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RESEARCH ARTICLE

Fractionated Distillation Behavior and Aroma Component Enrichment of Citronella Oil (*Cymbopogon winterianus* Jowitt) from West Sumatra

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Abstract: This study aimed to separate the constituent components of citronella oil into several fractions with high purity and to identify the characteristics of the resulting fractions. The research was conducted using an exploratory approach to investigate the fractionation behavior of citronella oil more deeply. The raw materials were citronella oils obtained from three regions in West Sumatra: Batusangkar, Solok, and Pasaman Timur. Fractionation was carried out at a pressure of 0.8 bar, with a gradual increase in temperature divided into four fractionation temperature ranges: F1 (138–150°C), F2 (150–160°C), F3 (160–170°C), and F4 (170–180°C). Analyses performed on the citronella oil before and after fractionated distillation included component concentration using Gas Chromatography–Mass Spectrometry (GC–MS), as well as density and yield analyses. The results showed that applying a pressure of 0.8 bar increased the purity of citronella oil components. The highest concentrations were obtained in limonene (10.57% at F1, Pasaman Timur), citronellal (56.04% at F1, Batusangkar), citronellol (22.67% at F4, Batusangkar), geraniol (26.98% at F4, Batusangkar), and geranyl acetate (17.71% at F4, Pasaman Timur). The highest fraction yield was found in F1 at 46% (Batusangkar), followed by F2 at 17% (Pasaman Timur), F3 at 12.5% (Solok), and F4 at 8.53% (Pasaman Timur). Furthermore, the best density, which met the Indonesian National Standard (SNI), was observed in the Pasaman Timur citronella oil. The measured densities were 0.8818 g/cm³ for the crude oil, 0.8674 g/cm³ for F1, 0.8843 g/cm³ for F2, 0.8890 g/cm³ for F3, and 0.8923 g/cm³ for F4.

Keywords: Citronella Oil, Components, Fractionation, Pressure, Temperature

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Introduction

Indonesia is recognized as the world's second-largest megabiodiverse country, possessing an abundance of natural resources, particularly in agricultural commodities. Among these, spices and essential oils have historically played a vital role in supporting the national economy and enhancing foreign exchange earnings. Since the pre–World War II era, essential oils have served as one of Indonesia's major non-oil export commodities [1]. Essential oils are volatile plant-derived oils that serve multiple functions as fragrances, flavoring agents, and therapeutic ingredients. They are typically liquid at room temperature, readily vaporize, and possess distinctive aromas [2, 3]. These oils are obtained through extraction or distillation of plant organs such as flowers, leaves, seeds, bark, wood, or roots [4].

Globally, around 150–200 plant species are known to produce essential oils, and Indonesia contributes approximately 40 of these species. Of that number, 19 are actively produced, with nine types—patchouli, citronella, clove, ginger, nutmeg, cinnamon, vetiver, ylang-ylang, and eucalyptus oils—being dominant and well-recognized in the global market [5]. Indonesia ranks as the world's third-largest producer of citronella oil, following China and Vietnam, with an estimated annual production of 350 tons [6]. Global citronella oil production is approximately 4,000 tons per year, with China and Indonesia contributing about 40% of the total [7]. Major importers of Indonesian citronella oil include the United States, China, Taiwan, Singapore, the Netherlands, Germany, and the Philippines. However, most citronella oil is exported in crude form due to limited access to refining technologies and technical expertise among local producers. Consequently, Indonesia reimports purified isolates and derivative compounds such as citronellal, citronellol, and geraniol at significantly higher prices.

Citronella oil and its derivatives have wide-ranging applications across various industries, including perfumery, flavoring, pharmaceuticals, insect repellents, antiseptics, cosmetics, and aromatherapy, making the purification of its major components economically valuable [8]. The price of crude citronella oil ranged between Rp120,000–140,000/kg in 2002 and increased to Rp215,000–225,000/kg by 2018 [9]. The prices of citronellal, geraniol, and their ester derivatives are reportedly more than ten times higher than that of crude oil. Despite being a long-standing essential oil producer, Indonesia still imports refined oils with high citronellal and citronellol content due to a lack of downstream processing capacity. In 2016, Indonesia's essential oil exports reached US$360.9 million, with an average annual growth rate of 14%, while imports amounted to over US$1 billion [10]. The commercial value of citronella oil is strongly influenced by its purity and the concentration of its major constituents. Contaminants or foreign substances can degrade oil quality and reduce market value [11]. Therefore, purification through physical or chemical methods is essential to improve color, physicochemical properties, and compositional quality [12].

