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Extraction of leaves oil from fresh leaves by using microwave-assisted extraction (MAE) and ultrasonic-assisted extraction (UAE) methods

Calaelma Logys Imalia[1], Firman Simbolon[1], Hendra Hendra[1], Nilam Junita[1], Yolanda Natalia[1], Viola Nurfitri[1], Nurul Afifah Zahra[1], Sry Oktavianty Purba[1], Tresya Siti Harni S[1], Shelty Aty Pribadi[1], Wika Atro Aryani[1,2], Feerzet Achmad[1,*]

Department of Chemical Engineering, Institut Teknologi Sumatera, Lampung, 35365, Indonesia
[2]Department of Chemical Engineering, College of Chemicals and Materials, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia

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ABSTRACT

Essential oils are natural chemical compounds that are volatile and have a distinctive aroma, which are produced by plants as part of their secondary metabolites. This study aims to examine the differences in % yield content, extract pH, color, FFA value, and essential oil structure of each sample from fresh leaves. The main materials used in this study were several types of aromatic leaves, namely lemongrass, pandan, lime, and eucalyptus leaves. The methods used were Microwave-Assisted Extraction (MAE) and Ultrasound-Assisted Extraction (UAE). The essential oil with the highest yield value and a specific gravity close to the Indonesian National Standard (SNI) is analyzed using Fourier Transform Infrared Spectroscopy (FTIR). The eucalyptus leaf sample yielded the highest percentage with the MAE method, achieving a yield of 46 %. The FTIR analysis identified a broad absorption peak at 3257.7 cm^{-1}, indicating the presence of hydroxyl groups (-OH), which suggests alcohols or phenols and possible moisture contamination. Peaks at 2124.6 cm^{-1} and 1744 cm^{-1} reveal methylene (C-H) and carbonyl (C=O) groups, suggesting the presence of terpenoids and oxidized compounds like esters or ketones. Additional peaks at 1640 cm^{-1} and 1013.8 cm^{-1} and ether (C-O) groups, with the latter confirming the presence of 1,8-cineole in eucalyptus oil.

1. Introduction

Indonesia is well known for its rich biodiversity, including a wide array of essential oil–producing plants. Approximately 70 types of essential oils are traded in the global market, with Indonesia contributing nearly 40 types, placing the country among the leading producers worldwide [1]. Essential oils are volatile aromatic compounds derived from the secondary metabolites of plants and are commonly extracted from leaves, flowers, roots, seeds, and bark [2,3]. Their applications span a wide range of industries including cosmetics, aromatherapy, pharmaceuticals, and food flavoring due to their antioxidant, antimicrobial, and aromatic properties [4,5].

Despite their wide applications and economic potential, the efficiency and quality of essential oil extraction are strongly influenced by the method employed. Conventional methods for essential oil extraction such as steam distillation, water distillation, maceration, and solvent extraction have been widely practiced. However, these methods are typically time-consuming and may result in oil degradation due to prolonged exposure to heat, leading to reduced yield, lower purity, and loss of functional compounds [6]. In response to these limitations, recent advances in green extraction technologies have brought attention to modern techniques such as Microwave-Assisted Extraction (MAE) and Ultrasound-Assisted Extraction (UAE) as more efficient and sustainable alternatives [7]. Both techniques have attracted considerable attention for their ability to enhance mass transfer, minimize solvent use, and reduce energy consumption.

Building upon these developments, it is essential to understand the underlying principles and mechanisms of each technique to evaluate their effectiveness in extracting essential oils. MAE employs microwave energy to heat plant tissues rapidly and uniformly, promoting cell wall rupture and enhancing the release of essential oils [8]. On the other hand, UAE utilizes high-frequency ultrasonic waves to generate cavitation bubbles within the extraction solvent. The collapse of these bubbles induces high local temperatures and pressures that disrupt plant cells and increase mass transfer rates, thereby improving extraction efficiency [9][10]. As a result, both MAE and UAE can achieve higher extraction efficiencies within shorter processing times while better preserving heat-sensitive compounds compared to conventional methods [11] .

Several studies have reported the advantages of these techniques. For instance, [12] found that UAE significantly increased extraction yield and antioxidant activity while reducing solvent usage and energy requirements compared to traditional approaches [12]. Similarly, Aulia and Widjarnoko [11] showed that microwave-hydro-distillation reduced the processing time and enhanced the citral content in lemongrass oil, indicating a potential for industrial upscaling [11]. These findings collectively underscore the promise of MAE and UAE as modern extraction strategies in essential oil processing.

