Jurnal Teknologi

Full paper

A Review Study of Agarwood Oil and Its Quality Analysis

Nurlaila Ismail[a*], Nor Azah Mohd Ali[b], Mailina Jamil[b], Mohd Hezri Fazalul Rahiman[a], Saiful Nizam Tajuddin[c], Mohd Nasir Taib[a]

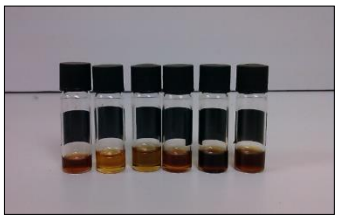
[a]*Faculty of Electrical Engineering,Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia*
[b]*Herbal Product Development Programme, Natural Products Division, Forest Research Institute Malaysia (FRIM), 52109 Kepong, Selangor, Malaysia*
[c]*Faculty of Industrial Science and Technology, Universiti Malaysia Pahang (UMP), Lebuhraya Tun Razak, 26300 Gambang, Pahang, Malaysia*

*Corresponding author: nrk_my@yahoo.com

Article history

Received :31 December 2013
Received in revised form :
11 February 2014
Accepted :15 March 2014

Graphical abstract



Abstract

This paper presents an overview of analysis agarwood oil and its quality grading. The review suggested agarwood oil can be graded according to their chemical properties and so that there is a common standard recognized worldwide on grading the agarwood oil. Analysis based on chemical profiles is required to ensure that agarwood oil can be classified based on their respective classes or grades where the accurate results can be measured. Conventionally, the grading of agarwood oil is performed by trained human graders (sensory panels) depends on its physical appearance such as color, odor, high fixative and consumer perception. However, this method is limited due to human nose cannot accept many samples in one time and easily get fatigues especially when dealing with continuous production. The human sensory panel also limited in terms of subjectivity, poor reproducibility, time consumption and large labour expense. These are constraining factors in increasing agarwood oil trade and market penetration.

Keywords: Grading; agarwood oil; chemical compounds; signal processing

Abstrak

Kertas ini membentangkan gambaran keseluruhan mengenai analisis minyak gaharu dan penggredan kualitinya. Kajian mencadangkan minyak gaharu boleh digredkan mengikut sifat-sifat kimia dan juga dicadangkan supaya diadakan satu standard yang diiktiraf di seluruh dunia untuk penggredan minyak gaharu. Analisis berdasarkan profil bahan kimia diperlukan untuk memastikan agar minyak gaharu boleh diklasifikasikan berdasarkan kelas atau gred supaya keputusan yang tepat boleh dicapai. Konvensionalnya, penggredan minyak gaharu dilakukan oleh penggred manusia terlatih (panel deria) iaitu bergantung kepada rupa fizikal minyak tersebut seperti warna, bau, persepsi dan gambaran yang tinggi oleh pengguna. Walau bagaimanapun, kaedah ini adalah terhad disebabkan oleh hidung manusia tidak boleh menerima banyak sampel dalam satu masa dan dengan cepat letih terutama apabila berurusan dengan pengeluaran berterusan. Panel deria manusia juga terhad dari segi subjektiviti, kebolehulangan yang terhad, penggunaan masa dan perbelanjaan buruh yang besar. Ini adalah faktor-faktor yang mengekang dalam meningkatkan perdagangan minyak gaharu dan penembusan pasaran.

Kata kunci: Gred; minyak gaharu; bahan kimia; pemprosesan isyarat

1.0 INTRODUCTION

Agarwood oil is the oil extracted from agarwood trees. Agarwood or *gaharu* is the resin impregnated heartwood of the *Aquilaria* species, a genus which belongs taxonomically to the *Thymelaeaceae* family. The agarwood oil is highly demanded due to its special usage; an incense for religious ceremony, in perfume and traditional medicine preparations [1]. In the Middle East, it is a symbol of wealth and widely used during the wedding ceremony [2-7].

The agarwood oil is traded according to its quality. High quality oil is expensive and low quality is cheap. The oil class also traded based on its physical properties; color and odor. Usually, dark color and long lasting odor are classified as high quality and sold at premier price [8]. It is normal for a high quality oils to cost between USD126 to USD633 per tola (12 ml) [2]. The wood prices for low qualities are USD19 per kg and up to USD100,000 per kg for superior quality [1, 9].

Many studies have been carried out to analyze the quality of agarwood oil [10-14]. Researchers from Japan has classified Kanankoh as the highest quality among many types of agarwood oil and Jinkoh as the low quality [11, 13, 14]. The relationship between high and low quality of oil has been widely investigated by comparing their chemical compositions [13, 14]. One of the investigations found that the abundances (percentage relative peak

area measured by GC-MS) of the same compound in high quality oil is more than in low quality [14].