Previous studies have identified citronellal, citronellol, and geraniol as the major constituents responsible for the characteristic aroma and bioactivity of citronella oil [13, 14]. The economic value of the oil can thus be enhanced by isolating and concentrating these components. Purification can be achieved through physical techniques such as fractional distillation, molecular distillation, or supercritical CO_2 extraction, as well as chemical isolation using adsorbents [15]. Among these, fractional distillation is widely recognized as an effective physical separation technique capable of achieving high-purity isolates. This method separates volatile compounds based on differences in boiling points under controlled pressure and temperature conditions. The use of reduced pressure minimizes thermal degradation during distillation [16, 17] demonstrated that fractional distillation yields higher purity levels than conventional distillation [17]. [18] achieved a citronellal concentration of 96.1% with a yield of 41.3% under optimized vacuum conditions (60 mmHg, 112.5–122.5°C distillate temperature) [18].

However, most previous investigations have primarily emphasized optimization of operational parameters using single-source raw materials, with limited discussion on how geographical origin influences fractionation behavior and compositional enrichment efficiency. Considering that essential oil composition varies according to agroclimatic conditions, cultivation practices, and post-harvest handling [13, 14], regional variability may significantly affect vapor–liquid equilibrium behavior during distillation. For a geographically diverse producer such as Indonesia [5], understanding this variability is crucial for designing standardized purification strategies.

In this context, the novelty of the present study lies in its integrated evaluation of fractionated distillation behavior of citronella oil sourced from different production regions in West Sumatra, combined with compositional verification using GC–MS to assess enrichment patterns of major constituents. Rather than solely reporting final purity and yield, this study elucidates how regional compositional differences influence fraction distribution profiles, separation dynamics under reduced pressure, and enrichment efficiency of citronellal. This approach provides a deeper physicochemical understanding of the fractionation mechanism and generates experimentally validated operational references for future scale-up.

From an industrial standpoint, the findings offer practical guidance for improving downstream processing capacity, enabling more efficient purification and higher-value isolate production. By strengthening technical refinement strategies, the study contributes to reducing reliance on imported refined derivatives and supports national efforts to enhance the competitiveness of Indonesian essential oils in the global market [1, 10]. Through controlled fractional distillation, this research aimed to separate citronella oil into distinct fractions with high-purity constituent components, thereby improving the oil's quality and value-added potential.

Materials and Methods

This research was conducted at CV. Vahana Scientific, Siteba, Padang, the Central Instrument Laboratory of FATETA, Laboratory of Chemistry, Biochemistry of Agricultural Products and Food Nutrition, Laboratory of Technology and Process Engineering of Agricultural Products, Department of Food Technology and Agricultural Products, Faculty of Agricultural Technology, Andalas University, Padang. The research was conducted from September 2025 to Februari 2026.

Materials

The main material used is Mahapengiri type citronella oil (*Cymbopogon winterianus* Jowitt) obtained from distillation in three areas of West Sumatra, namely Solok Regency, Batusangkar, and Pasaman Timur. The chemicals used are aquades and ethanol. The equipment used includes a set of laboratory-scale fractionation distillation instruments, a heating mantle, a vacuum pump, a thermometer, a graduated cylinder, a glass funnel, boiling stones, dark bottles, Gas Chromatography-Mass Spectrometry (GC-MS), an oven, an analytical balance, a desiccator, a pycnometer, tweezers, and 10 mL vials.

Methods

This research uses an explorative method with descriptive data analysis. Considering the ability of the instrument to operate at a pressure of 0.8 bar (0.789 atm) and a fractionation column height of 34 cm, the researcher divided the treatment into 4 groups of variations in fractionation distillation temperature, namely at temperatures F1 (138-150)℃, F2 (150-160)℃, F3 (160-170)℃ and F4 (170-180)℃.

Preparation of Raw Materials

The raw material used is crude citronella oil obtained from distillation in three areas in West Sumatra Province, namely Solok Regency, Batusangkar, and Pasaman Timur. The criteria for citronella oil used are:

1. Citronella oil comes from the Cymbopogon winteratus plant, commonly known as the Java type
2. The citronella oil is fresh (not oil that has been stored for a long time)
3. The oil comes from citronella plants that meet the harvest criteria
4. The oil is in good condition, free from the addition of other oils/ingredients

Isolation of Citronella Oil Components using Fractionation Distillation

The method of isolating citronella oil refers to the modified research of [19] Le M et al. (2023) on the isolation of citronellal from citronella oil by vacuum fractionation distillation [19]. 200 mL of citronella oil was put into a distillation flask containing boiling stones. The distillation instrument was set according to the desired parameters or variables, namely temperature (138-150; 150-160; 160-170, and 170-180)℃, which was carried out with a gradual increase in temperature. Other parameters, such as pressure, were set and maintained to remain constant. The peak temperature, heating temperature, and process time from when the distillate begins to emerge until completion are all recorded. The collected distillate is then measured for volume and stored in a dark bottle. The distillate from the fractionation process is subsequently analyzed.

