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Evaluation of Life Cycle Costs for Agarwood Oil Extraction with Microwave and Ultrasonic-Assisted Techniques

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Abstract— Agarwood oil extraction is a crucial process in the agarwood industry. However, this extraction is seldom performed by communities due to its lack of profitability and the extensive duration of the process. This study aims to investigate innovative techniques such as ultrasonic and microwave-assisted maceration to enhance the yield of agarwood oil extraction. Additionally, it seeks to calculate the efficiency of time and cost by determining the life cycle cost of agarwood oil extraction. The methodology employed in this study involved conducting extractions using ultrasonic-assisted maceration, microwave-assisted maceration, and a combination of ultrasonic and microwave-assisted maceration. The results indicated that the extraction method yielding the highest output utilized a combination of microwave-assisted maceration for 3 minutes and ultrasonic-assisted maceration for 60 minutes, producing a yield of 0.15%. When extrapolated to 24 hours, this method would yield 18 grams of agarwood oil extract with an additional cost of Rp13,037. In contrast, the solvent maceration process using microwaves yielded 0.096% of agarwood oil at a lower cost of Rp3,190, producing 12 grams of extract over a 24-hour extraction period.the compounds that make up the composition of agarwood oil are 2-((2S,4aR)-4a,8-Dimethyl-1,2,3,4,4a,5,6,7-octahydro-naphthalen (11.38%), Hydrocinnamic acid (11.13%), Hydrocinnamic acid (11.13%) and (3R,3aR,4aS,5R,9aS)-3,5,8-Trimethyl-3a,4,4a,5,6,7,9,9a-octahydro (10.90%).

Keywords: Agarwood, Life Cycle Costing, Microwave, Ultrasonic

1. Introduction

Agarwood, renowned for its substantial economic value, possesses a component known as agarwood sapwood that can be processed into agarwood oil [1]. The agarwood oil production process entails distillation costs, with business profitability potentially varying based on the sale of agarwood powder residue and hydrosol [2]. Agarwood oil is obtained through various extraction methodologies, including pressing, hydrodistillation, and solvent extraction, encompassing extraction with ethanol solvents via maceration [3]. In the context of agarwood industry development, a comprehensive understanding of business model development strategies and production cost analysis is essential for evaluating the economic potential of agarwood oil [4].

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Research has demonstrated that microwave-assisted and ultrasonic-assisted extraction methods offer advantages in terms of efficiency and rapidity in extracting active compounds from specific raw materials [5]. The ultrasonic-assisted extraction method, in particular, has been demonstrated to be efficacious in optimally and efficiently extracting active compounds [6]. Furthermore, the microwave-assisted extraction method has been employed in the extraction of essential oils from various plant materials, exhibiting potential for enhancing extraction efficiency [7].

The application of modern extraction technologies such as Microwave-Assisted Extraction (MAE) and Ultrasonic-Assisted Extraction (UAE) has become the focus of research in an effort to enhance the efficiency of extracting active compounds from various raw materials [8]. This extraction method aligns with the principles of Green Analytical Chemistry (GAC) by minimizing the utilization of energy, solvents, time, and costs, thereby promoting environmental sustainability. In the context of agarwood oil extraction, the implementation of microwave and ultrasonic assisted maceration methods presents a promising approach to improve the efficiency of agarwood oil extraction. Through the utilization of these modern extraction technologies, it is anticipated that more efficient and high-quality agarwood oil extraction results can be obtained.

Determination of life cycle costing (LCC) is crucial in evaluating the total costs associated with oil extraction, including agarwood oil. Several studies consider the costs incurred during the extraction process, from design to operation and maintenance, thus providing a comprehensive economic evaluation [9]. Integrating LCC with life cycle assessment (LCA) offers a holistic approach to assessing the environmental and economic impacts of the oil extraction process [10]. This combined approach enables a comprehensive understanding of the sustainability of the oil production process. Furthermore, life cycle cost analysis (LCCA) has been applied in various industries, such as biodiesel production, to estimate production costs and assess economic feasibility [11]. LCCA has also been utilized to evaluate the life cycle impacts of electricity production from biomass power plants, emphasizing the importance of considering economic factors in addition to environmental concerns [12]. This study aims to extract agarwood oil using several methods of microwave and ultrasonic assisted solvent maceration and to conduct a life cycle costing analysis to recommend effective and efficient methods for the yield and cost of agarwood oil processing.

