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Comparison Physicochemical Characterization of Essential Oils from Gajah and Emprit Ginger Varieties

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Abstract. Ginger (Zingiber officinale) is a high-economic-value essential oil commodity. This descriptive-exploratory study aimed to analyze and compare the physico-chemical profiles of essential oils from emprit ginger (Zingiber officinale var. Amarum) and giant ginger (Zingiber officinale var. Officinale) originating from Dadaprejo Village, Batu City. Essential oil extraction was performed using water distillation, while characterization employed organoleptic testing by 15 panelists, 96% alcohol solubility testing, yield calculation, and Gas Chromatography-Mass Spectrometry (GC-MS) analysis. Physical results showed emprit ginger oil was dominated by deep yellow color (41.7%) with a very strong aroma (41.7%), whereas giant ginger oil was light yellow (35.7%) with a moderate-strong aroma (35.7%). Emprit ginger yield (0.1067%) was higher than that of giant ginger (0.0800%). Both varieties dissolved completely in 96% alcohol at ratios of 1:3 for emprit ginger and 1:4 for giant ginger. Chemical characterization identified 119 volatile compounds in emprit ginger, dominated by cyclic ketone (Ketone, 1-cyclohexen-1-yl methyl, semicarbazone) at 16.15%, while giant ginger exhibited a simpler profile with 35 components, dominated by phenolic aldehyde (4-Hydroxy-2-nitro-m-anisaldehyde) at 7.67%. Thermal degradation during extraction converted sesquiterpene hydrocarbons such as zingiberene into more stable oxygenated groups. In conclusion, var. amarum holds high potential for the pharmaceutical industry due to its high ketone content, while var. officinale is ideal for the food and beverage industry.

Keywords: Elephant Ginger; Essential Oil; GC-MS; Organoleptic; Yield.

1. INTRODUCTION

Ginger (*Zingiber officinale*) is a high-value spice and medicinal crop in Indonesia, widely utilized across the pharmaceutical, cosmetic, and food and beverage industries (Ghasemzadeh *et al*., 2018; Mahboubi, 2019). The extensive utilization of ginger is mainly driven by its rich secondary metabolites, particularly essential oils and phenolic compounds, which exhibit significant biological activities such as antioxidant, antibacterial, and anti-inflammatory properties (Mao *et al*., 2019). In Indonesia, specifically in Dadaprejo Village, Batu City, the cultivation of emprit ginger (*Zingiber officinale* var. *Amarum*) and giant ginger (*Zingiber officinale* var. *Officinale*) serves as a prominent local agricultural commodity (Pratama *et al*., 2021). However, local processing of ginger rhizomes remains largely limited to raw consumption or traditional processing without standardization based on chemical constituent profiles (Bermawie *et al*., 2019).

The physico-chemical profile and volatile compound composition of ginger essential oil are qualitatively and quantitatively influenced by genetic variety, geographical origin, microclimate, soil nutrients, and extraction methods (Sharifi-Rad *et al*., 2017; Zhang *et al*., 2021). Previous studies have investigated essential oil profiles of ginger varieties across various regions in Indonesia (Nurlaili *et al*., 2020; Supriyadi *et al*., 2021). However, most existing research focuses on single varieties or lacks a comparative assessment linking the specific

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physico-chemical attributes of extracted oils directly to their targeted downstream industrial applications (state of the art). Furthermore, a comprehensive comparative profile of essential oils from var. *Amarum* and var. *Officinale* cultivated in the specific highland microclimate of Dadaprejo Village, Batu City, has not yet been thoroughly documented.

