses. *Journal of Chromatography A*, 1220, 122–131. <https://doi.org/10.1016/j.chroma.2011.11.021>
- Barbosa, H. M. A., De Melo, M. M. R., Coimbra, M. A., Passos, C. P., & Silva, C. M. (2014). Optimization of the supercritical fluid coextraction of oil and diterpenes from spent coffee grounds using experimental design and response surface methodology. *Journal of Supercritical Fluids*, 85, 165–172. <https://doi.org/10.1016/j.supflu.2013.11.011>
- Bhuiyan, N. I., Begum, J., & Bhuiyan, N. H. (2009). Analysis of essential oil of eaglewood tree (Aquilaria agallocha Roxb.) by gas chromatography mass spectrometry. *Bangladesh Journal of Pharmacology*, 4(1), 24–28. <https://doi.org/10.3329/bjp.v4i1.851>
- Bulama, J., Dangoggo, S., & Mathias, S. (2015). Isolation and characterization of palmitic acid from ethyl acetate extract of root bark of Terminalia glaucescens. *International Journal of Scientific and Research Publications*, 5(3), 1–3.
- Burfield, T. (2008). The adulteration of essential oils - and the consequence to aromatherapy and natural perfumery practice. Part 1. Oil adulteration. *Cropwatch*, 44(0), 1–22. <https://doi.org/10.1038/137255c0>
- Burkill, I. H., Birtwistle, W., Foxworthy, F. W., Scrivenor, J. B., & Watson, J. G. (1936). A Dictionary of the Economic Products of the Malay Peninsula. *Nature*, 137(3459), 255. <https://doi.org/10.1038/137255c0>
- Chen, G., Sun, F., Wang, S., Wang, W., Dong, J., & Gao, F. (2021). Enhanced extraction of essential oil from Cinnamomum cassia bark by ultrasound assisted hydrodistillation. *Chinese Journal of Chemical Engineering*, 36, 38–46. <https://doi.org/10.1016/j.cjche.2020.08.007>
- Chen, H., Yang, Y., Xue, J., Wei, J., Zhang, Z., & Chen, H. (2011). Comparison of compositions and antimicrobial activities of essential oils from chemically stimulated agarwood, wild agarwood and healthy Aquilaria sinensis (Lour.) Gilg trees. *Molecules*, 16(6), 4884–4896. <https://doi.org/10.3390/molecules16064884>
- Cheng, H., Chen, J., Chen, S., Wu, D., Liu, D., & Ye, X. (2015). Characterization of aroma-active volatiles in three Chinese bayberry (Myrica rubra) cultivars using GC-MS-olfactometry and an electronic nose combined with principal component analysis. *Food Research*

International, 72, 8–15. <https://doi.org/10.1016/j.foodres.2015.03.006>

- Chetpattananondh, P. (2012). Overview of the agarwood oil Industry. *IFEAT International Conference in Singapore*, 131–138.
- Chhipa, H., Chowdhary, K., & Kaushik, N. (2017). Artificial production of agarwood oil in *Aquilaria* sp. by fungi: a review. *Phytochemistry Reviews*, 16(5), 835–860. <https://doi.org/10.1007/s11101-017-9492-6>
- Chong, S. P., Abdul-Rahim, K., & Awang, M. R. (2014). Histology study of *Aquilaria malaccensis* and the agarwood resin formation under light microscope. *Journal of Agrobiotechnology*, 5, 77–83.
- Chung, T. Y., Eiserich, J. P., & Shibamoto, T. (1993). Volatile Compounds Isolated from Edible Korean Chamchwi (*Aster scaber* Thunb). *Journal of Agricultural and Food Chemistry*, 41(10), 1693–1697. <https://doi.org/10.1021/jf00034a033>
- Compton, J., & Ishihara, A. (2004). The use and trade of agarwood in Japan. *A TRAFFIC Report to the CITES Secretariat*, 6, 1–21. <http://144.76.93.178/sites/default/files/common/com/pc/15/X-PC15-06-Inf.pdf>
- Da Silva, R. P. F. F., Rocha-Santos, T. A. P., & Duarte, A. C. (2016). Supercritical fluid extraction of bioactive compounds. *TrAC - Trends in Analytical Chemistry*, 76, 40–51. <https://doi.org/10.1016/j.trac.2015.11.013>
- Dash, M., Patra, J. K., & Panda, P. P. (2008). Phytochemical and antimicrobial screening of extracts of *Aquilaria agallocha* Roxb. *African Journal of Biotechnology*, 7(20), 3531–3534. <https://doi.org/10.5897/AJB08.623>
- De Melo, M. M. R., Silvestre, A. J. D., & Silva, C. M. (2014). Supercritical fluid extraction of vegetable matrices: Applications, trends and future perspectives of a convincing green technology. *Journal of Supercritical Fluids*, 92, 115–176. <https://doi.org/10.1016/j.supflu.2014.04.007>
- Deep, K., & Tajuddin, S. N. (2019). King of Scents-AGARWOOD. In *Perfumer & flavorist* (Vol. 44, Issue 3, pp. 42–56).
- Desai, M. A., & Parikh, J. (2015). Extraction of essential oil from leaves of lemongrass using microwave radiation: Optimization, comparative, kinetic, and biological studies. *ACS Sustainable Chemistry and Engineering*, 3(3), 421–431. <https://doi.org/10.1021/sc500562a>
- Dhanani, T., Shah, S., Gajbhiye, N. A., & Kumar, S. (2017). Effect of extraction methods on yield, phytochemical constituents and antioxidant activity of *Withania somnifera*. *Arabian Journal of Chemistry*, 10, S1193–S1199. <https://doi.org/10.1016/j.arabjc.2013.02.015>
- Eurlings, M. C. M., & Gravendeel, B. (2005). TrnL-trnF sequence data imply paraphyly of *Aquilaria* and *Gyrinops* (Thymelaeaceae) and provide new perspectives for agarwood identification. *Plant Systematics and Evolution*, 254(1), 1–12. <https://doi.org/10.1007/s00606-005-0312-x>
- Fadzil, A. H. M., Hamid, K. H. K., Rodhi, M. N. M., & Kamaruddin, L. M. (2013). Extraction of essential oil from biologically inoculated agarwood. *BEIAC 2013 - 2013 IEEE Business Engineering and Industrial Applications Colloquium*, 889–892.

