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Analysis of the Effect of the Hydraulic Press Method on the Yield and Characteristics of Essential Oils from Various Varieties of Citrus Peel

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ABSTRACT

This study aims to determine the yield and characteristics of essential oil extracted from orange peel. Currently, citrus peel extraction is typically performed using solvents and high temperatures, which can affect oil yield and quality. In this study, a mechanical extraction method driven by hydraulic power without heating was employed to increase yield and optimise the essential oil's composition, particularly the content of bicyclic compounds and carenes, compared with conventional limonene-based methods. The utilisation of citrus peels, which have traditionally been treated as waste, holds significant potential for processing into value-added products, including essential oils. The materials used were Sundai peels, lemon peels, sweet orange peels, kaffir lime peels, and kasturi peels. The results of the study indicate that Sundai orange peel is more optimal compared to other varieties because it has a peel composition of $34.2125 \pm 0.20\%$, a moisture content of $64.482 \pm 0.75\%$, a yield of $0.779 \pm 0.03\%$, and a density of 0.8387 ± 0.003 g/ml. Based on the chromatogram data, at least 10 major peaks with different retention times were detected, representing the components of the essential oil. The identified compounds include 3-Carene, (+)-Carene, γ -Terpinene, Octanal, bicyclic compounds (bicyclo[3.1.1]heptane and its derivatives), and Nonyl chloroformate (a minor component).

Contribution to Sustainable Development Goals (SDGs):

SDG 9: Industry, Innovation and Infrastructure

SDG 12: Responsible Consumption and Production

SDG 15: Life on Land

1. INTRODUCTION

1.1. Research Background

Citrus fruits are a major fruit commodity that plays a significant role in both domestic and global markets, whether fresh or processed. Indonesia is home to many citrus varieties that are in high demand and widely utilised (1). Citrus fruits themselves can be processed into various highly beneficial products. Citrus fruits are typically consumed by squeezing them into beverages or as an ingredient in food. Until now, citrus peels have not been fully

utilized and are often disposed of as waste. Citrus peels contain various compounds and possess a distinctive fragrance depending on the variety. (2) (3).

To increase the economic value of citrus peel and increase the income of citrus farmers, it is necessary to study the use of citrus peel from various varieties as a source of essential oil. Citrus peel contains essential oil that has not fully evaporated, and the scent produced by the essential oil is still fresh, with the characteristic aroma of citrus fruit (3). This citrus peel contains valuable bioactive compounds, particularly essential oils that exhibit antioxidant, anticancer, anti-inflammatory, antimicrobial, and cardioprotective properties (2) (4). Essential oil is a name for



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volatile oils, which consist of a mixture of several substances with different compositions and boiling points (4). The yield of essential oil from citrus peel varies widely depending on factors such as the extraction method, citrus variety, processing conditions, and pretreatment of the raw material (5). Currently, conventional essential oil extraction methods include cold pressing and distillation, as well as non-conventional methods such as supercritical fluid extraction (2).

This essential oil is found in the oil glands, which must be released before distillation; this is done by finely chopping or crushing the plant tissue and opening as many oil glands as possible, allowing the oil to be easily vaporized during distillation (6). Essential oils are widely used in industry, including the soap and cosmetics industries, as fragrances and flavourings. The selling price of essential oils is determined by the quality of the oil and the concentration of its main components (3).

Permana extracted essential oil from citrus peel. (7) using the distillation method and ethanol as a solvent, yielding an optimal limonene content of 63.8% with a yield of 0.25%. Sawitri conducted the use of a press in the extraction of agricultural products (8) using a screw press on nuts, yielding 0.367 l/kg.

In this study, essential oil extraction was performed using a hydraulic press without heating to prevent damage to the compounds present and minimise the loss of volatile compounds. The objectives of this study were to determine the highest essential oil yield from several varieties of citrus, to identify their physical characteristics, and to analyze the composition of the essential oil yield using Gas Chromatography–Mass Spectrometry (GC-MS).