The significance of this study lies in establishing a scientific baseline regarding the physical properties (yield, color, aroma, and alcohol solubility) and volatile chemical profiles (*Gas Chromatography-Mass Spectrometry*/GC-MS) of essential oils from both emprit and giant ginger harvested in Dadaprejo Village. Identifying dominant compound groups such as cyclic ketones in emprit ginger and phenolic aldehydes in giant ginger is critical for defining quality standardization and guiding targeted utilization across different industrial sectors. Based on these considerations, this study aims to evaluate and compare the physico-chemical profiles and volatile chemical compositions of essential oils from emprit ginger (*Zingiber officinale* var. *Amarum*) and giant ginger (*Zingiber officinale* var. *Officinale*) originating from Dadaprejo Village, Batu City, to provide essential preliminary data for their optimal industrial application

2. MATERIALS AND METHODS

This exploratory descriptive study examined the physical characteristics and volatile chemical profiles of essential oils extracted from two different ginger varieties. The raw materials used were fresh, healthy rhizomes of small white ginger (*Zingiber officinale* var. *Amarum*) and large white ginger (*Zingiber officinale* var. *Officinale*). Sampling was conducted at the standard harvest age of 8–10 months to eliminate variations caused by maturity levels. Botanical samples were collected from a cultivation field located in Dadaprejo Village, Junrejo Subdistrict, Batu City, East Java. For each variety, a total of 3.3 kg of fresh biomass was obtained to ensure that the chemical evaluation accurately represented the entire harvest. After collection, the fresh rhizomes were temporarily stored in clean containers at room temperature, protected from direct sunlight, prior to processing. Sample preparation, physical characterization, and hydrodistillation procedures were conducted at the Balai Besar Pelatihan Pertanian (BBPP), while advanced chemical profiling was performed at the Integrated Laboratory of the Faculty of Agricultural Technology, Brawijaya University.

The process of extracting ginger essential oil begins by thoroughly washing the fresh rhizomes under running water to remove soil particles and external contaminants. The cleaned rhizomes are then weighed on a scale to accurately record their initial wet weight (m) in grams. Next, the sample is manually cut into small pieces with a uniform thickness of 1–2 mm to

maximize the surface area for the extraction process. The hydrodistillation process is carried out using a Clevenger-type apparatus connected to a distillation flask, a heating mantle, and a water-cooled condenser. The sliced ginger rhizomes were placed into the distillation flask, followed by the addition of distilled water at a fixed weight-to-volume ratio of 1:5 (w/v). The heater was turned on, and the operating temperature was strictly controlled while maintaining a continuous flow of cooling water through the condenser. The distillation process is run for 2 hours, precisely timed from the moment the first distillate droplet begins to condense until no more oil droplets are eluted from the matrix. The extracted essential oil is collected in a measuring cylinder, dried to remove residual moisture, and transferred to a sealed glass bottle. The total yield of essential oil (m_2) is determined gravimetrically using an analytical balance. The percentage of total extraction yield is calculated using the standard formula:

$$\text{Total Yield } (\%) = \frac{m2 - (m2 \times \text{residual solvent})}{m} \times 100\% \quad \text{....(i)}$$

Physical analysis of the isolated essential oils included organoleptic parameters, color profile evaluation, and alcohol solubility testing. Visual color profiles and olfactory aromas were evaluated through sensory panel testing involving 15 independent human assessors who were provided with instructions. Color intensity and clarity were subjectively assessed using a structured 1–5 scale to classify samples within a color spectrum ranging from yellow to clear, in accordance with national standards. Concurrently, aroma characteristics were categorized based on descriptive levels ranging from weak, moderate, to sharp, capturing the spicy, warm, and herbal aromas characteristic of the *Zingiber* genus. The physical solubility profile was investigated by gradually adding an organic solvent to a test tube containing 1 mL of ginger essential oil. The solvent used was 96% analytical-grade alcohol, which was added gradually at room temperature until the mixture reached a stable, clear, and homogeneous phase without any visible phase separation or turbidity.

The chemical identification of volatile components was performed using a gas chromatography–mass spectrometry (GC-MS) system equipped with a TG-5MS capillary column. Prior to injection, the dried essential oil was diluted in analytical-grade n-hexane or n-pentane and filtered through a syringe filter into a specialized GC vial. A microliter syringe was used to inject the sample into the GC-MS system. Chromatographic separation was controlled by a precise temperature program: the oven was initially maintained at 70°C for 3 minutes, then rapidly increased at a rate of 25.71°C per minute, and finally reached a final temperature of 250°C, which was maintained for an additional 2 minutes.