<https://doi.org/10.1109/BEIAC.2013.6560264>

- Fornari, T., Vicente, G., Vázquez, E., García-Risco, M. R., & Reglero, G. (2012). Isolation of essential oil from different plants and herbs by supercritical fluid extraction. *Journal of Chromatography A*, *1250*, 34–48. <https://doi.org/10.1016/j.chroma.2012.04.051>
- Fraga, B. M. (2013). Natural sesquiterpenoids. *Natural Product Reports*, *30*(9), 1226. <https://doi.org/10.1039/c3np70047j>
- French, D. (2017). Advances in Clinical Mass Spectrometry. *Advances in Clinical Chemistry*, *79*, 153–198. <https://doi.org/10.1016/BS.ACC.2016.09.003>
- Gabetti, E., Sgorbini, B., Stilo, F., Bicchi, C., Rubiolo, P., Chialva, F., Reichenbach, S. E., Bongiovanni, V., Cordero, C., & Cavallero, A. (2021). Chemical fingerprinting strategies based on comprehensive two-dimensional gas chromatography combined with gas chromatography-olfactometry to capture the unique signature of Piemonte peppermint essential oil (*Mentha x piperita* var *Italo-Mitcham*). *Journal of Chromatography A*, *1645*. <https://doi.org/10.1016/j.chroma.2021.462101>
- Gao, M., Han, X., Sun, Y., Chen, H., Yang, Y., Liu, Y., Meng, H., Gao, Z., Xu, Y., Zhang, Z., & Han, J. (2019). Overview of sesquiterpenes and chromones of agarwood originating from four main species of the genus *Aquilaria*. *RSC Advances*, *9*(8), 4113–4130. <https://doi.org/10.1039/C8RA09409H>
- Gardner, J. W., Boilot, P., & Hines, E. L. (2005). Enhancing electronic nose performance by sensor selection using a new integer-based genetic algorithm approach. *Sensors and Actuators, B: Chemical*, *106*(1 SPEC. ISS.), 114–121. <https://doi.org/10.1016/j.snb.2004.05.043>
- Gardner, J. W., Hines, E. L., & Wilkinson, M. (1990). Application of artificial neural networks to an electronic olfactory system. *Measurement Science and Technology*, *1*(5), 446–451. <https://doi.org/10.1088/0957-0233/1/5/012>
- Gardner, J. W., & Bartlett, P. N. (1994). A brief history of electronic noses. *Sensors and Actuators B*, *19*, 18–19. [https://doi.org/10.1016/0925-4005\(94\)87085-3](https://doi.org/10.1016/0925-4005(94)87085-3)
- Gobbi, E., Falasconi, M., Torelli, E., & Sberveglieri, G. (2011). Electronic nose predicts high and low fumonisin contamination in maize cultures. *FRIN*, *44*(4), 992–999. <https://doi.org/10.1016/j.foodres.2011.02.041>
- Gomez, L., Tiwari, B., & Garcia-Vaquero, M. (2020). Emerging extraction techniques: Microwave-assisted extraction. In *Sustainable Seaweed Technologies*. Elsevier Inc. <https://doi.org/10.1016/b978-0-12-817943-7.00008-1>
- Gross, J. H. (2004). *Mass spectrometry: A textbook*. Germany: Springer-Verlag.
- Gu, J. L., Li, Z. J., Zhang, H. X., & Du, Z. Z. (2014). Fragrant volatile sesquiterpenoids isolated from the essential oil of *laggera pterodonta* by using olfactory-guided fractionation. *Chemistry and Biodiversity*, *11*(9), 1398–1405. <https://doi.org/10.1002/cbdv.201400051>
- Gunn, B. V., Stevens, P., Singadan, M., Sunari, L., & Chatterton, P. (2004). Eaglewood in Papua New Guinea. *Resource Management in Asia-Pacific Working Paper No. 51, January 2004*, 18. http://rspas.anu.edu.au/papers/rmap/Wpapers/rmap_wp51.pdf

- Gupta, C. (2015). A Biotechnological Approach to Microbial Based Perfumes and Flavours. *Journal of Microbiology & Experimentation*, 2(1). <https://doi.org/10.15406/jmen.2015.02.00034>
- Gushue, J. N. (2013). Principles and Applications of Gas Chromatography Quadrupole Time-of-Flight Mass Spectrometry. *Comprehensive Analytical Chemistry*, 61, 255–270. <https://doi.org/10.1016/B978-0-444-62623-3.00011-3>
- Handa, S. S., Khanuja, S., Longo, G., & Rakesh, D. D. (2008). Extraction technologies for medicinal and aromatic plants. *International Centre for Science and High Technology*, 21–25.
- Harmsen, P., Huijgen, W., & Lopez, L. (2010). Literature review of physical and chemical pretreatment processes for lignocellulosic biomass. *Food and Biobased Research*, 1–49.
- Hashim, Y. Z.-Y., Phirdaous, A., & Azura, A. (2014). Screening of anticancer activity from agarwood essential oil. *Pharmacognosy Research*, 6(3), 191. <https://doi.org/10.4103/0974-8490.132593>
- Hashim, Y. Z. H. Y., Kerr, P. G., Abbas, P., & Mohd Salleh, H. (2016). Aquilaria spp. (agarwood) as source of health beneficial compounds: A review of traditional use, phytochemistry and pharmacology. *Journal of Ethnopharmacology*, 189, 331–360. <https://doi.org/10.1016/j.jep.2016.06.055>
- Haslina, E., Latib, A., Najib, M. S., Mohd, C., Che, A., & Tajuddin, S. N. (2018). Analysis of Different Quality Agarwood Oil (Aquilaria Malaccensis) and Sensory Study. *Journal of Telecommunication, Electronic and Computer Engineering*, 10(1), 57–61.
- Hodgins, D. (1995). The development of an electronic “nose” for industrial and environmental applications. *Sensors and Actuators: B. Chemical*, 27(1–3), 255–258. [https://doi.org/10.1016/0925-4005\(94\)01597-B](https://doi.org/10.1016/0925-4005(94)01597-B)
- Holzinger, A., Keiblinger, K., Holub, P., Zatloukal, K., & Müller, H. (2023). AI for life: Trends in artificial intelligence for biotechnology. *New Biotechnology*, 74, 16–24. <https://doi.org/10.1016/j.nbt.2023.02.001>
- Hong, E.-J., Na, K.-J., Choi, I.-G., Choi, K.-C., & Jeung, E.-B. (2004). Antibacterial and Antifungal Effects of Essential Oils from Coniferous Trees. *Biological & Pharmaceutical Bulletin*, 27(6), 863–866. <https://doi.org/10.1248/bpb.27.863>
- Huang, L., Liu, H., Zhang, B., & Wu, D. (2015). Application of Electronic Nose with Multivariate Analysis and Sensor Selection for Botanical Origin Identification and Quality Determination of Honey. *Food and Bioprocess Technology*, 8(2), 359–370. <https://doi.org/10.1007/s11947-014-1407-6>
- Hussain, N., Jabeen, Z., Li, Y. L., Chen, M. X., Li, Z. L., Guo, W. L., Shamsi, I. H., Chen, X. Y., & Jiang, L. X. (2013). Detection of tocopherol in oilseed rape (*Brassica napus* L.) using gas chromatography with flame ionization detector. *Journal of Integrative Agriculture*, 12(5), 803–814. [https://doi.org/10.1016/S2095-3119\(13\)60301-9](https://doi.org/10.1016/S2095-3119(13)60301-9)
- Idris, F. N., Nadzir, M. M., & Abd Shukor, S. R. (2020). Optimization of solvent-free microwave extraction of *Centella asiatica* using Taguchi method. *Journal of Environmental Chemical Engineering*, 8(3). <https://doi.org/10.1016/j.jece.2020.103766>

