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The Impact of Withering Pre-Processing and Distillation Durations on Yield and Quality of Citronella Oil

Usman Ahmad [a,*], Dentaka [a], Courage Y. Krah [b]

[a] Department of Mechanical and Biosystem Engineering, Faculty of Agricultural Engineering and Technology, IPB University, Bogor, Indonesia
[b] School of Management, People & Organization, Faculty of Business, Technological University Dublin, Aungier Street, Dublin, Republic of Ireland

Abstract. *The global essential oil market is expanding rapidly, driven by demand from the pharmaceutical, cosmetic, and food industries. This has positioned Indonesia as a key producer and exporter of citronella essential. However, inconsistent processing methods lead to variable quality and suboptimal oil yields. This study addresses this gap by investigating how withering duration (0-72 hours) and distillation time (2-4 hours) affect yield and quality of distilled oil from Cymbopogon nardus (Mahapengiri variety). The results show that the highest oil yield (1.14%) was achieved with 72 hours of withering followed by 4 hours of distillation, demonstrating that prolonged withering significantly enhances extraction efficiency by reducing moisture content and facilitating oil release from plant cells. Quality assessments revealed that extended processing improved key physical parameters, including density (0.8897 g/cm³) and refractive index (1.4694), which conformed to Indonesian export standards (SNI 06-3953-1995). Chemical analysis using gas chromatography-mass spectrometry (GC-MS) indicated that optimal processing conditions increased the concentrations of citronellal (43.24%) and geraniol (21.73%), critical compounds that enhance the oil's market value. However, longer distillation times also intensified the oil's color, shifting it from clear to a deep yellow, which may influence consumer preference despite meeting industry chromatic standards. The study highlights the trade-offs between yield, quality, and visual characteristics in citronella oil production. These findings provide actionable insights for Indonesian producers aiming to optimize post-harvest techniques and improve the competitiveness of citronella oil in global markets.*
Keywords: *citronella; distillation; essential oil; postharvest handling; withering.*

Type of the Paper: Regular Article.

1. Introduction

Citronella oil is one of Indonesia's leading export commodities, and globally, the essential oil market has been experiencing significant growth. This surge in demand is primarily driven by the expanding applications of essential oils across various industries, including cosmetics, personal care products, pharmaceuticals, food preservation, and pest control [1,2].

Essential oils are complex mixtures of volatile compounds, including phenolics, esters, ketones, terpenes, alcohols, and amides, which contribute to their antioxidant, antibacterial, and functional activities [2]. Specifically, the oil contains natural compounds, such as citronella, geraniol, myrcene, nerol, farnesol, methyl heptenol, and dipentene. It also contains eugenol-methyl

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* First corresponding author
Email: usmanahmad@apps.ipb.ac.id *

ether, citral, dipentene, eugenol, cadinene, caryophyllene, and limonene and belongs to the *Poaceae* family which gives it a spicy and warm taste [3]. Citronellal, citronellol, and geraniol are three key compounds that determine the export value of the oil. They also influence its intensity and help differentiate it from other essential oils [4]. Geraniol and citronellal are particularly critical for international trade, as they determine the oil's compliance with ISO 3849 standards and its suitability for perfumery and therapeutic uses [5]. The yield and quality affect the price of citronella essential oil. The quality standards for citronella oil for export are evaluated based on physical criteria such as color, specific gravity, refractive index, as well as chemical criteria, particularly the total geraniol and total citronellal [5].

The yield refers to the ratio of the weight of oil produced to the weight of the initial raw material used, expressed as a percentage. Higher yields indicate higher essential oil production. However, the quality of the oil is sometimes inversely proportional to the yield, meaning that higher yields may result in lower oil quality. According to Verma [5], the average yield of citronella oil distillation ranges from 0.8-1.2%, with some reports indicating yields as high as 2.17% [6]. Yield is influenced by various factors, including genetics, climate [7], extraction methods [8], altitude, soil fertility, plant age, distillation methods, location, and pest and disease attacks [9,10]. According to Ma'mun [11], withering citronella for up to 96 hours can increase oil yield. However, excessive withering can reduce both moisture and oil content, as higher material temperatures lead to increased water evaporation and concurrent oil evaporation. It has also been reported that prolonged distillation can reduce oil quality due to loss of volatile components [12].

The quality standards of citronella oil for export are based on physical criteria, such as color, specific gravity, and refractive index, as well as chemical criteria, including total geraniol and total citronellal [5]. These standards were established by the National Standardization Agency (BSN) in 1995 and remain the reference to this day. The quality standards for citronella oil, according to Nasional BSN [13], are presented in Table 1.

