MOLEKUL
eISSN: 2503-0310

Articles
https://doi.org/10.20884/1.jm.2026.21.2.19856

Qualification of Indonesian National Standard Parameters and GC–MS Identification of Chemical Compounds in Commercial Citronella Essential Oil (*Cymbopogon nardus* L.) Rendle

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Received March 03, 2026; **Accepted** July 04, 2026; **Available online** July 20, 2026

ABSTRACT. The demand for essential oils has increased rapidly in line with the growth of the cosmetic, food, perfume, pharmaceutical, and aromatherapy industries. Citronella essential oil is one of the essential oils with high economic value and significant therapeutic benefits. Its main active constituents—citronellal, citronellol, and geraniol—exhibit antibacterial, antiseptic, and antioxidant activities and are widely utilized in the perfume and cosmetic industries. Despite established quality standards (SNI 06-3953-1995), many commercial products fail to meet required specifications, particularly in active compound content. Previous reports have highlighted variability in citronellal and geraniol levels, raising concerns about product consistency and consumer safety. Therefore, this study aimed to evaluate the conformity of commercial citronella oils and to identify their chemical constituents using GC–MS method. Gas Chromatography–Mass Spectrometry (GC–MS) method allows to detect trace adulterants and confirm the precise chemical and botanical profile of the essential oil. A Total of six citronella essential oil samples were analyzed, consisting of three brands registered with the Indonesian Food and Drug Authority (BPOM) and three unregistered brands. Quality assessments included color, specific gravity, refractive index, solubility in ethanol, and the presence of foreign substances based on the Indonesian National Standard (SNI) 06-3953-1995. The results showed that all samples met the SNI quality requirements, exhibiting pale yellow to yellowish-brown coloration, specific gravity values of 0.8850–0.9127, refractive indices of 1.467–1.474, and clear solubility at a 1:2 ethanol ratio. GC–MS analysis identified dominant compounds such as cyclofenchene, citronellal, and geraniol, with cyclofenchene being the most abundant component. However, despite compliance with physicochemical parameters, the contents of citronellal and geraniol were still below the minimum limits specified by SNI. These findings indicate variations in the quality of commercial citronella essential oils and highlight the need for standardized production processes and continuous quality control.

Keywords: Essential oil, GC-MS, kaffir lime, lemongrass

INTRODUCTION

The demand for essential oils has increased rapidly in line with the development of the cosmetic, food, perfume, pharmaceutical, and aromatherapy industries. According to data from the Indonesian Information Portal, Indonesia has substantial potential to meet global essential oil demand, with an annual production capacity of approximately 5,000–6,000 tons supported by around 3,000 business actors. In 2022, Indonesia's essential oil export performance reached USD 172.9 million (Indonesian Information Portal, 2025). To date, 99 essential oil–producing plant species have been identified worldwide, 40 of which are found in Indonesia. Among these, 12 species have been commercially developed on an industrial scale, including patchouli, vetiver, ylang-ylang, cajuput, lemongrass, clove, sandalwood, nutmeg, cinnamon, cubeb, and pepper (Rosiana et al., 2017).

To ensure the quality of essential oils circulating in the free market, the Government of Indonesia has established mandatory standards through the National Standardization Agency (BSN) in the form of the Indonesian National Standard (SNI). These standards serve as the basis for quality testing, certification, and guidance in the production sector. Quality parameters for essential oils include color, specific gravity (20°/20°), refractive index (n^{D20}), solubility in ethanol (80%), foreign substances (fats, added alcohol, pelican oil, turpentine oil), marker compound content (w/w), acid value, and ester value (Ma'mun et al., 2011).

One of the distinctive essential oils widely distributed in the Indonesian commercial market is citronella essential oil derived from *Cymbopogon nardus* (L.). Citronella essential oil exhibits various pharmacological activities, including antibacterial, antiseptic, diuretic, and antioxidant effects, and is traditionally used in the treatment of eczema and rheumatism (Ahmed et al., 2024; Haneen et al., 2025). Antibacterial activity assays using the microdilution method have demonstrated that

citronella essential oil can inhibit the growth of *Bacillus cereus*, *Escherichia coli*, *Klebsiella pneumoniae*, *Candida albicans*, and *Staphylococcus aureus*, with varying levels of susceptibility (Zulfa et al., 2016).

The quality of citronella essential oil is regulated by the National Standardization Agency (BSN) under Indonesian National Standard No. 06-3953-1995 (SNI 06-3953-1995). Quality parameters include color, specific gravity (20°/20°), refractive index (n^{D20}), solubility in ethanol (80%), foreign substances (fats, added alcohol, pelican oil, turpentine oil), total geraniol (w/w), and citronellal content (w/w). The standard is used as a reference for quality testing, certification, and guidance in the production sector. According to SNI, high-quality citronella essential oil should contain citronellal (32–45%), citronellol (11–15%), geraniol (10–12%), geranyl acetate (3–8%), and citronellyl acetate (2–4%). However, some citronella oil extracts have been reported not to meet these requirements, with citronellal, citronellol, and geraniol contents of 13.67%, 21.18%, and 21.32%, respectively (Tongkeles, 2019).