- Ishihara, M., Tsuneya, T., & Uneyama, K. (1991). Guaiane sesquiterpenes from agarwood. *Phytochemistry*, 30(10), 3343–3347. [https://doi.org/10.1016/0031-9422\(91\)83206-Z](https://doi.org/10.1016/0031-9422(91)83206-Z)
- Ishihara, M., Tsuneya, T., & Uneyama, K. (1993a). Components of the agarwood smoke on heating. *Journal of Essential Oil Research*, 5(4), 419–423. <https://doi.org/10.1080/10412905.1993.9698252>
- Ishihara, M., Tsuneya, T., & Uneyama, K. (1993b). Components of the volatile concentrate of Agarwood. *Journal of Essential Oil Research*, 5(May 2015), 283–289. <https://doi.org/10.1080/10412905.1993.9698221>
- Ishihara, M., Tsuneya, T., & Uneyama, K. (1993c). *Fragrant sesquiterpenes from agarwood*. 33(5).
- Ismail, N., Rahiman, M. H. F., Taib, M. N., Ibrahim, M., Zareen, S., & Tajuddin, S. N. (2016). A review on agarwood and its quality determination. *Proceedings - 2015 6th IEEE Control and System Graduate Research Colloquium, ICSGRC 2015*, 103–108. <https://doi.org/10.1109/ICSGRC.2015.7412473>
- Jain, P. L. B., Srivastav, S., Patel, S. R., & Desai, M. A. (2022). Synergetic effect of ultrasound and hydrodistillation for extraction of patchouli oil: Screening, optimization and comparison. *Chemical Engineering and Processing - Process Intensification*, 179. <https://doi.org/10.1016/j.cep.2022.109079>
- Jalal, Z., El Atki, Y., Lyoussi, B., & Abdellaoui, A. (2015). Phytochemistry of the essential oil of *Melissa officinalis* L. growing wild in Morocco: Preventive approach against nosocomial infections. *Asian Pacific Journal of Tropical Biomedicine*, 5(6), 458–461. <https://doi.org/10.1016/j.apjtb.2015.03.003>
- James, A. T., & Martin, J. P. (1955). Gas-liquid partition chromatography: the separation and micro-estimation of volatile fatty acids from formic acid to dodecanoic acid. *The Biochemical Journal*, 61(1), 174–176. <https://doi.org/10.1042/bj0610174>
- Jamshidi, R., Afzali, Z., & Afzali, D. (2009). Chemical composition of hydrodistillation essential oil of rosemary in different origins in Iran and comparison with other countries. *Amer.Eurasian J.Agric.EnvIRON.Sci.*, 5(1), 78–81. <https://doi.org/10.1016/j.aes.2009.03.003>
- Jantan, I. Bin, Basni, I., Ahmad, A. S., Ali, N. A. M., Ahmad, A. R., & Ibrahim, H. (2001). Constituents of the rhizome oils of *Boesenbergia pandurata* (Roxb.) Schlecht from Malaysia, Indonesia and Thailand. *Flavour and Fragrance Journal*, 16(2), 110–112. <https://doi.org/10.1002/ffj.956>
- Jayachandran, K., Sekar, I., Parthiban, K. T., Amirtham, D., & Suresh, K. K. (2014). Analysis of different grades of Agarwood (*Aquilaria malaccensis* Lamk.) oil through GC-MS. *Indian Journal of Natural Products and Resources*, 5(1), 44–47.
- Jirovetz, L., Buchbauer, G., Ngassoum, M. B., & Geissler, M. (2002). Aroma compound analysis of *Piper nigrum* and *Piper guineense* essential oils from Cameroon using solid-phase microextraction-gas chromatography, solid-phase microextraction-gas chromatography-mass spectrometry and olfactometry. *Journal of Chromatography A*, 976(1–2), 265–275. [https://doi.org/10.1016/S0021-9673\(02\)00376-X](https://doi.org/10.1016/S0021-9673(02)00376-X)