Observation

Observations were made on the characteristics of crude citronella oil and fractionated oil, consisting of component analysis using GC-MS [20, 21], yield, and density.

Result and Discussion

Preliminary identification was conducted to characterize the chemical composition of crude citronella oil distilled from Cymbopogon winterianus (Java type) obtained from three regions in West Sumatra: Solok, Batusangkar, and Pasaman

Timur. The samples were analyzed using Gas Chromatography–Mass Spectrometry (GC-MS), which enables qualitative and quantitative identification of volatile compounds in complex mixtures [15, 22].

This analysis was performed prior to fractionation (pre-fractionation) to establish baseline compositional profiles of citronella oil from each region. These data were subsequently used to evaluate compositional changes after fractionation (post-fractionation), allowing assessment of the effectiveness of the distillation-based fractionation process in improving oil quality. The GC-MS results showed that crude citronella oil from the three regions contained approximately 29–35 components, indicating a complex chemical composition. However, this study focuses on five compounds with relatively high concentrations, namely citronellal, citronellol, geraniol, limonene, and geranyl acetate. Among these, citronellal, citronellol, and geraniol are recognized as the main determinants of citronella oil quality due to their significant contribution to aroma intensity and commercial value [14].

From an industrial perspective, variations in the composition of these compounds across different geographical sources are important for raw material selection and process optimization. Therefore, the comparative analysis conducted in this study provides insights into the relationship between raw material origin and fractionation efficiency, contributing to efforts to enhance the quality and economic value of citronella oil.

The GC-MS chromatograms of crude citronella oil from Solok, Batusangkar, and Pasaman Timur are presented in Figures 1, 2, and 3, respectively.