The quality of essential oils is determined not only by their physical properties but also by the composition and concentration of their active compounds. These active constituents are responsible for the biological activity and practical applications of essential oils, particularly in the health sector (Ben Miri, 2025). The quality and quantity of active compounds in essential oils are influenced by various factors, including the climate of the plant's growing region, production processes, packaging, and storage conditions (Mugao, 2024). Consequently, essential oils available in the commercial market may not always comply with established quality standards. Therefore, to ensure the quality of commercially available citronella essential oil, a comprehensive analysis based on SNI 06-3953-1995 is required, accompanied by the identification and quantification of active compounds using the Gas Chromatography–Mass Spectrometry (GC–MS) method.

EXPERIMENTAL SECTION

Materials and Equipment

The instruments used in this study included test tubes, an analytical balance, a 25 mL pycnometer, a water bath, a thermometer, a refractometer, an evaporating dish, a graduated cylinder, a GC–MS instrument, and other standard laboratory glassware.

The primary material used in this study was citronella essential oil (*Cymbopogon nardus* (L.) Rendle) obtained through e-commerce platforms. The sampling criteria consisted of three brands each with three replications registered with the Indonesian Food and Drug Authority (BPOM), classified as samples A1, A2, and A3, and three brands not registered with BPOM, classified as samples B1, B2, and B3. Additional materials included distilled water, 80% ethanol, potassium hydroxide, iodoform, ethyl benzoate, 10% NaOH, iodine–potassium iodide solution, benzoyl chloride, and ammonia.

Quality Testing of Citronella Essential Oil

The physical quality of citronella essential oil included color identification, measurement of specific gravity and refractive index, and solubility was tested based on the Indonesian National Standard (SNI) 06-3953-1995. Detection of contaminants or foreign substances such as fats, alcohol, pelican oil, and turpentine oil was conducted according to National Standardization Institution (BSN, 1995).

Determination of Color and Clarity

A total of 10 mL of essential oil was pipetted into a test tube and placed against a white cardboard background. Direct visual observation was conducted at a distance of 30 cm (Rahman et al., 2019). The oil color was observed ranging from pale yellow to yellowish-brown (Omarta, 2020).

Determination of Specific Gravity

The empty pycnometer was filled with 25 mL of distilled water and allowed to stand at 20°C for 30 minutes before being weighed with its contents (m_1). The pycnometer was then emptied, rinsed with ethanol and diethyl ether, and dried subsequently filled with 25 mL of citronella essential oil sample, equilibrated at, 20°C for 30 minutes, and weighed (m_2). The specific gravity of the sample was determined by comparing the weight of the oil to the weight of water at the same volume and temperature.

Determination of Refractive Index

The prism glass of the refractometer was cleaned with ethanol and dried prior to analysis. A drop of the essential oil sample refractometer at a temperature of approximately 20°C, was placed on the prism, and the refractive index was recorded once the temperature stabilized.

Solubility in Ethanol

A reference solution was prepared by adding 0.5 mL of 0.1 N silver nitrate and 50 mL of 0.0002 N sodium chloride solution into a beaker and mix until homogeneous. One drop of 25% dilute nitric acid was then added and mixed thoroughly. Subsequently, 1 mL of essential oil sample was placed into a test tube, and 2 mL of 80% ethanol was added dropwise while shaking until a clear solution was obtained at 25°C.

Foreign Substance Testing

Determination of added fats

Ten drops of the oil sample were added to a test tube containing 5 mL of ethanol, then placed in an ice–salt mixture (3:1) for 15 minutes. In a separate test tube, potassium hydroxide (KOH) was added to the essential oil sample and shaken until saponification of fatty oils occurred, indicated by foam formation (BSN, 1995).

Determination of added alcohol

A total of 50 mL of the oil sample was dried with sodium sulfate in a Ladenburg flask. The fraction was distilled below 100°C then collected, measured, and

diluted with 10 mL of distilled water. The diluted distillate was then tested using the iodoform and ethyl benzoate. Iodoform test was performed by diluting 5 mL distillate mixed with 10 drops of 10% NaOH solution, followed by the gradual addition of iodine–potassium iodide solution until a permanent pale yellow color was obtained. The mixture was allowed to stand for 5 minutes. If no positive result was observed, the test tube was heated at 60°C for 1 minute and then allowed to stand for 1 hour. The appearance of a yellow coloration indicated excess iodine and confirmed the presence of ethyl alcohol (BSN, 1995). Ethyl Benzoate test was performed using 5 mL of distillate mixed with 5 drops of benzoyl chloride and 2 mL of 10% NaOH solution, then heated in a water bath. The presence of a fruity odor characteristic of ethyl benzoate indicated the presence of ethyl alcohol.

