ISSN: 2621-4709 E-ISSN: 2621-2528
Journal of Applied Agricultural Science and Technology
Vol. 10 No. 4 (2026): 754-771

Performance Characteristics of a Small-Scale Citronella Oil Distillation Unit in Padang City, West Sumatra, Indonesia and GC-MS Analysis of Distillate Fractions

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Abstract. *Citronella oil production in Indonesia is commonly conducted on a small scale by farmers who also act as processors. This study examined a representative small-scale citronella oil industry in West Sumatra, Indonesia, to evaluate the characteristics and efficiency of its distillation equipment, determine the chemical composition of the essential oil, and observe changes in oil components during distillation. Distillation was performed for 1–4 hours using a steam-and-water system capable of processing 80 kg of wilted citronella leaves per batch. The unit used a 665.58 L material kettle with an actual material volume of 601.27 L. Distillation performance was assessed in three production repetitions (n = 3), while GC-MS analysis was conducted descriptively on one oil fraction collected from each distillation hour using a Shimadzu QP 2010 instrument. The highest oil yield was 1.10%. The average oil content, yield, and equipment effectiveness were 2.07 ± 0.06%, 0.97 ± 0.12%, and 46.67 ± 4.73%, respectively. Oil recovery was concentrated in the first two hours after distillate release, accounting for 85.72% of the total collected oil. GC-MS analysis identified five quality-relevant compounds across the fractions: citronellal, geraniol, citronellol, citronellol acetate, and geranyl acetate. Their average area percentages were 4.11%, 20.85%, 3.62%, 2.59%, and 21.66%, respectively. The low citronellal content and the geraniol-related profile indicated that the oil did not meet the expected quality requirements for Java-type citronella oil under SNI 3953:2019. The relatively low equipment effectiveness also indicated that the distillation process requires improvement. Recommended measures include optimizing kettle loading, steam distribution, temperature and pressure control, condensation efficiency, and raw material handling. These improvements are necessary to increase oil recovery, improve product quality, and support broader industrial application of small-scale citronella oil processing.*

Keywords: *citronella; distillation; geraniol; compounds; GC-MS.*

Type of the Paper: Regular Article.

1. Introduction

Indonesia is recognized as a country heavily reliant on the agricultural sector, including a which encompasses a diverse range of plant species. In this context, the significant progress in the agricultural sector has a positive impact on farmers' well-being and contributes to the national economy through the export of key commodities, such as essential oils and vegetable oils [1]. Citronella is one essential plant with high development potential, and its oil ranks among the 12 essential oils exported by Indonesia [2]. Citronella oil is used as a raw material in cosmetics, food,

https://doi.org/10.55043/jaast.v10i4.522
Received November 12, 2025; Received in revised form May 30, 2026; Accepted July 11, 2026; Published November 23, 2026
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pharmaceuticals, and various other industries. In the cosmetic field, it serves as a fragrance in soaps, sprays, perfume fillers [3] as well as an agent in deodorants, astringents, antibacterials, skin tonics, warmers, analgesics, and insect repellents [4]. In the food industry, citronella is used as a flavor enhancer [5] and is often incorporated into food blends [6]. In the pharmaceutical field, it is commonly used as aromatherapy agent [7], antibacterial agent [8], mosquito repellent [9], traditional medicine [10], and it is also utilized for postpartum care, massage oil for numbness, and relief for bloated stomachs [11]. In the energy sector, citronella oil is adopted as a bio-additive for gasoline [12] and fuel oil [13].

Citronella is a native plant extensively cultivated in India and Sri Lanka [14], as well as in tropical and subtropical regions such as America, Africa, and Asia, including Brazil [15]. Currently, the global production amounts to approximately 5,000 tons, with the majority produced in Taiwan, Guatemala, Malaysia, Brazil, Ceylon, India, Argentina, Ecuador, Madagascar, Mexico, and the West Indies [16]. The distribution of citronella plants and production of its oil are concentrated in Sumatra and Java, particularly in West Java and Central Java [17]. Active buyers include Singapore, Japan, the United States, Australia, the Netherlands, the United Kingdom, France, Germany, Italy, India, and Taiwan [18].

In 2020, the regions that cultivating citronella in Indonesia, along with their planting area and production, were Aceh (20,625 ha; 314 tons), North Sumatra (50 ha; 231 tons), West Sumatra (1,318 ha; 492 tons), South Sumatra (66 ha; 2 tons), Riau (10 ha), West Java (2,851 ha; 715 tons), Central Java (282 ha; 40 tons), East Java (90 ha; 28 tons), and Bangka Belitung (4 ha) [19]. In the same year, the total cultivation area and production were 25,788 ha and 4,922 tons, comprising smallholder (25,413 ha; 4,921 tons) and private (373 ha; 1 ton) plantations. Preliminary data for 2021 and estimates for 2022 show continued expansion of both cultivation area and production [19]. These data indicate that West Sumatra is one of the relevant provinces for studying smallholder-based citronella oil production, although production units differ in scale, equipment design, raw material handling, and operating control.

Preliminary mapping and literature-based observations indicate that small-scale citronella oil distillation activities in West Sumatra are found in several areas, including Padang, Solok, Sawahlunto, and surrounding districts. This study focused on one active distillation unit in Padang City because it met the following purposive criteria: it operated regularly, processed citronella leaves using a steam-and-water distillation system, used stainless-steel drum-type equipment; had a complete set of material kettle, boiler, condenser, and oil separator; allowed direct observation and repeated measurements; and represented a practical small-scale unit that still requires technical improvement. Therefore, this study should be interpreted as a case study of a Padang City small-

scale industry, not as a statistical representation of all citronella oil industries in West Sumatra or Indonesia [20].