- Jok, V. A., Radzi, N. C., & Hamid, K. H. K. (2015). Agarwood Oil Yield As A Result of Changes in Cell Morphology Due To Soaking Process. *Procedia - Social and Behavioral Sciences*, 195, 2443–2450. <https://doi.org/10.1016/j.sbspro.2015.06.387>
- Joulain, D., & König, W. A. (1998). *The Atlas of Spectral Data of Sesquiterpene Hydrocarbons*. E.B.-Verlag. <https://books.google.com.my/books?id=j3RgQgAACAAJ>
- Kim, L., & Marriott, P. J. (2012). Preparative Gas Chromatography. In *Gas Chromatography*. Elsevier Inc. <https://doi.org/10.1016/B978-0-12-385540-4.00016-X>
- Kim, L., Mitrevski, B., Tuck, K. L., & Marriott, P. J. (2013). Quantitative preparative gas chromatography of caffeine with nuclear magnetic resonance spectroscopy. *Journal of Separation Science*, 36(11), 1774–1780. <https://doi.org/10.1002/jssc.201201081>
- Kou, D., & Mitra, S. (2003). Extraction of Semivolatile Organic Compounds from Solid Matrices. In *Sample Preparation Techniques in Analytical Chemistry*. <https://doi.org/10.1002/0471457817.ch3>
- Krishnan, K. R., James, F., & Mohan, A. (2016). Isolation and characterization of n-hexadecanoic acid from *Canthium parviflorum* leaves. *Journal of Chemical and Pharmaceutical Research*, 8(8), 614–617. <http://www.jocpr.com/articles/isolation-and-characterization-of-nhexadecanoic-acid-from-canthium-parviflorum-leaves.pdf>
- Kusuma, H. S., & Mahfud, M. (2016). The extraction of essential oil from sandalwood (*santalum album*) by microwave air-hydrodistillation method. *Journal of Materials and Environmental Science*, 7(5), 1597–1606. <https://doi.org/10.1016/j.aej.2017.02.007>
- Kusuma, Heri Septya, & Mahfud, M. (2017). Microwave-assisted hydrodistillation for extraction of essential oil from patchouli (*Pogostemon cablin*) leaves. *Periodica Polytechnica Chemical Engineering*, 61(2), 82–92. <https://doi.org/10.3311/PPch.8676>
- Le Roux, M., Cronje, J. C., Burger, B. V., & Joubert, E. (2012). Characterization of volatiles and aroma-active compounds in honeybush (*Cyclopia subternata*) by GC-MS and GC-O analysis. *Journal of Agricultural and Food Chemistry*, 60(10), 2657–2664. <https://doi.org/10.1021/jf2048383>
- Lee, S. L., Zakaria, N. F., Tnah, L. H., Ng, C. H., Ng, K. K. S., Lee, C. T., Lau, K. H., & Chua, L. S. L. (2022). DNA databases of a CITES listed species *Aquilaria malaccensis* (Thymelaeaceae) as the tracking tools for forensic identification and chain of custody certification. *Forensic Science International: Genetics*, 57(August 2021), 102658. <https://doi.org/10.1016/j.fsigen.2021.102658>
- Leonelli, C., Veronesi, P., & Cravotto, G. (2012). Microwave-assisted extraction: An introduction to dielectric heating. In *Microwave-assisted extraction for bioactive compounds* (pp. 1–14). Springer.
- Li, A., Feng, M., Li, Y., & Liu, Z. (2016). Application of outlier mining in insider identification based on Boxplot method. *Procedia - Procedia Computer Science*, 91(May 2010), 245–251. <https://doi.org/10.1016/j.procs.2016.07.069>
- Li, W., Chen, Y. P., Blank, I., Li, F., Li, C., & Liu, Y. (2021). GC × GC-ToF-MS and GC-IMS based volatile profile characterization of the Chinese dry-cured hams from different regions. *Food Research International*, 142(February), 110222.

<https://doi.org/10.1016/j.foodres.2021.110222>

- Lias, S., Ali, N. A. M., Jamil, M., Jalil, A. M., & Othman, M. F. (2016). Discrimination of Pure and Mixture Agarwood Oils via Electronic Nose Coupled with k-NN kfold Classifier. *Procedia Chemistry*, 20, 63–68. <https://doi.org/10.1016/j.proche.2016.07.026>
- Lias, S., Ali, N. A. M., Jamil, M., Zainal, M. H., & Ab Ghani, S. H. (2015). Classification of pure and mixture Agarwood oils by Electronic Nose and Discriminant Factorial Analysis (DFA). *2015 International Conference on Smart Sensors and Application, ICSSA 2015*, 7–10. <https://doi.org/10.1109/ICSSA.2015.7322500>
- Lim, T. W., & Awang Anak, N. (2010). *Wood for trees: a review of the agarwood (gaharu) trade in Malaysia. A report commissioned by the CITES Secretariat.*
- Liu, Y., Wei, J., Gao, Z., Zhang, Z., & Lyu, J. (2017). Chinese Herbal Medicines (CHM) Review A Review of Quality Assessment and Grading for Agarwood. *Chinese Herbal Medicines*, 9(1), 22–30. [https://doi.org/10.1016/S1674-6384\(17\)60072-8](https://doi.org/10.1016/S1674-6384(17)60072-8)
- Lucchesi, M. E., Chemat, F., & Smadja, J. (2004). Solvent-free microwave extraction of essential oil from aromatic herbs: Comparison with conventional hydro-distillation. *Journal of Chromatography A*, 1043(2), 323–327. <https://doi.org/10.1016/j.chroma.2004.05.083>
- Luque-García, J. L., & Luque De Castro, M. D. (2003). Where is microwave-based analytical equipment for solid sample pre-treatment going? *TrAC Trends in Analytical Chemistry*, 22(2), 90–98. [https://doi.org/10.1016/S0165-9936\(03\)00202-4](https://doi.org/10.1016/S0165-9936(03)00202-4)
- Ma, S., Fu, Y., Li, Y., Wei, P., & Liu, Z. (2021). The formation and quality evaluation of agarwood induced by the fungi in *Aquilaria sinensis*. *Industrial Crops and Products*, 173. <https://doi.org/10.1016/j.indcrop.2021.114129>
- Mací, M., Garcí, C. J., & Gonzá, H. M. (2014). Improving Short Term Instability for Quantitative Analyses with Portable Electronic Noses. *Sensors*, 14, 10514–10526. <https://doi.org/10.3390/s140610514>
- Malaysia Industrial of Timber Board. (2014). *Panduan Pengkelasan Produk Gaharu Malaysia.*
- Mandal, V., Mohan, Y., & Hemalatha, S. (2008). Microwave assisted extraction of curcumin by sample-solvent dual heating mechanism using Taguchi L9 orthogonal design. *Journal of Pharmaceutical and Biomedical Analysis*, 46(2), 322–327. <https://doi.org/10.1016/j.jpba.2007.10.020>
- Manousi, N., Sarakatsianos, I., & Samanidou, V. (2019). Extraction Techniques of Phenolic Compounds and Other Bioactive Compounds From Medicinal and Aromatic Plants. *Engineering Tools in the Beverage Industry*, 283–314. <https://doi.org/10.1016/B978-0-12-815258-4.00010-X>
- Marques, A. M., & Kaplan, M. A. C. (2013). Preparative isolation and characterization of monoterpene isomers present in the citral-rich essential oil of *Pectis brevipedunculata*. *Journal of Essential Oil Research*, 25(3), 210–215. <https://doi.org/10.1080/10412905.2013.767756>
- Marriot, P. J., Shellie, R., & Cornwell, C. (2001). Gas chromatographic technologies for the analysis of essential oils. *Journal of Chromatography. A*, 936(1–2), 1–22. [https://doi.org/10.1016/S0021-9673\(01\)01314-0](https://doi.org/10.1016/S0021-9673(01)01314-0)