However, despite growing evidence of their individual

* Corresponding author. Tel.: +6281220126389
Email: feerzet.achmad@tk.itera.ac.id
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effectiveness, direct comparative studies between MAE and UAE under identical analytical parameters and across multiple aromatic leaf species remain scarce. Such comparative evaluations are essential to determine the most suitable extraction technique for specific plant matrices and to support process optimization in industrial-scale applications [13]

Therefore, this study aims to systematically compare Ultrasound-Assisted Extraction (UAE) and Microwave-Assisted Extraction (MAE) in extracting essential oils from four aromatic leaves—lemongrass (Cymbopogon citratus), pandan (Pandanus amaryllifolius), lime (Citrus aurantifolia), and eucalyptus (Eucalyptus globulus). These species were selected due to their high essential oil content and significant commercial value.

To further strengthen the contribution of this work, the study does not only focus on extraction performance but also emphasizes a holistic evaluation of product characteristics and process efficiency. The novelty of this research lies in its integrative and comparative approach, providing a comprehensive analysis of extraction yield, efficiency, pH, color, free fatty acid (FFA) value, and essential oil quality for different leaf matrices using UAE and MAE techniques. The findings are expected to contribute practical insights for optimizing essential oil extraction processes using sustainable technologies, particularly in Indonesia where plant biodiversity and essential oil production potential are vast but underutilized in technological innovation.

2. Materials and Methods

2.1. Tools and materials

The research employs MAE and UAE, rotary vacuum evaporator, titration equipment, and pH meter. The main materials used in this study were several types of aromatic leaves (lemongrass, pandan, lime, and eucalyptus). The solvent used in the extraction process was 96% technical ethanol.

2.2. Methods

2.2.1. Raw materials preparation

First, the leaves of lemongrass, pandan, lime, and eucalyptus are removed from their stems and thoroughly cleaned. They are then dried in an oven at 150°C for approximately 30 minutes. After the drying process, the leaves are ground into fine powder using a grinder. Next, 25 grams of this leaf powder are measured for the extraction process.

2.2.2. Leaf extraction

The extraction process employed two modern techniques: Microwave-Assisted Extraction (MAE) and Ultrasound-Assisted Extraction (UAE), as shown in Fig. 2 and 1, respectively. For each extraction, 25 grams of dried and powdered leaves were weighed and then treated with 125 mL of solvent. The extraction was conducted for 45 minutes at a consistent temperature of 70°C. The optimization of extraction parameters is essential to obtain high-quality essential oils while maintaining the integrity of thermolabile compounds. Olabinjo et al. [13] investigated pressurized liquid extraction (PLE) and identified 70°C as the optimal extraction temperature, which provided the highest essential oil yield and preserved key volatile constituents. Although their extraction duration was 60 minutes, the results highlight that maintaining the temperature around 70°C enables efficient rupture of plant cell walls and enhanced mass transfer without causing excessive thermal degradation. In the present study, similar thermal conditions.

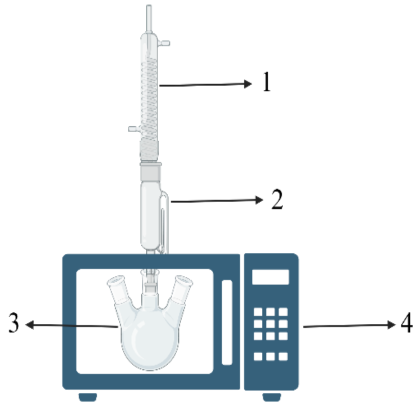

Fig. 1. Microwave-assisted extraction (MAE) apparatus: Condenser (1), Soxhlet (2), 3-neck boiling flask (3), and microwave (4)

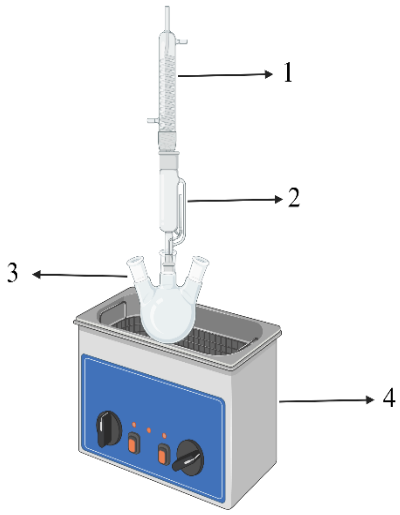

Fig. 2. Ultrasound-assisted extraction (UAE) apparatus: Condenser (1), Soxhlet (2), 3-neck boiling flask (3), and ultrasound (4).