2. Method

2.1 Materials and tools

The main raw material used is agarwood sapwood (Aquilaria malaccensis) which grows in the former mining area in Sawahlunto City, then the chemical used is methanol p.a. The tools used are Digital Analytic, Watt meter Type B, Ultrasonic Type Bath 60-70 Hz, Microwave Oven 450 W, Rotary Evaporator type BUCHI R215.

2.2 Research Procedure

1) Extraction of agarwood oil at room temperature

   A sample of agarwood powder was weighed 5 grams, dissolved in 100 ml of methanol p.a. in an Enlemeyer container, then maceration process was carried out at room temperature for 24 hours and then the oil was separated from the solvent using a rotary evaporator, then the agarwood oil yield was measured and calculated using equation (1).

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$$\text{Yield\%} = (\text{oil weight})/(\text{raw materials weight}) \times 100\% \quad (1)$$

2) Ultrasonic-assisted agarwood oil extraction

   A sample of agarwood powder was weighed 5 grams, dissolved in 100 ml of methanol p.a. in an Enlemeyer container, then maceration process was carried out in an

ultrasonic bath for 60 minutes and then the oil was separated from the solvent using a rotary evaporator, then the agarwood oil yield was measured and calculated using equation (1).

3) Microwave-assisted agarwood oil extraction

A 5-gram agarwood sample was weighed, dissolved in 100 ml of methanol in an Enlemeyer container, then macerated in a microwave for 3 minutes until the boiling point of the methanol solvent was reached, then left for 60 minutes, then separated the solvent from the oil using a rotary evaporator, then measured the yield of agarwood oil calculated using equation (1).

4) Microwave and Ultrasonic combination of agarwood oil extraction

A 5-gram agarwood sample was weighed, dissolved in 100 ml of methanol in an Enlemeyer container, then macerated in an ultrasonic device for 60 minutes, then separated the solvent from the oil using a rotary evaporator, then measured the yield of agarwood oil calculated using equation (1).

2.3 Calculation of Life Cycle Costing of the Extraction Process

The calculation of the life cycle cost of the extraction process aims to see the costs incurred in carrying out the agarwood oil extraction process on a laboratory scale, the calculation is done by calculating the use of electrical energy by calculating the KWh (Kilowatt hour) value obtained at each stage of the agarwood oil extraction process, the KWh value obtained is converted to the cost of electricity per 1 KWh in rupiah (Rp. 1,444.70) according to Equation (2). The results of this LCC calculation can be a reference in the decision-making system in large-scale production, and the efficiency of production and costs incurred in agarwood oil production can be seen. In addition to calculating the cost of energy spent in the extraction process, the waste produced in the extraction process is also calculated to optimize the extraction process.

Total Life Cycle Cost = KWh Value x Rp. 1,444.70 (2)

3. Result and Discussion

3.1 Extraction of Agarwood Oil

Extraction of agarwood oil is carried out using several maceration techniques with solvents, maceration is carried out using four methods, namely 1). maceration at room temperature for 24 hours, 2). maceration with microwave assistance for 3 minutes, 3). maceration assisted by ultrasonic for 60 minutes and 4). combined maceration assisted by microwave and ultrasonic. The highest extraction yield is by using the combined extraction method assisted by microwave and ultrasonic with a yield of 0.148%, followed by maceration with microwave of 0.096% then maceration at room temperature of 0.094%, and finally maceration assisted by ultrasonic with a yield of 0.093%. A comparison of agarwood oil yield with several extraction methods can be seen in Table 1.

Tabel 1. Yield from Extraction Methode

No	Extraction Method	Yield (%)
1	Room temperature maceration	0,085
2	Ultrasonic-assisted maceration	0,084
3	Microwave-assisted maceration	0,087
4	Combination Ultrasonic and Microwave maceration	0.139

The high value of agarwood oil extraction yield of 0.148% is due to the exposure process of the combination of microwave and ultrasonic, which causes the agarwood oil to dissolve and come out

maximally, according to the data seen in Figure 1. The application of modern extraction techniques such as microwave and ultrasonic in the maceration process has been proven effective in increasing the extraction results of active compounds from various raw materials [13], [14] as occurs in agarwood oil extraction using a combined microwave and ultrasonic extraction method can provide optimal and efficient results, and can be a promising approach in increasing the efficiency of agarwood oil extraction. Several studies have highlighted the application of microwaves to accelerate the maceration process, thereby reducing maceration time significantly. This supports the opinion that microwave-assisted extraction can increase extraction efficiency, which is very relevant considering the high results achieved from agarwood oil extraction using microwaves and ultrasonic-assisted maceration [15].