Table 1. Quality standards for citronella oil in Indonesia

No	Parameter	Unit	Requirement
1	Specific Gravity (20°C)	-	0.880 - 0.922
2	Viscosity	Cst	2.3245
3	Refractive Index	-	1.466 - 1.475
4	Ester Number	-	-
5	Total Geraniol	%	Min 85
6	citronella l	%	Min 35
7	Acid Number	-	-
8	Optical Rotation	-	-
9	Color	-	Pale yellow to brownish
10	Solubility in 80% Ethanol	-	1:2 clear and further

Source: National Standardization Agency (SNI 06-3953-1995)

Despite the growing global demand for citronella oil, standardized post-harvest protocols to optimize both yield and quality remain understudied. Existing research indicates that withering reduces moisture content by 30–50% within 24–72 hours, facilitating oil release by breaking down cell walls [9]. However, prolonged withering beyond 72 hours may result in the loss of volatile compounds through evaporation, while insufficient drying (<24 hours) can hinder oil extraction efficiency [10]. Similarly, distillation duration presents a trade-off: although extended distillation (4 hours) maximizes yield, it may degrade thermolabile compounds such as geraniol, which are critical for export quality [11]. Previous studies have examined withering or distillation in isolation; however, the synergistic effects of these parameters—especially under Indonesia's climatic and varietal conditions—are poorly documented. This study addresses this gap by systematically evaluating how withering duration (0–72 hours) and distillation time (2–4 hours) jointly influence yield, citronellal/geraniol content, and physicochemical properties.

The study aims to: (1) quantify the impact of withering and distillation durations on oil yield and quality, and (2) identify optimal conditions that balance production efficiency with compliance with international standards (e.g., SNI 06-3953-1995 and ISO 3849).

2. Materials and Methods

2.1. Materials, tools and equipment

Sampling and distillation of citronella oil were conducted at Harmonis Permaculture Company, located in Karacak Village, Leuwiliang Sub-District, West Java, Indonesia. The total citronellal and geraniol contents were analyzed using Gas Chromatography-Mass Spectrometry at the Center for Standardization of Sustainable Forest Management Laboratory, Jakarta (GC-MS Shimadzu QP-5000, 689 type with 0,5 mm × 30 m capillary column and film thickness of 0,25 µm). The operating condition of the GC-MS included an oven temperature from 100°C to 350°C for 25 minutes and an injector temperature of 250°C. Table 2 presents the list of equipment used in the research and their functions.

The primary material used in this research was citronella leaves (Mahapengiri variety) harvested from PT Harmonis Permaculture Garden in Karacak Village. Other supporting materials include LPG (Liquefied Petroleum Gas), water, and alcohol. Water served as the evaporation medium during the distillation process, and alcohol was used to test the solubility of the citronella oil. The distillation equipment used in this study is illustrated in Fig. 1. The main components of the apparatus included a boiler, condenser, distillate tube, cooling water tank, and high-pressure kerosene stove as the heat source.

The boiler stand served as a support for the boiler and as a base for the stove. The boiler functioned as a container for heating the water and storing the materials to be distilled. A perforated plate was fitted to separate the water from the materials to be distilled. The boiler was equipped with a faucet for filling and draining water and an indicator to monitor the water level. A rubber gasket was placed between the main body of the boiler and the lid to prevent steam leakage. The steam collected inside the boiler was directed through a spiral tube housed within a distillate tube and condenser. The dimensions of the distillate tube are 40.0 cm in height and 35.0 cm in diameter, with a volume of approximately 38.5 L, while its capacity is about 5 kg of fresh citronella leaves. The water cooling tank measures 80.0 cm in height and 57.5 cm in diameter, with a volume of approximately 207.5 L.