There are many techniques available to analyse the chemical compounds of essential oils; electronic nose (Enose), gas chromatography (GC), gas chromatography/mass spectrometric (GC/MS), solid phase micro extraction (SPME), gas chromatography –flame ionization detector (GC-FID), gas chromatography-olfactometry (GC-O) and comprehensive two dimensional gas chromatography (GCxGC) [12, 14-19]. GC-O is the odor-compounds extraction method with combining gas chromatography and human sensory panel [19]. This method is limited to the subject of fairness since human nose cannot tolerate with many samples at the same time [15]. In GC x GC, chemical compounds are separated by a single column based on its properties; the size, length and stationary phase. In GC-FID, the flame ionization detector was used to sense any molecule with a carbon-hydrogen bond. However, it provides poor response to compounds; H_2S, CCl_4 or NH_3. The technique is mass sensitive but not concentration sensitive. Furthermore, the flame ionization detectors require a high data rate at 200 Hz to operate [15]. The GC/MS technique is proven and has shown its promising result in analysing the chemical compounds of agarwood oil [8, 10, 13, 14, 16-18, 20-23]. The GC/MS technique combines gas chromatograph and mass spectrometry. The compounds mixture was separated by gas chromatograph and mass spectroscopy was used to characterize every component individually [15]. The other popular method is SPME where it was preferred to detect the odor compounds of agarwood oil [19, 24]. The SPME has produced reliable analysis in many studies since it can give fast result, sensitive, inexpensive, easy to handle, solvent free and selective [19, 24-31].

Based on practice and literature, it was found that there are two ways in grading the agarwood oil. Some countries use term quality of agarwood oil; high and low and some countries use term grade of agarwood oil; A, B, C and D. Each term is applied based on agarwood oil physical properties like color, odor and consumer perception [1, 7, 8, 13].

Technically, the grading of agarwood oil is performed by trained human graders (sensory panels) depends on its physical appearance; color, odor, high fixative and consumer perception [5, 6, 32-35]. However, this method is limited due to human nose cannot accept many samples in one time and easily get fatigues especially when dealing with continuous production [6]. The human sensory panel also limited in terms of subjectivity, poor reproducibility, time consumption and large labour expense [8]. These are constraining factors in increasing agarwood oil trade and market penetration [9].

A review from literature domain suggested agarwood oil can be graded according to their chemical properties and so that there is a common standard recognized worldwide on grading the agarwood oil [9]. Analysis based on chemical profiles is required to ensure that agarwood oil can be classified based on their respective classes or grades where the accurate results can be measured [9, 11, 13, 36].

2.0 AGARWOOD OIL

Aquilaria is the resinous part of wood and it is known as agarwood, eaglewood, oudh, oud, kanankoh, kyara, jinkoh and kalambak. Taxonomically, the wood comes from *Thymelaeaceae* family. It had been reported that there are nineteen species of *Aquilaria* found in the Asean region [1]. The agarwood has multiple usage from trunk, branches, chips, flakes of uniform quality powder to essential oil [16].

Many studies have shown that there has been a dramatic increase in agarwood oil usage in Malaysia [2, 3, 5, 6, 15, 20, 37-40]. Correspondingly, there is an increasing number of agarwood plantation in this country and the market demand of its oil from all over the world [34, 35]. Agarwood oil is concentrated volatile aromatic compounds produced by agarwood plant, extracted from the stem. Many researchers have highlighted that agarwood oil is produced as incense, perfumery and for traditional medicines [1, 16, 19, 41]. The agarwood oil is traded worldwide and getting high market demand especially from United Arab Emirates, Saudi Arabia, China and Japan. The agarwood oils are traded differently depending on its grade.

The demand of agarwood oil is high in the Middle East, where the oil symbolizes the society ranking, wealthiness and hospitality. It is an important ingredient in the perfumery industry and to generate aroma in wedding ceremonies or banquets [1, 2, 22, 35, 39, 42-44].

2.1 The Chemical Compounds of Agarwood Oils

Many researchers had studied the differences of chemical composition in agarwood oil [2, 13, 14, 16, 18, 19, 22, 23, 38, 40, 45]. Most of them agreed that sesquiterpenes components and its chromone derivative were the major compounds in agarwood oil [2, 13, 14, 16, 19, 23, 40]. The composition of the compounds, determine the high and low quality of agarwood oil [13, 14]. Forest Research Institute Malaysia (FRIM) has carried out classification of agarwood oil quality based on wood physical properties, long lasting aroma when burnt, color, resin content, high fixative properties and consumer perception [2]. For example basis odor and appearance can be applied to grade different quality of the agarwood oil falling from A to D [2, 23]. A research in Japan meanwhile has classified the quality of agarwood oil either high or low quality based on peak area percentage (or abundances) of chemical compounds. The wood oil which contain α-guaiene with the peak area less than 0.05% classified as a high quality oil however the wood oil which is not containing α-guaiene classified as low quality [13].

