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Application of Ultrasonic Waves as Pre-Treatment in the Extraction of Essential Oil from Basil Leaves (Ocimum Basilicum) Using Ultrasound-Microwave-Assisted Extraction (UMAE)

M T Qurrokhman[1], A A N Afifah[2] and N K Erliyanti[3]

[1] *Chemical Engineering, Faculty of Science and Technology, UPN "Veteran" Jawa Timur,Surabaya,Indonesia*
[2] *Chemical Engineering, Faculty of Science and Technology, UPN "Veteran" Jawa Timur,Surabaya,Indonesia*
[3] *Chemical Engineering, Faculty of Science and Technology, UPN "Veteran" Jawa Timur,Surabaya,Indonesia*

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CORRESPONDING AUTHOR

*E-mail:nove.kartika.nke.tk@upnjatim.ac.id Author

A B S T R A C T

This study investigated the effects of temperature and ultrasonic duration on the Ultrasound–Microwave Assisted Extraction (U-MAE) method for basil leaf essential oil. Key characteristics analysed included yield, density, refractive index, and colour, with results compared to commercial essential oil. The procedure involved drying basil leaves, applying ultrasonic pretreatment at 30- 70 °C for 5- 60 minutes, and performing microwave-assisted extraction at 450 W for 30 minutes. Findings indicated that both temperature and ultrasonic duration significantly influenced essential oil characteristics. Optimal conditions were achieved at 50 °C and 30 minutes, resulting in a yield of 2.5551%, a density of 0.9542 g/ml, a refractive index of 1.4960, and a pale yellow color consistent with commercial standards.

Contribution to Sustainable Development Goals (SDGs):
SDG 7: Affordable and Clean Energy
SDG 9: Industry, Innovation and Infrastructure
SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. *Research Background*

Essential oils are complex mixtures of volatile compounds extracted from various plant materials [1]. These oils play a critical role in global industries such as healthcare, cosmetics, aromatherapy, and food production [2]. Global demand for essential oils is expected to increase steadily, with annual consumption growth estimated at 5% to 10% [3]. As a country endowed with vast natural resources, Indonesia possesses significant potential to become a leading producer of essential oil commodities [4]. Notable aromatic plants include cloves, nutmeg, patchouli, and basil. Among these, basil (Ocimum basilicum) is identified as a promising candidate for large-scale production [5]. Basil contains essential oils, flavonoids, saponins, and other secondary metabolites that contribute to its functional properties [3]. The leaves possess the highest concentration of essential oil relative to the flowers and stems [6]. The principal constituents, estragole and linalool, are responsible for basil's characteristic aroma and its biological activities, including antimicrobial, antioxidant, and insecticidal effects. As a result, basil essential oil is extensively utilized in oral care products, perfumery, and flavor enhancement, highlighting its significant potential for further industrial development [7].

1.2. *Literature Review*

The quality and characteristics of essential oils are significantly affected by the extraction method employed. Extraction techniques are generally categorized as conventional or advanced methods [8]. Each approach differs in efficiency, processing time, and recovery, thereby impacting the final yield and chemical composition. Table 1 summarizes the extraction methods applied to basil leaves and their corresponding yields [9].

Table 1. Experimental extraction methods and basil essential oil yields

No	Extraction method	Extraction yield
1	HD	0.08%
2	SD	0.32%
3	MAHD	0.78%
4	SFME	0.78%

HD (hydrodistillation), SD (steam distillation), MAHD (microwave-assisted hydrodistillation), SFME (solvent-free microwave extraction).

Extraction efficiency is influenced by factors such as mass transfer, heat distribution, and the stability of volatile compounds. Conventional methods, including hydrodistillation (HD) and steam distillation (SD), are commonly utilized due to their low equipment costs; however, these methods often result in lower yields and may compromise oil quality [8]. For instance, HD of basil leaves for 60 minutes yields approximately 0.08%, whereas SD yields 0.32%. These limitations are primarily attributed to extended extraction times and elevated temperatures, which can cause thermal degradation and loss of heat-sensitive constituents [9]. To overcome these limitations, green extraction technologies such as Microwave-Assisted Extraction (MAE) and Ultrasound-Assisted Extraction (UAE) have attracted attention due to their energy efficiency [8]. MAHD enables rapid internal heating through dielectric mechanisms, thereby reducing extraction time. Studies have reported a 0.78% yield within 160 minutes, comparable to the yield achieved by SFME after 120 minutes [10]. Nevertheless, further optimization is necessary to maximize recovery [11]. A promising hybrid approach is Ultrasound-Microwave Assisted Extraction (U-MAE), which combines ultrasonic cavitation for cell wall disruption with microwave-induced molecular friction to accelerate internal heating [12]. This synergistic mechanism improves mass transfer and decreases processing time [13]. Previous studies on lime leaves demonstrated that U-MAE (1.684% yield) significantly outperformed MAE (1.045%) and HD (0.33%) [14]. Accordingly, the present study examines basil leaf extraction using U-MAE with aquadest as the solvent, selected for its high dielectric constant (80.4), which facilitates efficient energy absorption [15].

