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The Extraction of Essential Oil from Sandalwood (*Santalum album*) by Microwave Air-Hydrodistillation Method

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Abstract
Oil from sandalwood is commonly obtained by a conventional distillation process which requires great energy, significant amount of solvents, and quite a long process time. Therefore, the use of new 'green technique' for extracting essential oil with minimum/low energy, solvents, and time need to be considered. One extraction method which has been succesfully developed is microwave hydrodistillation method. This research employs a method developed from microwave hydrodistillation, that is microwave air-hydrodistillation for optimizing the extraction of essential oil. The purpose of this study is to examine the effect of the presence and absence of additional air flow to the microwave hydrodistillation method. The material used in this study includes sandalwood powder. The extractions by microwave hydrodistillation and microwave air-hydrodistillation methods were done on the power of 600W; the ratio of the raw material to be extracted and the solvent was 0.05 g mL^{-1} and the extraction time was 120 minutes. In the extraction by microwave air-hydrodistillation, the rates of air flow used were 0.1, 0.5, 1.5, 3.0, and 5.0 L/min. The results of the research show that the extraction of sandalwood oil by microwave air-hydrodistillation is faster and produces higher yields and recovery accumulation compared to the extraction by microwave hydrodistillation method. The testing of the physical properties of the sandalwood oil indicates that essential oil obtained by microwave hydrodistillation and microwave air-hydrodistillation has the same quality (refractive index and specific gravity). Further, the testing of the chemical properties of the sandalwood oil shows that essential oil obtained by microwave air-hydrodistillation has better quality (flavor) compared to the oil obtained by microwave hydrodistillation.

Keywords: Air flow, Microwave hydrodistillation, Microwave air-hydrodistillation, Sandalwood oil, *Santalum album*

1. Introduction
Indonesia is one of main essential-oil producer countries in the world. In Indonesia, there are about 45 plant species which can produce essential oil. However, only 15 plants have become export commodities. They are citronella oil, vetiver oil, patchouli oil, cananga oil, sandalwood oil, nutmeg and mace oil, clove leaf, stem, bud oil, cullilawan oil, massoi oil, sassafras oil, ginger oil, blackpepper oil, agarwood oil, turpentine oil, cajeput oil, and kafir lime oil.In the international market, there are 90 kinds of essential oil traded [1].
This can be seen from the extraction of sandalwood oil which is commonly done byhydrodistillation, steam-hydro distillation, and steam distillation.The extraction of sandalwood oil has long been done by refiners in Kupang bysteam distillation. It generally takes 40-70 hours. The distillation process is usually stopped when the distilled oil is estimated to run out and economically not viable/efficient. Further, the distillation of sandalwood oil is usually done at the vapor pressure of 20-40 lb. High-pressured distillation can also be done to produce higher oil yield; it is done in a shorter distillation process. This is because the use of high pressure can raise the temperature of distillation. However, the increase of temperature can result in the decomposition of oil components; this produces less oil fragnant. Therefore, the use of a new 'green technique' for extracting essential oil with low/minimal energy and solvent should be considered. A new method for extracting essential oil has been developed, that is bymicrowave.

A previous research has shown that extraction by microwave is an alternative method which can be further developed due to the high level of product purity, the minimal use of solvent, and short processing time [2]. Some extractions by microwave which have been developed include microwave hydrodistillation – which is the combination of hydrodistillation and heating with microwave [3], and microwave steam distillation – which is the combination of steam distillation and heating with microwave [4].
In this study, the development of microwave hydrodistillation will be used, that is microwave air-hydrodistillation for the extraction of essential oil. This method consists of three elements: a compressor which serves to inject air into the distiller containing matrix (parts of the plant to be extracted), microwave,and a condenser as the cooling system.
The addition of air flow in the microwave air-hydrodistillationis expected to improve the yield and quality of sandalwood oil extracted. The addition of the air flow is predicted to assist in carrying important oil components in the cell membrane or plant tissue that is difficult to diffuse. This is because sandalwood oil is a heavy oil containing heavy fraction components which are difficult to extract without an addition of air flow. Thus, to examine the effect of the airflow in microwave air-hydrodistillation, the extractions of essential oil from sandalwood (*Santalum album*)by the methods of microwave hydrodistillation and microwave air-hydrodistillationwere done in this research.

2. Experimental

2.1. *Materials and chemicals*

Sandalwood powder (*Santalum album*)used in this research was obtained from Kupang, East Nusa Tenggara and stored at room temperature until required.Aquadest and anhydrous sodium sulphate used in the experimental work were all of analytical grade.