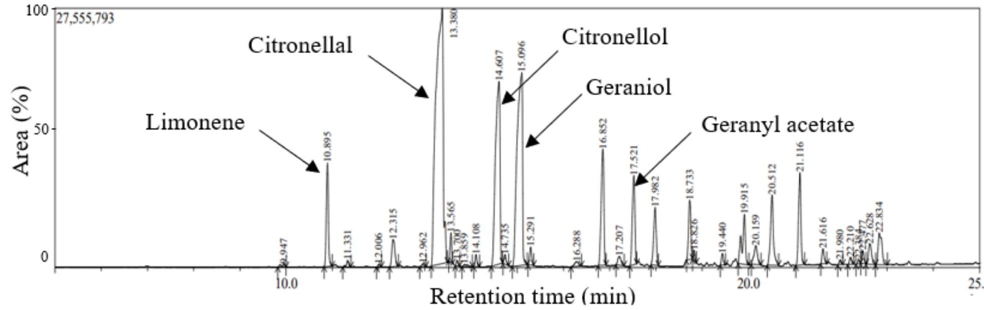

Fig. 1: Chromatogram of crude Solok citronella oil

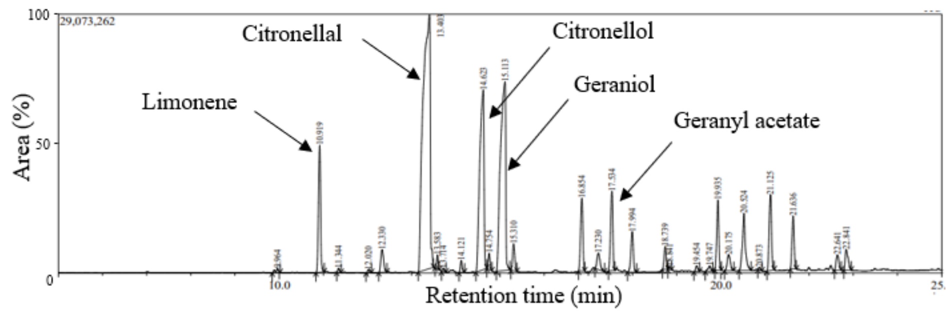

Fig. 2: Chromatogram of crude Batusangkar citronella oil

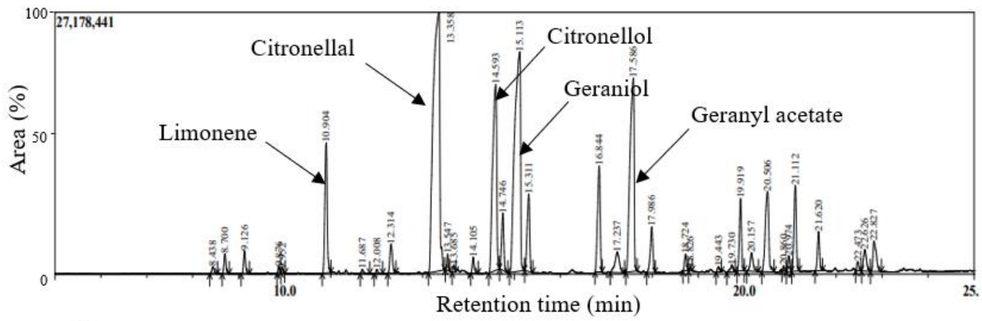

Fig. 3: Chromatogram of crude Pasaman Timur citronella oil

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Figures 1, 2, and 3 present the GC-MS chromatograms of crude Java-type citronella oil obtained from Solok, Batusangkar, and Pasaman Timur, respectively. The chromatograms show similar प्रमुख peaks corresponding to the target compounds identified in this study, namely limonene, citronellal, citronellol, geraniol, and geranyl acetate. However, the relative concentrations of these components vary among regions (Table 1).

These variations may be associated with differences in geographical and environmental conditions of the raw material sources. The citronella oil from Solok (Bukit Sundi District) is derived from plants grown in hilly and fertile valley areas at an altitude of 469–490 m above sea level [23]. In contrast, Batusangkar (Sungayang District) is characterized by hilly terrain located at the foothills of Mount Marapi and Mount Singgalang, with fertile volcanic soil and elevations ranging from 564 to 1,019 m above sea level [24]. Meanwhile, Pasaman Timur (Panti District) generally exhibits flatter and undulating topography, with elevations ranging from 221 to 1,521 m above sea level [25].

From an industrial perspective, such geographical variability is important as it may influence the biosynthesis and accumulation of key volatile compounds in citronella oil. Understanding these differences provides a basis for selecting optimal raw material sources and supports the development of more targeted fractionation strategies to improve product quality and consistency.

Table 1: Interpretation of crude citronella oil components based on GC-MS analysis

Components	**Area (%)**		
	Solok	**Batusangkar**	**Pasaman Timur**
Limonene	3.67	5.09	4.11
Citronellal	30.87	33.50	24.85
Citronellol	13.43	14.19	10.91
Geraniol	17.17	18.15	18.08
Geranyl acetate	3.61	3.45	11.04

Based on the GC-MS identification results (Table 1), the concentrations of प्रमुख chemical components in crude citronella oil from Solok, Batusangkar, and Pasaman Timur ranged from 3.67–5.09% for limonene, 24.85–33.50% for citronellal, 10.91–14.19% for citronellol, 17.17–18.15% for geraniol, and 3.45–11.04% for geranyl acetate. These values are generally comparable to those reported for Java-type citronella oil, although slightly lower citronellal levels were observed in this study.

Among the samples, citronella oil from Batusangkar exhibited higher concentrations of limonene (5.09%), citronellal (33.50%), citronellol (14.19%), and geraniol (18.15%) compared to Solok and Pasaman Timur. In contrast, Pasaman Timur showed the highest geranyl acetate content (11.04%) (Table 1). This variation confirms that citronella oil derived from different geographical regions possesses distinct chemical profiles [11].

Referring to the Indonesian National Standard (SNI 06-3953-1995), citronellal content in citronella oil should be at least 35%. The results obtained in this study indicate that all samples fall below this threshold, suggesting that the raw materials do not yet meet the required quality standards. This finding contrasts with previous work by [26], who reported citronellal content of 45.19% in citronella oil from Solok at a similar altitude (460 m above sea level), indicating that factors beyond altitude may play a significant role in determining oil quality.

Variations in citronella oil composition are influenced by multiple factors, including plant variety, geographical conditions, climate, harvesting time, and extraction methods. In commercial practice, citronella oil is mainly classified into two types: Ceylon type and Java type. The latter is generally more valuable due to its higher content of oxygenated compounds, particularly citronellal and geraniol [27]. Java-type citronella oil typically contains up to 85% total geraniol-related compounds (including approximately 35% citronellal), whereas Ceylon type contains only 55–65% (including 7–15% citronellal).