The highest quality of agarwood oil has a lot of resin which means that it contains various kind of oxygenated sesquiterpenes and chromone derivatives [11]. Three compounds of sesquiterpenes are detected only in the highest quality. They are *(-)-guaia-1(10),11-dien-15-al*, *(-)-selina-3,11-dien,9-one* and *(+)-selina-3,11-dien,9-ol* [12]. Reflective to that, the presence of sesquiterpenes differentiate the premium of agarwood oil in the market [12]. The grade A (also called as supreme or deluxe) agarwood oil is trading expensively at a cost between RM400 to RM2000 per tola (12 ml) [2, 15, 37].

2.2 The Agarwood Oil Quality Analysis

There are different techniques being used to analyse the quality of agarwood oil (i.e. high and low); gas chromatograph (GC) charts [13, 14], qualitative and quantitative difference (or chemical composition) table [19] and thin layer chromatogram (TLC) [22]. By using GC chart, the differences of relative peak area (%) for sesquiterpenes components in high and low quality oil can be observed visually [13, 14]. Various guaiene and eudesmane sesquiterpenes were found in high quality however most of them were not detected in low quality of agarwood oil [14]. Benzaldehyde and anisaldehyde compounds in high quality (i.e. Kanankoh) were found less than in low quality (i.e. Jinkoh) [13]. The components; 9-11-eremophiladien-8-one and oxo-agarospirol were found in low quality agarwood oil. β-agarofuran, α-agarofuran and 10-epi-ɤ-eudesmol were the major compounds in high quality [2, 14, 19, 40]. Among them, β-agarofuran is the

most important compound in high quality and it is contributed to the aroma of agarwood oil [19]. Some monoterpenes were not exist in high quality oil [13] which contain high resin content [22]. The empirical study showed that the characteristic spots with deeper color in TLC figures can be related to the high quality of agarwood oil [11]. Table 1 summarizes the component based characteristic of agarwood oil.

Table 1 Component based characteristic of agarwood oil

Component	Low Quality	High Quality	Ref
1. resin content	low	high	[23]
2. α-guaiene	no	yes	[18]
3. (-)-guaia-1(10),11-dien-15-al, (-)-selina-3,11-dien,9-one and (+)-selina-3,11-dien,9-ol	no	yes	[24]
4. guaiene and eudesmane	no	yes	[22]
5. benzaldehyde and anisaldehyde	less amount	more amount	[18]
6. 9-11-eremophiladien-8-one and oxo-agarospirol	yes	no	[7]
7. β-agarofuran, α-agarofuran and 10-epi-ɤ-eudesmol	not mentioned	yes	[17]
8. β-agarofuran	not mentioned	the most important compound	[19]
9. sesquiterpenes	not mentioned	major	[1, 13, 19, 22]

2.3 The Agarwood Oil Grading Method

Conventionally, the agarwood oil was graded according to its colour, aroma and fixative based on human's sense [2, 40]. However, it was difficult to standardise it's quality from the aroma due to human nose cannot smell many samples continuously [2, 3, 17, 19, 38, 44-46]. There were also limitation in terms of subjectivity, poor reproducibility, time consumption and expensive labor cost [47].

There are various grading methods applicable for agarwood oil. Different country has its own way to grade/classify the agarwood oil. Agarwood oil is traded on the basis of qualities; high and low but there are some countries prefer grades. In Malaysia, agarwood oil is classified according to the grade of A, B, C and D [7, 8]. In India, they use grades too; A, B, C and D but were based on the color of agarwood oil [1]. In Japan, agarwood oil is categorized as high and low quality where Kanankoh is the highest quality and Jinkoh is low quality [13]. Therefore, no standard available for this highly price oil [15].

Laboratory technique; GC-MS analysis was carried out to grade agarwood oil by analysing the chemical profiles of the oil [11-13, 19, 45]. GC-MS analysis identifies the significant existence of common compositions; valerianol [2, 23], pentadecanoic, tetradecanoic, dodecanoic and hexadecanoic acid [23], elemol [2, 38, 40], β-agarofuran, α-agarofuran, epi-ɤ-eudesmol and agarospirol and α-guaiene [2, 12]. The analysis characterized the volatile compounds of agarwood oil to different quality and showing that there were differences of oil compositions in agarwood oil [12, 13, 19, 36, 38, 48]. For example, agarospirol and β-agarofuran as Type A and α-agarofuran, 10- epi-ɤ-eudesmol and oxo-agarospirol as Type B [36].

Another grading method is by analysing the odour of the agarwood oil. The GC-MS helps to relate the compounds and odour based on odoriferous properties in agarwood oil [2, 12, 19]. For example, (-)-guaia-1(10), 11-dien-15-al has a pleasant note, β-damascenone like woody note with a touch of camphor and (-)-selina-3, 11-dien-9-one has a fresh and sweet odour to represent gorgeous and elegant character of agarwood oil [12].

Instead of odour, colour has been used to grade the agarwood oil; different colour corresponds to different quality of oil [11-13]. Dark colour (especially black) refer to the high quality with very expensive market price [40]. Researches on colour in oil volatile components have been carried out and they found that different colour has different chemical constituents [38, 45]. For an example, GC-MS found that oxidoagarochromone as a pale yellow in oil component [49].