Determination of pelican oil

This test was based on the determination of the refractive index of the distillate. A total of 20 mL of the oil sample was distilled under vacuum at approximately 12 mmHg. The temperatures at the first and last drops of approximately 1 mL of distillate were recorded. The distillate was then cooled, the refractive index was measured using a refractometer. If the refractive index was less than 1.46, the sample was considered positive for pelican oil contamination.

Determination of Turpentine Oil

The oil sample was distilled at 156°C, and the distillate was mixed with ammonia at a ratio of 1:5. The formation of a milky white reaction or gel-like appearance indicated the presence of turpentine oil.

Identification of Chemical Compounds Using GC–MS

Compound identification was performed using an Agilent GC–MS 5975C system with a mass range of 35–550 m/z. Citronella essential oil samples were injected at a volume of 0.2 μL into the GC–MS under the following conditions: a capillary column (HP-5MS, DB-5; 60 m × 250 μm × 0.25 μm), helium as the carrier gas, injector temperature of 250°C, split ratio of 1:200 with a split flow of 50 mL/min, and an initial oven temperature of 50°C held for 2 minutes. The oven temperature was increased at a rate of 10°C/min to 99°C, followed by 2°C/min to 225°C with a holding time of 20 minutes, and then increased at 5°C/min to a final temperature of 250°C.

Data Analysis

Data analysis was conducted using both quantitative and qualitative approaches. Quantitative analysis involved comparing test results with established standard values and determining the concentrations of active compounds from GC–MS chromatograms. Qualitative analysis involved identifying active compounds present in the samples by comparing chromatogram readings with reference spectra available in the GC–MS spectral library.

RESULTS AND DISCUSSION

Quality Test Results

Physical characteristic of citronella essential oil

The physical characteristics of citronella essential oil from BPOM-unregistered samples (A1, A2, and A3) are presented in **Table 1**, while the quality characteristics of BPOM-registered citronella essential oil samples (B1, B2, and B3) are shown in **Table 2**.

Determination of color and clarity

Color is one of the primary visual indicators used by consumers to directly assess essential oils through visual observation. Color evaluation of samples A1, A2, A3, B1, and B3 showed similar results, namely pale yellow, while sample B2 exhibited a bright yellow color (Figure 1). Referring to the Indonesian National Standard (SNI) 06-3953-1995, which specifies that citronella oil should range from pale yellow to yellowish-brown in color, all samples were determined to meet the required quality standards. These color characteristics are consistent with previous studies reporting that citronella essential oil obtained through distillation typically exhibits a pale yellow coloration (Mieso & Kinky, 2020; Hartatie et al., 2019).

Freshly extracted essential oils are generally colorless to yellowish; however, some may appear reddish, green, or brown, depending on factors such as the drying method of the raw material, distillation duration, and distillation temperature, all of which influence essential oil color. In addition, color variations in essential oils may result from exposure to oxygen and sunlight. Prolonged storage in non-airtight containers can lead to oxygen absorption, causing the essential oil to become darker and more viscous over time (Yuxin et al., 2025).

Table 1. Physical characteristics of BPOM-Unregistered Citronella Essential Oil

	Color	Specific gravity	Refractive index	Solubility in ethanol	Foreign Substances			
					Lipid	Alcohol	Pelican oil	Turpentin oil
A1	Light yellow	0.9119 ± 0,019	1,468 ± 0,053	clear	-	-	-	-
A2	Light yellow	0.8850 ± 0,037	1,471 ± 0,018	clear	-	-	-	-
A3	Light yellow	0.8997 ± 0,082	1,467 ± 0,064	clear	-	-	-	-
Requirement	yellow to brown	0.880 - 0.922	1,466 – 1,475	1 : 2 clear	-	-	-	-

Note: (-) = not detected; (+) = detected

Table 2. Physical characteristics of BPOM-Registered Citronella Essential Oil

Sampel	Color	Specific gravity	Refractive index	Solubility in ethanol	Foreign Substances			
					Lipid	Alcohol	Pelican oil	Turpentin oil
B1	Light yellow	0.9050 ± 0,063	1.472 ± 0,082	clear	-	-	-	-
B2	Light	0.9043 ± 0,069	1.469 ± 0,077	clear	-	-	-	-
B3	yellow Light	0.9127 ± 0,047	1.474 ± 0,093	clear	-	-	-	-
Requirements	yellow to brown	0..880 – 0.922	1.466 – 1,475	1 : 2 clear	-	-	-	-

Note: (-) = not detected; (+) = detected

Figure 1. Physical appearance of lemongrass essential oil from the marketplace (Description: A1 Pale yellow, B1 Pale yellow, A2 Pale yellow, B2 Bright yellow, A3 Pale yellow, B3 Pale yellow)

Results of Specific Gravity Determination

Specific gravity is an important parameter for evaluating the quality of essential oils (Gumelaret et al., 2022). The specific gravity values of samples A1, A2, and A3 were 0.912, 0.885, and 0.899, respectively, while those of samples B1, B2, and B3 were 0.905, 0.904, and 0.913, respectively. According to the Indonesian National Standard SNI 06-3953-1995, the acceptable range for the specific gravity of citronella essential oil is 0.880–0.922 (BSN, 1995). Based on these results, all citronella essential oil samples obtained from the marketplace met the Indonesian National Standard requirements for specific gravity.