The main components of citronella oil consist of citronellal, citronellol, and geraniol [17]. Distilled citronella oil contains citronellal, citronellol, citronellol, geranyl acetate, and citronellal acetate at 32-42%, 11-15%, 10-12%, 3-8%, and 2-4%, respectively as well as trace amounts of other compounds [21]. The content of citronella oil from leaves aged 1-5 months includes citronellal, citronellol, and geraniol at 39%, 13%, and 18.8% [22]. Meanwhile, leaves aged 6-10 months yield citronellal, citronellol, geraniol, citral (cis, trans), and nerol at 4.8%, 6.9%, 46%, 26.6%, and 4.2%, respectively [17]. The main content is also influenced by the geographical conditions of the growing regions [22]. Citronellal content varies by region with reported values of 22.1% in Malaysia. 29.7% [14], 26.2%, in China [23], 19.9%, in India, 19.9 % in Morocco [24], 47.2 in Brazil, and 29.2% in Africa respectively [25].

The average yield of citronella oil ranges from 0.6 to 1.2%, depending on the type, handling, and effectiveness of distillation technology. It is recommended to dry the leaves for approximately 3-4 hours in good weather conditions, flipping them periodically before distillation. After drying, the leaves should be distilled promptly as prolonged storage decreases the quality of resulting citronella oil. Oil yield depends on climate, soil fertility, plant age, and distillation method [22,26]. Furthermore, it is influenced by the harvesting season and when harvested during the dry and rainy seasons, the average yields are 0.7% and 0.5%, respectively. The oil yield from fresh leaves is approximately 0.5-1.2% and is higher during the dry season [14].

Extraction of citronella leaves with various solvents such as methanol, hexane, and petroleum ether, has been conducted [27]. The highest of 0.8% is obtained with methanol as the solvent, while hexane extraction produces better results compared to other solvents [28]. Hexane is the best solvent for obtaining high levels of citronellal [29], and maceration extraction with distilled water as the solvent results in an essential oil yield of 0.72% [30]. Extraction using steam-and-water distillation produces 0.65% [31].

The essential oil distillation process is carried out with various time variations. Distillation is performed at a temperature of 120°C with times ranging from 3, 3.5, 4, 4.5 to 5 hours. The main problem in citronella oil distillation industry is the inability of practitioners to meet market demand. The most important aspect is enhancing competitiveness through improved quality, pricing, continuous supply, integrated mentoring, and appropriate technology [32].

The characteristics of equipment and operating conditions for citronella oil distillation vary widely. The process is often ineffective and inefficient, resulting in relatively long and poorly controlled distillation times to increase fuel consumption [33]. Equipment effectiveness can be measured by comparing the oil actually recovered by the production-scale distillation unit with the

potential oil content determined by a laboratory reference distillation method. This comparison provides a practical estimate of how much recoverable oil is captured by the field equipment. Accordingly, this study aimed to: (1) describe the characteristics and operating conditions of one small-scale citronella oil distillation unit; (2) calculate oil content, yield, and equipment effectiveness; (3) analyze the chemical composition of hourly distillate fractions by GC-MS; and (4) identify practical improvements needed for small-scale production.

Information on characteristics of distillation equipment and operating conditions is important in the effort to develop citronella oil industry. Similarly, information on the effectiveness of distillation equipment is minimally published. This research was conducted to provide information on the characteristics of distillation equipment, operating conditions, equipment effectiveness, and the main compound in the essential oil. This study aims to convey the reality of the small-scale citronella industry in terms of equipment and chemical composition and to serve as a guideline for improvement on its shortcomings.

2. Materials and Methods

The materials used in this study were wilted citronella leaves (*Cymbopogon nardus*) obtained directly from one active small-scale citronella oil distillation unit in Padang City, West Sumatra, Indonesia, and water used for the distillation process. The equipment observed at the production site consisted of a material kettle, steam boiler, condenser, and oil-water separator. The material kettle had a volume of 665,579.52 cm^3, while the boiler and condenser each had a volume of 262,697.895 cm^3.

A purposive case-study approach was used. The research site was selected after preliminary mapping of small-scale citronella oil industries in West Sumatra, which indicated the presence of approximately eight small-scale units distributed across Padang, Solok, Sawahlunto, and surrounding areas. Only one unit in Padang City was sampled because it fulfilled the study criteria: active operation during the research period, use of a steam-and-water distillation system; stainless-steel drum-type construction; availability of complete equipment components; willingness of the processor to allow repeated observation; and feasibility of collecting hourly distillate fractions for GC-MS analysis. No industrial samples were taken from Solok, Sawahlunto, or other regions; therefore, the results describe the selected Padang City unit and should not be generalized statistically to all small-scale citronella oil industries in West Sumatra or Indonesia.

Citronella oil small-scale industries in West Sumatra are scattered in areas such as Padang, Solok, Sawahlunto, and other regions. Approximately eight small-scale industries were identified based on the literature review. In this research, a sampling of citronella oil distillation was conducted in one of the small-scale industries located in Padang City, West Sumatra Province. The

processing steps included: (1) harvesting, performed by cutting citronella 10-15 cm from the base; (2) weighing, followed by wilting for 24 hours after harvesting; (3) distillation, conducted using steam-and-water distillation for 4 hours after the first distillate appears; (4) separation of essential oil and hydrosol after which the essential oil was drained and collected in a separate container, followed by weighing to determine the volume and weight; and (5) calculation of yield and oil content.