Both colour and odour has a complex mixture of sesquiterpenes and chromone derivatives [15]. As major volatile components, the presence of sesquiterpenes is popular in market [16].

3.0 AGARWOOD OIL ANALYSIS TECHNIQUE

There are many techniques applied to analyze the chemical composition in essential oil [2, 13, 14, 16, 18, 19, 22, 23, 38, 40, 45]. Some of them are electronic nose (Enose) [3, 31, 50, 51], gas chromatography (GC), gas chromatography-mass spectrometric (GC-MS), solid phase micro extraction (SPME), gas chromatography –flame ionization detector (GC-FID), gas chromatography-olfactometry (GC-O) [12, 14, 16-19] and comprehensive two dimensional gas chromatography (GC x GC) [15, 39].

Electronic nose or Enose has been applied in wide range of applications; in food, beverages and cosmetics industries [3, 28, 52-59]. It is used to classify the quality of essential oil and food [3, 52, 53, 60, 61], to discriminate the different blends, to pattern recognition the aroma [50, 60] and to determine the odour discrimination in cosmetics [1] and agarwood oil [3, 28, 52, 56-59, 62]. Besides that, Enose is able to monitor the modified atmosphere (MA) for different temperature regimes especially in food [8].

GC-O is the odor-compounds extraction method which combine gas chromatography and human sensory panel [19, 63]. This hybrid method was applied to measure the sensory activity of chemical, to process human olfactory and to detect the chemical compounds in fruit [63, 64]. The GC-O is depends on human nose which can influence the description on the odor quality of the oil [64] Thus, it is limited to the subject of fairness since human nose cannot tolerate with too many samples at the same time [15].

The other analysis method is GC x GC. The first concept of this method was introduced by Giddings in 1984 before it is being used in petroleum, food and fragrance analysis [39]. By using this technique chemical compounds are separated by a single column based on its properties; the size, length and stationary phase. The detector for this analysis should has a high rate of data acquisition so that the system can respond very fast enough during the evaluation [15]. The concept in GC-FID is the flame ionization detector applicable to sense any molecule with a carbon-hydrogen bond [15]. This analysis was performed to extract the chemical compositions in essential oils, fatty acids and chemical products [38]. However, it provides poor response or not all to compounds; H_2S, CCl_4 or NH_3. The technique is mass sensitive but not

concentration sensitive. Furthermore, the flame ionization detectors require a high data rate at 200 Hz to operate [15].

The GC-MS technique is proven and has shown its promising result in analysing the chemical compounds of agarwood oil [8, 10, 13, 14, 16-18, 20-23]. The concept of GC/MS is combining two techniques; gas chromatograph and mass spectrometry. The compounds mixture was separated by gas chromatograph and mass spectroscopy was used to characterize every component individually [15].

The other preferred method is SPME detecting the odour compounds of agarwood oil [19, 24]. The SPME has shown as a reliable analysis in many studies since it can give fast result, sensitive, inexpensive, easy to handle, solvent free and selective.

3.1 The GC-MS Analysis

The GC/MS is a well known, easy, fast and proven method to study the chemical profiles in agarwood oil [2, 38, 45]. This technique has shown it capability by discriminating the chemical compounds from the herbal material [65] and identify the most abundances in fruits [64].

The GC/MS has been used to successfully determine the oil composition from agarwood smoke by heating [13]. The analyses of GC and GC/MS showed the existence of major sesquiterpenes and its chromone derivatives in agarwood oil [38]. Different compositions marked in the agarwood oil using GC and GC/MS will establish whether the oils are generated from healthy wood or artificially inoculated wood [23]. Different oil grade applies even though there are similarities in agarwood oil sampled through GC profiles but different in percentage concentration from GC/MS analysis [2].

3.2 The SPME Analysis

The aroma compounds of essential oils have caught interest of many researchers in identifying their volatile profiles [9, 15, 19, 24, 25, 29, 52, 66, 67]. One of the famous methods for this study is solid phase microextraction (SPME) which has been proven its effectiveness in various application; plants, food, beverage biological and environmental samples [15, 25, 29, 52]. It is also used to identify the agarwood oil compounds [9, 19, 24]. The chemical compounds identified using this technique are useful to ensure the accuracy in grading agarwood based on their chemical properties [9].

The SPME is recognized as a fast, solvent free, easy to use and sensitive method to isolate the volatile chemical compounds of essential oil [15, 24]. The technique was determined by a fiber existence where different fibers result in different sensitivity [15, 19].