- Meier, M., Kohlenberg, B., & Braun, N. A. (2003). Isolation of anisyl acetone from agarwood oil. *Journal of Essential Oil Research*, 15(1), 54–56. <https://doi.org/10.1080/10412905.2003.9712266>
- Meinert, C., Moeder, M., & Brack, W. (2007). Fractionation of technical p-nonylphenol with preparative capillary gas chromatography. *Chemosphere*, 70(2), 215–223. <https://doi.org/10.1016/j.chemosphere.2007.06.055>
- Memarzadeh, S. M., Ghasemi Pirbalouti, A., & AdibNejad, M. (2015). Chemical composition and yield of essential oils from Bakhtiari savory (*Satureja bachtiarica* Bunge.) under different extraction methods. *Industrial Crops and Products*, 76, 809–816. <https://doi.org/10.1016/J.INDCROP.2015.07.068>
- Mir, A. H., Roy, D. K., & Upadhaya, K. (2017). Taxonomy, Recollection and Conservation Implications of *Aquilaria khasiana* (Thymelaeaceae): An endemic and threatened species of India. *Rheedea*, 27(2), 85–89. <https://doi.org/10.22244/rheedea.2017.27.2.14>
- Mohamed, R., & Lee, S. Y. (2016). *Keeping Up Appearances: Agarwood Grades and Quality*. 149–167. https://doi.org/10.1007/978-981-10-0833-7_10
- Moore, S. W., Gardner, J. W., Hines, E. L., Göpel, W., & Weimar, U. (1993). A modified multilayer perceptron model for gas mixture analysis. *Sensors and Actuators: B. Chemical*, 16(1–3), 344–348. [https://doi.org/10.1016/0925-4005\(93\)85207-Q](https://doi.org/10.1016/0925-4005(93)85207-Q)
- Naef, R. (2011). The volatile and semi-volatile constituents of agarwood, the infected heartwood of *Aquilaria* species: A review. *Flavour and Fragrance Journal*, 26(2), 73–87. <https://doi.org/10.1002/ffj.2034>
- Nakanishi, T., Yamagata, E., Yoneda, K., Nagashima, T., Kawasaki, I., Yoshida, T., Mori, H., & Miura, I. (1984). Three fragrant sesquiterpenes of agarwood. *Phytochemistry*, 23(9), 2066–2067. [https://doi.org/https://doi.org/10.1016/S0031-9422\(00\)84975-4](https://doi.org/https://doi.org/10.1016/S0031-9422(00)84975-4)
- Nät, R., Velluz, A., Thommen, W., Brauchli, R., Sigwart, C., & Gaudin, J. -M. (1993). New compounds identified in agarwood (*Aquilaria agallocha* Roxb.). *Flavour and Fragrance Journal*, 8(6), 307–313. <https://doi.org/10.1002/ffj.2730080604>
- Nath, P. C., Nath, A. J., Sileshi, G. W., & Das, A. K. (2020). Stand structure and functional attributes of agarwood (*Aquilaria malaccensis* Lam.) based smallholder farms in Northeast India. *Trees, Forests and People*, 2(July), 100027. <https://doi.org/10.1016/j.tfp.2020.100027>
- Ng, L., Chang, Y. ., & Kadir, A. A. (1997). A review on agar (gaharu) producing *Aquilaria* species. *Journal of Tropical Forest Products*, 2(2), 272–285. <https://eurekamag.com/research/003/026/003026182.php>
- Ng, T., Fang, E., Bekhit, F., & Wong, J. H. (2016). Methods for the Characterization, Authentication, and Adulteration of Essential Oils. *Essential Oils in Food Preservation, Flavor and Safety*, 11–17. <https://doi.org/10.1016/B978-0-12-416641-7.00002-X>
- Ngadiran, S., Baba, S., Nor, N. F. A., Yahayu, M., Muhamad, M. F., Kushairi, A. K. A., Zaidel, D. N. A., & Muhamad, I. I. (2023). The induction techniques of resinous agarwood formation: A review. *Bioresource Technology Reports*, 21, 101337. <https://doi.org/10.1016/j.biteb.2023.101337>

- Ngan, T. T. K., Thuy, D. T. T., Tuyen, T. T., Inh, C. T., Bich, H. T., Long, P. Q., Chien, N. Q., Linh, H. T. K., Trung, L. N. Y., Tung, N. Q., Nguyen, D. C., Bach, L. G., & Toan, T. Q. (2020). Chemical Components of Agarwood (*Aquilaria crassna*) Essential Oils Grown in Various Regions of Asia. *Asian Journal of Chemistry*, 32(1), 36–40. <https://doi.org/10.14233/ajchem.2020.22177>
- Nn, A. (2015). A Review on the Extraction Methods Use in Medicinal Plants, Principle, Strength and Limitation. *Medicinal & Aromatic Plants*, 04(03), 3–8. <https://doi.org/10.4172/2167-0412.1000196>
- Nojima, S., Apperson, C. S., & Schal, C. (2008). A simple, convenient, and efficient preparative GC system that uses a short megabore capillary column as a trap. *Journal of Chemical Ecology*, 34(3), 418–428. <https://doi.org/10.1007/s10886-008-9437-z>
- Nor Azah, M. A., Saidatul Husni, S., Mailina, J., Sahrim, L., Abdul Majid, J., & Mohd Faridz, Z. (2013). Classification of agarwood (gaharu) by resin content. *Journal of Tropical Forest Science*, 25(2), 213–219.
- Nor Fazila, K., & Ku Halim, K. H. (2012). Effects of soaking on yield and quality of agarwood oil. *Journal of Tropical Forest Science*, 24(4), 557–564.
- Nurhaslina, C. R., Zahari Harip, M. K., Musa, M., Md Zaki, N. A., Alwi, H., Muhd Rodhi, M. N., & Ku Hamid, K. H. (2018). Analysis of sesquiterpenes in agarwood essential oil from hydrodistillation process. *Malaysian Journal of Analytical Sciences*, 22(2), 353–357. <https://doi.org/10.17576/mjas-2018-2202-23>
- Nuzzo, R. L. (2016). The Box Plots Alternative for Visualizing Quantitative Data. *PM&R*, 8(3), 268–272. <https://doi.org/10.1016/j.pmrj.2016.02.001>
- Ochiai, N., & Sasamoto, K. (2011). Selectable one-dimensional or two-dimensional gas chromatography-olfactometry/mass spectrometry with preparative fraction collection for analysis of ultra-trace amounts of odor compounds. *Journal of Chromatography A*, 1218(21), 3180–3185. <https://doi.org/10.1016/j.chroma.2010.10.027>
- Okugawa, H., Ueda, R., Matsumoto, K., Kawanishi, K., & Kato, A. (1996). Effect of Jinkoh-eremol and agarospirol from agarwood on the central nervous system in mice. *Phytomedicine : International Journal of Phytotherapy and Phytopharmacology*, 3(2), 147–153. [https://doi.org/10.1016/S0944-7113\(96\)80028-6](https://doi.org/10.1016/S0944-7113(96)80028-6) [doi]
- Okugawa, H., Ueda, R., Matsumoto, K., Kawanishi, K., & Kato, K. (2000). Effects of sesquiterpenoids from “Oriental incenses” on acetic acid-induced writhing and D2 and 5-Ht(2A) receptors in rat brain. *Phytomedicine*, 7(5), 417–422. [https://doi.org/10.1016/S0944-7113\(00\)80063-X](https://doi.org/10.1016/S0944-7113(00)80063-X)
- Palit, M., Tudu, B., Bhattacharyya, N., Dutta, A., Dutta, P. K., Jana, A., Bandyopadhyay, R., & Chatterjee, A. (2010). Comparison of multivariate preprocessing techniques as applied to electronic tongue based pattern classification for black tea. *Analytica Chimica Acta*, 675(1), 8–15. <https://doi.org/10.1016/j.aca.2010.06.036>
- Park, H. E., Yang, S. O., Hyun, S. H., Park, S. J., Choi, H. K., & Marriott, P. J. (2012). Simple preparative gas chromatographic method for isolation of menthol and menthone from peppermint oil, with quantitative GC-MS and ¹H NMR assay. *Journal of Separation Science*, 35(3), 416–423. <https://doi.org/10.1002/jssc.201100670>