2.2. *Microwave air-hydrodisto avoidtillation*

A domestic microwave oven (EMM-2007X, Electrolux, 20 L, 800 W; variable in 200 W increments, 2.45 GHz) was modified for microwave hydrodistillation operation. The dimensions of the PTFE-coated cavity of the microwave oven were 46.1 cm x 28.0 cm x 37.3 cm. Twenty grams of sandalwood powder samples were placed in a 1 L flask containing deionized water (400 mL). The flask was setup within the microwave oven cavity and a condenser was used on the top (outside the oven) to collect the extracted essential oils. Using the compressor (MELZER V-777, electric motor: 1/5H.P., max pressure: 3 bar), air flow was added into the distiller containing the sandalwood powder and deionized water. Next, the air flow is set in accordance with the operational condition and the determined research variables using a flowmeter(Figure 1). The microwave oven was operated at 600 W power level for a period of 2 h. This period was sufficient to extract all the essential oil from the sample.

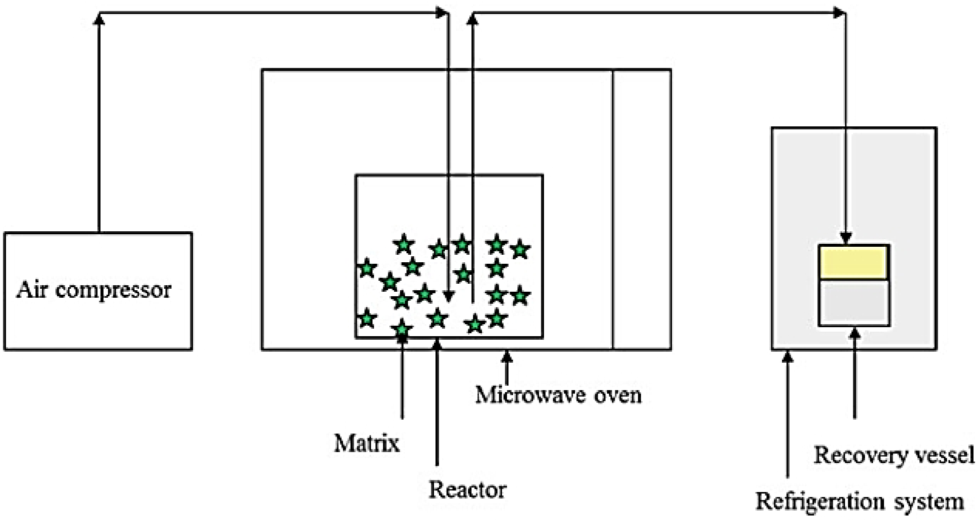

Figure 1: Schematic representation of the microwave air-hydrodistillation apparatus used in this study

The essential oil was separated using a separating funnel.The extracted essential oil was then dried over anhydrous sodium sulphate, weighed and stored in amber vials at 4^{o}C until used for analysis. The yield of sandalwood oil was found by the following equation (1):

$$y = \frac{V}{W} \text{X } 100 \quad (1)$$

where y is the sandalwood oil yield (%, w/w), V is the weight or mass of extracted sandalwood oil (g) and W is the weight or mass of sandalwood powder (g).

2.3. *Microwave hydrodistillation*

Twenty grams of sandalwood powder were placed in a 1 L flask containing deionized water (400 mL). The flask was setup within the microwave oven cavity and a condenser was used on the top (outside the oven) to collect the extracted essential oil (Figure 2). The microwave oven was operated at 600 W power level for a period of 2 h. This period was sufficient to extract all the essential oil from the sample. The essential oil was separated using a separating funnel.To remove water, the extracted essential oils were then dried over anhydrous sodium sulphate, weighed and stored in amber vials at 4^{o}C until they were used for analysis.