Environmental conditions also play a critical role in determining oil quality. Citronella plants optimally grow at altitudes up to 1,200 m above sea level, with annual rainfall of 2,500–4,000 mm, sunlight intensity of 75–100%, and temperatures of 24–28°C [28]. In addition, premature harvesting has been reported to reduce citronellal and alcohol content below acceptable standards [29], while appropriate extraction techniques, such as direct steam distillation, can improve both yield and quality

From an industrial perspective, the relatively low citronellal content observed in this study highlights the need for process optimization, particularly through fractionation, to enrich high-value components. The compositional variability identified across regions further emphasizes the importance of raw material selection and controlled processing conditions to ensure consistent product quality and compliance with industry standards.

Fractionation

Correlation between Fractional Distillation and the Ideal Gas Law Principle

Fractional distillation is a separation technique based on differences in boiling points or volatility of components in a mixture. This method depends on the pressure and temperature applied in the system [19]. It is particularly suitable for separating components with relatively close boiling points through repeated evaporation and condensation processes.

During distillation, temperature influences the vapor pressure of a substance; higher temperatures result in higher vapor pressure. Boiling occurs when the vapor pressure equals the surrounding pressure. According to the Ministry of Education and Culture, a liquid can boil below its normal boiling point when the external pressure is reduced (vacuum conditions).

The relationship between fractional distillation and thermodynamic principles can be described using the ideal gas law: {$PV = nRT$}. This equation represents the relationship between pressure, volume, and temperature of gases and is derived from Boyle Mariotte's law, Charles's law, and Gay-Lussac's law [30]. In fractional distillation, the vapor phase in the column is often approximated as an ideal gas due to relatively low pressure and high temperature conditions. Under these conditions, intermolecular forces are considered negligible, and molecular volume is small compared to the total gas volume.

Dalton's law explains that the total pressure in the vapor phase is the sum of the partial pressures of each component [31]. Components with higher partial pressure will have higher concentrations in the vapor phase. Raoult's law relates the composition of the liquid phase to its partial vapor pressure. As a result, separation occurs because the vapor and liquid phases have different compositions at equilibrium under specific temperature and pressure conditions.

According to Gay-Lussac's law, at constant volume, pressure is directly proportional to temperature. Therefore, control of temperature and pressure is essential in determining vapor–liquid equilibrium and improving separation efficiency. The selection of operating pressure also depends on the boiling point of the target compound [32].

Based on available thermodynamic data on the boiling points of citronella oil components at various pressures, and considering the operational limitations of the fractionation equipment used in this study, the predicted behavior of the fractionation process is presented in Table 2.

Table 2: Variations in fractionation conditions for citronella oil components

Condition	Pressure (bar)	Temperature (^oC)				
		Limonene	Citronellal	Citronellol	Geraniol	Geranyl acetate
Normal*	1.013	175	206.6	221.5	230	243.5
Vacuum	0.8	138.2	163.1	174.8	181.6	192.3

Sources:[33]

Characteristics of the Fractionated Citronella Oil

Component Analysis Using GC-MS (Gas Chromatography-Mass Spectrometry)

Component analysis of essential oils is commonly performed using Gas Chromatography–Mass Spectrometry (GC–MS). In gas chromatography, separation is based on differences in boiling point and interactions between analytes and the stationary and mobile phases. Compounds with higher boiling points or stronger interactions with the stationary phase exhibit longer retention times. Mass spectrometry is used to detect and identify compounds eluting from the GC column [25].

In mass spectrometry, the analyte is bombarded with an electron beam, producing positively charged ion fragments that are recorded as a mass spectrum and separated based on their mass-to-charge ratio. Compounds are first separated in the GC system according to their volatility using an inert carrier gas as the mobile phase and a stationary phase within the column [34]. The MS then detects these compounds as spectral peaks [34, 35].

Based on GC–MS analysis of citronella oil fractions derived from Solok, Batusangkar, and Pasaman Timur, the data were processed and visualized using OriginLab software. The results are presented in tabular form, showing the component distribution in each fraction: Solok (Table 3), Batusangkar (Table 4), and Pasaman Timur (Table 5). Across all regions, the main components identified in this study, limonene, citronellal, citronellol, geraniol, and geranyl acetate, were consistently detected. However, fractionation at different temperatures resulted in variations in their concentrations across fractions. Detailed compositional data are provided in Tables 3, 4, and 5.