2.2.3. Essential oil purification

Once the extraction process is complete, the essential oil extract is purified using a rotary vacuum evaporator. This purification process aims to efficiently remove any remaining solvent while preserving the quality of the essential oil obtained.

2.3 The analysis of the essential oils

2.3.1. Yield analysis

The essential oil extract, separated from the solvent, is placed into a clean and dry glass bottle. Next, the oil is weighed using an analytical balance to determine its precise mass. To calculate the percentage yield Eq. (1) of the essential oil, the formula is applied based on the mass of the oil and the mass of the initial sample used:

$$Yield = \frac{Mass\ of\ extract\ (g)}{Mass\ of\ dry\ matter\ (g)} x\ 100 \ldots\ldots \quad (1)$$

Yield: mass of extract/mass of dry matter (%)
Mass of extract : mass of essential oil (g)
Mass of dry matter : mass of raw material/ sample (g)

2.3.2. Fourier transform infrared analysis (FTIR)

The essential oil with the highest yield value and a specific gravity close to the Indonesian National Standard (SNI) is analyzed using Fourier Transform Infrared Spectroscopy (FTIR) Agilent Technologies Cary 630. The FTIR operating conditions used in this study with a range 4000 – 650 cm^{-1}, resolution of 1600 cm^{-1}, and number of scans 32. This analysis helps identify the functional groups and primary chemical components in essential oils.

2.3.3. Characteristic of leave

The analysis of essential oil characteristics involves observing color, aroma, and free fatty acid content. Color testing is conducted visually to evaluate the purity and quality of the oil. The aroma analysis ensures that the characteristic scent of the produced oil conforms to established standards. To determine the free fatty acid content, essential oil place it in a 250 mL erlenmeyer flask. Add 50 mL of 96% alcohol that has been neutralized with 0.1 N NaOH, along with 2 mL of phenolphthalein (PP) indicator. Titrate the solution with 0.1 N NaOH, adding it drop by drop from a burette until a pink color appears and lasts for at least 30 seconds.

The free fatty acid content can then be calculated using the appropriate formula Eq. (2) :

$$FFA(\%) = \frac{V\ x\ N\ x\ MW}{W\ x\ 1000} x100\% \ldots \quad (2)$$

Notes:
V = Volume NaOH as a Titrant (mL)
N = NaOH Normality (N)
MW = Molecular weight of essential oil (extract of leaves(gr/mol)
M = Essential oil/extract weight (gr)

3. Results and Discussion

3.1. Extraction yield

The results clearly demonstrate that extraction yield is significantly influenced by both the type of plant material and the extraction technique employed. As shown in Figure 3, lemongrass and lime leaves exhibited notably higher yields when extracted using the Ultrasonic-Assisted Extraction (UAE) method, yielding 23.4% and 12%, respectively. In contrast, the Microwave-Assisted Extraction (MAE) method, also depicted in Figure 4 resulted in lower yields of 12.7% for lemongrass and 9.04% for lime leaves. This discrepancy suggests that UAE is particularly effective for plant matrices with softer or more porous cellular structures, which are more easily disrupted by the cavitation effect produced during ultrasonication. The rapid formation, growth, and collapse of microbubbles enhance cell wall rupture and facilitate the release of intracellular compounds into the solvent, thereby improving extraction efficiency.

In contrast, pandan and eucalyptus leaves yielded significantly better results when extracted using the MAE method, with extraction efficiencies of 12% and 46.2%, respectively. Under the UAE method, yields for the same materials were substantially lower, at 8% for pandan and only 2% for eucalyptus. This highlights the greater effectiveness of MAE for tougher, lignified, or waxy leaf structures, where the volumetric heating induced by microwave radiation enhances solvent penetration and disrupts more rigid cell walls. The markedly high yield from eucalyptus leaves using MAE may also be attributed to their high concentration of polar essential oils and volatile compounds, which are particularly responsive to microwave-induced dipole rotation and ionic conduction [10]. The detailed results can be found in Table 1.