3.2 Life Cycle Cost Calculation

LCC is significant to know to see the efficiency of time and cost in the agarwood oil extraction process when viewed from the yield of the combined microwave and ultrasonic assisted maceration extraction process, which produces the highest yield, but when viewed from the efficiency of time and cost shows that microwave-assisted maceration is the most effective, namely with a shorter time and cheaper cost. The cost incurred for the agarwood oil extraction process for 24 hours is IDR 3,191 with a total extract of 13 grams. However, compared to ultrasonic-assisted maceration, the cost incurred is quite large if the extraction process is for 24 hours, namely IDR 12,761 with a lower extraction result than a microwave, namely 12 grams.

The cost incurred is small for room temperature maceration and does not show a high yield. This is because there is no additional process to accelerate the agarwood oil extraction process so the extraction process takes a long time to produce maximum yield. In addition, the low extraction cost using microwave-assisted maceration has a good impact on yield and cost where the amount of cost incurred is manageable because the energy used is only 3 minutes so the results obtained can be effective in extraction costs. A comparison of the costs of the agarwood oil extraction cycle can be seen in Table 2.

Table 2. Results of LCC calculations for agarwood oil

No	Extraction Method	Equipment	Energy (KWh)	Energy Total (KWh)	1 KWh (Rp)	Cost Total (Rp)	Extract (gr)	Cost Total in 24 Hour (Rp)	Extract Total in 24 Hour (gr)
1	Room temperature maceration	Rotary Evaporator (Details) 1. Rotary Pompa Vacum 2. Rotary Rpm 3. Rotary Waterbath	0,083 0,008 0,002 0,071	0,085	Rp.1.444,70	121,36	0,47	Rp122	0,6
2	Microwave-assisted maceration	Microwave Rotary Evaporator	0,007 0,083	0,093	Rp.1.444,70	132,92	0,49	Rp3.191	13
3	Ultrasonic assisted maceration	Ultrasonic Rotary Evaporator	0,282 0,083	0,369	Rp.1.444,70	531,66	0,47	Rp12.761	12
4	Combination	Microwave Ultrasonic Rotary Evaporator	0,007 0,283 0,083	0,377	Rp.1.444,70	543,22	0,74	Rp13.038	19

In calculating the LCC of agarwood oil extraction, the most efficient extraction method is maceration using microwave. This is due to the lower cost compared to the maceration method using

ultrasonic [16]. The use of microwave in the agarwood oil extraction process can provide advantages in cost efficiency, which is important in evaluating the total costs associated with the agarwood oil extraction process. Research has shown that the use of microwave in the extraction process can provide high efficiency in cost expenditure, making it a more economical choice in calculating the life cycle costing [17].

3.3 Inventory of Extraction Process Stages

Inventory data is needed to see the amount of waste generated from the agarwood oil extraction process, namely solid waste and liquid waste, the results of the calculation of the most solid waste produced are in microwave-assisted maceration with an amount of 15 grams and the least is with ultrasonic-assisted maceration, which is 12 grams, then the maceration process that produces the highest amount of liquid waste is microwave-assisted maceration, which is 82 ml and the lowest is combined microwave and ultrasonic maceration with a total of 75 ml of liquid waste, this category of liquid waste can be used again for the extraction process, therefore a more effective extraction process is the microwave-assisted maceration process because the amount of solvent lost is less than other maceration methods. The small amount of solvent lost with microwave maceration is because the extraction process is not long, only taking 3 minutes so the evaporation of the solvent is not too large. When compared to the combination of microwave and ultrasonic methods, it causes a high amount of solvent lost due to the long extraction process, causing the solvent to evaporate in the process. Comparison of the inventory of the stages of the extraction process can be seen in Table 3.

Tabel 3. Inventory data on the stages of the agarwood oil extraction process

No	Extraction Methods	Input		Output				Lost Solvent (ml)
				Extraction		Evaporation		
		Sample (gr)	Solvent (ml)	Solid Waste (gr)	Filtrate (ml)	Liquid Waste (ml)	Extract (gr)	
1	Room temperature maceration	5	100	14	60	77	0,47	23
2	Microwave-assisted maceration	5	100	15	58	82	0,48	18
3	Ultrasonic assisted maceration	5	100	12	58	77	0,47	23
4	Combination	5	100	13	61	75	0,74	25

Several studies have shown that microwave-assisted maceration can be more effective in producing high essential oil yields with less waste compared to ultrasonic maceration. For example, a study by showed that the time required for oil extraction ranged from 1.77 to 2.00 minutes for microwave treatment and 1.79 to 2.21 minutes for ultrasonic treatment [18]. In addition, a study by showed that oil extraction from Gordonia axillaris fruit using the microwave assisted extraction (MAE) method resulted in higher antioxidant power compared to room temperature maceration and Soxhlet extraction methods [19]. However, there are also studies that highlight the advantages of ultrasonic maceration in terms of time efficiency and lower energy consumption. For example, a study by stated that ultrasonic treatment is considered advantageous due to shorter process time, lower energy consumption, and environmental friendliness [20].