Table 3: Interpretation of the chromatogram of the components of Solok citronella oil fraction

Components	Area (%)					
	Crude	F1:150℃	F2:160℃	F3:170℃	F4:180℃	Residue
Limonene	3.67	3.92				
Citronellal	30.87	54.01	37.75			
Citronellol	13.43	11.24	16.09	22.31	20.65	9.07
Geraniol	17.17	11.5	17.26	24.47	25.5	12.32
Geranyl acetate	3.61	1.24	2.89	6.54	8.57	6.42

Table 4: Interpretation of the chromatogram for the components of Batusangkar citronella oil fraction

Components	Area (%)					
	Crude	F1:150℃	F2:160℃	F3:170℃	F4:180℃	Residue
Limonene	5.09	9.32				
Citronellal	33.5	56.04	39.13			
Citronellol	14.19	10.99	16.21	22.09	22.67	10.71
Geraniol	18.15	11.46	17.96	24.3	26.98	17.03
Geranyl acetate	3.45	1.05	2.82	5.08	7.38	6.46

Table 5: Interpretation of the chromatogram for the components of Pasaman Timur citronella oil fraction

Components	Area (%)					
	Crude	F1:150℃	F2:160℃	F3:170℃	F4:180℃	Residue
Limonene	4.11	10.57				
Citronellal	24.85	47.96	34.74			
Citronellol	10.91	8.66	13.03	16.4	17.66	6.73
Geraniol	18.08	11.47	18.21	24.2	23.13	11.51
Geranyl acetate	11.04	4.4	9.12	14.65	17.71	18.21

Differences in component concentrations among the fractions of citronella oil from the Solok region are presented in Table 3. Fractionation was performed using 200 mL of crude citronella oil under a pressure of 0.8 bar (0.789 atm) with a 34 cm Vigreux column.

Under these conditions, several fractions showed higher concentrations of specific components compared to the crude oil. The highest concentrations observed were limonene at 3.92% in fraction 1 (150°C), citronellal at 54.01% in fraction 1 (150°C), citronellol at 22.31% in fraction 3 (170°C), geraniol at 25.5% in fraction 4 (180°C), and geranyl acetate at 8.57% in fraction 4 (180°C).

The limonene concentration (3.92%) showed only a slight change compared to the crude oil (3.67%) and was detected only in fraction 1 (138–150°C). It was not detected in subsequent fractions as the temperature increased. Citronellal was detected in fractions 1 and 2 but not in fractions 3 and 4. Its concentration increased significantly, reaching 54.01% in fraction 1, compared to 30.87% in the crude oil.

In contrast, citronellol, geraniol, and geranyl acetate were detected in all fractions (F1–F4) and in the residue, with varying concentrations. The highest citronellol concentration (22.31%) was found in fraction 3 (160–170°C), while the highest geraniol (25.5%) and geranyl acetate (8.57%) concentrations were observed in fraction 4 (170–180°C). These values are higher than those in the crude oil (13.43%, 17.17%, and 3.61%, respectively).

The component concentrations in each fraction of Batusangkar citronella oil are presented in Table 4.

Based on Table 4, the highest concentrations of components in the fractions of Batusangkar citronella oil were 9.32% for limonene (F1: 150°C), 56.04% for citronellal (F1: 150°C), 22.67% for citronellol (F4: 180°C), 26.98% for geraniol (F4: 180°C), and 7.38% for geranyl acetate (F4: 180°C).

The limonene concentration increased from 5.09% in the crude oil to 9.32% in fraction 1, indicating a noticeable change. Under the applied fractionation conditions, limonene was detected only in fraction 1 (138–150°C) and was not detected in subsequent fractions as the temperature increased. A similar trend was observed for citronellal, which was present in fractions 1 and 2 but not detected in fractions 3 and 4. The highest citronellal concentration (56.04%) was obtained in fraction 1, which is higher than its concentration in the crude oil (33.5%).

In contrast, citronellol, geraniol, and geranyl acetate were detected in all fractions (F1–F4) and in the residue, although at varying concentrations. The highest citronellol concentration (22.67%) was found in fraction 4 (170–180°C), compared to 14.19% in the crude oil. Similarly, the highest concentrations of geraniol (26.98%) and geranyl acetate (7.38%) were also observed in fraction 4, both exceeding their respective concentrations in the crude oil (18.15% and 3.45%).

The component analysis of citronella oil fractions from Pasaman Timur is presented in Table 5.

Based on Table 5, the fractionation process altered the concentration profile of citronella oil components. The highest concentrations were 10.57% for limonene (F1: 138–150°C), 47.96% for citronellal (F1: 138–150°C), 17.66% for citronellol (F4: 170–180°C), 24.2% for geraniol (F3: 160–170°C), and 18.21% for geranyl acetate (residual fraction). Compared to the crude oil (4.11% limonene and 24.85% citronellal), fractionation increased the concentration of these components, particularly in the early fractions. The distribution of components across fractions reflects differences in boiling point and vapor pressure. Limonene was detected only in fraction 1, indicating rapid vaporization under 0.8 bar (0.789 atm). Similarly, citronellal was concentrated in fractions 1 and 2, with the highest value (47.96%) in fraction 1. In contrast, citronellol, geraniol, and geranyl acetate were detected in multiple fractions (F1–F4), indicating overlapping boiling ranges.