Table 2. Equipment used in the Research and their Functions

	Equipment Name	Function
1	Distillation kettle	Holds water and stores the material to be distilled
2	Vial bottles	Collects the oil
3	Scales	Measures mass
4	Measuring cylinder	Measures the volume of oil
5	GC-MS Shimadzu QP-5000	Measures total citronellal and geraniol
6	Refractometer	Measures the refractive index of the oil
7	Pycnometer	Measures density
8	Camera	Captures images of the oil for color parameters
9	Stopwatch	Measures time
10	Distillate bottle	Collects the distillate
11	Test tubes	Measures solubility in 80% ethanol
12	White cardboard	Background for capturing oil images for color parameters
13	Separatory funnel	Separates essential oil from hydrosol
14	Condenser	Converts hot steam into liquid distillate
15	Distillate bottles	Collects distillate
16	Semawar stove	Heats the distillation kettle
17	Oil bath	Holds oil for calibration
18	Gasket	Prevents leakage

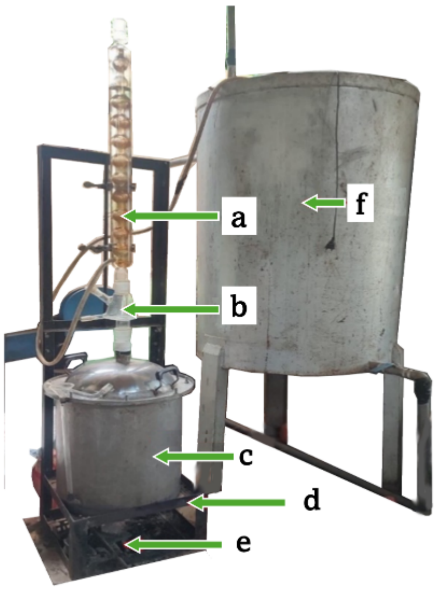

Fig. 1. Equipment setup for citronella oil distillation (a. Condenser, b. Distillate Tube, c. Boiler, d. Boiler stand, e. Stove as a heat source, and f. Cooling water tank)

2.2. Sample preparation

The sample preparation phase began with observing and harvesting citronella grass (Mahapengiri variety) from the PT Harmonis Permaculture plantation field. Fresh leaves were randomly selected from the plantations for withering and distillation.

2.3. Withering and distillation process

Fresh citronella leaves were trimmed to remove stalks, dry parts, and other debris before withering and distillation. The withering process involved air-drying fresh leaves for 24 hours, 48 hours, and 72 hours to reduce their moisture content. The leaves were air-dried by spreading them on a wooden surface in a well-ventilated room. Distillation was carried out for 2 hours and 4 hours. While the withering time could be extended up to 72 hours, the distillation time was kept short due to sensitivity to processing cost.

Before distillation of the leaves (withered and non-withered), portions of the material were separated for moisture content testing. Moisture content was measured according to AOAC standards [14]. The dish was dried in an oven at 105°C for 15 minutes, then placed in a desiccator for 10 minutes. After obtaining a constant weight as the initial weight of the dish, a 2 g sample was weighed into the dish and placed in an oven at 105°C for 3 hours. The dish was then removed and placed in a desiccator for 15 minutes before weighing. This process was repeated until a constant weight was obtained. The moisture content of the material (%wb) was calculated using equation (1).

$$MC\ (\%) = \frac{A - B}{A - C} \times 100\% \quad (1)$$

where MC: moisture content (%wb); A: weight of the sample and the dish before drying (g); B: weight of the sample and the dish after drying (g); C: weight of the dish (g).

Subsequently, distillation was conducted using the water-steam distillation method. The necessary equipment and materials were prepared using the setup at PT Harmonis Permaculture. The duration of the distillation process and the volume of oil produced (yield) were recorded.

A control experiment was also conducted, in which leaves harvested on the same day (day 0) were distilled without withering. Following a 4×2 factorial design with three replications (Table 3), approximately 72 kg of citronella leaves were used. Each sample weighed approximately 3 kg and was divided according to a combination of withering and distillation duration factors.

Table 3. Combination of the two factors at each treatment level

Withering duration (A)	Distillation duration (B)	
	2 h	4 h
Control (0 h)	A1B1	A1B2
24 h	A2B1	A2B2
48 h	A3B1	A3B2
72 h	A4B1	A4B2

2.4. Assessment of yield and quality parameters

Citronella oil produced by distillation was analyzed to compare the yield and quality. The quality parameters assessed included density, refractive index, solubility in 80% ethanol, color, and total citronellal and geraniol content.

2.4.1. Yield measurement

The citronella oil yield was measured as the ratio of the weight of produced oil to the weight of the initial raw material, expressed as a percentage. The yield calculation is expressed in equation (2).

$$R\ (\%) = \frac{m_m}{m_s} \times 100\% \tag{2}$$

where R: yield (%); m_s: weight of raw material (g); m_m: weight of produced oil (g).