The specific gravity range must comply with the standard as it is closely related to the purity and quality of the oil. A higher specific gravity indicates a higher content of chemical constituents, whereas a lower specific gravity suggests a lower concentration of compounds present in the essential oil (Amanullah & Shukumar, 2025).

Refractive Index

The Indonesian National Standard SNI 06-3953-1995 specifies that the refractive index of citronella oil at 25 °C should be within the range of 1.466–1.475. The refractive index values of samples A1, A2, and A3 were 1.468, 1.471, and 1.467, respectively, while those of samples B1, B2, and B3 were 1.472, 1.469, and 1.474, respectively. These results indicate that the refractive indices of all samples complied with the required quality standards.

The closer the refractive index of a sample is to the reference value, the higher the purity of the citronella essential oil. The refractive index plays an important role in controlling the quality and purity of essential oils (Ospina et al., 2016). Higher refractive index values generally indicate better quality in accordance with established standards. Variations in refractive index may be influenced by the presence of solvents or adulterants mixed with the oil. Lower refractive index values may result from solvents that also refract incident light, thereby altering the measurement (ShiJun & XiaoKang, 2021).

Ethanol Solubility Test

Each essential oil has a specific solubility value in ethanol, making this property useful for assessing essential oil purity. According to SNI 06-3953-1995, citronella essential oil should be soluble and form a clear solution in ethanol at a ratio of 1:2. The test results showed that all samples were soluble and produced clear solutions at a 1:2 ratio, thus meeting the Indonesian National Standard requirements. These findings are consistent with previous studies on the solubility of citronella essential oil in ethanol, which

also reported clear solutions at a 1:2 ratio (Anwar & Diningsih, 2022).

The solubility of essential oils in alcohol is determined by the types of chemical components present. In general, essential oils containing oxygenated terpene compounds are more readily soluble in alcohol than those dominated by non-oxygenated terpenes. Therefore, greater solubility in ethanol is indicative of higher essential oil quality.

Foreign Substance

Additional Fat

The presence of fats can affect the physicochemical properties of essential oils, such as specific gravity, refractive index, and solubility in ethanol, which are key parameters specified in the Indonesian National Standard (SNI) for citronella essential oil. All samples analysed in this study showed negative results for added fats, as indicated by the absence of turbidity when the samples were mixed with ethanol (Figure 2).

Based on these results, it can be concluded that all citronella essential oil samples obtained from the marketplace exhibited good quality and did not contain added fats. The presence of added fats can reduce the quality and purity of essential oils, as fats may accelerate oxidative processes, leading to changes in aroma and biological activity. Therefore, to ensure purity and effectiveness, citronella essential oil must be free from fat contamination (Boren et al., 2015).

Additional Alcohol

The addition of alcohol to citronella essential oil is not permitted, as it can reduce the quality and purity of the oil. The Indonesian National Standard (SNI) 06-3953-1995 stipulates that citronella essential oil must be free from foreign substances such as added fats and alcohol.

The alcohol test results for all essential oil samples were negative, as indicated by the absence of an alcohol distillate during the sample distillation process. These findings demonstrate that all samples possessed high purity and good quality, meeting the essential oil quality standards with respect to added alcohol. The presence of added alcohol can decrease oil purity and quality by altering physicochemical properties such as specific gravity, refractive index, aroma, and stability. Moreover, the addition of synthetic alcohol may reduce the effectiveness of the oil in therapeutic and cosmetic applications, thereby lowering its commercial value in the essential oil industry (Capetti et al., 2021).

Additional Pelican Oil

Pelican oil, also referred to as mineral oil, is derived from refined crude petroleum. Although mineral oil has various applications in general and healthcare industries, it is sometimes used as a solvent or adulterant in essential oils. Therefore, the presence of pelican oil in essential oils indicates adulteration and reduced purity (Rawlings & Lombard, 2012).

The results of pelican oil testing in this study were negative, indicating that none of the citronella essential oil samples contained pelican oil. These findings are consistent with the requirements specified in SNI 06-3953-1995, which state that citronella essential oil must be free from pelican oil contamination.

Additional Turpentine Oil

The addition of turpentine oil to essential oils, particularly citronella essential oil, can alter the chemical composition and overall quality of the oil, necessitating strict quality control measures (Rusli et al., 2022). The results of this study showed no evidence of contamination arising from the addition or mixing of turpentine oil into citronella essential oil, as indicated by the absence of milky white or gel-like reactions. These results meet the requirements established by the National Standardization Agency (BSN) in SNI 06-3953-1995, which specify that citronella essential oil must yield negative results in turpentine oil testing.