This behavior is consistent with distillation theory, where components with higher vapor pressure evaporate earlier. Accordingly, limonene elutes first, followed by citronellal, citronellol, geraniol, and geranyl acetate. The enrichment of limonene and citronellal in early fractions confirms the effect of volatility differences under reduced pressure. Pressure influences boiling temperature and separation efficiency. Lower pressure reduces boiling temperature and limits thermal degradation [32]. reported citronellal purity of 96% at 40 mmHg (53 mBar), whereas this study achieved 56.04%, indicating that lower pressure may further improve separation.

Temperature interval selection also affects component distribution. Citronellal was still detected in fraction 2 (150–160°C), indicating that the fractionation range was not sufficiently narrow for complete separation. Similar overlap occurred for citronellol, geraniol, and geranyl acetate, reducing purity due to co-distillation [32]. Other factors influencing separation include condenser performance, distillation time, reflux ratio, and column height [18, 27]. The 34 cm Vigreux column used in this study may have limited separation efficiency. Previous studies reported higher citronellal concentrations using taller columns, indicating that column height affects the number of theoretical plates and overall separation performance. Overall, Batusangkar citronella oil showed the most favorable enrichment after fractionation. However, improvements in pressure, temperature control, column height, and condensation efficiency are required to achieve higher purity.

Yield

Yield was calculated as the ratio of the distillate obtained after fractionation to the initial amount of crude citronella oil, expressed as a percentage. The yield results for citronella oil fractions from Solok, Batusangkar, and Pasaman Timur are presented in Table 6.

The results showed that fraction 1 (138–150°C) produced the highest yield across all regions. The highest yield was obtained from Batusangkar citronella oil (46.00±3.91%), followed by Pasaman Timur (41.33±4.51%) and Solok (39.50±3.28%). In contrast, the lowest yield was observed in fraction 4 (170–180°C), ranging from 5.67±0.29% to 8.53±2.18%.

The yield is related to the composition of components in each fraction. The amount of evaporated components directly influences the fraction yield. Based on the chromatogram results (Tables 3–5), lower temperatures (fraction 1) produced more complex compositions, including limonene, citronellal, citronellol, geraniol, and geranyl acetate. The higher yield in fraction 1 is associated with the dominance of light volatile components, particularly limonene and citronellal, which have relatively low boiling points [36]. Batusangkar showed the highest yield in fraction 1 (46.00±3.91%), which corresponds to its higher citronellal content (56.04%) compared to Solok (54.01%) and Pasaman Timur (47.96%) (Tables 3–5). This indicates that component composition influences the fractionation yield.

Table 6: Mean Yield Value of Citronella Oil Fractions from Three Regions

Treatment	Yield (%) (Means ± SD)		
	Solok	Batusangkar	Pasaman Timur
F1 (138-150)℃	39.5±3.28	46.00±3.91	41.33±4.51
F2 (150-160)℃	8.83±2.55	15.70±3.29	17.00±2.29
F3 (160-170)℃	12.5±3.91	11.17±2.02	7.67±1.01
F4 (170-180)℃	5.95±0.97	5.67±0.29	8.53±2.18
Residue	23.25±6.38	14.42±4.02	15.00±1.32
CV	21.39%	16,39%	14,37%

In fraction 2 (150–160°C), the yield remained relatively high (8.83±2.55 to 17.00±2.29%), indicating that several components were still evaporating at this temperature range. Chromatogram data show that fraction 2 still contained multiple components, including citronellal, citronellol, geraniol, and geranyl acetate. In contrast, yields decreased in fractions 3 and 4, likely due to the presence of heavier components with higher boiling points that are less volatile at 160–180°C. The residual fraction showed yields ranging from 14.42±4.02 to 23.25±6.38%, indicating the presence of non-volatile or high-boiling-point compounds that were not evaporated within the applied temperature range (138–180°C). These may include citronellol, geraniol, sesquiterpenes, and non-volatile substances such as paraffin, wax, and resin [37]. Differences in residual yields among regions may reflect variations in raw material quality.