The injection port temperature is set to 250°C with an operating pressure of 98.3 kPa. The carrier gas is maintained at a total flow rate of 306.5 mL/min, a column flow rate of 1.51 mL/min, a purge flow rate of 3.0 mL/min, a linear velocity of 45 cm/s, and a split ratio of 200. For mass spectrometry analysis, the ion source temperature was maintained at 200°C with an interface temperature of 250°C, and electron ionization data were scanned over a mass-to-charge ratio (*m/z*) range of 40–400. Identification of major and minor chemical compounds was performed by matching the resulting mass spectra and retention times against a predefined NIST library database. Peak area percentage comparison data were systematically tabulated to evaluate chemical distribution patterns.

3. RESULTS AND DISCUSSION

The hydrodistillation of fresh rhizomes of *Zingiber officinale* var. *Amarum* and *Zingiber officinale* var. *Officinale* successfully produced distinct essential oil profiles. The appearance of the essential oils extracted from these two ginger varieties is shown **in Figure 1**

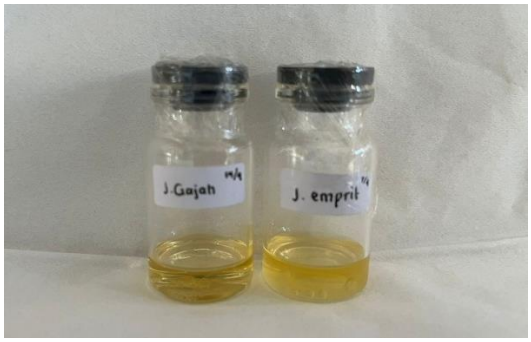

Figure 1. Hydrodistillation result of two sampels

To systematically evaluate the physical and sensory characteristics, a guided panel evaluation was conducted, yielding percentage distribution data for color intensity and aroma, shown in Figure 2 and Figure 3, respectively. Based on the data in Figure 2, a striking difference is evident between the two samples. For var. *Amarum*, panelist scores were concentrated at the higher end of the scale, with 41,7% categorizing it as dark yellow and another 33,3% as bright yellow. In contrast, the visual characteristics of the var. *Officinale* oil were dominated by low to medium scores, with 35,7% of panelists rating the oil as light yellow and 28,6% as pale yellow.

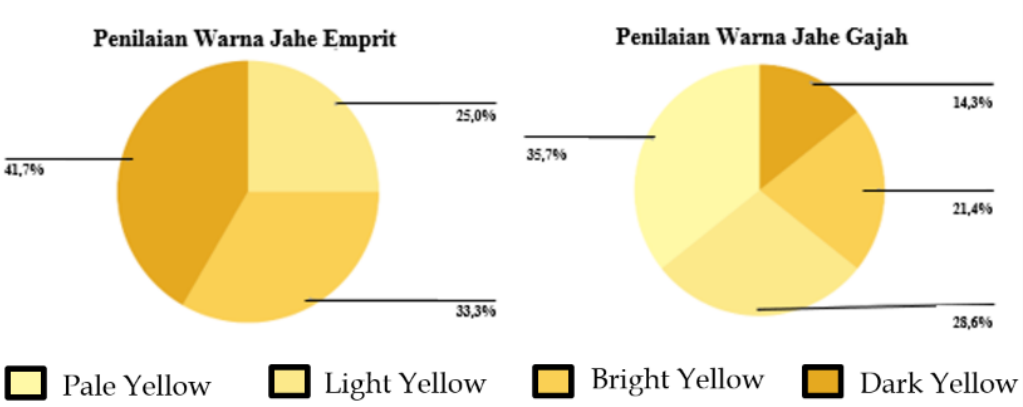

Figure 2. Distribution diagram of the percentage of color intensity in ginger essential oil

The evaluation of the olfactory characteristics shown in Figure 3 followed a distribution pattern very similar to that of the color test results. All 15 panelists consistently rated the aroma intensity of var. *Amarum* as high, with 41.7% categorizing it as very pungent and 33,3% as sharp/strong. Meanwhile, the scores for var. *Officinale* indicated a much milder aroma, with 35,7% rating it as moderately sharp and 28,6% as weak.