- Politis, S. N., Colombo, P., Colombo, G., & Rekkas, D. M. (2017). Design of experiments (DoE) in pharmaceutical development. In *Drug Development and Industrial Pharmacy* (Vol. 43, Issue 6, pp. 889–901). Taylor and Francis Ltd. <https://doi.org/10.1080/03639045.2017.1291672>
- Poole, C. F. (2015). Ionization-based detectors for gas chromatography. *Journal of Chromatography A*, *1421*, 137–153. <https://doi.org/10.1016/j.chroma.2015.02.061>
- Pornpunyapat, J., Chetpattananondh, P., & Tongurai, C. (2011). Mathematical modeling for extraction of essential oil from *Aquilaria Crassna* by hydrodistillation and quality of agarwood oil. *Bangladesh Journal of Pharmacology*, *6*(1), 18–24. <https://doi.org/10.3329/bjp.v6i1.7902>
- Pourmortazavi, S. M., & Hajimirsadeghi, S. S. (2007). Supercritical fluid extraction in plant essential and volatile oil analysis. *Journal of Chromatography A*, *1163*(1–2), 2–24. <https://doi.org/10.1016/j.chroma.2007.06.021>
- Pripdeevech, P., Khummueng, W., & Park, S.-K. (2011). Identification of Odor-active Components of Agarwood Essential Oils from Thailand by Solid Phase Microextraction-GC/MS and GC-O. *Journal of Essential Oil Research*, *23*(4), 46–53. <https://doi.org/10.1080/10412905.2011.9700468>
- Priyanka, & Khanam, S. (2018). Influence of operating parameters on supercritical fluid extraction of essential oil from turmeric root. *Journal of Cleaner Production*, *188*, 816–824. <https://doi.org/10.1016/j.jclepro.2018.04.052>
- Ramezani, N., Raji, F., Rezakazemi, M., & Younas, M. (2020). Juglone extraction from walnut (*Juglans regia* L.) green husk by supercritical CO₂: Process optimization using Taguchi method. *Journal of Environmental Chemical Engineering*, *8*(3). <https://doi.org/10.1016/j.jece.2020.103776>
- Richter, B. E., & Raynie, D. (2012). Accelerated solvent extraction (ase) and high-temperature water extraction. In *Comprehensive Sampling and Sample Preparation* (Vol. 2). Elsevier. <https://doi.org/10.1016/B978-0-12-381373-2.00047-8>
- Ríos, J. L. (2016). Essential Oils: What They Are and How the Terms Are Used and Defined. *Essential Oils in Food Preservation, Flavor and Safety*, 3–10. <https://doi.org/10.1016/B978-0-12-416641-7.00001-8>
- Rudnicka, J., Kowalkowski, T., Ligor, T., & Buszewski, B. (2011). Determination of volatile organic compounds as biomarkers of lung cancer by SPME – GC – TOF / MS and chemometrics. *Journal of Chromatography B*, *879*(30), 3360–3366. <https://doi.org/10.1016/j.jchromb.2011.09.001>
- Rühle, C., Eyres, G. T., Urban, S., Dufour, J. P., Morrison, P. D., & Marriott, P. J. (2009). Multiple component isolation in preparative multidimensional gas chromatography with characterisation by mass spectrometry and nuclear magnetic resonance spectroscopy. *Journal of Chromatography A*, *1216*(30), 5740–5747. <https://doi.org/10.1016/j.chroma.2009.06.006>
- Rühle, C. P. G., Niere, J., Morrison, P. D., Jones, R. C., Caradoc-Davies, T., Cauty, A. J., Gardiner, M. G., Tolhurst, V. A., & Marriott, P. J. (2010). Characterization of tetra-aryl benzene isomers by using preparative gas chromatography with mass spectrometry, nuclear