Oil content was determined using a Stahl-type distillation apparatus, which operates on a hydrodistillation principle. A weighed portion of homogenized wilted citronella leaves was placed in a distillation flask with sufficient distilled water to submerge the material. The flask was connected to the Stahl apparatus and heated until boiling. Distillation was continued until the oil volume in the calibrated receiver no longer increased. After cooling, the essential oil layer was read directly from the calibrated arm of the apparatus. Oil content was calculated according to the following Eq. (1)–(3).

$$\text{Oil Content } (\%) = \frac{weight\ of\ oil\ obtained\ by\ Stahl\ distillation}{weight\ of\ leaf\ sample}\ x\ 100 \quad (1)$$

Yield was calculated according to the following Eq. (2).

$$\text{Yield } (\%) = \frac{weight\ of\ citronella\ oil\ obtained\ from\ the\ production}{weight\ of\ wilted\ citronella\ leaves\ loaded\ into\ the\ kettle}\ x\ 100 \quad (2)$$

Equipment effectiveness was calculated according to the following Eq. (3).

$$\text{Equipment effectiveness } (\%) = \frac{\text{production} - \text{scale yield}}{\text{oil content determined by Stahl distillation}}\ x\ 100 \quad (3)$$

GC-MS analysis was conducted to determine the compounds contained in citronella. Chemical compound analysis was performed using a Shimadzu QP 2010 plus GC-MS with the following operational conditions; injection temperature of 210°C; column temperature at 100°C; temperature increase of 10°C/min; helium carrier gas; pressure at 111 kPa; and an Rtx-5MS column (30 m × 0.25 mm).

3. Results and Discussion

3.1 Distillation equipment specifications

Technology is a crucial factor in production success, yet its use in citronella oil distillation remains relatively simple. Generally, distillation can be performed using water distillation, water-and-steam distillation, or direct steam distillation. The selection of distillation method is based on considerations such as raw material type, oil characteristics, oil diffusion with hot water, oil

decomposition due to heat effects, production efficiency, economic factors, and production effectiveness [34]. Some citronella oil distillation methods include hydrodistillation [35], which yields 0.8% and 0.9% based on dry and wet weight over 4 and 2 hours, respectively [36]. In practice, the water-and-steam distillation system is more efficient than the water method because it requires less fuel and time while increasing oil production yields [37]. The main components of citronella oil distillation units include a steam boiler, heating furnace, distillation boiler, cooler, collector, and oil separator (decanter). The general construction consists of a boiler, condenser, and oil separator tank with water [38]. Therefore, distillation equipment in the research object complies with the standard. The main components in one of the small-scale industries in West Sumatra and their specifications can be observed in Fig. 1 and Table 1, respectively.



Equipment Description:

a. Boiler is a closed vessel capable of generating steam with a pressure of more than 1 atmosphere.
b. Material kettle is a container designed to hold essential oil materials.
c. Condenser is responsible for converting all steam into a liquid phase. Water is circulated through the condenser tube as a cooling medium.
d. Oil separator is a device for collecting distillate and separating distillation fluid (hydrosol) from citronella oil.

Fig.1. Steam-and-water distillation equipment at a small-scale industry in Padang City.

According to SNI 8028-1:2014, distillation equipment falls under the medium-class specifications, with a kettle volume of 665 liters, which falls within the 501–1000 L range [38]. The drum construction in this distillation equipment already uses stainless steel. In industrial settings, stainless steel is used for containers in hot and cold processes due to corrosion resistance. This resistance is attributed to the presence of iron compounds and at least 12% chromium, which prevents the corrosion process. The corrosion resistance is achieved through the formation of a chromium oxide film that hinders the oxidation of iron [39]. Stainless steel has applications in various industries, including cleaning and washing machines, construction, transportation, food, energy production, chemicals, oil and gas, as well as paper [39]. In some places, the use of technology in citronella oil distillation processes remains low, drums made of easily corroding iron, resulting in dirty and dark-colored products [40]. This dark color leads to low oil clarity, caused by metal content introduced during distillation processes [41].

Table.1. Distillation equipment specifications in small-scale industry.

Equipment Components	Description	Specification
Material Kettle	Type	Drum
	Material	Mild Stainless Steel
	Dimension	Diameter 64 cm, height 207 cm
	Volume	665,579.52 cm^3
	Function	A place to steam materials
Boiler	Type	Drum
	Material	Mild Stainless Steel
	Dimension	Diameter 57 cm, height 103 cm
	Volume	262,697.895 cm^3
	Function	Closed vessel to form steam with a pressure of more than 1 atmosphere
Condenser	Type	Drum
	Material	Mild Stainless Steel
	Cooling fluid	Water
	Dimension	Diameter 57 cm, height 103 cm
	Volume	262,697.895 cm^3
	Function	Coolant to aid in the condensation of steam into liquid
Oil Water Separator	Function	Used to separate oil and water (hydrosol)

Various distillation equipment is used in industries, such as PT Mesin Jatim, which provides equipment with a capacity of 10 kg of raw material [42]. In certain regions, citronella oil distillation still employs simple equipment, such as in Nagari Gurun, Harau Subdistrict, where farmers use makeshift distillation equipment made from used drums with a limited capacity of 125 kg. Essential oil distillation is also carried out in Siabu Village, Salo Subdistrict, using equipment with a 130 kg capacity and a distillation duration of 6 to 7 hours [43]. In Nepal, there is a small-scale unit capable of processing 200 to 500 kg of raw materials during a 4 to 8-hour distillation process. The essential oil produced can penetrate European and American markets [44]. The design of a steam boiler with a 100 kg capacity has also been accomplished, with an average effective capacity of 0.0205 mL/s [45].

Table 2. Distillation process conditions in the small-scale industry.