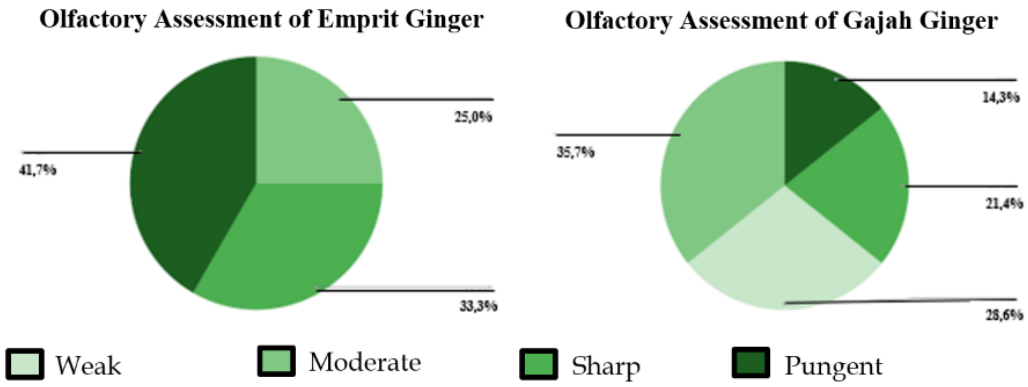

Figure 3. Distribution diagram of the percentage of aroma in ginger essential oil

Gravimetric calculations showed that 3.3 kg of raw biomass of the *Amarum* variety yielded 4.0 mL of essential oil over a 2-hour distillation period, whereas the *Officinale* variety yielded 3.0 mL under the same conditions. By converting the volume using a standard density of 0.88 g/mL, the exact extraction parameters and total yield percentage were determined, as systematically presented in Table 1. Mathematical calculations show that var. amarum achieved a total extraction yield of 0.1067%, which is higher than the yield of var. *Officinale* at 0.0800%.

Table 1. Extraction parameters and essensial oil yields of two ginger varieties.

Ginger Variety	Fresh Sample Weight (g)	Obtained Oil Volume (mL)	Calculated Oil Mass (g)	Total Yield (%)
Zingiber officinale var. *Amarum*	3300	4.0	3.52	0.1067
Zingiber officinale var. *Officinale*	3300	3.0	2.64	0.0800

Additionally, the physical quality and chemical authenticity of the oil were verified through a stepwise organic solubility test; the physical state of both samples before and after interaction with 96% alcohol is documented in Figure 4. The gradual addition of alcohol revealed different solubility thresholds, with var. *Amarum* achieving full homogeneity at a 1:3 ratio, whereas var. *Officinale* required a 1:4 ratio to dissolve completely. This ratio indicates that to dissolve 1 volume (1 mL) of var. *Amarum* essential oil, 3 volumes (3 mL) of 96% alcohol are required to ensure it mixes completely and homogeneously. Meanwhile, for var. *Officinale*, the 1:4 ratio indicates that a larger volume of solvent is needed namely, 4 volumes (4 mL) of 96% alcohol to dissolve 1 volume (1 mL) of elephant ginger essential oil.