1.2. Literature Review

Indonesia has a wide variety of citrus fruits. The citrus fruits considered native are mandarins, large oranges, and citrons, while the others are hybrids of these three groups. The presence of these local citrus varieties likely reflects variations within populations across regions. The sweet orange (*C. sinensis*) is a shrub-like plant, reaching 3–10 meters in height, with thorny branches; the thorns are short and nail-shaped. The leaf stalks are 0.5–3.5 cm long, and the leaf blades are ovate, elliptical, or elongated, with blunt or slightly pointed tips. The flower petals are white or yellowish-white. The fruit is spherical or slightly flattened, yellow, orange, or green with yellow. The flesh is light yellow, orange yellow, or reddish with segments that are fused together.

The kaffir lime (*Citrus hystrix* DC) is egg-shaped, with green skin characterized by a wrinkled, uneven, bumpy surface and a sour, slightly bitter taste. Kaffir lime is rich in bioactive compounds such as essential oils, phenolic compounds, and several other molecules (9). Sundai orange (*C. amblycarpa*) is a local orange variety commonly found in West Sumatra and used by the local community as a food source, in traditional remedies, and as a raw material for essential oils. The peel of the sundai orange is known to contain essential oil with limonene as the primary component, offering potential as an antioxidant and a natural aromatic compound. Research by Sovia Lenny (10) shows that essential oil extracted from fresh Sundai orange peel contains up to 58.49% limonene, whereas dried peel contains 55.80% limonene, as determined by GC-MS analysis.

The sundai is characterized by round to slightly flattened fruit of small to medium size, with a thin, dark green peel that turns greenish yellow when ripe, and a smooth surface that contains strongly aromatic essential oils. The flesh is pale yellow, has a

high water content, and a distinctive fresh, tart flavor, making it a common ingredient in traditional foods and beverages. The Sundai orange plant also has a relatively small canopy with glossy green, oblong leaves—a morphological study by Budiarto et al. (11) notes that *Citrus amblycarpa* possesses high aesthetic value due to its compact size and distinctive fruit aroma, making it a promising candidate for development as both a functional and ornamental plant. Additionally, its fruit peel is rich in volatile compounds such as limonene and sabinene, which influence its aroma and physical characteristics.

Lemons are medium sized and oval in shape; their skin is green when young and bright yellow when ripe, while the surface of the skin is slightly rough due to its high concentration of essential oil glands. The fruit measures approximately 5 to 8 cm and emits a distinctive aroma from volatile compounds. These physical characteristics make lemons widely used as an ingredient in food, beverages, and traditional medicine, as well as a source of essential oil.

1.3. Research Objective

The study aims to determine the highest essential oil yield from several orange varieties, identify the physical characteristics of the essential oils, and analyze the compounds present using Gas Chromatography–Mass Spectrometry (GCMS).

2. MATERIALS AND METHODS

The materials used in this study are various types of citrus peels, including: A: Sundai (*C. amblycarpa*), B: lemon (*C. limon*), C: kaffir lime (*C. hystrix* DC), D: sweet orange (*C. sinensis*), and E: calamansi (*C. microcarpa*). The equipment used in this study consists of a series of modified presses utilizing a hydraulic drive with a pressure of 2,000 lb/in² without a heating medium, 70-mesh filter cloth, a centrifuge (Corona 80-2) at 1,500 rpm for 10 minutes, scissors, a funnel, a beaker, a stirrer, and a Gas Chromatography Mass Spectrometry TQ 8050 NX (Shimadzu). This study utilized 5 varieties of citrus peel. The whole weight and peel weight of each variety were measured. The citrus peel was then reduced to a size of 0.5 cm. The peel was subsequently extracted using a hydraulic press to yield oil. The resulting oil was then separated by centrifugation at 1500 rpm for 10 minutes. The analyses conducted in this study included raw material analysis, moisture content, essential oil yield, essential oil density, and GC-MS analysis.