2.4.2. Density measurement

To determine the density of the oil, the empty pycnometer was dried in an oven and weighed. It was then filled with distilled water at 20°C and placed in a water bath at 25°C for 30 minutes before being weighed again to determine the weight of the water. A sample of the oil, cooled to 20°C was poured into the cleaned and dried pycnometer until it overflowed, ensuring no air bubbles were present. After drying the exterior, the pycnometer was placed in a water bath at 25°C for 30 minutes, then dried and weighed. The sample weight was calculated as the difference between the weights of the oil-filled and empty pycnometers. Density was calculated according to the Indonesian National Standard (SNI) 06-3953-1995 using equation (3).

$$\rho = \frac{m_2 - m_1}{v} \tag{3}$$

where ρ: density (g/cm³); m_1: mass of empty pycnometer (g); m_2: mass of pycnometer with citronella oil (g); v: volume of oil in pycnometer (ml).

2.4.3. Refractive index measurement

The refractive index of the essential oils was determined using a refractometer. Water was circulated through the refractometer to maintain a consistent temperature for accurate measurements. The refractometer temperature was maintained at approximately 20°C. The essential oil was introduced into the refractometer, and the reading was taken once the temperature stabilized. The corrected refractive index was calculated using equation (4).

$$I_b = n_1 + 0{,}0004\ (T_1 - T) \tag{4}$$

where I_b: refractive index; n_1: reading at working temperature; T_1: actual temperature (°C); T: reference temperature (°C); 0.0004: correction factor for the refractive index of citronella oil.

2.4.4. Color measurement

Color analysis was conducted following the visual observation method by Wibowo et al. [15]. Approximately 10 mL of the essential oil was carefully poured into a test tube to avoid the formation of air bubbles. The test tube was then placed against a white background, and a camera was used to capture the images. Observations were made at a distance of approximately 30 cm, and the results were compared with the SNI 06-3953-1995 standards.

Visual observations were supported by data obtained from the RGB (red, green, blue) value readings, which were then converted to the CIE-L*ab. L*, a*, and b* values represent brightness, redness, and yellowness, respectively. The L* values indicate brightness on a scale from 0 (black) to 100 (white). The a* values range from red (+127) to green (-128), while b* values range from yellow (+127) to blue (-128). The a* and b* values were used to determine the chromaticity of the samples. Chroma values indicate the intensity or saturation of a material's color and were calculated using equation (5).

$$c^* = \sqrt{a^{*2} + b^{*2}} \quad (5)$$

where a^*= a^*: red (positive) or green (negative) value; b^*: yellow (positive) and blue (negative) value; c^*: chromaticity value

2.5. Oil Compound analysis

The content of citronella oil was analyzed using GC-MS on a GC 689 instrument equipped with an HP-5MS capillary column (0.5 mm × 30 m with a film thickness of 0.25 μm). The oven temperature was programmed from a minimum temperature of 100°C to a maximum of 350°C over 25 minutes. The injected sample was vaporized and flowed through a capillary column using helium as the carrier gas. Helium was supplied at an inlet pressure of 10.17 psi with a flow rate of 1.00 mL/min and a mean linear velocity of 27 cm/s. The front inlet operated in split mode with a split flow rate of 194.5 mL/min and a split ratio of 200:1. The injector temperature was set at 250 °C, and the outlet pressure was maintained under vacuum. The spectroscopic data of the separated compounds were recorded using a spectrophotometer and presented as chromatograms with corresponding %area values for each compound.

2.6. Statistical analysis

The data obtained were processed using MS Excel and then statistically analyzed using IBM SPSS Statistics 27 software. A two-way Analysis of Variance (ANOVA) was conducted to evaluate the effects of withering and distillation duration on the yield and quality of the resulting citronella oil. When significant differences were identified, further analysis was performed using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

3. Results and Discussion

3.1. Moisture content

The average moisture content of citronella leaves after withering for 24 to 72 hours ranged from 16.72% to 48.56%, compared to 61.07% in fresh leaves (control). This reduction in moisture is critical, as it weakens the cell walls and facilitates the release of essential oils during distillation. The evaporation process during withering leads to cellular breakdown, thereby enhancing oil accessibility and extraction efficiency [12]. Withering substantially reduced the moisture content of the material, which is directly linked to higher oil yields, as fresh leaves with intact cell walls impede efficient oil release [12]. Interestingly, Blank et al. reported that drying influenced the volatile oil content. The study also found that seasonal changes had a significant effect on fresh herbage yield, oil yield, and volatile oil content [16]. While this suggests that factors beyond moisture content impact oil yield, reducing the moisture through withering remains a necessary step to enhance oil extraction efficiency.