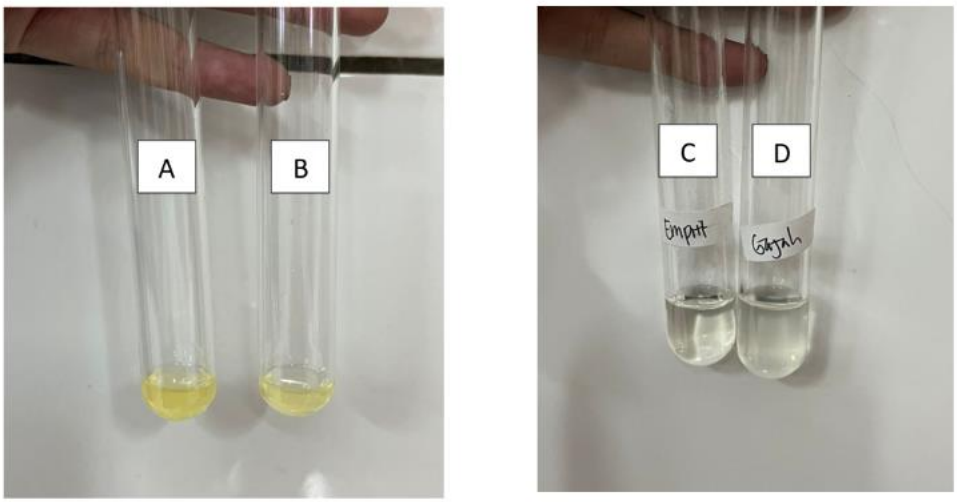

Figure 4. Essential Oils Before Testing; (A) Emprit Ginger Oil Solution at a Ratio of 1 ml, (B) Elephant Ginger Oil Solution at a Ratio of 1 ml, (C) Sample of Emprit Ginger Essential Oil at a 1:3 ratio after testing, (D) Sample of Gajah Ginger Essential Oil at a 1:4 ratio after testing.

In addition to these physical parameters, further separation via gas chromatography–mass spectrometry (GC-MS) revealed significant differences in the composition of volatile metabolites as well as variations in peak patterns between the two plants. Of the total 119 chromatographic peaks detected in var. *Amarum*, 9 major chemical compounds exhibited a relative abundance of $\geq$2.0%, as listed in Table 2

Table 2. Major chemical compounds identified in *emprit* ginger essential oil via GC-MS.

Peak#	R. Time	Name	Area%	Class of compounds
Peak# 53	17.42 –	Ketone, 1-cyclohexen-1-yl methyl,	16,15%	Cyclic Ketones
Peak# 56	18.32	semicarbazone		
Peak# 22	10.98	1,6-Cyclodecanediol	6,49%	Sesquiterpenoid Diol
Peak# 10	8.49	Cis-p-mentha-1(7),8-dien-2-ol	5,07%	Monoterpenoid Alcohol
Peak# 75	23.99	4-Methoxyphenoxyformamide, N-methyl-N-[4]	3,48%	Methoxy Phenol
Peak# 9	7.99	Tricyclo[5.3.0.0(4.8)] decane	2,08%	Cyclic Sesquiterpenes

In addition to the major compounds of var. *Amarum*, several minor chemical compounds were identified with concentrations below 1.0%, as listed in Table 3.

Table 3. Minor chemical compounds identified in *emprit* ginger essential oil via GC-MS.

Peak#	R. Time	Name	Area%	Class of compounds
Peak# 3	7.94	Eucalyptol (1,8-Cineole)	0,92%	Oxygenated Monoterpenes
Peak# 16	21.05	Geraniol	0,55%	Oxygenated Monoterpenes
Peak# 31	35.30	Aplha-Farnesene	0,27%	Sesquiterpene Hydrocarbons
Peak# 35	40.71	Beta-Sesquiphellandrene	0,40%	Sesquiterpene Hydrocarbons

In contrast, GC-MS analysis of var. *Officinale* revealed a completely different elution profile of volatile compounds, with lower peak complexity compounds detected. Among these compounds, 9 major compounds with concentrations of ≥2.0% were identified; the details are listed in Table 4.

Table 4. Major chemical compounds identified in *gajah* ginger essential oil via GC-MS.

Peak#	R. Time	Name	Area%	Class of compounds
Peak# 50	17.50	4-Hydroxy-2-nitro-m-anisaldehyde	7,67%	Benzaldehyde/Phenolic Derivatives
Peak# 25	11.09	Acetic acid, 2-(1,2,4-triazol-4-yl)amino-,ethyl	7,15%	Carboxylic Acid Derivatives
Peak# 16	8.55	(1-Cyclopropylimidazol-2-yl)methanamine	5,99%	Amina Heterocyclic
Peak# 39	14.70 –	Isopulegol/dl-Isopulegol	5,15%	Monoterpenoid Alcohol
Peak# 42	15.22			
Peak# 68	24.05	Ethanone, 2-azido-1-(4-methyl-3-furazanyl)	3,25%	Cyclic Azido Derivatives
Peak# 15	8.02	Tricyclo[5.3.0.0(4,8)] decane	2,61%	Tricyclic Sesquiterpene

In addition, the characterization of the essential oil of var. *Officinale* was refined by identifying its minor volatile components (≤ 1.0%), which are listed in Table 5.

Table 5. Minor chemical compounds identified in *gajah* ginger essential oil via GC-MS.