3.4 Agarwood oil Profil

The profile of compounds that make up agarwood oil using a combination of ultrasonic and microwave methods from the highest yield results shows that the compounds that make up the composition of agarwood oil are 2-((2S,4aR)-4a,8-Dimethyl-1,2,3,4,4a,5,6,7-octahydro-naphthalen (11.38%), Hydrocinnamic acid (11.13%), Hydrocinnamic acid (11.13%) and (3R,3aR,4aS,5R,9aS)-3,5,8-Trimethyl-3a,4,4a,5,6,7,9,9a-octahydro (10.90%). Table 4. shows the profile of agarwood oil using the combination method.

Table 4. Agarwood Oil Profile of Ultrasonic and Microwave Assisted Maceration Combination Method

R.Time	Compound	Area (%)
17.691	2-Butanone, 3-phenyl-	5.26
20.495	Hydrocinnamic acid	11.13
24.838	2-Butanone, 4-(4-methoxyphenyl)-	0.74
26,274	(3R,5aS,9aR)-2,2,5a,9-Tetramethyl-3,4,5,5a,6,7-hexahydro-2H	9.06
26,891	3-(4-Methoxyphenyl)propionic acid	4.29
28.128	2-((2S,4aR)-4a,8-Dimethyl-1,2,3,4,4a,5,6,7-octahydronaphthalen	11.36
28,939	1,4-Dimethyl-7-(prop-1-en-2-yl)decahydroazulen-4-ol	0.25
31.307	3-Methoxymethoxy-6,6-dimethyl-2-methylene-bicyclo[3.1.1]heptane	3.31
33.922	(3R,3aR,4aS,5R,9aS)-3,5,8-Trimethyl-3a,4,4a,5,6,7,9,9a-octahydroa	2.23
34.860	1-(4-Methoxyphenyl)-1-cyclopentanecarboxylic acid	0.33
35.010	(4aS,7R)-7-(2-Hydroxypropan-2-yl)-1,4a-dimethyl-4,4a,5,6,7,8	8.51
35.509	(3R,3aR,4aS,5R,9aS)-3,5,8-Trimethyl-3a,4,4a,5,6,7,9,9a-octahydro	10.90
37.349	(E)-5-((1S,5R,8aR)-5-Formyl-5,8a-dimethyl-2-methylenedecahydr	6.04
37.769	(E)-5-((1S,5R,8aR)-5-Formyl-5,8a-dimethyl-2-methylenedecahydr	2.99
38,864	Cycloprop[e]indene-1a,2(1H)-dicarboxaldehyde, 3a,4,5,6,6a,6b-	6.12
41.915	Atractylenolide III, acetate	4.48
42,812	2-Phenethyl-4H-chromen-4-one	8.44
51.578	Acetamide, N-(4-benzyloxyphenyl)-2-cyano-	4.58

The extraction process also plays an important role in determining the composition and quality of agarwood oil. The right distillation method can increase the yield and quality of the oil produced, which in turn affects the aroma and selling value of the final product. Therefore, choosing an efficient extraction method is very important to maximize the potential of agarwood oil as a commercial product. Overall, the main content of agarwood oil that produces fragrant aroma consists of various chemical compounds, especially sesquiterpenes, which are produced through the plant's metabolic process and are affected by the extraction method. Further research on the chemical composition and processing methods can help improve the quality and added value of agarwood oil in the market.

4. Conclusion

Extraction using a combined maceration method assisted by microwave for 3 minutes and ultrasonic for 60 minutes can increase the yield of agarwood oil by 0.418%, from the calculation of LCC shows the most effective extraction method and the cheapest cost is microwave-assisted maceration, which costs Rp3,190 and the extract yield is 12 grams during the 24-hour extraction process. then from the inventory data of the extraction process shows that extraction with microwave is also the most optimal in the use of solvents so that the solvent lost in one extraction process is only a little, namely 19 ml.

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