1.3. Research Objective

The objective of this study is to optimize extraction yield and oil quality, thereby contributing to the sustainable utilization of Indonesia's botanical resources.

2. MATERIALS AND METHODS

2.1. Tools and Material

An ultrasonic cleaning bath and a microwave were employed in this study. Basil leaves served as the raw material, and aquadest was utilized as the solvent during the extraction process.

2.2. Research Procedure

2.2.1. Preparation of raw materials

Basil leaves are separated from the stems and cut into pieces approximately 1 cm in size. The leaves are then dried in an oven at 70 °C for 50 minutes. Subsequently, 30 grams of dried basil leaves are weighed and used as raw material for the extraction process.

2.2.2. Extraction of basil leaves

The extraction process employs two non-conventional methods, beginning with a pretreatment stage using ultrasonic waves, as illustrated in Figure 1. Thirty grams of chopped and dried basil leaves are placed in a closed container, and 300 mL of distilled water is added to achieve a material-to-solvent ratio (w/v) of 1:10. The mixture is then placed in an ultrasonic cleaning bath. Ultrasonic treatment is conducted at temperatures of 30, 40, 50, 60, and 70 °C, with treatment durations of 5, 15, 30, 45, and 60 minutes, respectively. Following pretreatment, extraction is performed using microwaves as shown in Figure 2. at a power of 450 W for 30 minutes. The essential oil produced is separated from the distilled water using a Clevenger apparatus and collected in an Erlenmeyer flask

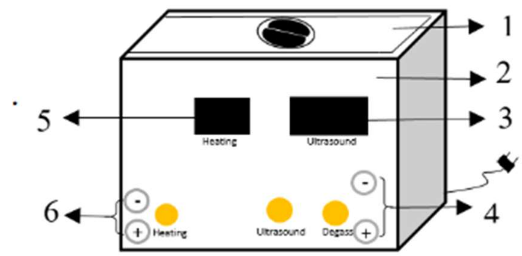

Figure 1. Ultrasonic Extraction Apparatus

Components:

1. Protective cover for the sonicator
2. Main body of the sonicator
3. Time display indicator
4. Time adjustment control button
5. Temperature display indicator
6. Temperature adjustment control button

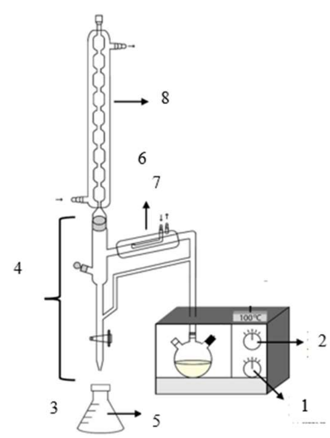

Figure 2. Microwave Extraction Apparatus

Components:

1. Timer
2. Power Regulator
3. Erlenmeyer Flask
4. Clavenger Apparatus
5. Essential Oil
6. Liebig Condenser
7. Water Flow System
8. Reflux Condenser

2.2.3. *Analysis of essential oil*

Yield analysis of essential oils quantifies the amount of essential oil obtained per gram of extracted raw material, expressed as percent weight by weight (%w/w) [16]. The yield percentage is calculated using the formula presented in Eq. (1)

$$Yield = \frac{W_1}{W_2} x100 \qquad (1)$$

Where :

Yield : mass of extract obtained (%)

W_1 : Mass of essential oil (g)

W_2 : Mass of raw material after drying (g)

Density is determined using a cleaned and pre-weighed pycnometer. The pycnometer is placed on an analytical balance to measure its mass [17]. The density is then calculated using Eq. (2)

$$\rho = \frac{m_1 - m_2}{v} \qquad (2)$$

Where:

ρ : Density of essential oil (g/ml)

m_1 : Mass of pycnometer contents (g)

m_2 : Mass of pycnometer empty (g)

v : Volume of pycnometer (ml)

The refractive index is defined as the ratio of the speed of light in air to the speed of light in the substance. It is measured using a refractometer to assess the water content in essential oils. A higher oil content corresponds to a lower refractive index value [18]. The color of basil leaf essential oil serves as an indicator for assessing essential oil quality [16]. Color results are compared with those of commercial essential oils.