Peak#	R. Time	Name	Area%	Class of compounds
Peak# 3	7.95	Eucalyptol (1,8-Cineole)	0,82%	Oxygenated Monoterpenes
Peal# 15	22.36	Borneol	0,69%	Oxygenated Monoterpenes
Peak# 31	38.64	Ar-curcumene	0,44%	Sesquiterpene Hydrocarbons
Peak# 34	41.52	Zingiberene	0,79%	Sesquiterpene Hydrocarbons

The extraction and testing processes in this study were conducted using a single sampling because of highly unpredictable weather conditions during the raw material collection period. Unpredictable weather changes significantly accelerated rhizome decay and caused physical damage to the ginger plants. To ensure strict data validity and purity, a single-sampling approach was chosen without repeating the extraction using material harvested at different time intervals, thereby preventing external environmental factors from interfering with the core physicochemical results. A single batch of samples was considered highly representative of the authentic basic characteristics of *Zingiber officinale* var. *Amarum* and *Zingiber officinale* var. *Officinale*. During periods of heavy rainfall, micro-humidity within the rhizome tissue increases drastically, which rapidly triggers the activity of microorganisms and decay-causing fungi, leading to severe post-harvest biomass degradation (Guenther, 2006). Previous studies have shown that the overall quality, aromatic profile, and concentration of volatile compounds in ginger are highly sensitive to postharvest decay; therefore, chemical identification must be performed immediately after hydrodistillation to prevent extensive degradation of bioactive compounds (Wohlmuth *et al*., 2005). In botanical research, the evaluation of single samples is scientifically accepted when natural conditions pose a high risk of degradation acting as a crucial protocol to eliminate confounding variables (Bakkali *et al.*, 2008).

Sensory Color and Odor Profile Evaluations

Visual Color

The sensory color profile revealed clear physical differences between the isolated essential oils. For var. *Amarum*, panelists scores were highly concentrated at the upper end of the spectrum, 41.7% in the deep/dark yellow category, 33.3% in the bright yellow category, and 25% in the light yellow category. In contrast, regarding the visual characteristics of var. *Officinale* essential oil, the panelists ratings were predominantly in the lower-middle range; 35.7% in the light yellow category, 28.6% in the pale yellow category, followed by 21.4% in the bright yellow category, and 14.3% in the dark yellow category. These distinct differences in color intensity are directly influenced by the volumetric density of volatile components and the unique dominant compounds in each variety. The abundant content of oxygenated cyclic ketones in var. *Amarum* triggers a very deep and saturated yellow color, whereas the short aromatic structures with dominant nitrogen bonds in var. *Officinale* make the final liquid much more transparent. These findings align with the foundational research by Setianingrum *et al*. (2019), which noted that small white ginger is characterized by high concentrations of phenolic ketones and higher levels of basic volatile compounds, which are highly reactive and prone to

polymerization. Furthermore, during high-temperature thermal processing, the oxidation and chemical degradation of these ketone structures consistently trigger the formation of darker, more opaque, and highly concentrated pigments, thereby altering its appearance from clear to dark brownish-yellow (Prajawanti and Ramadanti, 2025).

Olfactory Aroma

The sensory distribution pattern of olfactory properties was very similar to that of visual color parameters. Panelists consistently reported high aroma intensity for var. *Amarum*, Consistently, the panelists rated the odor intensity of var. *Amarum* as very pungent at 41.7%, sharp at 33.3%, and moderate at 25%. As for var. *Officinale*, the panelists ratings indicated that it has a much milder aroma, with 35.7% in the moderate category, 28.6% in the weak aroma category, and 21.4% in the sharp category. The high concentration of volatile ketones in var. *Amarum* has a very low evaporation threshold at room temperature, rapidly stimulating human olfactory receptors upon exposure. This phenomenon is supported by Lestari *et al*. (2020), who reported that plant-derived phenolic ketone groups exhibit rapid gas-phase transitions under ambient conditions, allowing them to disperse rapidly into the surrounding air. In contrast, the mild aroma of var. *Officinale* is derived from a more balanced and moderately distributed volatile fraction supported by the tricyclic sesquiterpene Tricyclo[5.3.0.0(4.8)]decane, which provides a characteristic fresh and woody aroma. This chemical distribution explains the faded visual color and mild aroma of var. *Officinale*, as its low molecular weight aromatic bonds are highly volatile and disperse without undergoing severe color changes or triggering strong olfactory reactions (Saeful *et al*., 2025).