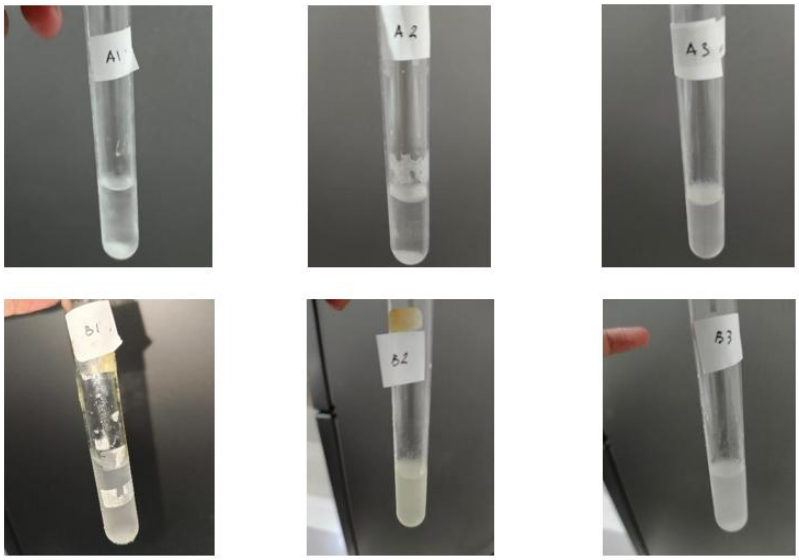

Figure 2: Additional oil test after sample was added with ethanol

Turpentine oil, which is rich in α-pinene, can increase the α-pinene content in citronella essential oil. Elevated α-pinene levels may reduce the specific gravity and ethanol solubility of the oil and alter its aroma profile. Therefore, authentication of essential oils is essential to detect and prevent the adulteration of citronella oil with turpentine oil (Husnun et al., 2022).

GC–MS Analysis of Citronella Essential Oil

The chemical compositions of all citronella essential oil samples (A1, A2, A3, B1, B2, and B3) are presented in **Table 3**. These data represent the results of compound identification using Gas Chromatography–Mass Spectrometry (GC–MS). The compounds were identified based on the obtained mass spectra and subsequently matched with reference spectra from the National Institute of Standards and Technology (NIST) library. Only compounds with a match score greater than 90% were included in the table, ensuring high accuracy and reliability in identifying the major constituent compounds of citronella essential oil (Amirav et al., 2025; Ali et al., 2017).

Table 3 shows the dominant compounds present in citronella essential oil, including β-pinene, citronellal, cyclofenchene, D-limonene, geraniol, and terpinolene. Among these constituents, cyclofenchene exhibited the largest peak area, indicating that it was the most abundant compound. Cyclofenchene is a polycyclic aromatic hydrocarbon derived from fenchene. To date, cyclofenchene has not been reported to possess specific pharmacological activities or experimentally validated medical applications (Scott et al., 2012); rather, it has primarily been explored for structural and functional purposes in materials engineering (Ouyang et al., 2019). A high cyclofenchene content may reflect a distinct chemotype of *Cymbopogon nardus*, environmental influences such as soil, climate, harvest maturity, extraction conditions, or analytical factors such as compound identification based solely on mass spectral library matching.

Methyl salicylate and *p*-cymene appeared as minor constituent which occur at relatively low concentrations in some samples, but these compounds may contribute significantly to its biological activity through additive or synergistic interactions with the major terpenoids. These compounds may be considered as complementary indicators in future quality assessments, particularly for evaluating chemotypic variation and predicting biological activity (Bassolé & Juliani, 2012).

The chemical constituents of citronella essential oil, as listed in **Table 3**, contribute to various pharmacological activities, particularly antibacterial effects, which are associated with the presence of citronellal, citronellol, limonene, and eugenol (Tibenda et al., 2022), as well as insect-repellent activity (Avoseh et al., 2015). In addition, citronellal, geranial, geraniol, citronellol, and neral have been confirmed to exhibit antifungal activity, with minimum inhibitory concentration (MIC) values ranging from 15.8 to 1000 μg/mL against *Candida albicans* (De Toledo et al., 2016).

Citronellal and Geraniol Content

As shown in Table 5, the citronellal and geraniol contents of commercial citronella essential oil samples, both unregistered (A1, A2, A3) and BPOM-registered (B1, B2, and B3), did not meet the standards established by the National Standardization Agency (BSN). The highest citronellal content among the six samples was 14.4% in sample A1, while the highest geraniol content was 4.42%, also in sample A1. Citronellal and geraniol are the principal components of citronella essential oil (Jones & Smith, 2019). Citronellal is a monoterpenoid aldehyde that imparts a fresh, lemon-like aroma and is commonly found in essential oils of plants such as citronella (*Cymbopogon nardus*) (Lee, 2018). Geraniol is another important constituent frequently present in citronella plants; it is a monoterpene alcohol that plays a key role in determining the aromatic characteristics of citronella essential oil (Wang, 2017).