The SPME fiber is reported to be many types; divinylbenzene-carboxen-polydimethylsiloxane (DVB-CAR-PDMS), polydimethylsiloxane-divinylbenzene (PDMS-DVB), polydimethylsiloxane (PDMS) and polyacrylate (PA) [15, 19, 24]. Several studies showed that the oil compounds vary according to different fibers [9, 19, 29]. This is because every fiber has different properties that rely on their thickness and chemical properties [9]. A study has shown that PA fiber has low dispersion and CAR/PDMS has high sensitivity [15]. Other studies found that DVB-CAR-PDMS fiber extracted the highest number of volatile compounds compared to others [15, 19].

The analysis technique of agarwood oil; Enose, GC, GC-MS, SPME GC-FID and GC-O will be producing a lot of chemical compounds from the extraction [19, 23, 38]. In order to do further analysis; signal processing, not all compounds are being used. Data transformation should be applied so that only significant chemical compounds will be utilized; classification and modelling [68, 69]. The application of data transformation will reduce the sample size of data collection from a large number to a smaller number of data [70]. Besides that, the technique also benefit in term of economical reason [69].

4.0 CONCLUSION

From the above review, it can be seen that agarwood oil is an important commodity and its trade highly dependent on its quality and/or grade. Currently the grading of agarwood oil is done manually which is based on its physical appearances; colour and odour. However, there were studies mentioned that chemical compounds of agarwood oil can be used to decide the quality of agarwood oil, since they found that agarwood oil were made up of complex mixture of sesquiterpenes, oxygenated sesquiterpenes and its chromone derivation. Thus, the agarwood oil classification system using these chemical components can be used to provide fast, robust, automatic and accurate result. The review found that GC-MS and SPME techniques provided many advantages; well established, easy to use, fast, sensitive method and solvent free analyzer.

Acknowledgement

This research was supported by Ministry of Science, Technology and Innovation (MOSTI fund no: 07-03-10-PB001), Ministry of Agriculture and Agrobased Industry (05-03-10-SF1017, 05-03-10-SF0070) and Research Intensive Faculty grant from Universiti Teknologi MARA (600-RMI/DANA 5/3/RIF (614/2012)). The authors would like to thank all staff involved especially from Herbal Product Development Programme, Natural Products Division, Forest Research Institute Malaysia for their technical assistance.

References

[1] R. Naef. 2011. The Volatile and Semi-volatile Constituents of Agarwood, the Infected Heartwood of Aquilaria Species: A Review. *Flavour and Fragrance Journal*. 26: 73–87.

[2] M. A. NorAzah, J. A. Majid, J. Mailina, A. A. Said, S. S. Husni, H. N. Hasnida, M. A. M. N. M. Arip, and Y. S. Chang. 2009. Profiles of selected supreme Agarwood oils from Malaysia. Herbal Globalisation: A New Paradigm for Malaysian Herbal Industry (MAPS 2008). 393–398.

[3] W. Hidayat, A. Y. M. Shakaff, M. N. Ahmad, and A. H. Adom. 2010. Classification of Agarwood Oil Using an Electronic Nose. *Sensors*. 10: 4675–4685.

[4] M. S. Najib, N. A. M. Ali, M. N. M. Arip, A. M. Jalil, and M. N. Taib. 2010. Classification of Agarwood region using ANN. IEEE Control and System Graduate Research Colloquium (ICSGRC 2011). 7–13.

[5] M. S. Najib, N. A. M. Ali, M. N. M. Arip, A. M. Jalil, M. N. Taib, and N. Kasuan. 2010. Classification of Malaysian and Indonesian Agarwood using k-NN.

[6] M. S. Najib, M. N. Taib, N. A. M. Ali, M. N. M. Arip, and A. M. Jalil. 2011. Classification of Agarwood Grades using ANN. International Conference on Electrical, Control and Computer Engineering.

[7] N. A. B. Sidik. 2008. Comparison of Gaharu (Aquilaria Malaccensis) Essential Oil Composition Between Each Country. Bachelor of Chemical Engineering, Faculty of Chemical Engineering and Natural Resources, University Malaysia Pahang.

[8] N. A. M.A., Y. S. Chang, M. J., A. S. A, A. M. J., S. H. S., N. H. H., and N. Y. Y. 2008. Comparison of Chemical Profiles of Selected Gaharu Oils from Peninsular Malaysia. *The Malaysian Journal of Analytical Sciences.* 12: 340.

[9] A. K. Pravina. 2008. Application of Solid Phase Microextraction in Gaharu Essential Oil Analysis. Bachelor of Chemical Engineering, Faculty of Chemical Engineering and Natural Resources, Univerisiti Malaysia Pahang (UMP), Pahang.