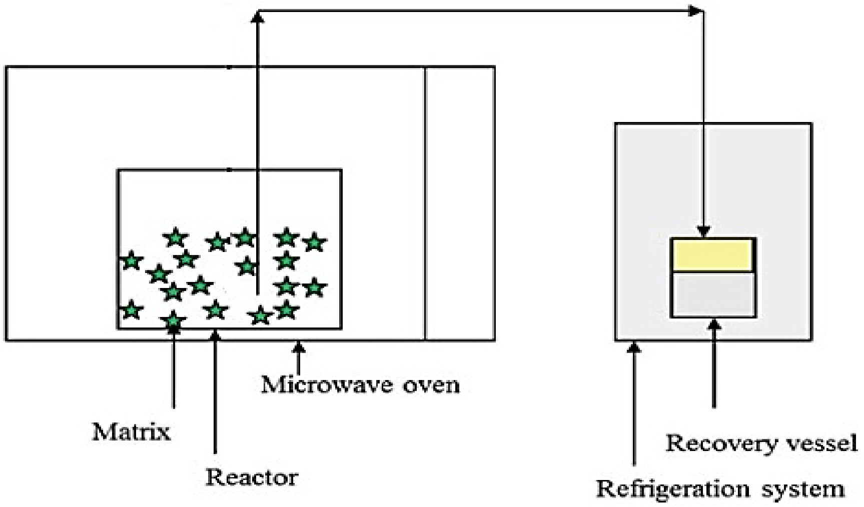

Figure 2: Schematic representation of the microwave hydrodistillation apparatus used in this study

2.4. *Physical constants*

Specific gravity and refractive index of the essential oils extracted from sandalwood (by both methods) were measured according to the method suggested by ISO 3518:2002(E). Specific gravity and refractive index were measured at 20^{o}C.

2.5. *Chemical analysis of essential oil constituents*

Essential oils composition was determined by gas chromatography coupled to mass spectrometry (GC–MS) analysis on a Hewlett–Packard 6890 gas chromatograph coupled to a 5973A mass spectrometer, using two fused-silica-capillary columns with different stationary phases. The non-polar column was HP5MS™ (30 m length, 0.25 diameter and 0.25 μm film thickness) and the polar one was a Stabilwax ™ consisting of Carbowax™-PEG (60 m length,0.25 mm diameter and0.25 μm film thickness). GC–MS spectra were obtained using the following conditions: carrier gas He; flow rate 1.0 ml min^{-1}; split 1:50; injection volume 1.0 μL; injection temperature 300^{o}C; oven temperature progress from 100 to 250^{o}C at 10^{o}C min^{-1}; the ionisation mode used was electronic impact at 70 eV. Most constituents were tentatively identified by comparison of their GC Kovats retention indices (RI), determined with reference to an homologous series of C_5–C_{28}*n*-alkanes and with those of authentic standards available in the authors' laboratory. Identification was confirmed by comparison of their mass spectral fragmentation patterns with those stored in the MS database (National Institute of Standards and Technology and Wiley libraries) and withmass spectra literature data [5,6]. For each compound on the chromatogram, the percentage of peak area relative to the total peak areas from all compounds was determined and reported as relative amount of that compound.

3. Results and Discussion

3.1. *The effect of the addition of airflow to microwave air-hydrodistillation method on the yield of sandalwood oil*

In the extraction of sandalwood oil, it can be observed that the yield of sandalwood oil obtained bymicrowave air-hydrodistillation is higher thanthe yield obtained by microwave hydrodistillation. The comparison chart of sandalwood yield obtained by microwave hydrodistillation and microwave air-hydrodistillation methods in a variety of microwave power can be seen in Table 1. As presented in Table 1, it can be seen that the higher the air flow, the higher the obtained yield of sandalwood.

Table 1: Yield of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation

Extraction method	Air flow rate(L/min)	Sandalwood oilyield (%)
Microwave hydrodistillation	0	1.2184 ± 0.1139
Microwave air-hydrodistillation	0.1	1.2248 ± 0.1037
	0.5	1.2985 ± 0.0762
	1.5	1.3170 ± 0.0634
	3.0	1.3170 ± 0.0968
	5.0	1.3170 ± 0.0973

To determine the effect of the addition of airflow in the method of microwave air-hydrodistillation for extracting sandalwood oil, the extraction was done using 600W power; the ratio of sandalwood and distilled water was 0.05 g mL^{-1}. Extraction by microwave hydrodistillation produced sandalwood oil yield of 1.2184 ± 0.1139%. On the other hand, extraction by microwave air-hydrodistillation with the air flow rate of 5.0 L/min produced sandalwood oil yield of 1.3170 ± 0.0973%. The microwave hydrodistillation method required up to 80 minutes to obtain yield of 1.1930 ± 0.0404%, while the microwave air-hydrodistillation method only needed 40 minutes to produce an almost similar amount of yield, 1.1938 ± 0.0979%. Furthermore, the microwave hydrodistillation method took up to 120 minutes to obtain yield of 1.2184 ± 0.1139%, while the microwave air-hydrodistillation method only took 50 minutes to obtain an almost similar amount of yield, 1.2423 ± 0.0986%. The comparison of sandalwood oil yield obtained by microwave hydrodistillation and microwave air-hydrodistillation with the air flow rate of 5.0 L/min can be seen in Figure 3.