Table 3. Compound Profile of Citronella Essential Oil Samples from the Marketplace

No	Compounds	RT	% Area					
			A1	A2	A3	B1	B2	B3
1.	Beta-pinene	7.0105	1.4	1.64	2.16	1.72	1.47	1.2
2.	Citronellal	11.1985	14.4	13.55	6.84	8.55	8.02	6.37
3.	Citronellol	13.6630	2.79	-	-	-	2.22	2.4
4.	Cyclofenchene	6.1812	52.91	59.61	37.36	64.51	59.24	56.49
5.	D-Limonene	8.0162	2.18	2.51	4.47	1.38	1.7	1.29
6.	Geraniol	14.5924	4.42	3.11	1.27	2.61	4.26	4.08
7.	Hexylene glycol	6.0635	-	-	-	-	1.76	-
8.	Methyl salicylate	12.5572	-	-	-	-	-	8.14
9.	p-Cymene	7.9163	-	-	1.93	-	-	-
10.	Terpinolene	9.3222	1.11	1.12	3	1.05	1.16	-

Table 5. Citronellal and Geraniol Content of Lemongrass Essential Oil

Marker compound	% Area						Qualification
	A1	A2	A3	B1	B2	B3	(SNI 3953:2019)
Citronellal	14.4	13.55	6.64	8.55	8.02	6.37	30 %
Geraniol	4.42	3.11	1.27	2.61	4.26	4.08	18 %

The variation in geraniol and citronellal contents among the six samples and their non-compliance with established standards may be attributed to several factors. Environmental conditions such as climate, soil characteristics, and light intensity significantly influence enzyme activity and plant metabolism (Salamon, 2007). In addition, extraction methods—including steam distillation, water distillation, and vacuum distillation—contribute to variations in yield and in the relative proportions of citronellal and geraniol in citronella oil. The temperature and pressure applied during distillation affect the stability of volatile compounds; geraniol is particularly susceptible to thermal degradation, whereas citronellal exhibits greater thermal stability. Furthermore, distillation duration and raw material conditions, such as moisture content and freshness, play crucial roles in determining extraction efficiency and the quality of the resulting essential oil (Park et al., 2023; Lemberkovics, 2004).

The consistently low concentrations of citronellal and geraniol compared with the Indonesian National Standard (SNI) can be explained by several factors occurring throughout the production chain, including cultivation practices, extraction methods, storage conditions, and possible adulteration. These variations directly reduce commercial value, impact therapeutic and fragrance efficacy, and can pose consumer safety risks (Sacchetti et.al., 2005).

Citronellal is classified as a monoterpenoid aldehyde with the molecular formula $C_{10}H_{18}O$ and is characterized by a strong lemon-like aroma. It is a major component of the essential oils of plants such as *Cymbopogon nardus* (citronella grass), *Eucalyptus citriodora* (lemon eucalyptus), and *Pelargonium graveolens* (geranium) (Handayani et al., 2018). Due to the presence of a reactive aldehyde functional group, citronellal can be converted into various derivatives, including citronellol. Citronellol is widely used in perfumes, soaps, and lotions because of its mild fragrance and antibacterial activity (Pereira et al., 2013). Esterification of citronellol with acetic acid produces citronellyl acetate, a compound valued as a fragrance ingredient with a fresh floral aroma (Burdock, 2010). Citronellal can also undergo cyclization to form isopulegol, which can subsequently be reduced to menthol—an important compound in the food industry and in topical cooling products (Jutta et al., 2014). Further oxidation of citronellal yields citronellic acid, a key intermediate in the synthesis of various chemical products (Rao et al., 2011).

Geraniol and geranial are monoterpenoid compounds that share a close structural and biosynthetic relationship. Geraniol is a monoterpene alcohol characterized by a terminal hydroxyl (–OH) group, whereas geranial is a monoterpene aldehyde formed through the oxidation of geraniol, in which the –OH group is converted into an aldehyde (–CHO) via enzymatic oxidation mediated by enzymes such as geraniol dehydrogenase (Giri et al., 2014). Geraniol is commonly found in the essential oils of aromatic plants such as *Cymbopogon nardus* (citronella grass) and is associated with a rose-like aroma, while geranial (also known as citral A) exhibits a strong lemon-like fragrance (Azizan et al., 2019). Both geraniol and geranial play important roles in the development of essential oil–based products, as they not only contribute desirable aromatic properties but also exhibit significant biological activities, including antimicrobial, anti-inflammatory, and antioxidant effects (Bakkali et al., 2008).