[10] M. Ishihara, T. Tsuneya, M. Shiga, and K. Uneyama. 1991. Three sesquiterpenes from agarwood. Phytochemistry. 30: 563–566.
[11] M. Ishihara, T. Tsuneya, and K. Uneyama. 1993. Fragrant Sesquiterpenes from Agarwood. *Phytochemistry*. 33: 1147–1155.
[12] M. Ishihara, T. Tsuneya, and K. Uneyama. 1991. Guaiane Sesquiterpenes from Agarwood. *Phytochemistry*. 30: 3343–3347.
[13] M. Ishihara, T. Tsuneya, and K. Uneyama. 1993. Components of the Agarwood Smoke on Heating. *Journal of Essential Oil Research*. 5: 419–423.
[14] M. Ishihara, T. Tsuneya, and K. Uneyama. 1993. Components of the Volatile Concentrate of Agarwood. *Journal of Essential Oil Research*. 5: 283–289.
[15] S. N. Tajuddin. 2011. Resolution of Complex Sesquiterpene Mixture in Aqualaria Malaccensis (Gaharu) Volatile Oils Using Gas Chromatography Methods. PhD, Faculty of Industry and Science Technology (FIST), Universiti Malaysia Pahang (UMP).
[16] P. Wetwitayaklung, N. Thavanapong, and J. Charoenteeraboon. 2009. Chemical Constituents and Antimicrobial Activity of Essential Oil and Extracts of Heartwood of Aquilaria crassna Obtained from Water Distillation and Supercritical Fluid Carbon Dioxide Extraction. *Silpakorn University Science and Technology Journal*. 3: 25–33.
[17] M. Meier, B. Kohlenberg, and N. A. Braun. 2003. Isolation of Anisyl Acetone from Agarwood Oil. *Journal of Essential Oil Research*. 15: 54–56.
[18] M. N. I. Bhuiyan, J. Begum, and M. N. H. Bhuiyan. 2008. Analysis of essential Oil of Eaglewood Tree (Aquilaria agallocha Roxb.) by Gas Chromatography Mass Spectrometry. *Bangladesh Journal of Pharmacology*. 4: 24–28.
[19] P. Pripdeevech, W. Khummueng, and S. K. Park. 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: 46–53.
[20] H. F. Lim, A. M. A. Rashid, S. S. Lee, P. A. Fauzi, Y. S. Chang, Y. A. Zuhaidi, M. M. Parid, E. H. Lok, A. M. Farid, and M. A. N. Azah. 2010. Penanaman Aquilaria dan Penghasilan Gaharu di Malaysia. Forest Research Institute Malaysia (FRIM), Kepong, Malaysia 93.
[21] N. A. Latif. 2009. Analysis volatile compound of Gaharu oil Composition via solid phase micro extraction (SPME). Bachelor of Chemical Engineering, Faculty of Chemical Engineering, Universiti Malaysia Pahang, Pahang.
[22] X. L. Zhang, Y. Y. Liu, J. H. Wei, Y. Yang, Z. Zhang, J. Q. Huang, H. Q. Chen, and Y. J. Liu. 2012. Production of High-quality Agarwood in Aquilaria Sinensis Trees via Whole-tree Agarwood-induction Technology. *Chinese Chemical Letters*. 23: 727–730.
[23] P. Tamuli, P. Boruah, S. C. Nath, and P. Leclercq. 2005. Essential Oil of Eaglewood Tree: A Product of Pathogenesis. *Journal of Essential Oil Research.* 17: 601–604.
[24] N. A. Latif. 2009. Analysis volatile compound of Gaharu oil composition via solid phase micro extraction (SPME). Bachelor of Chemical Engineering, Faculty of Chemical & Natural Resources Engineering, University Malaysia Pahang.
[25] H. P. Bais, B. Dattatreya, and G. Ravishankar. 2003. Production of volatile compounds by hairy root cultures of Cichorium intybus L under the Influence of Fungal Elicitors and Their Analysis Using Solid Phase Micro Extraction Gas Chromatography–Mass Spectrometry. *Journal of the Science of Food and Agriculture*. 83: 769–774.
[26] R. J. Bryant and A. M. McClung. 2011. Volatile profiles of Aromatic and Non-aromatic Rice Cultivars using SPME/GC–MS. *Food Chemistry.* 124: 501–513.
[27] W. Chen, P. Zhou, K. C. Wong-Moon, and N. S. Cauchon. 2007. Identification of Volatile Degradants in Formulations Containing Sesame Oil Using SPME/GC/MS. *Journal of Pharmaceutical and Biomedical Analysis.* 44: 450–455.
[28] [28] A. Cimato, D. Dello Monaco, C. Distante, M. Epifani, P. Siciliano, A. M. Taurino, M. Zuppa, and G. Sani. 2006. Analysis of Single-cultivar Extra Virgin Olive Oils by Means of an Electronic Nose and HS-SPME/GC/MS Methods. *Sensors and Actuators B: Chemical.* 114: 674–680.
[29] L. Jirovetz, G. Buchbauer, M. B. Ngassoum, and M. Geissler. 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: 265–275.
[30] Z. Meng, W. Dan, R. Shao-Xiong, and P. Ling. 2011. Head-Space Solid Phase Microextraction and GC-MS Analysis of Aroma Compounds in Feijoa Sellowiana. In 2011 5th International Conference on Bioinformatics and Biomedical Engineering, (iCBBE). 1–4.
[31] H. Reinhard, F. Sager, and O. Zoller. 2008. Citrus Juice Classification by SPME-GC-MS and Electronic Nose Measurements. *LWT - Food Science and Technology*. 41: 1906–1912.