3. RESULT AND DISCUSSION

3.1. Citrus Fruit Section

The citrus varieties used in this study exhibit various characteristics in terms of shape, size, and weight (Figure 1). Each variety of citrus fruit has a different size, color, and aroma. Sundai (*C. amblycarpa*) are medium sized, with skin that can be thinner or somewhat rough; they tend to be yellowish green in color and have a sharper, more distinctive aroma. Lemons are oval shaped with pointed ends, bright yellow and relatively thick skin, a somewhat rough texture, and a fresh citrus aroma. The texture of *C. Hystrix* (lime) is quite distinctive and different from most other oranges. The skin of the lime is very rough, wrinkled (wavy), and thick and stiff when pressed; its surface is not as

smooth as that of sweet oranges or lemons, and it contains many essential oil glands, which feel slightly oily when rubbed.



Figure 1. a: Sundai (*C. amblycarpa*), b: Lemon (*C. limon*), c: Kaffir lime (*C. hystrix DC*), d: Sweet orange (*C. sinensis*), and e: Kalamansi (*C. microcarpa*)

The sweet orange (*C. sinensis*) peel has a smooth, elastic texture with fine pores; it is medium-thick and easy to peel. Compared to the kaffir lime (*C. hystrix*), which is very rough, or the lemon (*C. limon*), which is thicker and stiffer, the sweet orange tends to have a softer texture. Kalamansi (*C. microcarpa*) peel has a smooth, thin, and fairly soft texture, with oil pores that are not too coarse. These characteristics distinguish it from lime (rough and thick) and lemon (thicker and stiffer).

The study results obtained various measurements of the weight of whole oranges, orange pulp, and orange peel according to variety. Table 1 shows that the peel accounts for 21.03–34.21% of the total weight of each orange. The peel content of sundai, lemon, and purut oranges is significantly higher than that of sweet oranges and kalamansi oranges.

Table 1 Comparison of Fruit Components

Variety	Gross Weight	Fruit weight	Peel	% peel
Sundai (<i>C. Amblycarpa</i>)	105.221±1.39	69.222±1.69	35.998±0.79	34.213±0.20
Lemon (<i>C. Limon</i>)	133.129±1.67	96.168±1.63	39.961±0.79	35.286±0.24
Kaffir Lime (<i>C. Hystrix DC</i>)	56.033±0.21	36.574±0.95	19.459±1.67	33.479±1.61
Sweet Orange (<i>C. Sinensis</i>)	92.287±2.78	70.272±0.99	22.015±0.30	23.854±0.32
Calamansi (<i>C. Microcarpa</i>)	11.812±0.56	9.328±0.76	2.484±0.93	21.029±0.41

3.2. Moisture Content of Citrus Peels

The research results showed the average water content as presented in Figure 2. The highest water content was found in lemon (*C. limon*) at 81.075%, while the Sundai orange (*C. amblycarpa*) had a water content of 64.482%. Lemon peel has a higher moisture content than other varieties because it is thicker and has a thinner white albedo/pith layer. Sundai and kaffir lime peels have a similar wrinkled texture and a fairly thick pith layer.

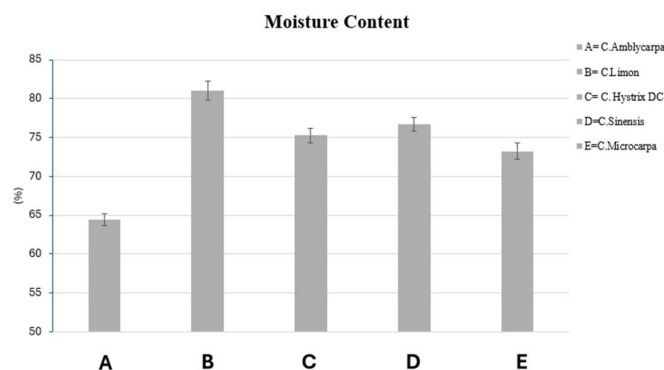


Figure 2. Moisture Content of Citrus Peel

This is consistent with the results of previous studies by Amborowati et al. (12) and Assyera et al. (13), who found that the moisture content of freshly harvested lemons was around 70%. This difference in moisture content is closely related to the anatomical structure of the fruit peel, particularly the thickness of the flavedo layer (outer layer), which contains essential oils, and the albedo layer (inner layer), which is spongy and stores water.