Processing Conditions	Description
Material volume in kettle	601,272.32 cm^3
Material weight	80 kg (citronella leaves)
Water volume in the boiler	40 L
Material density in the kettle	0.13 gr/mL
Distillation method	steam-and-water distillation
Fuel weight used	0.5 m^3 (500 kg)
Kettle and boiler connection	Connected via pipe
Steam pressure	>1 atm
Time to first distillate	2 hours
Total distillation duration	4 hours after first distillate appears

3.2 Distillation process conditions

The duration of distillation for raw materials depends on the selected method, kettle capacity, and distillation speed. Steam-and-water distillation typically takes 5–10 hours, while direct steam lasts around 4–6 hours [46]. According to SNI 8028-1:2014, the essential oil distillation process occurs over 3–5 hours at 100°C. In this research, the average total process time was 6 hours, with the first distillate appearing after 2 hours of kettle heating, followed by an additional 4 hours of distillation. Subsequently, citronella oil content was tested from the 1st to the 4th hour using GC-MS, as presented in Table 2. Based on other research, distillation was carried out at 120°C with varied times of 3, 3.5, 4, 4.5, and 5 hours. The lowest and highest density values were obtained at 5 and 3 hours, with values of 0.882 g/mL and 0.886 g/mL, respectively [47].

3.3 Oil content, yield, and equipment effectiveness

This research analyzed the essential oil content and distillation yield from citronella leaves. Distillation was performed using the available equipment in the small-scale industry. To assess equipment effectiveness, the yield obtained was compared with the essential oil content, expressed as a percentage. The relationship between essential oil content, yield, and equipment effectiveness at the 4th hour of distillation is presented in Table 3.

Table 3. Effectiveness of Essential Oil Distillation Equipment in Small-Scale Industry.

Repetition	Oil Content (%)	Yield (%)	Equipment Effectiveness (%)
1	2.1	1.1	52
2	2.1	0.9	43
3	2.0	0.9	45
Mean ± SD	2.07 ± 0.06	0.97 ± 0.12	46.67 ± 4.73

The effectiveness of distillation equipment is influenced by oil content and yield. Meanwhile, distillation yield is influenced by several factors, including the accuracy of harvesting time, citronella variety, initial material handling, and the effectiveness of the technology used.

The results will not always match the essential oil content, and equipment effectiveness may vary between repetitions [34]. The lowest and highest yields were obtained with distillation times of 3 and 5 hours, with values of 0.998% and 1.228% at 120°C, respectively [47]. According to SNI 8028-1:2014, citronella oil yield falls in the range of 0.7–1.02%, while SNI 3953:2019, specifies a range of 0.9 to 1.1%.

3.4 Relationship between distillation time and yield

In the small-scale essential oil industry, distillation processes often take 6 hours, with a minimum and maximum of 4 and 7 hours, respectively. Some research has conducted distillation processes for 3 to 7 hours, with a yield of 0.64% obtained at 3 hours of distillation [48]. This is influenced by many factors, such as the effectiveness of the equipment used [34]. Distillation of essential oil for 2.5, 3, 3.5, 4, 4.5, and 5 hours resulted in yields ranging from 0.97% to 1.2%, with the highest yield obtained at the 4th hour [49].

Table 4. Yield distribution data for each hour of distillation in the small-scale industry.

Hour	Oil Volume (ml)	Yield (%)	Percentage (%)
1st	14	1.4	66.67
2nd	4.6	0.4	19.05
3rd	2	0.2	9.52
4th	1	0.1	4.76
Total	21.6	2.1	100
Average	5.4	0.5	-

* The percentage distribution of the yield produced each hour in 1 distillation process is determined by a formula: $\frac{Yield\ at\ the\ nth\ hour}{Total\ yield} x100\%$

Based on Table 4, the relationship between yield and distillation time yielded the formula y = -0.953ln(x) + 1.2819, with an R^2 value of 0.9217, as shown in Fig. 2.

The yield distribution of citronella oil for each hour was determined based on observation. Based on the percentages, the yield distribution is inversely related to the distillation time. This finding is consistent with previous research that calculated the yield for each fraction from 1 to 4 hours, resulting in yields of 0.24%, 0.15%, 0.06%, and 0.02%, respectively [45]. The faster the steam flows through the distillation kettle, the lower the oil produced per kilogram of steam condensate. Conversely, the slower the steam movement, the longer the distillation time and the lower the oil yield per hour. A yield of 85.72% of the total oil was achieved when the distillation process was carried out for 2 hours after the first distillate was collected.

Table 5. Main Compounds in Citronella Oil Based on GC-MS Results.

No	Compound Name	Area (%) 1st Hour	Area (%) 2nd Hour	Area (%) 3rd Hour	Area (%) 4th Hour	Chemical Formula	IUPAC Name
1	Citronellal	7.12	3.40	2.74	3.17	$C_{10}H_{18}O$	6-Octenal, 3,7-dimethyl-
2	Geraniol	19.71	22.14	20.89	20.66	$C_{10}H_{18}O$	(2E)-3,7-Dimethyl-2,6-Octadien-1-Ol
3	Citronellol	4.27	3.03	*nf	3.57	$C_{10}H_{20}O$	6-Octen-1-ol, 3,7-dimethyl-
4	Citronellol acetate	2.44	2.83	2.55	2.52	$C_{12}H_{22}O_2$	6-Octen-1-ol, 3,7-dimethyl-, acetate
5	Geranyl acetate	17.09	23.75	23.19	22.59	$C_{12}H_{20}O_2$	(2E)-3,7-Dimethyl-2,6-Octadienyl Acetate
6	Neral	5.76	4.10	2.90	3.01	$C_{10}H_{16}O$	2,6-Octadienal, 3,7-dimethyl-, (Z)
7	Geranial	5.12	4.55	3.65	3.79	$C_{10}H_{16}O$	2,6-Octadienal, 3,7-dimethyl-, (E)-
8	Naphthalene	2.73	7.41	9.19	8.39	$C_{15}H_{24}$	Naphthalene,1,2,3,4,4a,5,6,8a-octahydro-7-methyl-4-methylene-1-(1-methylethyl)-, (1.alpha.,4a.alpha.,8a.alpha.)-
9	Caryophyllene	2.47	4.15	4.15	3.92	$C_{15}H_{24}$	Trans(.Beta.)-Caryophyllen
10	Germacrene	1.58	3.20	3.34	3.22	$C_{15}H_{24}$	8-Isopropyl-1-Methyl-5-Methylene-1,6-Cyclodecadiene