3. RESULT AND DISCUSSION

3.1. *Yield*

Yield is a primary indicator of extraction performance, defined as the percentage of oil recovered per gram of raw material [16]. The effects of ultrasonic temperature and duration as pretreatment variables in the U-MAE process are depicted in Figure 3.

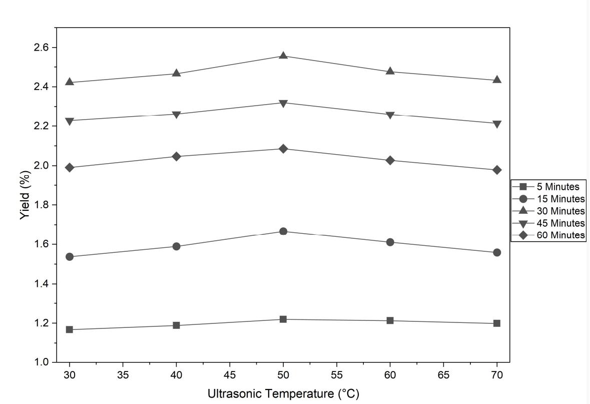

Figure 3. The effect of temperature and ultrasonic time on yield using the U-MAE method

Figure 3 indicates that yield increases progressively with temperature from 30°C to 50°C across all sonication durations. This trend is attributed to enhanced acoustic cavitation intensity at moderate temperatures. Cavitation produces microbubbles that collapse violently, generating localized high pressure and shear forces that disrupt plant cell walls [19]. This structural breakdown significantly improves solvent accessibility and facilitates the release of intracellular compounds during subsequent microwave irradiation. Additionally, microwave heating induces rapid volumetric heating in plant tissues, leading to internal pressure buildup and the further rupture of cellular structures, thereby accelerating essential oil release [20]. At temperatures above 50°C, yield decreases due to excessive heat, which promotes evaporation and thermal degradation of heat-sensitive components. Additionally, increased solvent vapor pressure at higher temperatures diminishes cavitation intensity [21]. Similarly, extending sonication time up to 30 minutes enhances mass transfer, but prolonged exposure beyond this duration may result in compound decomposition. The optimal extraction condition was identified as 50°C for 30 minutes, yielding a maximum of 2.5551% [22].

3.2. *Density*

Density serves as a key parameter for assessing the quality of essential oils, as it indicates the concentration of compounds with specific molecular weights within a given oil volume [17]. Commercial basil leaf essential oil typically exhibits a density ranging from 0.930 to 0.965 g/ml at 25°C. Figure 4 presents the effects of temperature and ultrasonic time variations.

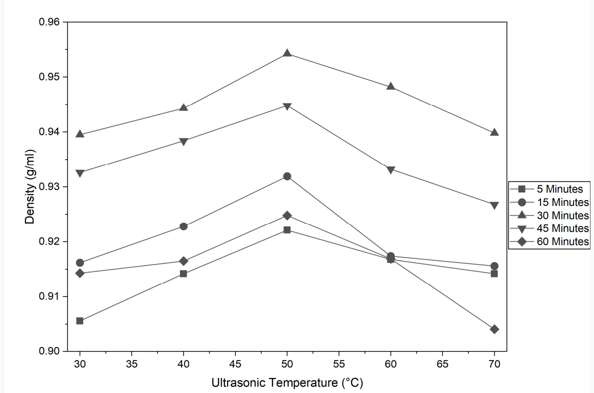

Figure 4. The effect of temperature and ultrasonic time on density in the U-MAE method

Figure 4 demonstrates that the density of basil leaf essential oil increases as the ultrasonic temperature rises from 30 °C to 50 °C. This increase results from acoustic cavitation, where ultrasonic waves generate microbubbles that collapse and produce mechanical forces capable of disrupting plant cell walls. This disruption increases solvent penetration and enhances contact between the solvent and oil components, thereby accelerating mass transfer [23]. Microwave radiation further enhances this process by inducing rapid intracellular heating, increasing internal pressure, and accelerating cell membrane rupture, which optimizes essential oil release [20]. At temperatures above 50 °C, the density decreases due to thermal degradation of essential oil components and a reduction in cavitation intensity caused by increased solvent vapor pressure [23]. Extending the ultrasonic treatment time to 30 minutes increases density, as prolonged cavitation exposure accelerates cellular tissue damage and enhances mass transfer of oil into the solvent. However, at durations of 45 to 60 minutes, density decreases due to the degradation of compounds into lighter and

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more volatile components [24]. The optimal conditions were observed at 50 °C and 30 minutes, yielding a density of 0.9542 g/ml, remaining within the standard range for commercial essential oils [25].