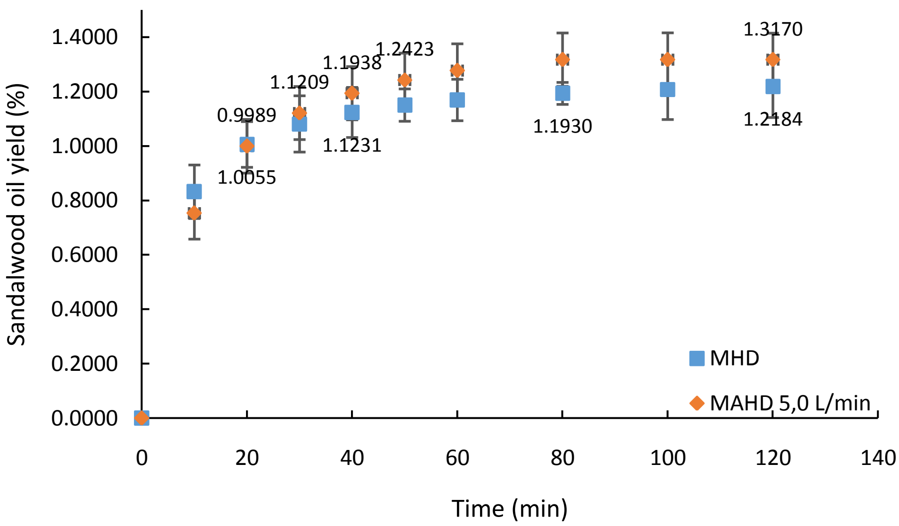

Figure 3: Comparison of sandalwood oil yield obtained by microwave hydrodistillation and microwave air-hydrodistillation methods

Microwave air-hydrodistillation method produces sandalwood oil yield higher than that produced by the microwave hydrodistillation method, because the air flow will help to optimize the process of mixing during the extraction. The mixing process directly affects the mass tranfer process in the dissolving phase. This results in the balance of liquid and steam phases in the extraction of sandalwood oil obtained by microwave air-hydrodistillation, which can be achieved more quickly than that obtained bymicrowave hydrodistillation [7].
Furthermore, the air flow is suspected to help to carry the important oil components in the cell membrane or plant tissue difficult to diffuse. This is because sandalwood oil is heavy oil; there are several components of heavy fraction which is difficult to be extracted without the addition of air flow. To determine and confirm the

components of heavy fraction difficult to extract without the addition of air flow, the composition of compounds in sandalwood oil can be obtained by microwave hydrodistillation and microwave air-hydrodistillation methods presented in Table 5. In general, it can be seen that the composition of compounds of sandalwood oil which is obtained by microwave air-hydrodistillation is larger/bigger than that obtained by microwave hydrodistillation. The air flow in microwave air-hydrodistillation can also be said to serve as a transfer medium for the components of essential oil, contained in the material to evaporate. This has an implication for the increase of the sandalwood oil yield obtained.

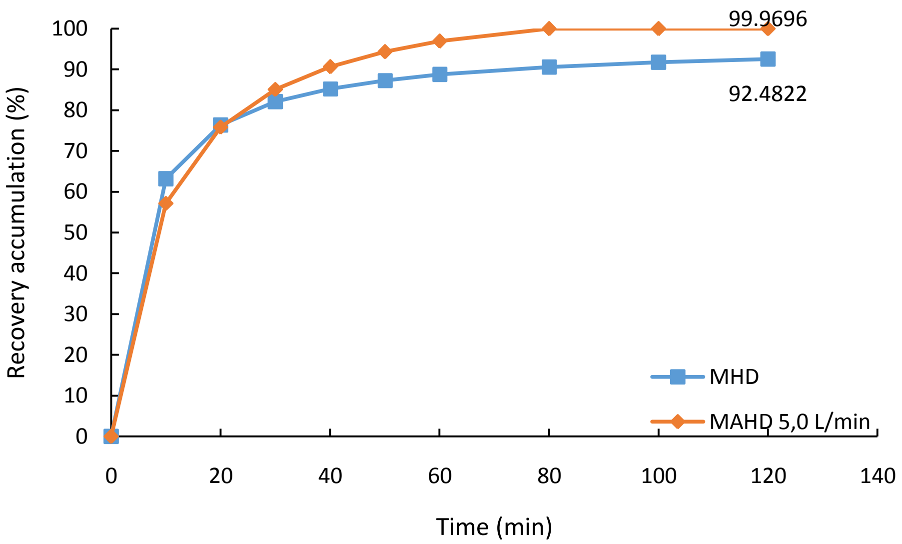

Figure 4: The recovery accumulation of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation

3.2. *The recovery comparison in the extraction of sandalwood oil by microwave hydrodistillation and microwave air-hydrodistillation*

In this research, a recovery calculation was done to determine the effect of the use of air flow in the method of microwave air-hydrodistillation in the extraction of essential oil from sandalwood, compared to the method of microwave hydrodistillation.The accumulated value of recovery can be obtained by comparing the yield of sandalwood oil obtained by two methods and the yield of sandalwood oil obtained by Soxhlet. The yield of sandalwood oil obtained by Soxhlet method has a value of 1.3174%.

Table 2: The recovery of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation

Extraction method	Air flow rate(L/min)	Sandalwood oilrecovery (%)
Microwave hydrodistillation	0	92.4822
Microwave air-hydrodistillation	0.1	92.9710
	0.5	98.5654
	1.5	99.9696
	3.0	99.9696
	5.0	99.9696

For the extraction of sandalwood oil bymicrowave hydrodistillation, based on Table 2, it can be seen that the recovery accumulation obtained was 92.4822%. The highest recovery accumulation for microwave air-hydrodistillation was 99.9696%. The highest value of recovery accumulation for microwave air-hydrodistillation was obtained when the extraction of sandalwood oil was done using an air flow rate of 1.5 L/min. In the extraction of sandalwood oil by microwave air-hydrodistillation,it can be seen that the extraction which was done using an air flow rate of 1.5 L/min has a recovery accumulation value equal to the value in the extraction using an air flow rate higher than 1.5 L/min (3.0 L/min and 5.0 L/min).

Sandalwood oil produced by the extraction using microwave air-hydrodistillation shows a better pattern with the recovery accumulation value higher compared to the extraction using microwave hydrodistillation. Figure 4 shows that the addition of air flow in the method of microwave air-hydrodistillation is able extract/push out more sandalwood oil compared to the extraction by microwave hydrodistillation.

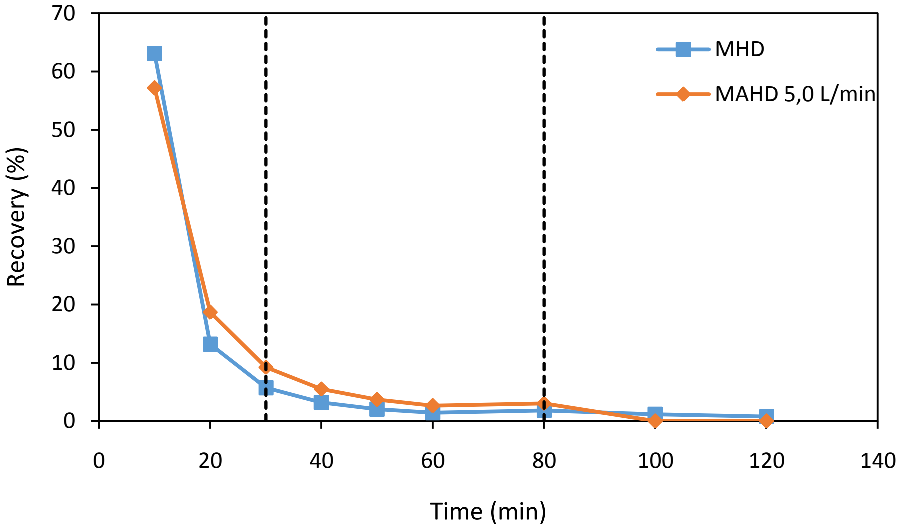

Figure 5: Recovery of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation

In the extraction of sandalwood oil by microwave hydrodistillation and microwave air-hydrodistillation, the fastest increase occured in the extraction time of 0-20 minutes. After the extraction ran for 20 minutes, the increase of recovery accumulation of the sandalwood oil became less significant. It can be seen in Table 5 that the recovery of sandalwood oil extracted by microwave hydrodistillation and microwave air-hydrodistillation showed a decrease during the extraction process. The significant decrease of sandalwood oil recovery in the extraction process may be because many components of the essential oil have are polar (have a high polar moment) which has been extracted at the beginning of the process. This is because the efficiency of the extraction by microwave as a heater (microwave-assisted extraction) will become higher if the target compound to extracted or the solvent used are polar [7]. However, the organic compounds in essential oil which have a high dipolar moment will interact easily with the microwave and can be easier to be extracted, compared to aromatic compounds which have a low dipolar moment.