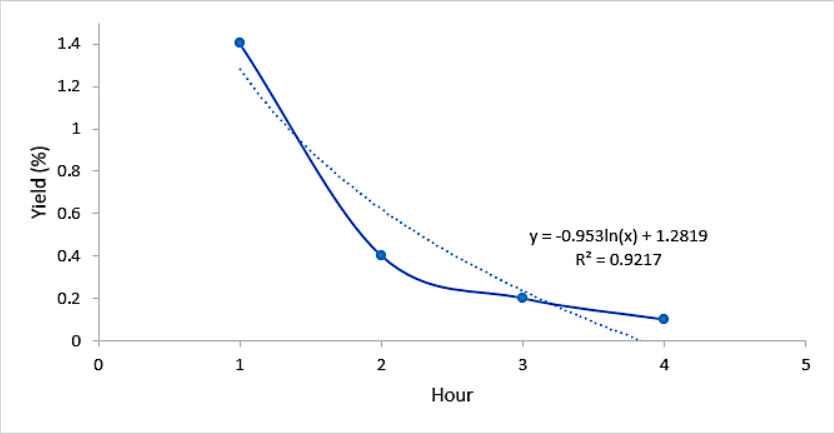
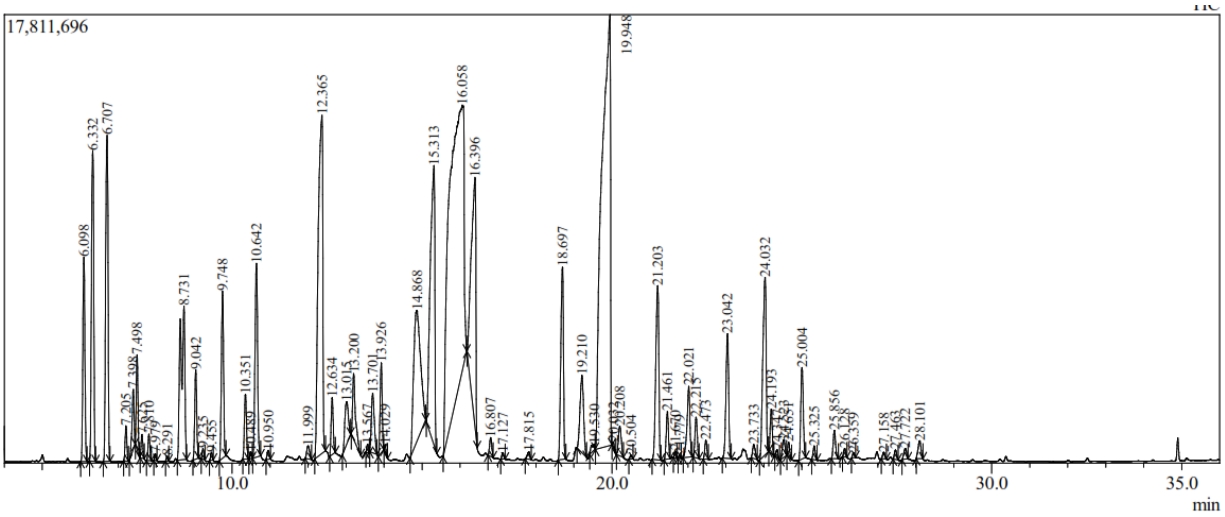


Fig.2. Regression curve of yield and distillation time.

3.5 Analysis of citronella oil with gc-ms

The results of the GC-MS analysis of citronella oil distilled for 1 hour to 4 hours are presented sequentially in Fig. 3, Fig. 4, Fig. 5 and Fig. 6, while the chromatogram for the 4-hour distillation is presented in Table 5.



*nf: not found

Fig. 3. Chromatogram for the analysis results of citronella oil at the 1st hour using GC-MS.