Overall data show that citronella oil complies with physical quality standards (e.g., color, specific gravity, refractive index, solubility, and optical rotation) but fails to meet chemical composition requirements, the oil may still appear to be of acceptable quality while exhibiting reduced biological activity, inconsistent performance, and lower commercial value. Chemical composition is the primary determinant of citronella oil quality because the therapeutic and functional properties depend on the concentration of key bioactive constituents, particularly citronellal, geraniol, and citronellol. Consequently, failure to satisfy chemical specifications can significantly affect consumer safety, therapeutic efficacy, and industrial applications. Further in vitro and in vivo study should be conduct to evaluate the pharmacological properties of citronella commercial oil.

Fragmentation Pattern of Citronellal and Geraniol

The mass spectrum shown in Figure 5 exhibits characteristic peaks at *m/z* 154, 139, 121, 111, 95, 84, 69, 55, 41, 29, and 15. These peaks closely correspond to the fragmentation pattern of citronellal reported in the NIST23.L mass spectral library. The peak at *m/z* 154 represents the molecular ion of citronellal; however, this ion is often weak or undetectable due to the compound's tendency to undergo rapid initial fragmentation. One of the primary fragmentation pathways involves the loss of a methyl group ($–CH_3$), resulting in a relatively stable ion at *m/z* 139 (Silverstein et al., 2005). Subsequent fragmentation may include the loss of a water

molecule (H_2O) and methane (CH_4), leading to the formation of an ion at *m/z* 121 (NIST, 2024).

Other commonly observed fragments include ions at *m/z* 95 and *m/z* 84, which indicate stabilization through the formation of conjugated systems within the hydrocarbon chain (Silverstein et al., 2005). The proposed fragmentation pathway of citronellal is illustrated in **Figure 6**.

The mass spectrum shown in Figure 7 exhibits prominent peaks at *m/z* 154, 139, 123, 111, 96, 93, 84, 69, 53, and 41. These peaks closely resemble the characteristic fragmentation pattern of geraniol reported in the NIST23.L mass spectral library. The molecular ion peak at *m/z* 154 corresponds to a monoterpenoid compound with the molecular formula $C_{10}H_{18}O$, identified as geraniol.

Upon electron impact ionization, the geraniol molecule undergoes the loss of a hydrogen radical (H•), leading to fragmentation via a McLafferty rearrangement pathway. This process is followed by the appearance of a fragment ion at *m/z* 136, corresponding to the loss of a water molecule (H_2O). Subsequent fragmentation yields an ion at *m/z* 121 due to the loss of a methyl group ($–CH_3$). Further cleavage results in a fragment at *m/z* 95 arising from the loss of a C_2H_2 unit, followed by the formation of an ion at *m/z* 69 through the elimination of a butyl fragment ($–CH_2CH_2CH_2CH_2$). This ion represents the characteristic base peak of geraniol. At this stage, molecular rearrangement may occur, followed by cleavage to produce an ion at *m/z* 41 via the loss of an ethylene unit ($–C_2H_4$).

In addition, fragmentation of the ion at *m/z* 136 can produce an ion at *m/z* 93 through the loss of a propyl group ($–C_3H_7$). Rearrangement may also occur at this stage, followed by further cleavage to generate an ion at *m/z* 79 via the loss of a methylene group ($–CH_2$). Overall, the mass spectrum shows the most intense (base) peak at *m/z* 41, consistent with previously reported data (Abd El-Kareem et al., 2020). The fragmentation pattern of the geraniol compound can be seen in **Figure 8**.

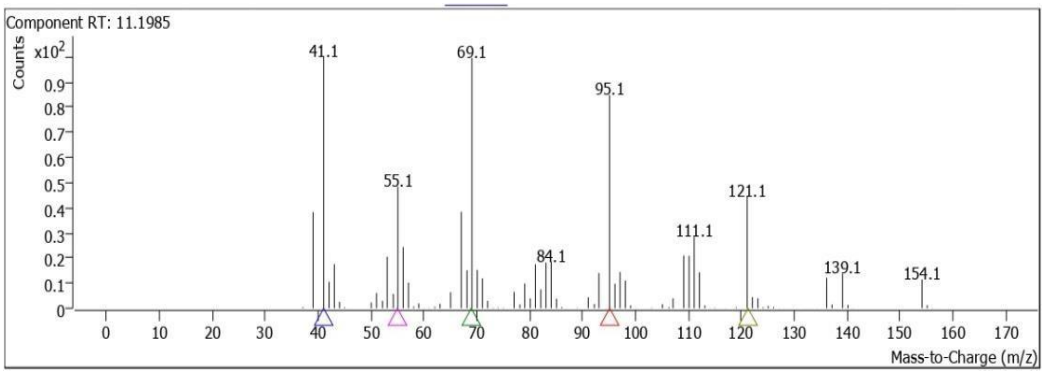

Figure 5. Mass Spectrum of Citronellal in Citronella Oil

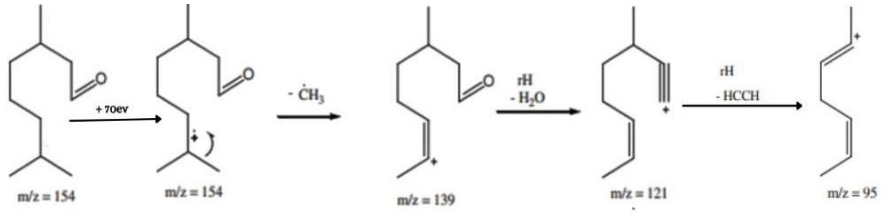

Figure 6. Fragmentation pattern of Citronellal compound (Wijayanti L.W., 2015)