Table 3: The decrease of recovery of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation

Extraction method	Sandalwood oil recovery (%)		
	Phase I Minutes 0-30	Phase II Minutes 30-80	Phase III Minutes 80-120
Microwave hydrodistillation	82.0508	8.5097	1.9217
Microwave air-hydrodistillation (5.0 L/min)	85.0854	14.8843	0.0000

Furthermore, it is predicted that the decrease of the recovery of sandalwood oil is due to the diffusion between steam and oil from the material (sandalwood), which became slower, and the oil content in the material which kept decreasing. The decrease of sandalwood oil recovery can be seen from the slope of the graph. Generally, based on the slope of the line, the decrease can be classified into three phases: phase I in minute 0-30, phase II in minute 30-80, and phase III in minute 80-120; the longer the extraction, the recovery of sandalwood oil will become smaller (Table 3). Based on the accumulated value of the sandalwood oil recovery, it can be proposed that the addition of air flow in the microwave air-hydrodistillation method can extract much more sandalwood oil contained in the material than the microwave hydrodistillation method.

3.3. *The analysis of physical and chemical properties of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation*

In determining the quality of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods, an analysis of physical and chemical properties of the oil needs to be conducted.The analysis of the physical properties of the sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods can be done by determining the specific gravity and refractive index. Further, the analysis of the chemical properties of the sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods can be done by identifying the composition of compounds contained in the essential oil using GC-MS. Besides indicating the purity and quality of essential oil, the comparison of physical and chemical properties using quality standard data can show the forgery of the essential oil. However, the analysis of the physical and chemical properties is not always directly related to the fragnance produced by essential oil [8].

Table 4: Results of the analysis of the physical properties of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods

Extraction method	Air flow rate(L/min)	Quality standard (ISO 3518:2002(E))		The physical properties of essential oil	
		Refractive index(20^{o}C)	Specific gravity(20^{o}C/20^{o}C)	Refractive index(20^{o}C)	Specific gravity(20^{o}C/20^{o}C)
Microwave hydrodistillation	0	1.5030-1.5080	0.9680-0.9830	1.5087	0.9720
Microwave air-hydrodistillation	0.1			1.5087	0.9751
	0.5			1.5057	0.9833
	1.5			1.5047	0.9784
	3.0			1.5037	0.9822
	5.0			1.5037	0.9762

Based on the analysis of the physical properties of the sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods, it can be proposed that in general, the values of the refractive index and specific gravity have met the quality standard. Additionally, based on the analysis of the physical properties of the sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods, it can be seen that the values of the refractive index and specific gravity have met the quality standard. Additionally, based on the analysis of the physical properties of the sandalwood oil, it can be seen that the values of the refractive index and specific gravity of the oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods do not show a significant difference. Therefore, it can be proposed that sandalwood oil obtained by microwave air-hydrodistillation has a similar quality (the refractive index and specific gravity) with sandalwood oil obtained by microwave hydrodistillation. The results of the analysis of the physical properties of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods can be seen in Table 4.

Based on the analysis of the chemical properties of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods, it can be proposed that the quality of the sandalwood oil has met the quality standard, shown by the composition of the main compounds. The quality of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods can be seen from some main compounds, such as as α-santalol, β-santalol, α-bergamotol, cis-lanceol, α-santalene, β-santalene, α-bergamotene, and α-curcumene. Additionally, based on the standard of the International Organization for Standardisation, the quality of sandalwood oil can also be seen from the total content of santalol. Commercial sandalwood oil contains 50-70% santalol [9]. Therefore, it can be proposed that sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods has the same quality with commercial sandalwood. The composition of compounds of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods can be seen in Table 5.