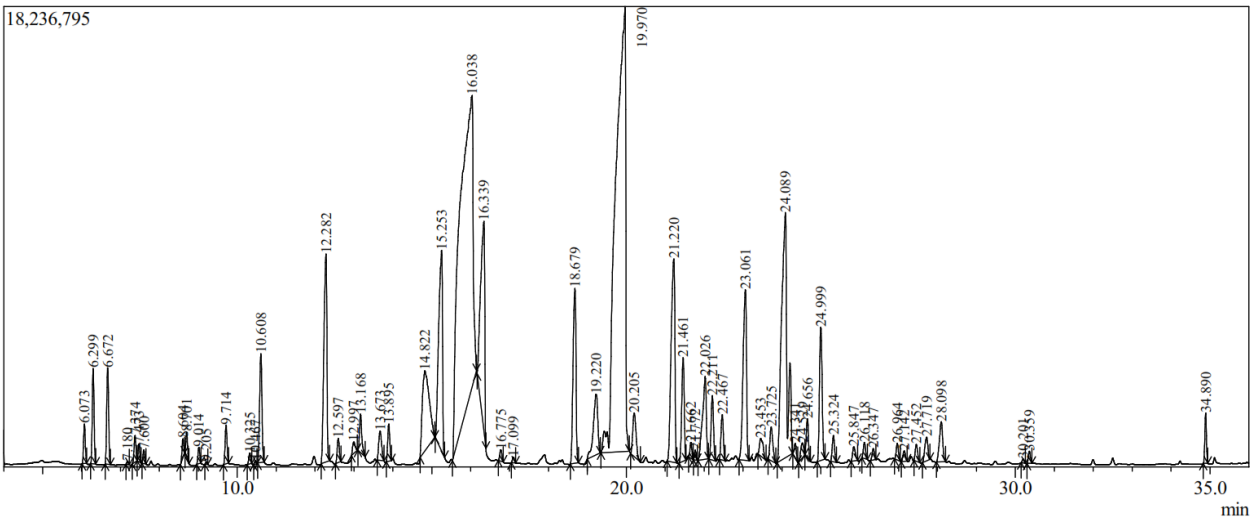


Fig. 4. Chromatogram for the analysis results of citronella oil at the 2nd hour using GC-MS.

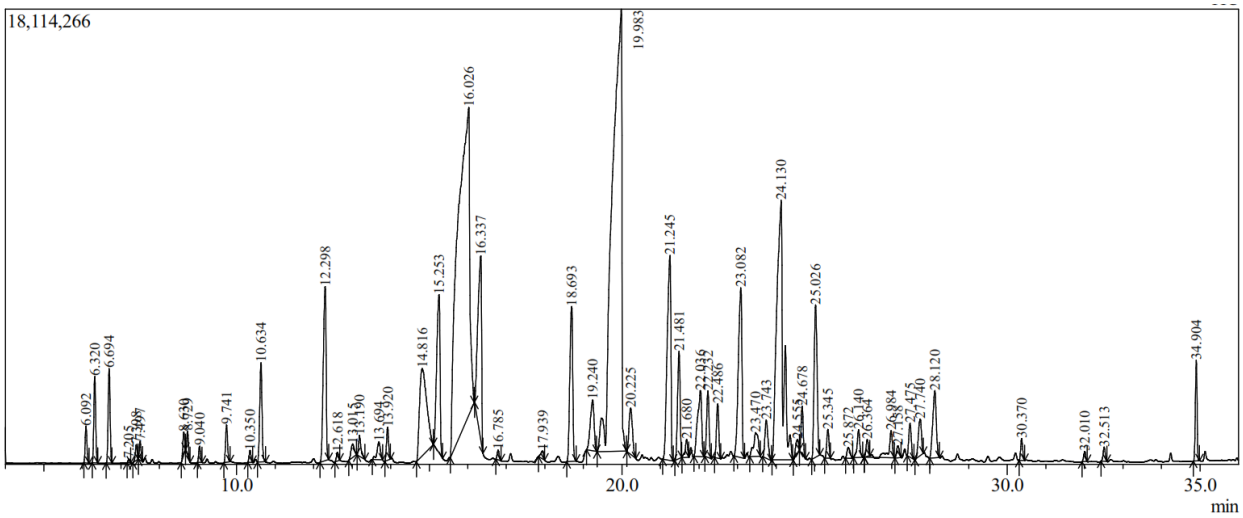


Fig. 5. Chromatogram for the analysis results of citronella oil at the 3rd hour using GC-MS.

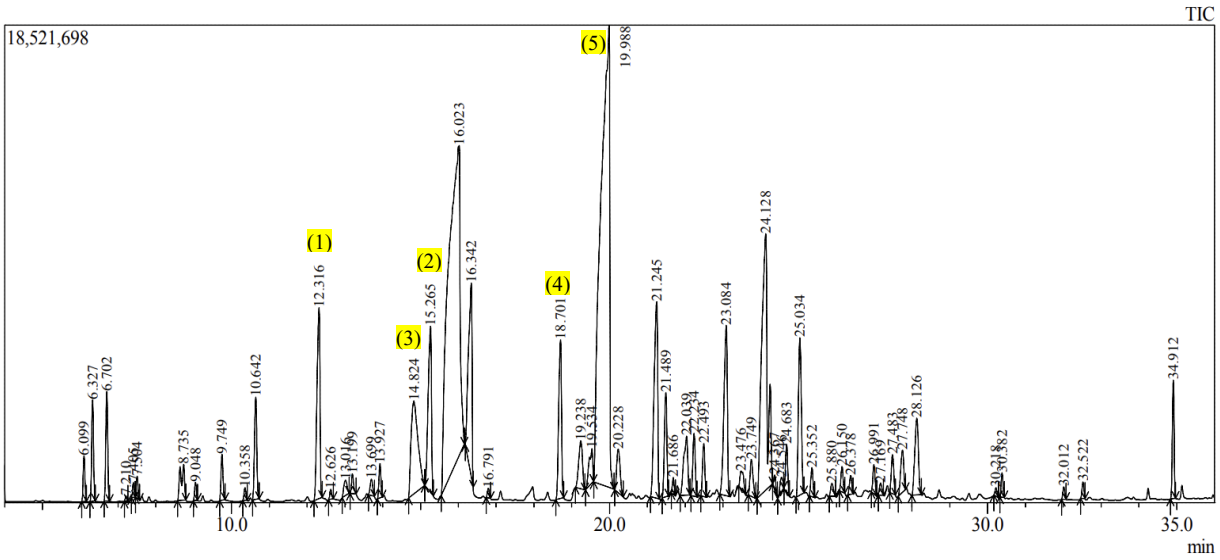


Fig.6. Chromatogram for the analysis results of citronella oil at the 4th hour using GC-MS. (1)Citronellal,(2)Geraniol, (3)Citronellol, (4) Citronellol acetate, (5) Geranyl acetate.