[32] M. H. F. Rahiman. 2009. System Identification of Steam Distillation Essential Oil Extraction System. Ph.D. dissertation, Universiti Teknologi MARA, Shah Alam.
[33] N. Ismail, N. Tajjudin, M. H. F. Rahiman, and M. N. Taib. 2009. Modeling of Dynamic Response of Essential Oil Extraction Process. In 5th International Colloquium on Signal Processing & Its Applications, CSPA 2009. 298–301.
[34] K. H. K. Hamid. 2011. Ed., Professional lecture: enhancing the world of fragrance through Malaysian Bio-Gaharu. Shah Alam, Selangor, Malaysia: University Publication Centre (UPENA), UiTM.
[35] A. M. A. Rashid and Y. A. Zuhaidi. 2011. Eds., Tapping the wealth from Karas (Aquilaria malaccensis) tree. Selangor, Malaysia: Forest Research Institute Malaysia.
[36] T. Nakanishi, E. Yamagata, K. Yoneda, and T. Nagashima. 1984. Three Fragrant Sesquiterpenes of Agarwood. *Phytochemistry.* 23: 2066–2067.
[37] K. H. K. Hamid. 2011. Professorial Lecture: Enhancing The World of Fragrance Through Malaysian Bio-Gaharu, 1st ed. UiTM Shah Alam: University Publication Centre (UPENA).
[38] S. N. Tajuddin and M. M. Yusoff. 2010. Chemical Composition of Volatile Oils of Aquilaria malaccensis (Thymeleaceae) from Malaysia. *Natural Product Communications.* 5: 1965–1968.
[39] S. N. Tajuddin, N. S. Muhamad, M. A. Yarmo, and M. M. Yusoff. 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: 51–52.
[40] M. A. NorAzah, Y. S. Chang, J. Mailina, A. A. Said, J. A. Majid, S. S. Husni, H. N. Hasnida, and Y. N. Yasmin. 2008. Comparison of Chemical Profiles of Selected Gaharu Oils from Peninsular Malaysia. *The Malaysian Journal of Analytical Sciences.* 12: 338–340.
[41] A. Barden, N. A. Anak, T. Mulliken, and M. Song. 2000. Heart of the Matter: Agarwood Use and Trade and CITES implementation for Aquilaria malaccensis. TRAFFIC International, Cambridge, UK.
[42] N. H. Yusoff, M. M. Salleh, M. Yahaya, and M. R. Awang. 2006. The Use of Photoluminescence Spectra of TiO2 Nanoparticles Coated With Porphyrin Dye Thin Film for Grading Agarwood Oil. In Proceedings of ICSE2006. 193–197.
[43] H. Takemoto, M. Ito, T. Shiraki, T. Yagura, and G. Honda. 2008. Sedative Effects of Vapor Inhalation of Agarwood Oil and Spikenard Extract and Identification of Their Active Components. *J Nat Med.* 62: 41–6.
[44] M. A. NorAzah, N. Ismail, and M. N. Taib. 2012. Analysis of Agarwood oil (Aquilaria Malaccensis) based on GC-MS data. In 2012 IEEE 8th International Colloquium on Signal Processing and its Applications (CSPA). 470–473.
[45] J. Pornpunyapat, P. Chetpattananondh, and C. Tongurai. 2011. Mathematical Modeling for Extraction of Essential Oil from Aquilaria Crassna by Hydrodistillation and Quality of Agarwood Oil. *Bangladesh Journal of Pharmacology.* 6: 18–24.
[46] S. F. A. Rahman. 2009. Analysis of Agarwood Oil Composition Via Preparative Thin Layer Chromatography..
[47] P. E. Keller. 1999. Mimicking Biology: Applications of Cognitive Systems to Electronic Noses. 447–451.
[48] M. Maheshwari, T. Jain, R. Bates, and S. Bhattacharyya. 1963. Terpenoids—xli: Structure and Absolute Configuration of α-agarofuran, b-agarofuran and Dihydroagarofuran. *Tetrahedron.* 19: 1079–1090.
[49] T. Yagura, N. Shibayama, M. Ito, F. Kiuchi, and G. Honda. 2005. Three Novel Diepoxy Tetrahydrochromones from Agarwood Artificially Produced by Intentional Wounding. *Tetrahedron Letters.* 46: 4395–4398.
[50] A. Ortega, S. Marco, T. Sundic, and J. Samitier. 2000. New Pattern Recognition Systems Designed for Electronic Noses. *Sensor and Actuators B.* 69: 302–307.
[51] M. S. Najib, M. U. Ahmad, P. Funk, M. N. Taib, and N. A. M. Ali. 2012. Agarwood classification: A Case-Based Reasoning approach based on E-nose. In 2012 IEEE 8th International Colloquium on Signal Processing and its Applications (CSPA). 120–126.
[52] N. Barié, M. Bücking, and M. Rapp. 2006. A Novel Electronic Nose Based on Miniaturized SAW with SPME Enhanced Headspace-analysis and Sensor Arrays Coupled Its Use for Rapid Determination of Volatile Organic Compounds in Food Quality Monitoring. *Sensors and Actuators B: Chemica*l. 114: 482–488.
[53] C. Cevoli, L. Cerretani, A. Gori, M. F. Caboni, T. Gallina Toschi, and A. Fabbri. 2011. Classification of Pecorino Cheeses Using Electronic Nose Combined with Artificial Neural Network and Comparison with GC–MS Analysis of Volatile Compounds. *Food Chemistry.* 129: 1315–1319.