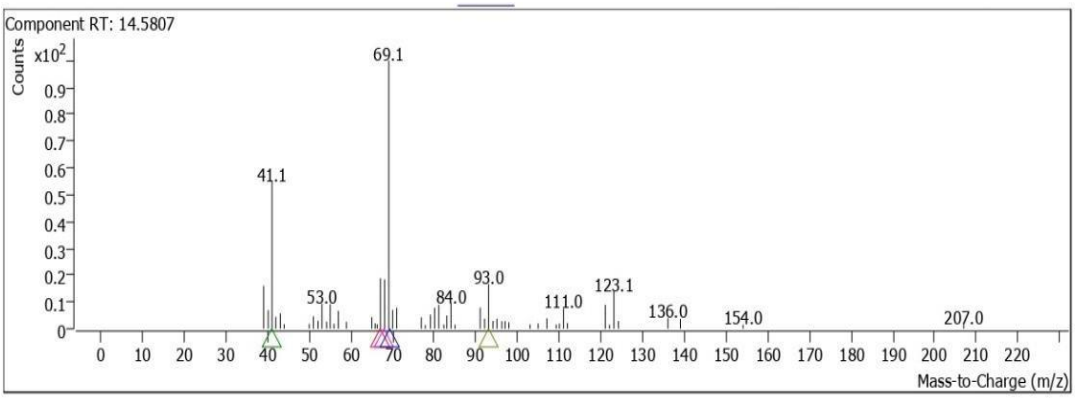

Figure 7. Mass spectrum of geraniol in citronella oil

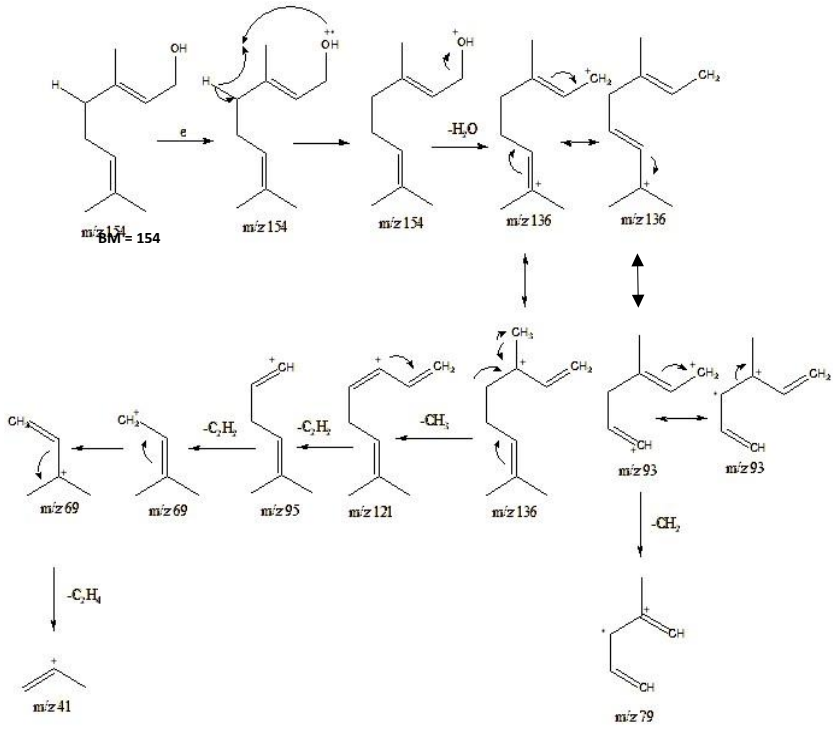

Figure 8. The fragmentation pattern of the geraniol compound

CONCLUSIONS

The results of this study indicate that the quality profile of commercially available citronella essential oil—both unregistered and registered products—complies with the requirements of SNI 06-2953-1995 for the parameters of specific gravity, refractive index, solubility in ethanol, and foreign matter contamination. Regarding the citronellal and geraniol content, all samples were within the maximum limits established by the SNI standard, thereby meeting the specified requirements in which BPOM-registered citronella essential oils exhibited higher levels of citronellal and geraniol compared to unregistered products. These findings highlight the need to improve the consistency of the quality of essential oils marketed commercially, as inconsistent quality may reduce their therapeutic effectiveness.

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