Density

Density is defined as the ratio of mass to volume. It is determined by comparing the weight of oil at a specific temperature with the weight of water at the same volume and temperature. According to the Indonesian National Standard (SNI 06-3953-1995), density measurements for citronella oil are conducted at 20±0.2°C to ensure accuracy and minimize temperature effects. Temperature variations can influence density values; higher temperatures may cause evaporation, while lower temperatures may lead to contraction. Density analysis of crude citronella oil was conducted to evaluate its compliance with SNI requirements and to provide a comparison with fractionated oil. The density values of crude and fractionated citronella oil from Solok, Batusangkar, and Pasaman Timur are presented in Table 7.

The density of crude and fractionated citronella oil from the three regions ranged from 0.8565±0.0018 g/cm³ (F1 Batusangkar) to 0.9230±0.0017 g/cm³ (Pasaman Timur residue). The densities of crude oil were 0.8763±0.0037 g/cm³ (Solok), 0.8747±0.0011 g/cm³ (Batusangkar), and 0.8818±0.0053 g/cm³ (Pasaman Timur), compared to the SNI 06-3953-1995 standard of 0.880–0.922 g/cm³ (20°C/20°C). Only Pasaman Timur met the SNI specification, while Solok and Batusangkar were slightly below the minimum limit. Density variation may be influenced by environmental factors such as altitude and growing temperature [38]. Solok (469–490 m asl) and Batusangkar (564–1,019 m asl) are predominantly highland areas [23, 24], whereas Pasaman Timur (221–1,521 m asl) includes more lowland zones [25].

Table 7: Mean Density Values of Citronella Oil from Three Regions

Treatment	Density (g/cm³) (Means ± SD)		
	Solok	Batusangkar	Pasaman Timur
Crude	0.8763±0.0037	0.8747±0.0011	0.8818±0.0053
F1 (138-150)℃	0.8596±0.0081	0.8565±0.0018	0.8674±0.0101
F2 (150-160)℃	0.8757± 0.0017	0.8714±0.0069	0.8843±0.0079
F3 (160-170)℃	0.8776±0.0050	0.8844±0.0042	0.8890±0.0042
F4 (170-180)℃	0.8853±0.0003	0.8881±0.0034	0.8923±0.0027
Residue	0.9176±0.0080	0.9181±0.0129	0.9230±0.0017
CV	0.61%	0.73%	0.68%

Lower temperatures in highland areas may favor the presence of low-boiling monoterpenes such as limonene and citronellal, which have lower densities, resulting in lower crude oil density. In contrast, higher temperatures in lowland areas may reduce these lighter components, leaving higher-boiling compounds such as citronellol, geraniol, and geranyl acetate, thereby increasing density. Fractionation at 0.8 bar (0.789 atm) with temperature ranges of 138–180°C increased density across all samples. Early fractions (F1: 138–150°C) showed the lowest densities (0.8565–0.8674 g/cm³), while residues showed the highest (0.9176–0.9230 g/cm³).

This trend indicates that higher fractionation temperatures concentrate heavier components with higher boiling points and densities. Distillates containing heavier fractions tend to exhibit higher density [27]. These results are consistent with [32], who reported increasing density with fraction number under vacuum conditions. Therefore, pressure and temperature influence fraction characteristics, with density reflecting the relative composition of light and heavy components.

Conclusion

This study demonstrates that laboratory-scale fractional distillation can enrich key aroma components of citronella oil (Cymbopogon winterianus Jowitt*)* from West Sumatra. The highest concentrations were observed for limonene (10.57% in F1 Pasaman Timur), citronellal (56.04% in F1 Batusangkar), citronellol (22.67% in F4 Batusangkar), geraniol (26.98% in F4 Batusangkar), and geranyl acetate (17.71% in F4 Pasaman Timur).

The fractionation process also influenced physical properties, with the highest yield obtained in F1 (46% in Batusangkar) and density values meeting SNI standards observed in Pasaman Timur (0.8818 g/cm³ in crude oil; 0.8674–0.8923 g/cm³ across fractions). These results indicate that fractional distillation can improve citronella oil quality by increasing the concentration of major components. Further optimization of operating conditions is required to improve efficiency and support potential industrial application.

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Author's Contributions

Anni Faridah: Conceptualization, Methodology, investigation and laboratory work, writing original draft, writing review and edited.
Daimon Syukri: Conceptualization, Methodology, supervision, writing original draft, writing review and edited.
Annisa Rahmi ZJ and Andriyana Setyawati: Investigation and laboratory work.
Yusti Atika: Methodology, investigation and laboratory work.
Bayu Indra Lesmana: Formal analysis.
I Ketut Budiraga: Project administration and manuscript revision.
Durain Parmanoan: Language polishing.
All authors have read and agreed to the published version of the manuscript.

Ethics

This study did not involve human participants or animals. Therefore, ethical approval was not required.

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