[54] F. Che Harun, J. Taylor, J. Covington, and J. Gardner. 2009. An Electronic Nose Employing Dual-channel Odour Separation Columns with Large Chemosensor Arrays for Advanced Odour Discrimination. *Sensors and Actuators B: Chemical*. 141: 134–140.
[55] M. A. Craven, J. W. Gardner, and P. N. Bartlett. 1996. Electronic noses_Development and Future Prospects. *Trends in Analytical Chemistry*. 15 (9).
[56] R. Dutta, D. Morgan, N. Baker, J. W. Gardner, and E. L. Hines. 2005. Identification of Staphylococcus Aureus Infections in Hospital Environment: Electronic Nose Based Approach. *Sensors and Actuators B: Chemica*l. 109: 355–362.
[57] J. W. Gardner and P. N. Bartlett. 2000. *Electronic Noses. Principles and Applications*. Oxford University Press.
[58] J. W. Gardner, H. W. Shin, and E. L. Hines. 2000. An Electronic Nose System to Diagnose Illness. *Sensors and Actuators B: Chemical*. 70: 19–24.
[59] J. W. Gardner, H. W. Shin, E. L. Hines, and C. S. Dow. 2000. An Electronic Nose System for Monitoring the Quality of Potable Water. *Sensors and Actuators B: Chemical*. 69: 336–341.
[60] G. E. Scarle, J. W. Gardner, M. J. Chappell, K. R. Godfrey, and M. J. Chapman. 2002. System Identification of Electronic Nose Data from Cyanobacteria Experiments. *IEEE Sensors Journal*. 2: 218–229.
[61] S. Panigrahi, S. Balasubramanian, H. Gu, C. Logue, and M. Marchello. 2006. Neural-network-integrated electronic nose system for identification of spoiled beef. *LWT - Food Science and Technology*. 39: 135–145.
[62] P. J. Hobbs, T. H. Misselbrook, and B. F. Pain. 1994. Assessment of Odours from Livestock Wastes by a Photoionization Detector, an Electronic Nose, Olfactometry and Gas Chromatography-Mass Spectrometry. *J. Agric. Engng Res.* 60: 137–144.
[63] T. E. Acree. 1997. Peer Reviewed: GC/Olfactometry GC With a Sense of Smell. *Analytical Chemistry*. 69: 170A–175A.
[64] Á. Högnadóttir and R. L. Rouseff. 2003. Identification of Aroma Active Compounds in Orange Essence Oil Using Gas Chromatography–Olfactometry and Gas Chromatography–Mass Spectrometry. *Journal of Chromatography A*. 998: 201–211.
[65] C. Deng, N. Liu, M. Gao, and X. Zhang. 2007. Recent Developments in Sample Preparation Techniques for Chromatography Analysis of Traditional Chinese Medicines. *Journal of Chromatography A*. 1153: 90–96.
[66] J. Rohloff. 1999. Monoterpene composition of essential oil from peppermint (Mentha× piperita L.) with Regard to Leaf Position Using Solid-Phase Microextraction and Gas Chromatography/Mass Spectrometry Analysis. *Journal of Agricultural and Food Chemistry*. 47: 3782–3786.
[67] E. Marengo, C. Baiocchi, M. Gennaro, P. Bertolo, S. Lanteri, and W. Garrone. 1991. Classification of Essential Mint Oils of Different Geographic Origin by Applying Pattern Recognition Methods to Gas Chromatographic Data. Chemometrics and Intelligent *Laboratory Systems*. 11: 75–88.
[68] M. N. Taib, R. Andres, and R. Narayanaswamy. 1996. Extending the Response Range of an Optical Fibre Ph Sensor Using an Artificial Neural Network. *Analytica Chimica Acta*. 330: 31–40.
[69] M. N. Taib, R. Adnan, and M. H. F. Rahiman. 2007. Practical System Identification. Shah Alam: Faculty of Electrical Engineering, UiTM.
[70] C. DiStefano, M. Zhu, and D. Mindrila. 2009. Understanding and using Factor Scores: Considerations for the Applied Researcher. *Practical Assessment, Research & Evaluation.* 14: 1–11.