Beyond the physical characteristics of the plant tissue, the nature of the phytochemicals being targeted also plays a critical role in determining extraction efficiency. UAE is generally more suitable for extracting thermolabile and low molecular weight compounds, as it operates at relatively mild temperatures and shorter durations, reducing the risk of compound degradation. In contrast, MAE utilizes higher temperatures, which can be advantageous for the extraction of heat-stable or matrix-bound compounds, often embedded in complex or lignocellulosic structures [11,12].

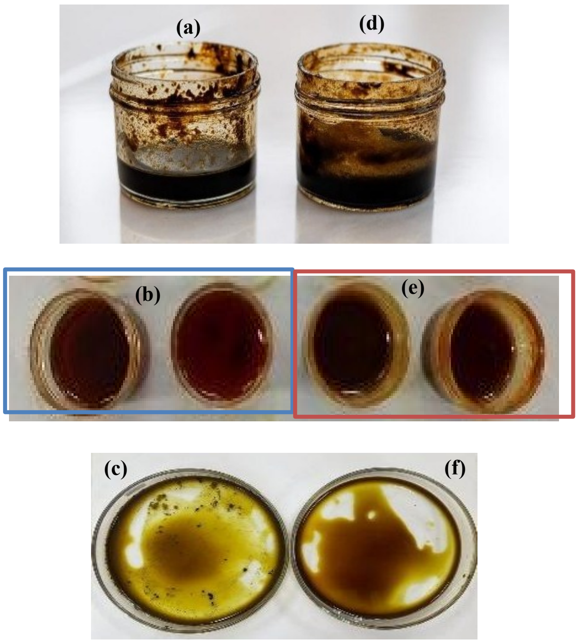

Fig. 3. (a) MAE pandan leaf extraction (b) MAE lemongrass leaf extraction (c) MAE lime leaf extraction (d) UAE pandan leaf extraction (e) UAE lemongrass leaf extraction (f) UAE lime leaf extraction

Table 1. Extraction yield of leaves by MAE and UAE

Leaves	MAE (%)	UAE (%)
Lemongrass	12,70	23,40
Pandan Wangi	12,00	8,00
Lime	9,04	12,00
Eucalyptus	46,00	2,00

Overall, these findings underscore the necessity of tailoring the extraction method to the morphological and biochemical properties of the plant material. In practice, optimizing extraction should involve a careful consideration of both the physical matrix of the sample and the thermal and polarity-related characteristics of the desired compounds. This strategic alignment is essential to achieving both high yield and compound integrity, particularly when targeting specific bioactives for applications in pharmaceuticals, cosmetics, or food industries.

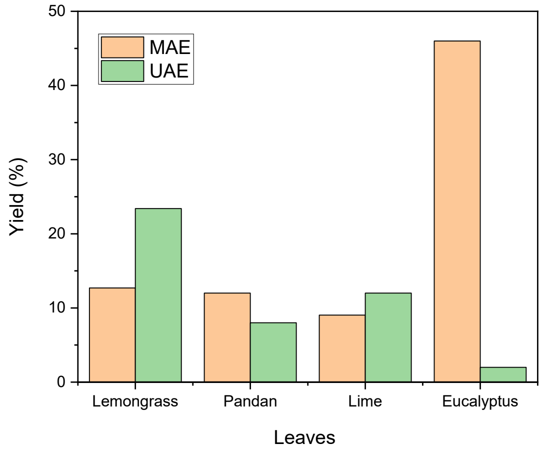

Fig. 4. The Impact of extraction methods and leaf type on yield

The results of the yield calculation using the Microwave Assisted Extraction (MAE) and Ultrasonic Assisted Extraction (UAE) methods are presented in Table 3.1. Based on the results of the yield test for the four types of leaf samples, the one that produced the highest yield percentage using the MAE method was eucalyptus leaves at 46%. Therefore, the FTIR test was carried out on the best essential oil sample, namely eucalyptus leaves, using the MAE method. The results of the FTIR test are illustrated in Figure 5.