3.3. Refractive Index

Refractive index analysis evaluates the optical properties and purity of the oil [18]. For commercial basil leaf essential oil, the standard refractive index range is established between 1.490 and 1.512 at 20°C. For commercial basil oil, the standard range is 1.490 to 1.512 at 20°C. Figure 5 summarizes the influence of pretreatment conditions on the refractive index.

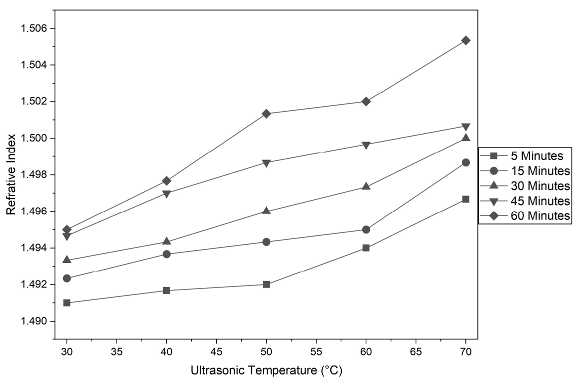

Figure 5. The effect of temperature and ultrasonic time on the refractive index in the U-MAE method

Figure 5 indicates that ultrasonic temperature and duration have a subtle but measurable effect on the refractive index. Generally, the index shows a slight upward trend as temperature increases from 30°C to 70°C. This suggests that process conditions influence oil composition, yet overall quality remains within acceptable commercial standards. The observed increase in refractive index is associated with changes in the chemical composition of the extracted oil, particularly the relative proportions of volatile and non-volatile components [25]. At higher temperatures, lighter and more volatile compounds evaporate more readily, while heavier compounds such as estragole and linalool are preferentially retained or extracted in greater proportions [26]. As these heavier components become dominant, the oil becomes optically denser, thereby increasing the refractive index [27].

3.4. Color

The color of essential oils serves as a preliminary indicator for assessing the quality and stability of their chemical composition [16]. Figure 6 presents the effects of temperature and ultrasonic duration on the color of basil leaf essential oil.

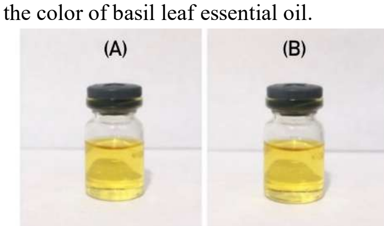

Figure 6. Color comparison of basil leaf essential oil (a) essential oil obtained from research (b) commercial basil leaf essential oil

Figure 6 presents a comparison between the color of basil leaf Experimental results indicate that the color of basil leaf essential oil ranges from pale yellow to deep yellow. Visual color assessment was performed at a distance of approximately 30 cm against a white background to enhance identification [16]. ariations in color are attributed to differences in the chemical composition of the essential oil, including the type, concentration, and structure of its constituent compounds [28]. Increased yellow intensity correlates with ultrasonic treatment, as extended sonication times can alter chemical composition through chlorophyll pigment degradation and decomposition of complex compounds such as phospholipids [29].. Figure 6 demonstrates that basil leaf essential oil extracted using the U-MAE method displays a pale yellow color similar to that of commercial basil leaf essential oil. This similarity suggests that the UMAE method produces essential oil with satisfactory visual quality and that compositional changes during extraction remain within acceptable limits, thereby preserving the quality of the final product [28].

4. CONCLUSION

The study demonstrates that variations in temperature and ultrasonic time during Ultrasound–Microwave Assisted Extraction (U-MAE) significantly influence the yield, density, refractive index, and color of basil leaves. Optimal extraction conditions were identified at an ultrasonic temperature of 50 °C and a duration of 30 minutes, resulting in a yield of 2.5551%, a density of 0.9542 g/ml, a refractive index of 1.4960, and a pale yellow color. These values fall within the standard range for commercial basil leaf essential oil (density 0.930–0.965 g/ml; refractive index 1.490–1.512; pale yellow color).

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