The relatively thick, porous lemon peel allows for greater water retention, resulting in the highest moisture content. In contrast, sundai oranges, which tend to have thinner skin or a higher oil content, exhibit lower water content. According to the literature, the thick albedo layer contributes significantly to water content because it is composed of parenchyma tissue capable of storing fluid (14).

3.3. Essential Oil Yield

Orange peels were extracted using a hydraulic press to produce essential oil. The essential oil yields are shown in Table 2

Table 2. Essential Oil Yields from Various Varieties of Citrus Peels

Variety	Vol (ml)	Yield (%)
Sundai (<i>C. Amblycarpa</i>)	4.031±0.01	0.779±0.03
Lemon (<i>C. Limon</i>)	2.716±0.02	0.765±0.01
Kaffir Lime (<i>C. Hystrix DC</i>)	1.145±0.05	0.172±0.07
Sweet Orange (<i>C. Sinensis</i>)	0.421±0.06	0.146±0.02
Calamansi (<i>C. Microcarpa</i>)	0.253±0.03	0.076±0.04

Table 2 shows that essential oil yields from various citrus peel varieties differ significantly. The sequence of highest to lowest yields is: Sundai (*C. amblycarpa*) (0.779%), lemon (*C. Limon*) (0.765%), lime (*C. Hystrix DC*) (0.172%), sweet orange (*C. Sinensis*) (0.146%), and Calamansi (*C. Microcarpa*) (0.076%). These differences indicate that citrus variety significantly influences the content and yield of the essential oil produced.

In general, the high yield in sundai oranges and lemons is due to the higher concentration of oil glands in the fruit peel's flavedo. The essential oil in citrus fruits is dominated by monoterpene compounds such as limonene, the amount of which varies among species. Research indicates that lime peel can yield up to $\pm 1.38\%$ via steam distillation, demonstrating that the *C. Amblycarpa* group indeed possesses high essential oil potential.

Meanwhile, the relatively high yield of lemons in the table aligns with studies stating that lemon peel is an agroindustrial byproduct with a significant essential oil content that can be enhanced through pretreatment methods such as microwave pretreatment. This indicates that, in addition to variety factors, extraction methods and material pretreatment also influence yield (15). The lower yields in lime, sweet orange, and kalamansi are likely due to several factors, including the thickness and structure of the fruit peel, the chemical composition of the essential oil, and the moisture content of the material.

Research conducted on sweet oranges indicates that drying the fruit prior to distillation can significantly increase the yield by reducing moisture content and facilitating oil release. In fact, other studies have reported that the yield of sweet orange essential oil increased by up to 0.5% following specific drying treatments. Additionally, environmental factors such as growing conditions, fruit ripeness, and genetic variety also influence essential oil yield. Sweet orange essential oil is a complex mixture of volatile compounds that contribute to its aroma and economic value; thus, variations in chemical composition among varieties directly impact the amount of oil obtained. The lowest yield in kalamansi (0.076%) indicates that this variety has lower essential oil potential compared to other varieties. This can be attributed to smaller fruit size and lower oil content, as well as the possible dominance of non-volatile compounds.

3.4. Density of Citrus Peel Essential Oil

Density is a number that indicates the amount of substance contained in a given unit of volume. The density of each substance is different even if they have the same mass and volume; conversely, the same substance has the same density regardless of its amount. In addition to the state of the substance and its constituent particles, density is one of the characteristics that distinguishes one substance from another.