Based on the results presented in Table 4, the average moisture content decreased as the withering duration increased. This decline is attributed to the evaporation process—longer withering durations result in greater moisture loss. The reduction in content causes the rupture of oil cells, thereby facilitating oil extraction.

Table 4. Effect of withering duration on moisture content of citronella leaves

Treatment	Moisture Content (%)
A1 (no withering)	61.07
A2 (24 h of withering)	48.56
A3 (48 h of withering)	22.94
A4 (72 h of withering)	16.72

3.2. Yield of distillation

The ANOVA test revealed that both withering treatment and distillation duration significantly ($p < 0.05$) affected the yield of citronella oil at 95% confidence level ($\alpha = 0.05$), whereas their interaction did not. As shown in Fig. 2, the yield across all withering treatments was significantly ($p < 0.01$) higher than that of the control (0.65 ± 0.11). Additionally, a distillation duration of 4 h (0.94 ± 0.19) resulted in a higher yield than 2 h (0.69 ±0.08). These results indicate that both withering treatment and distillation duration independently influence the yield of citronella oil.

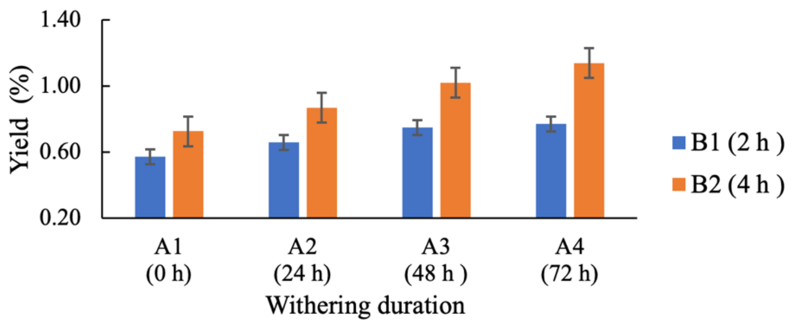

Fig. 2. Essential oil yield from various withering and distillation durations

In this study, the yield of citronella oil ranged from 0.57% to 1.14%, derived from 3 kg of citronella leaves. This finding aligns with [5], who reported average yields between 0.8% and 1.2%, and with Sembiring and Manoi [6], who reported yields of up to 2.17%. The highest yield (1.14%) in this study was obtained with treatment A4B2 (72 h of withering with 4 h of distillation). In contrast, the control treatments A1B1 and A1B2 yielded lower amounts—0.57% and 0.73%, respectively—followed by treatment A2B1 at 0.66%. These findings suggest that longer withering and distillation durations can increase yield. However, the optimal distillation time is not indefinite; excessive durations may lead to thermal degradation of volatile compounds [17]. For instance, Thanh et al. [17] reported that a distillation time of 180 minutes (3 h) was optimal for citronella oil, beyond which the yields plateaued or declined.

3.3. Quality of citronella oil

The parameters for assessing citronella oil quality in this study included density, refractive index, color, and chemical composition, specifically citronellal and total geraniol content. According to Verma [5], these are key parameters for determining the export quality of citronella oil.

3.3.1. Density

As shown in Fig. 3, all treatments resulted in higher density values compared to the controls with 1 or 2 hours of distillation (A1B1 or A1B2). The highest density was achieved after 72 hours of withering, reaching 0.8897 ± 0.0016 g/cm³. With the distillation treatment, the highest oil density was obtained after 4 hours of distillation, with an average of 0.8886 ± 0.0019 g/cm³, suggesting that both withering treatment and distillation duration affect the density of the essential oil. However, at a 2 hours distillation duration, there was no significant difference ($p>0.05$) between the control and 24 hours withering treatments. The densities of the oils in this study ranged from 0.885 to0.891 g/cm³, meeting the Indonesian standards requirement (0.880-0.922 g/cm³) [13].