Extraction Mechanism and Alcohol Solubility Behavior

The isolation of this essential oil through hydrodistillation relies heavily on differences in boiling point and thermal volatility to separate the volatile fraction from the underlying rhizome matrix. Components isolated during this thermal phase include hydrophobic volatiles primarily terpenoid branches trapped within the specialized parenchymal oil cells of the ginger rhizome. The heat generated by the boiling water induces hydrodiffusion, forcing water molecules into the plant tissue, which then ruptures the inner cell walls and transports the hydrophobic oil molecules as vapor to the condenser system (Utami *et al*., 2026). Following isolation, a step-by-step solubility evaluation in 96% alcohol confirmed the excellent physical quality and high authenticity of the material, fully meeting commercial standards mandated by national regulations (SNI 06-1312-1998). High-quality 96% alcohol acts as a highly efficient organic solvent due to its minimal moisture content. Although the initial 1:1 ratio was not volumetrically sufficient to homogenize the hydrophobic branches, the gradual addition of

solvent increased the interaction area, allowing the semi-polar oxygenated components of the *Amarum* variety to achieve stable and clear homogeneity at a 1:3 ratio. This highly responsive solubility behavior is consistent with the report of Spyrou *et al.* (2024), who noted that higher concentrations of oxygenated components in small white ginger oil conferred greater affinity to short-chain organic alcohols. In contrast, the more hydrophobic hydrocarbon array of the *Officinale* variety required a wider 1:4 ratio to achieve a clear and identical single-phase solution.

GC-MS Chemical Profiling and Pharmacological Significance

Advanced GC-MS chromatograms validated the visual and sensory variations by mapping the striking metabolic differences between the two varieties. In the *Amarum* variety, cyclic ketone compounds (*Ketone, 1-cyclohexene-1-yl methyl, semicarbazone*) emerged as the absolute dominant component at 16.15%. Chemically, this high concentration of ketones directly explains the strong pungent flavor and sharp thermogenic sensation experienced upon consumption. Volatile ketones play a crucial role in stimulating human metabolism, contributing approximately 5% to 20% of total energy expenditure by acting as an alternative cellular fuel source through the lipolysis-induced ketogenesis pathway regulated by a hormone-sensitive lipase feedback mechanism (Caleb and Shamim, 2023). Identification of semicarbazone derivatives by the NIST database indicated a thermal rearrangement phenomenon, where natural ginger ketones undergo structural shifts due to exposure to extreme heat within the GC injector port (Igor and Tatiana, 2025). Pharmacologically, this volatile ketone group has immense therapeutic value, functioning as a potent anti-inflammatory and antiemetic agent that successfully suppresses nausea and central nervous system swelling (Sharma *et al.*, 2016). In contrast, var. *Officinale* is dominated by a phenolic aldehyde derivative (*4-Hydroxy-2-nitro-m-anisaldehyde*) at 7.67%. This plant-derived phenolic structure, synthesized via the acetate-polyketide pathway, is renowned for its ability to inhibit cancer cell initiation, metastasis, and angiogenesis by altering the expression of specific carcinogenesis genes (Singh and Jain, 2022).

The presence of *Isopulegol* (8.57% in var. *Amarum* and 5.15% in var. *Officinale*) and *Tricyclo[5.3.0.0(4.8)]decane* (2.08% in var. *Amarum*; 2.61% in var. *Officinale*) in both samples provides irrefutable chemotaxonomic validation that both varieties belong to the same single phylogenetic lineage of the *Zingiberaceae* family. Isopulegol is a cyclic monoterpenoid alcohol that serves as an essential intermediate building block for complex aromatic monoterpenes, which have been scientifically proven to possess anti-hyperlipidemic, anxiolytic, gastroprotective, and analgesic properties. Simultaneously, the tricyclic