Based on Figure 3, the density of essential oils from several citrus peel varieties varies across citrus types. The highest density value was obtained from kalamansi peel essential oil (*Citrus microcarpa*) at 0.8915 ± 0.01 g/ml, while the lowest density was found in sweet orange (*C. sinensis*) at 0.8085 ± 0.01 g/ml. Meanwhile, Sundai (*C. Amblycarpa*), kaffir lime (*C. Hystrix DC*), and lemon (*Citrus limon*) had densities of 0.8387 ± 0.003 g/ml, 0.801 ± 0.01 g/ml, and 0.8758 ± 0.001 g/ml, respectively. These density differences indicate that the composition of the compounds in the essential oils of each orange variety varies. The density test results are shown in Figure 3. The measurement results indicate that the density of citrus peel essential oils ranges from 0.8085 to 0.8915 g/ml.

In general, the density of essential oils is influenced by the content of their constituent volatile compounds, particularly monoterpenes, sesquiterpenes, aldehydes, and alcohols. Essential oils with a higher content of oxygenated compounds tend to have a higher density than oils dominated by monoterpene hydrocarbons such as limonene. The high density of kalamansi essential oil is believed to be related to its higher content of complex oxygenated compounds, which increases the density of the resulting essential oil.

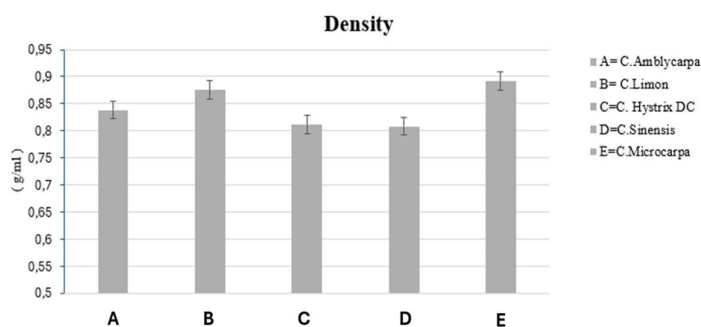


Figure 3. Density of Essential Oil

Citrus varieties influence the density of the resulting essential oil. These differences in physical characteristics are closely related to the chemical composition of each essential oil and the extraction process used. Additionally, a study on citrus peel essential oil produced by steam distillation reported a density of 0.8484 g/ml. These results are included in a series of research results, particularly considering that the values are comparable to those of sundai and kalamansi essential oils. This indicates that the citrus peel essential oil produced in this study still possesses physical characteristics consistent with general standards for citrus essential oils.

The low density of sweet orange essential oil is thought to result from the predominance of lighter, more volatile compounds. Extracting citrus peel using a hydraulic press without heating has also resulted in moisture content that affects the components of the essential oil obtained, which in turn affects the oil's physical properties, including its density.

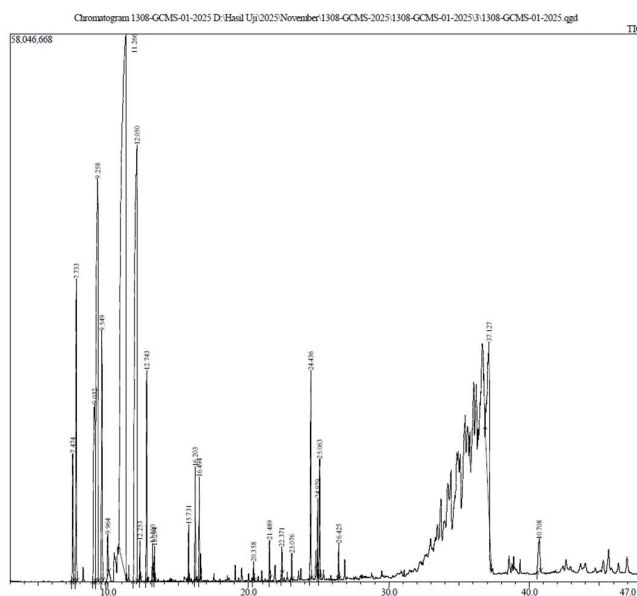
3.5. GCMS Analysis

GCMS analysis was performed on the treatment with the highest yield, Sundai, which yielded $0.779 \pm 0.03\%$. The GCMS results are shown in Figure 4 below.