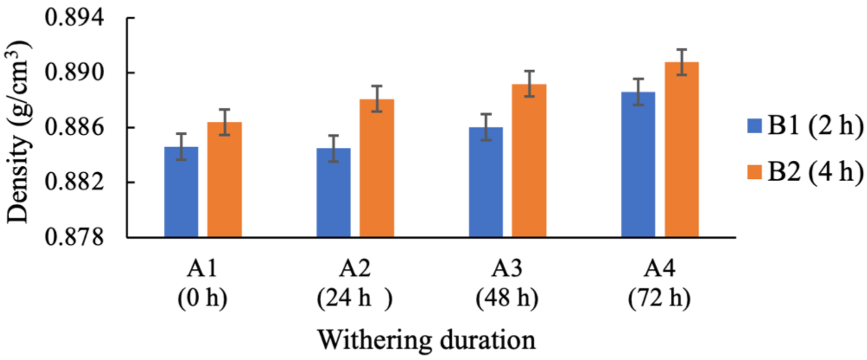

Fig. 3. Effect of withering and distillation duration on the density of essential oil

The trends displayed in the graph suggest a positive correlation between oil density and longer distillation time. This observation aligns with the previous findings indicating that extended distillation durations can increase the specific gravity and density of essential oils. Generally, oil density is influenced by its constituent compounds. Longer the carbon chain and greater molecular weight contribute to higher density [18]. The increase in citronella oil density with longer distillation time may be attributed to the distillation of heavier components containing oxygen groups [19]. Similarly, Ermaya et al. suggested that the yield and associated density of patchouli oil were influenced by distillation duration, with a higher yield achieved after 5 hours of distillation

[20].

However, it is important to note that although longer distillation times may increase specific gravity and density, this relationship is not necessarily linear or consistent across different types of oils and distillation processes. The compositional profiles of essential oils changes throughout distillation, with certain compounds becoming more prevalent at different stages, which can affect specific gravity and density in complex ways [21]. Specific gravity is often associated with a heavy fraction of the oil's constituents—compounds with higher molecular weights and boiling points [22]. The greater the proportion of these heavy fractions in the distillate, the higher the specific gravity. Moreover, variations in oil density can also be influenced by planting locations and climatic conditions, which affect the biosynthesis of volatile compounds [23].

3.3.2. *Refractive index of oil*

A comparison of the refractive index values of citronella oil obtained from each treatment is presented in Fig. 4. Statistical analysis revealed that the withering treatment, distillation time, and their interaction significantly ($p<0.05$) affected the refractive index value of the citronella oil. These findings indicate that both the withering treatment and distillation time influence the refractive index of the produced oil.

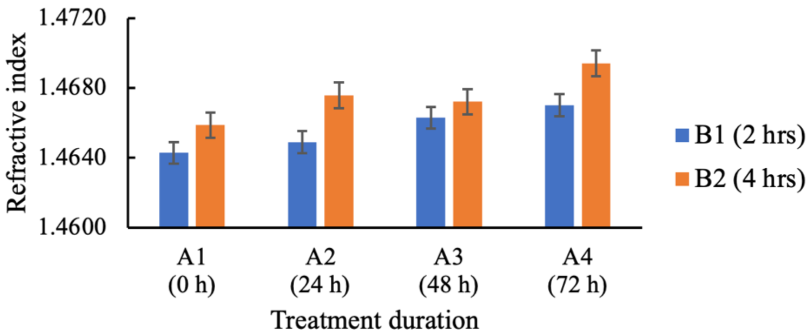

Fig. 4. Effect of withering and distillation duration on the refractive index of essential oil

The combination of 72 hours of withering and 4 hours of distillation yielded the highest refractive index value of 1.4694 (SE = ± 0.0003), significantly higher than the control treatments (A1B1 and A1B2), indicating its potential as the optimal treatment. However, the treatment A2B1 did not significantly differ from the control. All refractive index values obtained in this study were within the range specified by SNI 06-3953-1995 (1.466–1.475).

The refractive index of essential oils reflects the degree to which the oil bends light and is influenced by its chemical composition. According to Hu et al. [24], variations in refractive index can be attributed to differences in the compounds present in the oil. Additionally, external factors such as temperature, light wavelength, and purity can also affect refractive index measurements.

The duration of extraction, particularly distillation time, affects both yield and composition of essential oils, which can indirectly influence the refractive index. Previous studies have shown that longer distillation time can enhance the quantity and quality of essential oils extracted. For instance, in lavender oil extraction, the yield increased with distillation time, reaching a maximum at 60 minutes [25]. Božović et al. further noted that different plants may require varying extraction durations to achieve desired quality or quantity of extracted oil [25,26]. Additionally, the condition of the plant material, such as whether it has undergone withering, can influence the chemical properties and quality of the resulting oil.

The preparation of plant material, including processes such as withering, has been shown to influence the yield and chemical composition of patchouli oils, as demonstrated by Yahya and Yunus [27]. Although the study did not directly address the refractive index, changes in the chemical composition suggest the potential for variations in physical properties, including the refractory nature of the oil. In summary, both the duration of distillation and the condition of the plant material, such as withering, can influence the chemical composition of essential oils, which may, in turn, affect their refractive index.