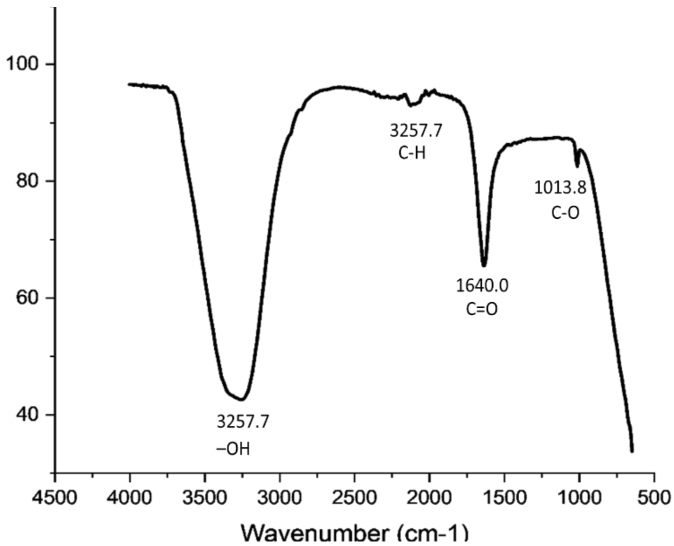

Fig. 5. FTIR analysis results of eucalyptus essential oil

This analysis was conducted in the range of 4000 cm^{-1} - 650 cm^{-1} with a resolution of 1600 cm^{-1} using the Happ-Genzel method. The resulting FTIR spectrum reveals an absorption peak at 3257.7 cm^{-1}, which is broad and characteristic of the hydroxyl group (-OH). This indicates the presence of alcohol or phenol and suggests that the essential oil contains water moisture, implying that it is not completely pure or may have been contaminated with water during extraction or storage [5].

These findings are in line with research [14] which uses eucalyptus globulus leaf extract as an antimicrobial and antioxidant agent, where the –OH group detected in the FTIR spectrum of Eucalyptus globulus leaves is directly related to the chemical structure of secondary metabolite compounds (especially phenols and terpenoid alcohols) in the leaves. This group plays an important role in the bioactive properties of eucalyptus — such as antioxidant and antimicrobial activity — and is a characteristic of the FTIR spectrum of eucalyptus leaves.

Table 2. Range of compounds present in FTIR testing of eucalyptus oil analysis

Type of oil	Wave Number (cm^{-1})	Type of Bond	Wave Number Range
Eucalyptus	3257.7	O-H	3550-3200
	2124.6	C-H	2175-2140
	1640	C=O	1690-1640
	1013.8	C-O	1075-1020

Additionally, the absorption band at 2124.6 cm^{-1} indicates the presence of a methylene group (C-H), suggesting that terpenoid or hydrocarbon compounds are present in the essential oils. This is in line with research conducted by [15] who observed that the C–H bands act as spectral markers for the hydrophobic layer and the main biopolymer structure of eucalyptus leaves. The relative intensity of these bands can be used to assess essential oil content. The highest essential oil content was obtained in the study from eucalyptus leaf samples.

The peak at 1640 cm^{-1} shows the presence of carbonyl groups (C=O), which may derive from esters, aldehydes, or ketones, likely resulting from the secondary oxidation of active compounds. This is supported by [16] research, Carbonyl groups (C=O) detected in the range of 1730–1700 cm^{-1} in the FTIR spectrum of Eucalyptus globulus leaves reflect the presence of acetyl and ester groups in cell wall components such as hemicellulose and pectin, as well as in the cuticle wax layer that coats the leaf surface.

Structurally, these groups play a role in the rigidity and hydrophobic properties of leaf tissue, which can affect the ability of solvents to penetrate the tissue during the extraction process. Furthermore, the absorption peak at 1640 cm^{-1} indicates the presence of amine groups (N-H), while the absorption at 1013.8 cm^{-1} signifies the presence of an ether group (C-O), specifically indicating the presence of 1.8 cineole in eucalyptus oil, due to its ether oxygen ring (cyclic ether) [6].

According to Morais et al. [17], the C–O–C group in eucalyptus leaves has a dual function: (1) as part of the leaf biopolymer structure (cellulose and hemicellulose) which determines the strength and permeability of the tissue, and (2) as the main marker for oxygenate compounds (eucalyptol and α-terpineol) in essential oils.

3.2. Characteristic of leaves

The analysis of essential oil characteristics involves observing color, aroma, and free fatty acid content. The results of the Characteristic Analysis can be seen in the following Table 3.