The yield of Sundai oranges was higher than that of other citrus varieties, which is consistent with the predominance of volatile compounds detected by GCMS. The chemical composition, dominated by monoterpenes, indicates that Sundai orange oil has potential for use as a flavoring agent in the food and beverage industry, an aromatherapy agent, a natural antimicrobial, and an antioxidant.

Analysis of the chemical components of Sundai oil using Gas Chromatography Mass Spectrometry revealed the presence of various volatile compounds dominated by the terpenoid group, particularly monoterpenes and their derivatives. Based on the chromatogram data, at least 10 major peaks with different retention times were detected, representing the constituent components of the essential oil. The identified compounds include 3-Carene, (+)-Carene, γ -Terpinene, Octanal, bicyclic

compounds (bicyclo[3.1.1]heptane and its derivatives), and Nonyl chloroformate (a minor component).



Peak	R.Time	Area (%)	Compound Name
1	7.474	1.40	Bicyclo[3.1.0]hex-2-ene
2	7.733	3.780	(1R)-2,6,6-Trimethylbicyclo
3	9.032	4.90	Bicyclo[3.1.0]hexane,
4	9.258	11.41	3-Carene
5	9.549	3.39	Bicyclo[3.1.1]heptane,
6	9.964	0.50	Octanal
7	11.266	41.17	Cyclobutane,1,2-bis(1-methylethenyl
8	12.050	16.47	γ -terpinene
9	12.253	0.30	Nonyl chloroformate
10	12.743	2.02	4-Carene

Figure 4. Chromatogram results for Sundai oranges

The presence of compounds such as γ -terpinene and carene indicates that sundai orange oil exhibits the characteristic profile of citrus essential oils, namely a composition dominated by monoterpene hydrocarbons ($C_{10}H_{16}$). Additionally, the presence of aldehydes such as octanal contributes to the fresh, citrus-like aroma.

Based on the percentage of area (Area%), the main component in this oil is found at peak 7 (41.17%), namely a Cyclobutane (presumed to be a monoterpene derivative). Peak 8 (16.47%) contains γ -terpinene, peak 4 (11.41%) contains 3-carene, while other components are present in smaller amounts (<10%). The dominance of one or two major components is a common characteristic of essential oils, where major compounds play a significant role in determining the oil's physical, chemical, and aromatic properties.

The prevalence of monoterpenes indicates that sundai oil is a highly volatile essential oil with a strong aroma. Monoterpenes such as γ -terpinene and carene are known to possess antioxidant and antimicrobial properties and to contribute to citrus and woody aromas. Meanwhile, aldehydes such as octanal contribute to the fresh, sharp aroma commonly found in orange peel oil.

Compared to various studies on other citrus oils (e.g., Citrus sinensis, Citrus aurantifolia, and Citrus reticulata), the composition of the essential oil is generally dominated by limonene (60–90%) as the main component, followed by γ -terpinene, β -pinene, and myrcene in smaller amounts.

However, in these results, limonene does not appear as the dominant component; instead, it is replaced by bicyclic compounds and carene. This may be due to differences in the species or variety of Sundai oranges, the essential oil extraction method, the material's maturity stage, and genetic variations among the plants. This phenomenon indicates that sundai oranges have a chemical profile distinct from that of typical commercial oranges, potentially possessing unique aromatic characteristics and biological activities.

4. CONCLUSION

The results of this study indicate that essential oil from Sundai peel is more optimum than other varieties because it has a peel composition of $34.213 \pm 0.20\%$, a moisture content of $64.482 \pm 0.75\%$, a yield of $0.779 \pm 0.03\%$, and a density of $0.839 \pm 0.003\%$. GC-MS analysis indicates that Sundai essential oil consists of volatile compounds dominated by monoterpenes, with the main components being bicycloalkanes and carene derivatives. This composition differs from that of typical orange oils, which are usually dominated by limonene, indicating the Sundai's unique characteristics. These variations are likely influenced by genetic, environmental, and extraction-method factors and offer broad potential applications in the food, pharmaceutical, and cosmetic industries.

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