The determination of the main compounds in citronella oil has also been conducted in previous studies. The identified compounds include citronellal (39.7%), citronellol (13%), and geraniol (18.8%) [48]. Other studies have reported varying compositions: isopulegol (47.43%), citronellol (2.31%), and geranyl (3.46%) [50]; citronellal (21.59%), citronellol (7.43%), and geraniol (34.27%) [51]; and citronellal (27%), trans-geraniol (22.78%), and citronellol (10.09%) as the main components. Essential oil from India contained geraniol, citronellal, and citronellol [52]. Different results were also reported by Doumbia et al. [25], namely citronellal (29.2%), citronellol (12.7%), geraniol (29.3%), elemol (5.0%), and limonene (4.1%). An additional study revealed varying levels of essential compounds: citronellal (32–45%), geraniol (12–18%), citronellol (12–15%), geranyl acetate (3–8%), and citronellyl acetate (2–4%) [50]. Based on these findings, the dominant compounds in citronellaloil from each producing region include citronellal, geraniol, and citronellol, with varying percentages.The naphthalene-type compound,

caryophyllene, and germacrene may originate from the sesquiterpene/hydrocarbon fraction of the oil or from library-based identification of structurally related compounds. Their presence at 3–9% area indicates that the oil profile cannot be assessed solely based on the five quality-relevant oxygenated compounds, although those five compounds remain the most relevant for citronella oil quality evaluation.

3.6 Changes in major chemical components during distillation

There are 16 compound components in citronella, and the main 5 are citronellal, citronellol, geraniol, citral, and eugenol, as presented in Table 6 [50]. The compounds present in essential oils vary depending on genetic differences, geographical location, environmental cultivation conditions, plant age, planting period, farming methods, harvesting time, and extraction methods [50,51]. In this study, the concentration of major compounds fluctuated from the 1st to the 4th hour of distillation. Citronellal decreased from the 1st to the 3rd hour and increased at the 4th hour.

Geraniol also exhibited insignificant fluctuations, and its content has not met export quality standards, which require a minimum of 85% [38,49]. In the 4th hour of distillation, geraniol decreased with increased distillation time. This is attributed to prolonged heating, which leads to the decomposition of geraniol into isoprene compounds. Since geraniol is a volatile oil component, prolonged heating causes the loss of the compound. Furthermore, prolonged heating may lead to the polymerization of geraniol, producing polymers with higher molecular weights [49].

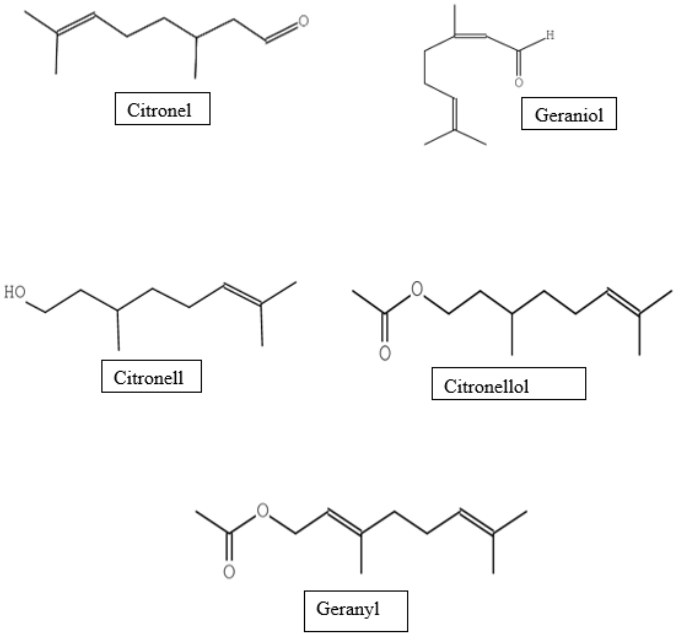


Fig.7. Chemical structure.

Citronellal was not detected in the chromatogram during the 3rd hour but returned as a main component at the 4th hour. The highest and lowest levels of citronellol and geranyl acetate were found in the 2nd and 1st hours, respectively. From Table 6, the highest and lowest contents of citronellal, geraniol, citronellol acetate, and geranyl acetate were found during the 1st and 3rd

hours at 7.12% and 2.74%, the 2nd and 1st hours at 22.14% and 19.71%, the 2nd and 1st hours at 2.83% and 2.44%, and the 2nd and 1st hours at 23.75% and 17.09%, respectively. Therefore, the highest content of the main compounds was produced at the 2nd hour of distillation. The citronellal content obtained in this research was lower than in other studies [25,29,52,53]. while the geraniol content was higher than in some reports [48,50] but lower than others [25,53]. The chemical structures of the five main compounds identified by GC-MS analysis are presented in Fig. 7.

Table 6. Content of 5 Main Compounds in Essential Oil *(%)*.

Hour	Citronellal	Geraniol	Citronellol	Citronellol Acetate	Geranyl Acetate
1st	7.12	19.71	4.27	2.44	17.09
2nd	3.40	22.14	3.03	2.83	23.75
3rd	2.74	20.89	*nf	2.55	23.19
4th	3.17	20.66	3.57	2.52	22.59

* Citronellol is not found in GC-MS results.

Based on the data on the compound content of citronella oil, formulations can be found on the main compound content of citronella such as Table 7 and the distribution graph of regression values are presented in Fig. 8.

Table 7. Quantification of five volatile aromatic compounds from 1st to 4th hour by GC-MS.