3.3.3. Color appearance

Table 5 presents the visual observation of the color of citronella essential oil obtained from various withering and distillation treatments. The oil generally appeared clear, especially at a distillation time of 2 hours. However, the treatment involving 72 hours of withering combined with a 4 hours distillation time resulted in a more intense yellow color. These findings suggest that withering time affects the color of the produced oil, and the extending distillation time from 2 to 4 hours enhances the intensity of the oil's color.

Table 5. Results from Color Analysis of Distilled Citronella Oil

Treatment	Observation results		
	Rep 1	Rep 2	Rep 3
1B1	Clear	Clear	Clear
A1B2	Clear	Yellow+	Clear
A2B1	Clear	Clear	Clear
A2B2	Yellow+	Yellow+	Yellow+
A3B1	Clear	Clear	Clear
A3B2	Clear	Yellow+	Yellow++
A4B1	Yellow++	Yellow+	Clear
A4B2	Yellow++	Yellow++	Yellow++

NB: += high yellow intensity ++ = higher yellow intensity

This result was further supported by the RGB values converted to CIE-L*ab, as shown in Fig. 5. The L* value, which represents the brightness or darkness on a scale of 0 (black) to 100 (white), decreased with increasing withering and distillation durations. The highest L* (70.04 ± 0.64) was recorded for the 2-hour distillation treatment, which was significantly different ($p < 0.005$) from the 4-hour distillation (69.63 ± 0.74). Among the withering treatments, the highest L* value (69.19 ± 0.16) was observed after 72 hours of withering. According to the Indonesian

National Standard (SNI), high-quality citronella oil should range from pale yellow to yellowish brown. Therefore, the A4B2 treatment (72 hours withering and 4 hours distillation) may be considered optimal for producing citronella essential oil with desirable color characteristics.

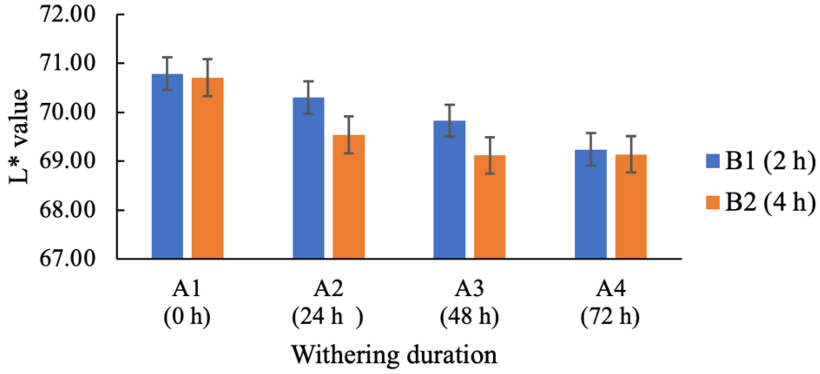

Fig. 5. Effect of withering and distillation duration on changes in the L* value of essential oil

3.3.4. Chroma values

As shown in Fig. 6, the chroma value of citronella oil tended to increase following the withering and distillation treatments. The highest chroma value (29.26) was observed in the treatment involving 72 hours of withering and 4 hours of distillation, compared to the control treatments A1B1 and A1B2, which recorded values of 3.13 and 4.88, respectively. The results indicate that prolonged withering and distillation result in a darker and more intense oil color, consistent with the visual observation in Table 6, where the control treatment (without withering) produced a nearly colorless oil.

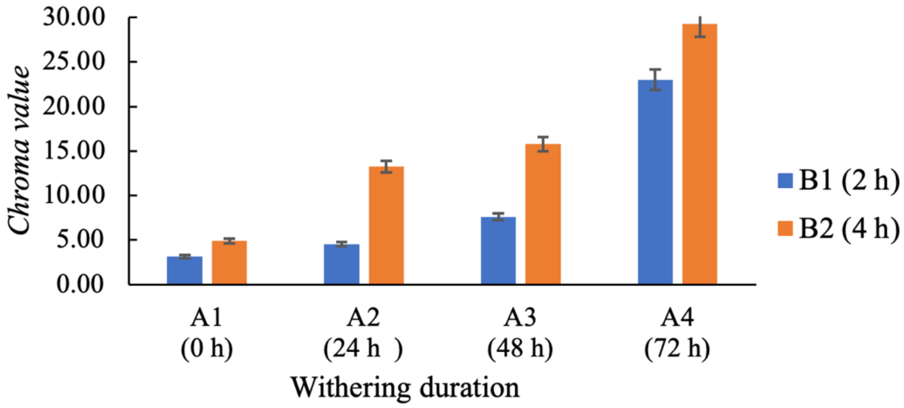

Fig. 6. Effect of withering and distillation duration on chroma value of essential oil