As shown in Table 5, it can be seenthat the compound composition of sandalwood oil obtained by microwave air-hydrodistillation method is larger than that obtained by microwave hydrodistillation. In the extraction of sandalwood oil by microwave air-hydrodistillation, there are 37 compounds identified, while in the extraction of sandalwood oil obtained by microwave air-hydrodistillation, there are 43 compounds identified. Therefore, it can be proposed that the addition of air flow in the microwave air-hydrodistillation method can help to extract the heavy fraction components in the cell membrane or plant tissue difficult to diffuse. This is supported by the more heavy fraction components contained in sandalwood oil by microwave air-hydrodistillation method, compared to oil obtained by microwave hydrodistillation. In the extraction of sandalwood oil obtained by microwave hydrodistillation, there are only 2 heavy fraction components (mol. Weight ≥ 222.37). On the other hand, In the extraction of sandalwood oil obtained by microwave air-hydrodistillation, there are 7 heavy fraction components (mol. Weight ≥ 222.37).

Table 5: The chemical compositions of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods

No.	Compound name	Mol. Formula, mol. weight	Area (%)	
			MHD	MAHD (5,0 L/min)
1	N-Phenylformamide	C_7H_7NO, 121,14	0.67	0.57
2	Camphene	$C_{10}H_{16}$, 136,23	0.95	0.82
3	α-Pinene	$C_{10}H_{16}$, 136,23	0.06	nd
4	Santolina triene	$C_{10}H_{16}$, 136,23	0.07	nd
5	β-Ocimene	$C_{10}H_{16}$, 136,23	0.58	nd
6	cis-Ocimene	$C_{10}H_{16}$, 136,23	1.87	0.09
7	(Z)-Alloocimene	$C_{10}H_{16}$, 136,23	0.06	nd
8	α-Terpinene	$C_{10}H_{16}$, 136,23	1.04	1.11
9	1-Cyclohexylidene-2-methylpropene	$C_{10}H_{16}$, 136,23	nd	1.19
10	Isoterpinolene	$C_{10}H_{16}$, 136,23	0.31	nd
11	4,6-Dimethyl-2-propylpyridine	$C_{10}H_{15}N$, 149,23	0.55	0.27
12	8-Methylene-2-exo-noradamantanol	$C_{10}H_{14}O$, 150,22	nd	0.04
13	3a,6-Methano-3aH-inden-7(4H)-one, hexahydro-7a-d-, (3aa,6a,7ab)-	$C_{10}H_{14}O$, 150,22	0.72	nd
14	m-Carbomethoxyphenol	$C_8H_8O_3$, 152,15	nd	4.05
15	4-Propylresorcinol	$C_9H_{12}O_2$, 152,19	1.72	nd
16	Teresantalol	$C_{10}H_{16}O$, 152,23	4.58	1.45
17	Sabinene hydrate	$C_{10}H_{18}O$, 154,25	0.10	nd
18	3-Methyl-4-quinazolinone	$C_9H_8N_2O$, 160,17	nd	0.37
19	9-Methyl-10-azatricyclo[5.2.2.0(1,5)]undec-2-ene	$C_{11}H_{17}N$, 163,26	nd	0.02
20	Dispiro[2.1.2.1]octane,1,1,6,6-tetramethyl	$C_{12}H_{20}$, 164,29	nd	0.02
21	Cyclododecyne	$C_{12}H_{20}$, 164,29	nd	0.31
22	Vitispirane	$C_{13}H_{20}O$, 192,30	nd	0.05
23	α-Curcumene	$C_{15}H_{22}$, 202,34	0.19	0.12
24	α-Farnesene	$C_{15}H_{24}$, 204,35	0.50	1.88
25	β-Patchoulene	$C_{15}H_{24}$, 204,35	0.62	nd
26	α-Santalene	$C_{15}H_{24}$, 204,35	nd	0.03
27	α-Cedrene	$C_{15}H_{24}$, 204,35	nd	0.05
28	γ-Curcumene	$C_{15}H_{24}$, 204,35	nd	0.17
29	α-Guaiene	$C_{15}H_{24}$, 204,35	0.66	0.11
30	Isosativene	$C_{15}H_{24}$, 204,35	0.18	nd
31	β-Santalene	$C_{15}H_{24}$, 204,35	0.05	0.07
32	Seychellene	$C_{15}H_{24}$, 204,35	0.77	nd
33	α-Patchoulene	$C_{15}H_{24}$, 204,35	0.38	nd
34	Germacrene B	$C_{15}H_{24}$, 204,35	5.50	0.10
35	α-Selinene	$C_{15}H_{24}$, 204,35	0.06	nd
36	δ-Guaiene	$C_{15}H_{24}$, 204,35	0.48	0.15
37	γ-Elemene	$C_{15}H_{24}$, 204,35	nd	3.69
38	α-Bergamotene	$C_{15}H_{24}$, 204,35	nd	0.20