- magnetic resonance spectroscopy, and x-ray crystallographic methods. *Analytical Chemistry*, 82(11), 4501–4509. <https://doi.org/10.1021/ac100417h>
- Samadi, M., Abidin, Z. Z., Yoshida, H., Yunus, R., & Awang Biak, D. R. (2020). Towards oil yield and quality of essential oil extracted from *aquilaria malaccensis* wood via the subcritical technique. *Molecules*, 388, 539–547.
- Schaller, E., Bosset, J. O., & Escher, F. (1998). “Electronic Noses” and Their Application to Food. *Lebensmittel-Wissenschaft Und-Technologie*, 31(4), 305–316. <https://doi.org/10.1006/fstl.1998.0376>
- Schwertman, N. C., Ann, M., & Adnan, R. (2004). *A simple more general boxplot method for identifying outliers*. 47, 165–174. <https://doi.org/10.1016/j.csda.2003.10.012>
- Sciarrone, D., Pantò, S., Cacciola, F., Costa, R., & Dugo, P. (2015). Advanced preparative techniques for the collection of pure components from essential oils. *Natural Volatiles & Essential Oils*, 2(2), 1–15.
- Sciarrone, D., Panto, S., Ragonese, C., Dugo, P., & Mondello, L. (2015). Evolution and status of preparative gas chromatography as a green sample-preparation technique. *TrAC - Trends in Analytical Chemistry*, 71, 65–73. <https://doi.org/10.1016/j.trac.2015.02.024>
- Senatore, F., Arnold, N. A., & Piozzi, F. (2004). Chemical composition of the essential oil of *Salvia multicaulis* Vahl. var. *simplicifolia* Boiss. growing wild in Lebanon. *Journal of Chromatography A*, 1052(1–2), 237–240. <https://doi.org/10.1016/j.chroma.2004.08.095>
- Setyaningrum, H. D., & Saparinto, C. (2002). *Gaharu Panduan Lengkap*. Penebar Swadaya.
- Shah, K., Darshak, B., Vallabhbhai, S., Desai, M. A., & Jadeja, G. (2017). Extraction of essential oil from patchouli leaves using hydrodistillation: Parametric studies and optimization Vapor phase synthesis of cyclic lactones using solid catalysts View project Selective extraction using hydrotropes from biomass View project. In Article in Indian Journal of Chemical Technology. <https://www.researchgate.net/publication/319098343>
- SNI 7631:2011. (2011). Standar Nasional untuk Gaharu. *Standar Nasional Untuk Gaharu*.
- Sodeifian, G., Sajadian, S. A., & Saadati Ardestani, N. (2017). Experimental optimization and mathematical modeling of the supercritical fluid extraction of essential oil from *Eryngium billardieri*: Application of simulated annealing (SA) algorithm. *Journal of Supercritical Fluids*, 127(April), 146–157. <https://doi.org/10.1016/j.supflu.2017.04.007>
- Sosa-Hernández, J. E., Escobedo-Avellaneda, Z., Iqbal, H. M. N., & Welte-Chanes, J. (2018). State-of-the-art extraction methodologies for bioactive compounds from algal biome to meet bio-economy challenges and opportunities. *Molecules*, 23(11). <https://doi.org/10.3390/molecules23112953>
- Stauffer, E., Dolan, J. A., & Newman, R. (2008). Gas Chromatography and Gas Chromatography—Mass Spectrometry. *Fire Debris Analysis*, 235–293. <https://doi.org/10.1016/B978-012663971-1.50012-9>
- Subehan, Ueda, J. Y., Fujino, H., Attamimi, F., & Kadota, S. (2005). A field survey of agarwood in Indonesia. *Journal of Traditional Medicines*, 22(4), 244–251. <https://doi.org/10.11339/jtm.22.244>

- Sulaiman, N., Idayu, M. I., Ramlan, A. Z., Fashya, M. N., Farahiyah, A. N. N., Mailina, J., & Azah, M. A. N. (2015). Effects of extraction methods on yield and chemical compounds of gaharu (*Aquilaria malaccensis*). *Journal of Tropical Forest Science*, 27(4), 413–419. <https://doi.org/10.1111/joa.12396>
- Sutton, P. A., Lewis, C. A., & Rowland, S. J. (2005). Isolation of individual hydrocarbons from the unresolved complex hydrocarbon mixture of a biodegraded crude oil using preparative capillary gas chromatography. *Organic Geochemistry*, 36(6), 963–970. <https://doi.org/10.1016/j.orggeochem.2004.11.007>
- Swee, L., & Chua, L. (2008). *Aquilaria malaccensis*. 3, 1–17.
- Tajuddin, S. N., Muhamad, N. S., Yarmo, M. A., & Yusoff, M. M. (2013). Characterization of the Chemical Constituents of Agarwood Oils from Malaysia by Comprehensive Two-Dimensional Gas Chromatography–Time-of-Flight Mass Spectrometry. *Mendeleev Communications*, 23(1), 51–52. <https://doi.org/10.1016/j.mencom.2013.01.019>
- Tajuddin, S. N., & Yusoff, M. M. (2010). Natural Product Communications Chemical Composition of Volatile Oils of. *Natural Product Communications*, 1(7), 10–13.
- Takamatsu, S., & Ito, M. (2018). Agarotetrol: a source compound for low molecular weight aromatic compounds from agarwood heating. *Journal of Natural Medicines*, 0123456789. <https://doi.org/10.1007/s11418-018-1185-y>
- Takemoto, H., Ito, M., Shiraki, T., Yagura, T., & Honda, G. (2008). Sedative effects of vapor inhalation of agarwood oil and spikenard extract and identification of their active components. *Journal of Natural Medicines*, 62(1), 41–46. <https://doi.org/10.1007/s11418-007-0177-0>
- Tamuli, P., Boruah, P., Nath, S. C., & Leclercq, P. (2005). Essential Oil of Eaglewood Tree: a Product of Pathogenesis. *Journal of Essential Oil Research*, 17(6), 601–604. <https://doi.org/10.1080/10412905.2005.9699008>
- Tasfiyati, A. N., Antika, L. D., Dewi, R. T., Septama, A. W., Sabarudin, A., & Ernawati, T. (2022). An experimental design approach for the optimization of scopoletin extraction from *Morinda citrifolia* L. using accelerated solvent extraction. *Talanta*, 238(P1), 123010. <https://doi.org/10.1016/j.talanta.2021.123010>
- Thakker, M. R., Parikh, J. K., & Desai, M. A. (2016). Microwave assisted extraction of essential oil from the leaves of Palmarosa: Multi-response optimization and predictive modelling. *Industrial Crops and Products*, 86, 311–319. <https://doi.org/10.1016/j.indcrop.2016.03.055>
- Tsimidou, M., & Boskou, D. (2003). ADULTERATION OF FOODS | Detection. *Encyclopedia of Food Sciences and Nutrition*, 47–55. <https://doi.org/10.1016/B0-12-227055-X/00013-4>
- Utami, R. S., Puspasari, I., Shyuan, L. K., Mohamed, A. B., & Alva, S. (2016). Kesan pembolehubah proses terhadap sintesis polipirola menggunakan kaedah taguchi. *Malaysian Journal of Analytical Sciences*, 20(3), 660–669. <https://doi.org/10.17576/mjas-2016-2003-27>
- Varma, K. R., Maheshwari, M. L., & Bhattacharyya, S. C. (1965). Terpenoids—LXII. *Tetrahedron*, 21(1), 115–138. [https://doi.org/10.1016/S0040-4020\(01\)82208-0](https://doi.org/10.1016/S0040-4020(01)82208-0)