3.3.5. Citronella oil compound

Table 6 shows the results of laboratory analysis of key compounds in citronella oil using Gas Chromatography-Mass Spectrometry. The analysis revealed how varying durations of withering and distillation treatment influence the percentage of citronellal, geraniol and citronellol in the oil.

Longer withering and distillation time resulted in increased levels of citronellal and total geraniol. Among the three compounds analyzed, citronellal was the most abundant across all treatments, with the highest concentration (43.24%) observed in the treatment combining 72 hours of withering and 4 hours of distillation. Conversely, citronellol recorded the lowest percentages, with the least exhibited in the treatment A2B2. These results indicate that both withering and distillation durations significantly influence the proportions of citronellal, geraniol, and citronellol in citronella essential oil. Varying the distillation time, along with system pressure and packing types, can significantly influence the separation and recovery of citronellal and geraniol from citronella oil [28]. Specifically, extended distillation time is associated with higher system pressure, which improves the separation of these compounds. Distillation time, in conjunction with temperature and pressure, is therefore a critical parameter for optimizing yield while maintaining the desired geraniol content in citronella essential oil [29]. However, the amount of raw material in the distillation tank has a more pronounced effect on the percentage of citronellal, geraniol, and citronellol, with larger quantities leading to a decrease in these components [30]. In summary, although the duration of withering and distillation significantly influences the concentration of key compounds in citronella essential oil, other factors, such as system pressure, temperature, the amount of raw material, and the developmental stage of the plant, also play significant roles. Therefore, optimizing distillation conditions requires careful calibration to maximize the yield and purity of citronellal, geraniol, and citronellol.

Table 6. Shows the GCMS test results of citronella oil.

Treatment	Citronellal (%)	Geraniol (%)	Citronellol (%)
A1B2	39.72	17.68	16.34
A2B2	41.08	19.65	14.11
A4B2	43.24	21.73	15.46
SNI 06-3953-1995	Min 35	Min 85	-

These findings offer valuable insights for agricultural scientists, essential oil manufacturers, and policymakers aiming to strengthen Indonesia's competitiveness in the global essential oil market. Nevertheless, further research is needed to explore energy-efficient distillation methods and the long-term stability of oil quality under different storage conditions. By optimizing processing parameters, the industry can achieve a balance between high yield, product quality, and cost-effectiveness, supporting sustainable production to meet the growing global demand for essential oils.

4. Conclusions

The findings of this study demonstrate that both withering duration and distillation time play a critical role in determining the yield and quality of citronella oil extracted from *Cymbopogon nardus* (Mahapengiri variety). The highest oil yield (1.14%) was obtained with 72 hours of withering followed by 4 hours of distillation, confirming that prolonged withering significantly enhances oil extraction efficiency.

In terms of quality, the study revealed that longer processing times positively influenced key physical and chemical parameters. Both the density (0.8897 g/cm^3) and refractive index (1.4694) increased with extended withering and distillation, aligning with the specifications outlined in the Indonesian National Standard (SNI 06-3953-1995). Gas chromatography-mass spectrometry (GC-MS) analysis further confirmed that optimal processing conditions enhanced the concentrations of citronellal (43.24%) and geraniol (21.73%), two critical components contributing to the commercial value of citronella oil. However, extended distillation was also associated with a darker oil color, shifting from a clear to an intense yellow color.

The study underscores the importance of optimizing post-harvest processing techniques to maximize both yield and quality in citronella oil production. The recommended combination of 72 hours withering and 4 hours of distillation presents a viable method for Indonesian producers seeking to enhance the competitiveness of their essential oils in international markets.

Abbreviations

Not applicable.

Data availability statement

Data will be shared upon request from the readers.

CRediT authorship contribution statement

Usman Ahmad: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Supervision, Review, Editing, Finishing. **Dentaka**: Conceptualization, Methodology, Experiment, Data analysis, Writing. **Courage Y. Krah**: Data visualization, Writing, Formatting.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest or competing interest.

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