No.	Compound name	Mol. Formula, mol. weight	Area (%)	
			MHD	MAHD (5,0 L/min)
39	Bicyclogermacrene	$C_{15}H_{24}$, 204,35	0.64	0.45
40	2-Methyl-6-(4-methylcyclohex-3-en-1-ylidene)hept-2-ene	$C_{15}H_{24}$, 204,35	nd	0.71
41	Acoradiene	$C_{15}H_{24}$, 204,35	1.39	0.59
42	Bicycloelemene	$C_{15}H_{24}$, 204,35	nd	1.36
43	Viridiflorene (ledene)	$C_{15}H_{24}$, 204,35	0.91	nd
44	Cyclopentanepropanoic acid, 3-oxo-2-(2-propynyl)-, methyl ester, trans-	$C_{12}H_{16}O_3$, 208,25	nd	0.08
45	β-Costal	$C_{15}H_{22}O$, 218,33	0.53	nd
46	(E)-Nuciferol	$C_{15}H_{22}O$, 218,33	6.59	7.07
47	5-Hydroxycalamenene	$C_{15}H_{22}O$, 218,33	nd	2.15
48	β-Santalol	$C_{15}H_{24}O$, 220,35	22.67	24.80
49	α-Santalol	$C_{15}H_{24}O$, 220,35	27.81	28.73
50	α-Bergamotol	$C_{15}H_{24}O$, 220,35	10.82	10.18
51	cis-α-Copaene-8-ol	$C_{15}H_{24}O$, 220,35	1.86	nd
52	cis-Lanceol	$C_{15}H_{24}O$, 220,35	3.42	2.74
53	α-Cedrol	$C_{15}H_{26}O$, 222,37	nd	2.65
54	Caryophylla-3,8(15)-dien-5.alpha.-ol	$C_{15}H_{26}O$, 222,37	0.47	0.52
55	Isolongifolol	$C_{15}H_{26}O$, 222,37	0.21	0.59
56	3-Phenyl-1,4(E)-dodecadiene	$C_{18}H_{26}$, 242,40	nd	0.21
57	Dodecenyl succinic anhydride	$C_{16}H_{26}O_3$, 266,38	nd	0.19
58	2-Octylcyclopropaneoctanal	$C_{19}H_{36}O$, 280,49	nd	0.03
59	Oleic acid	$C_{18}H_{34}O_2$, 282,46	nd	0.07
Monoterpenes			4,94	3,21
Sesquiterpenes			12,33	9,68
Oxygenated terpenes			81,50	85,39
Other compounds			1,22	1,77

The heavy fraction components found in sandalwood oil are important oil components, because most of the components belong to oxygenated terpenes. The components of oxygenated terpenes contribute more to the aroma/fragnance produced by essential oil, compared to other compounds [10].Therefore, the more components of oxygenated terpenes found in sandalwood oil obtained by microwave air-hydrodistillation, the better the quality of the oil; it can improve the aroma/fragnance of the oil. Thus, it can be predicted that sandalwood oil obtained by microwave air-hydrodistillation has better quality (aroma/fragnance) compared to that obtained by microwave hydrodistillation.

Conclusions

The extraction of sandalwood oil by microwave air-hydrodistillation is faster and produces higher yield and recovery accumulation compared to the extraction by microwave hydrodistillation. The addition of air flow in the microwave air-hydrodistillation method can increase the yield and recovery accumulation of the obtained sandalwood oil. The bigger the air flow, the more yield and recovery accumulation of sandalwood oil will be obtained. Based on the obtained yield and recovery accumulation, it can be proposed that the addition of air flow in the microwave air-hydrodistillation method can extract more sandalwood oil from the raw material, compared to the microwave hydrodistillation method. The quality of sandalwood oil obtained by microwave hydrodistillation and microwave air-hydrodistillation methods can be determined by analyzing the physical and chemical properties of the oil. Based on the analysis of the physical properties of the sandalwood oil, it can be proposed that the sandalwood oil obtained by microwave air-hydrodistillation has the same quality (refractive index and specific gravity) with that obtained by microwave hydrodistillation. Furthermore, based on the analysis of the chemical properties of the sandalwood oil, it can be proposed that sandalwood oil obtained by microwave air-hydrodistillation has better quality (aroma/fragnance) compared to that obtained by microwave hydrodistillation.

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