sesquiterpene hydrocarbon *Tricyclo[5.3.0.0(4,8)]decane* serves as a fundamental structural modification of the *zingiberene* core skeleton, acting as a key chemical marker guaranteeing the authentic woody-herbal aroma of the *Zingiber* genus (Aminov *et al*., 2022). Furthermore, var. *Amarum* exhibits specific sesquiterpenoid diols, including *1,6-Cyclodecanediol* (6.49%) and *1,4-Naphthalenediol, decahydro-* (2.90%), which are characteristic high-level metabolites associated with potent antimalarial, cytotoxic, and antiviral defense mechanism pathways (Maurice *et al*., 2023).

The presence of *Eucalyptol (1,8-Cineole)* in nearly equal minor concentrations 0.92% in the *Amarum* variety and 0.82% in the *Officinale* variety gives both essential oils a uniform fresh and minty aroma. However, the nuances of each aroma are distinguished by secondary minor monoterpenes and the *Officinale* variety incorporates *Borneol* (0.69%) to create a herbal-earthy base aroma, while the *Amarum* variety uses *Geraniol* (0.55%) to sweeten the aroma. These oxygenated monoterpenes act as universal markers of botanical freshness across all ginger cultivars (Sharifi-Rad *et al*., 2017). Bioanalytically, the alcohols and ethers of minor monoterpenes are remarkable membrane permeation enhancers and they efficiently disrupt the lipid membrane walls of pathogenic bacteria and work synergistically with the major ketones to block inflammatory responses in the human central nervous system (Silva *et al*., 2009).

Thermal Degradation of Sesquiterpens and Authenticity Validation

A key observation in this study was the complete absence of *Zingiberene* in the *Amarum* variety and its very low concentration (0.79%) in the *Officinale* variety, despite it traditionally being a major constituent of ginger oil. This absence highlights the apparent thermal hydrolysis distortion caused by continuous exposure to high temperatures during water distillation. Pure sesquiterpene hydrocarbons such as *Zingiberene* are highly thermolabile and sensitive to prolonged processing heat triggers structural rearrangements, degrading these unstable hydrocarbons into more thermodynamically stable oxygenated derivatives, such as cyclic ketones and phenolic aldehydes (An *et al*., 2016). Different ginger varieties exhibit different degradation tolerances to boiling temperatures and in the *Amarum* variety, high thermal energy promotes a complete structural transformation of its volatile unsaturated hydrocarbons toward highly stable functional groups (Schaller and Schieberle, 2016). Nevertheless, the persistent detection of traces of *Zingiberene* and *Ar-curcumene* (0.44%) in the *Officinale* variety indicates the presence of trace amounts of *Zingiberene* in the *Amarum* variety, along with *beta-Sesquiphellandrene* (0.40%) and *alpha-Farnesene* (0.27%) in the *Amarum* variety, which legally validates that both distillates are pure and authentic natural extracts of the original *Zingiber* plant and not synthetic imitations.

4. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, this study successfully established the physical chemical basis and specific volatile compounds for *Zingiber officinale* var. *Amarum* and *Zingiber officinale* var. *Officinale*. Significant physical contrasts were observed, where var. *Amarum* showed a higher extraction yield (0.1067%), dark to bright yellow color, a very sharp aroma, and tight solubility in 96% alcohol at a ratio of 1:3. In contrast, var. *Officinale* produced a lower yield (0.0800%), appearing as a pale to bright yellow liquid with a milder fresh woody aroma and a wider alcohol solubility threshold of 1:4. Further chromatographic analysis revealed that var. *Amarum* has a very complex chemical composition with 119 volatile compounds dominated by cyclic ketones (16.15%), making it highly potential for phytopharmaceuticals and fine chemical formulations. Meanwhile, var. *Officinale* exhibits a leaner chemical profile with complex components led by phenolic aldehydes (7.67%), making its mild sensory characteristics ideal for commercial food processing and industrial beverage applications. Furthermore, the detection of traces and absence of *Zingiberene* throughout the distillate scientifically validates the occurrence of a partial thermal degradation phenomenon during hydrodistillation, which structurally rearranges thermolabile hydrocarbons into thermodynamically stable oxygenated functional groups.

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