NO	COMPOUND	Regression equation	R^2
1	Citronellal	$y = 1.0375x^2 – 6.4385x + 12.423$	0.9843
2	Geraniol	$y = -0.665x^2 + 3.485x + 17.125$	0.632
3	Citronellol	$y = 1.2025x^2 – 6.5255x + 10.013$	0.6686
4	Citronellol Acetate	$y = -0.105x^2 + 0.521x + 2.07$	0.5108
5	Geranyl Acetate	$y = -1.815x^2 + 10.669x + 8.595$	0.9094

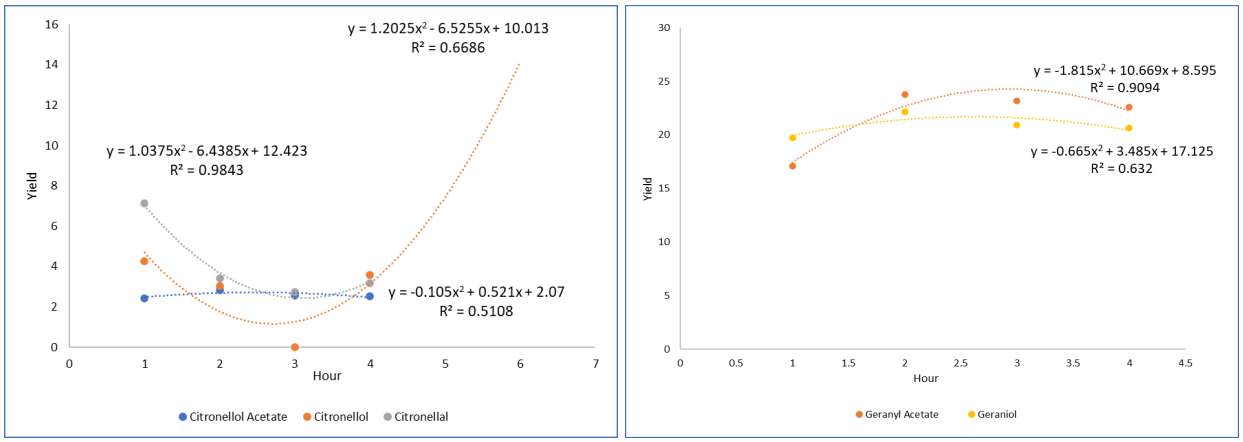


Fig.8. Regression curve of selected quality-relevant compounds in citronella oil fractions.

4. Conclusions

In conclusion, the small-scale citronella oil distillation industry in West Sumatra was designed using stainless steel material with the following characteristics, a capacity of 80 kg (leaves and stems), as well as a steam and water distillation system. Distillation was carried out for 4 hours after the first distillate drops, resulting in average yield and efficiency of 0.97% and 47%. Distillation for 2 hours after the first distillate achieved a yield of 85.72%. Meanwhile,

distillation process was directly proportional to the percentage of yield obtained. The 5 main compounds present in citronella oil were citronellal, geraniol, citronellol, citronellol acetate, and geranyl acetate. The obtained essential oil contained relatively low levels of citronellal and citronellol.

This case study described the characteristics, performance, and chemical profile of citronella oil produced by one small-scale steam-and-water distillation unit in Padang City, West Sumatra, Indonesia. The unit used stainless-steel drum-type equipment with an 80 kg batch capacity and a 665.58 L material kettle. The mean oil content, production-scale yield, and equipment effectiveness were 2.07 ± 0.06%, 0.97 ± 0.12%, and 46.67 ± 4.73%, respectively. Oil recovery was highest during the early distillation period; 85.72% of total oil was recovered within the first two hours after the first distillate appeared, and hourly recovery decreased as distillation time increased. GC-MS analysis showed that citronellal, geraniol, citronellol, citronellol acetate, and geranyl acetate were the main quality-relevant compounds, while sesquiterpene/hydrocarbon compounds such as a naphthalene-type compound, caryophyllene, and germacrene were also detected. The citronellal level and geraniol-related profile indicated that the oil did not yet reach the expected quality level for Java-type citronella oil under SNI 3953:2019. The low equipment effectiveness has practical implications for small-scale processors because it reduces oil recovery, increases fuel use per unit of oil, and may lower product competitiveness. Technical improvements should prioritize better raw material chopping and wilting control, reduced kettle overloading, improved steam distribution, insulation to reduce heat loss, tighter control of temperature and pressure, improved condenser cooling, and more efficient oil-water separation. The main limitation of this study is that only one production unit was observed and GC-MS analysis was conducted descriptively for hourly fractions; therefore, future research should compare multiple units across Padang, Solok, Sawahlunto, and other citronella-producing areas using replicated GC-MS analysis and complete SNI 3953:2019 quality testing.

Abbreviations

GC-MS	Gas Chromatography–Mass Spectrometry
SNI	Standar Nasional Indonesia (Indonesian National Standard

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Alfi Asben: Conceptual Idea, Methodology design,. **Anwar Kasim:** Conceptual Idea, Methodology design, Writing and editing. **Yefsi Malrianti:** Methodology design, Data analysis and interpretation, Writing and editing. **Nia Syahrani:** Methodology design, Data collection. **Nofita Chintya Sirait:** Methodology design, Data collection. **Angga Defrian:** Data analysis and interpretation, Writing and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Use of AI in the Writing Process

Nothing to disclose

Acknowledgement

This research has been successfully carried out with the support and collaboration of various parties. The authors are grateful to the Ministry of Research, Technology, and Higher Education for providing funding through the Matching Fund Kedai Reka program in the 2022 budget, Contract Number: 161/EI/KS.06.02/2022 and Directorate General of Research and Development of the Ministry of Higher Education, Science, and Technology with contract number No.097/PL25/AL.04/2025.

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