Essential oil from lemongrass typically appears as a clear light yellow, indicating a high critical content and a well-conducted distillation process. Pandan oil has a brownish-green color derived from chlorophyll and aromatic compounds such as 2-acetyl-1-pyrroline. This color can vary depending on the age of the leaves and the extraction method used. Eucalyptus oil shows a greenish-yellow hue, which is characteristic of its primary component, eucalyptol (1,8-cineole). On the other hand, lime oil exhibits a deep green color due to the presence of limonene, linalool, and natural pigments from the lime peel, such as chlorophyll and carotenoids. These color differences not only offer a visual characteristic but also serve as important indicators for assessing the quality and purity of the resulting essential oils [7].

Table 3. Characteristic analysis of leaves

Parameters	Type of Leaves				
	Lemon grass	Pandan	Lime	Eucalyptus	SNI
Colors	Clear yellows	Brownish green	Deep green	Greenish yellow	[18] [19] [20] [21]
Fragrance	Fresh and sharp	Soft and sweet	Fresh and sharp	Mint, fresh and sharp	[18] [19] [20] [21]
FFA	0,2 %	0,2%	0,5%	0,3%	[18]
pH	4	5	4	5	[18] [19] [20] [21]

Aroma or fragrance is one of the main characteristics that determine the quality and usability of essential oils, especially in the perfume, aromatherapy, and cosmetic industries. Essential oil from lemongrass has a distinctive lemongrass scent that is strong, fresh, and invigorating. This fragrance comes from its dominant compound, citral. Essential oil from pandan has a characteristic pandan aroma that is soft and sweet, resembling the scent of fresh pandan leaves commonly. Eucalyptus oil has a sharp, fresh, and slightly camphoraceous scent. This aroma is due to the presence of eucalyptol (1,8-cineole), which functions as a natural decongestant. Meanwhile, lime essential oil has a distinctive citrus leaf aroma that is fresh, tangy, and refreshing [8].

The Free Fatty Acid (FFA) content in essential oils is an important parameter in determining the quality and stability of the oil. High FFA levels may indicate degradation or oxidation of fatty acids, usually caused by suboptimal extraction processes or improper storage. Based on the available data, essential oils from lemongrass and pandan have relatively low FFA levels, each at 0.2%. This suggests that both oils are in good condition, with low acidity levels indicating chemical stability and resistance to oxidation.

Eucalyptus oil is a slightly higher FFA content of 0.3%, which is still within acceptable limits for industrial and health-related applications. Meanwhile, lime oil shows the highest FFA level at 0.5%, which may indicate a greater degree of fatty acid degradation, possibly due to exposure to heat, light, or oxygen during extraction or storage. However, this level is still considered moderate and does not necessarily reduce the functional benefits of the oil, though it should be monitored to maintain long-term quality. Overall, low FFA content reflects good production practices and indicates high-quality essential oil [11].

The pH of essential oils is one of the key parameters that can influence their chemical stability and application, especially in cosmetic and aromatherapy products. Based on the available data, lemongrass essential oil has a pH of 4, indicating a slightly acidic nature that is common in herbal essential oils. This acidity helps maintain the oil's stability and prevents the growth of microorganisms. Pandan and eucalyptus essential oils both have a pH of 5, which is still mildly acidic but more neutral compared to lemongrass oil. This pH level makes them suitable for use in skincare products, as they are less aggressive and generally gentle on the skin [7].

Meanwhile, lime essential oil also has a pH of 4, similar to lemongrass oil. The acidity in lime oil can provide a mild exfoliating effect and help preserve the freshness of its aroma. However, its acidic nature also requires extra caution when applied to sensitive skin to avoid irritation [12].

Overall, the slightly acidic pH values of these four essential oils indicate that they are natural and possess good stability potential for various applications, especially in products that require a mildly acidic environment.

4. Conclusion

Based on the research, the eucalyptus samples extracted using the Microwave-Assisted Extraction (MAE) method showed the highest extraction yield, reaching 46%. Additionally, the same method resulted in the highest free fatty acid (FFA) content among the samples analyzed. Furthermore, Fourier Transform Infrared (FTIR) analysis of the eucalyptus oil revealed the presence of several functional groups, including hydroxyl groups (-OH), methyl groups (C-H), carbonyl groups (C=O), and ether groups (C-O), indicating the complex chemical composition of the extracted oil.

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