- Veggi, P. C., Martinez, J., & Meireles, M. A. A. (2012). Fundamentals of microwave extraction. In *Microwave-assisted extraction for bioactive compounds* (pp. 15–52). Springer.
- Virgiliou, C., Zisi, C., Kontogiannopoulos, K. N., Nakas, A., Iakovakis, A., Varsamis, V., Gika, H. G., & Assimopoulou, A. N. (2021). Headspace gas chromatography-mass spectrometry in the analysis of lavender's essential oil: Optimization by response surface methodology. *Journal of Chromatography B: Analytical Technologies in the Biomedical and Life Sciences*, 1179(July), 122852. <https://doi.org/10.1016/j.jchromb.2021.122852>
- Wanikawa, A., Hosoi, K., Kato, T., & Nakagawa, K. I. (2002). Identification of green note compounds in malt whisky using multidimensional gas chromatography. *Flavour and Fragrance Journal*, 17(3), 207–211. <https://doi.org/10.1002/ffj.1073>
- Weyerstahl, P., Marschall, H., Wahlburg, H., Christiansen, C., Rustaiyan, A., Mirdjalili, F., & Wiley, C. J. (1999). Constituents of the essential oil of *Pulicaria gnaphalodes* (Vent.) Boiss. from Iran. *Flavour and Fragrance Journal*, 130.
- Wilson, A. D. (2013). *Diverse Applications of Electronic-Nose Technologies in Agriculture and Forestry*. 2295–2348. <https://doi.org/10.3390/s130202295>
- Wong, Y. F., Chin, S. T., Perlmutter, P., & Marriott, P. J. (2015). Evaluation of comprehensive two-dimensional gas chromatography with accurate mass time-of-flight mass spectrometry for the metabolic profiling of plant-fungus interaction in *Aquilaria malaccensis*. In *Journal of Chromatography A* (Vol. 1387, pp. 104–115). <https://doi.org/10.1016/j.chroma.2015.01.096>
- Xia, L. L., Li, W., Wang, H., Dong, W. H., Cai, C. H., Gai, C. J., Yang, L., Mei, W. L., & Dai, H. F. (2019). One new 2-(2-Phenylethyl)chromone Derivative from Agarwood of *Aquilaria crassna* in Cambodia. *Phytochemistry Letters*, 31(November 2018), 69–72. <https://doi.org/10.1016/j.phytol.2019.03.008>
- Yan, G., Ji, L., Luo, Y., & Hu, Y. (2012). Preparative isolation and purification of three sesquiterpenoid lactones from *Eupatorium lindleyanum* DC. by high-speed counter-current chromatography. *Molecules*, 17(8), 9002–9009. <https://doi.org/10.3390/molecules17089002>
- Yan, J., Guo, X., Duan, S., Jia, P., Wang, L., Peng, C., & Zhang, S. (2015). Electronic nose feature extraction methods: A review. *Sensors (Switzerland)*, 15(11), 27804–27831. <https://doi.org/10.3390/s151127804>
- Yoneda, K., Yamagata, E., Nakanishi, T., Nagashima, T., Kawasaki, I., Yoshida, T., Mori, H., & Miura, I. (1984). Sesquiterpenoids in two different kinds of agarwood. *Phytochemistry*, 23(9), 2068–2069. [https://doi.org/https://doi.org/10.1016/S0031-9422\(00\)84976-6](https://doi.org/https://doi.org/10.1016/S0031-9422(00)84976-6)
- Yoswathana, N. (2013). Extraction of agarwood (*Aquilaria crassna*) oil by using supercritical carbon dioxide extraction and enzyme pretreatment on hydrodistillation. *Journal of Food, Agriculture and Environment*, 11(2), 1055–1059.
- Yoswathana, N., Eshiahi, M. N., & Jaturapornpanich, K. (2012). Enhancement of Essential Oil from Agarwood by Subcritical Water Extraction and Pretreatments on Hydrodistillation. *World Academy of Science, Engineering and Technology*, 65(5), 832–838.
- Young, F. W., Valero-Mora, P., & Friendly, M. (2006). *Visual Statistics Seeing Data with*

- Dynamic Interactive Graphic* (P. A John Wiley & Sons, Inc (ed.)). Wiley-Interscience.
- Yumi Z.H, et. al. (2014). Analysis of Chemical Compounds of Agarwood Oil From Different Species By Gas Chromatography Mass Spectrometry (Gcms). *IJUM Engineering Journal*, 15(1), 55–60.
- Zahari, M. F., Julius, T. A., Halim, F. A., Najib, M. S., Ghazali, K. H., & Azoddein, A. A. M. (2015). Intelligent Classification Hazardous Gas Using Sensors Array. *Journal of Advances in Information Technology*, 6(4), 233–237. <https://doi.org/10.12720/jait.6.4.233-237>
- Zahari, M. F., Najib, M. S., Ghazali, K. H., Halim, F. A., Tajuddin, S. N., & Latib, E. H. A. (2014). Gaharu Sensor : Classification Using Case Based Reasoning (CBR). *Colloquium On Robotics, Unmanned Systems And Cybernetics 2014 (CRUSC 2014)*, 2014(Crusc), 6–9
- Zahed, N., Najib, M. S., & Azhani, N. F. N. N. M. (2016). Classification of honey odor-profile using case-based reasoning technique (CBR). *ARPN Journal of Engineering and Applied Sciences*, 11(10), 6675–6679. http://www.arpnjournals.org/jeas/research_papers/rp_2016/jeas_0516_4333.pdf
- Zhang, X. L., Liu, Y. Y., Wei, J. H., Yang, Y., Zhang, Z., Huang, J. Q., Chen, H. Q., & Liu, Y. J. (2012). Production of high-quality agarwood in *Aquilaria sinensis* trees via whole-tree agarwood-induction technology. *Chinese Chemical Letters*, 23(6), 727–730. <https://doi.org/10.1016/j.ccllet.2012.04.019>
- Zhang, Y., Meng, H., Lyu, F., Fan, X., Liu, P., He, X., Huang, Y., Chen, B., Yang, Y., & Wei, J. (2022). Temporal characteristics of agarwood formation in *Aquilaria sinensis* after applying whole-tree agarwood-inducing technique. *Chinese Herbal Medicines*. <https://doi.org/10.1016/j.chmed.2022.07.003>
- Zougagh, M., Valcárcel, M., & Ríos, A. (2004). Supercritical Fluid Extraction: A Critical Review of its Analytical Usefulness. *TrAC Trends in Analytical Chemistry*, 23, 399–405. [https://doi.org/10.1016/S0165-9936\(04\)00524-2](https://doi.org/10.1016/S0165-9936(04)00524-2)
- Zorga, J., Kunicka-Styczyńska, A., Gruska, R., & Śmigielski, K. (2020). Ultrasound-Assisted Hydrodistillation of Essential Oil from Celery Seeds (*Apium graveolens* L.) and Its Biological and Aroma Profiles. *Molecules*, 25(22). <https://doi.org/10.3390/MOLECULES25225322>
- Zuo, H. L., Yang, F. Q., Huang, W. H., & Xia, Z. N. (2013). Preparative gas chromatography and its applications. *Journal of Chromatographic Science*, 51(7), 704–715. <https://doi.org/10.1093/chromsci/bmt040>