



# Analysis of Essential Oil Content from Cajuput Leaves (*Melaleuca leucadendra*) Using Soxhlet Extraction: Comparison of Ordinary Water and Methanol Solvents

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The manuscript was received on November 17<sup>th</sup>, 2025, revised on December 3<sup>rd</sup>, 2025, and accepted on January 05<sup>th</sup>, 2026, date of publication February 02<sup>nd</sup>, 2026

## Abstract

This research aims to quantitatively analyze the essential oil content extracted from *Melaleuca leucadendra* leaves using the Soxhlet method, and to evaluate and compare the efficiency of ordinary water (*aquadest*) and methanol as solvents based on the resulting essential oil yield and the co-extracted secondary metabolite compounds (total phenolics). The study employed a comparative-experimental design focusing on two primary independent variables: the type of solvent (ordinary water and methanol) and the solvent-to-cajuput leaf ratio (1:1 and 1:2), in addition to comparing local and imported cajuput leaf types. Soxhlet extraction was consistently carried out for 190 minutes. The samples were analyzed through qualitative phytochemical screening to identify flavonoids and tannins, as well as quantitative analysis for the determination of Total Phenolic Content (TPC) using the Folin-Ciocalteu spectrophotometric method and LC/MS analysis. Test results showed that cajuput leaf extracts contain flavonoids, tannins, and phenolic compounds in all samples. Imported cajuput leaves consistently exhibited a higher content of bioactive compounds compared to local leaves. The methanol solvent proved to be more effective than distilled water across all parameters, attributed to its optimal polarity for dissolving both polar and semi-polar compounds. The most optimal condition for obtaining the highest content of secondary metabolite compounds was found to be the combination of imported leaves, methanol solvent, and a 1:6 ratio.

**Keywords:** *Aquadest*, *Cajuput Leaves*, *Methanol*, *Soxhlet*, *Total Phenolics*

## 1. Introduction

Indonesia, positioned uniquely within the tropical belt, possesses immense natural biodiversity that presents substantial opportunities for the development of industries based on sustainable resources. Among the high-value, non-timber forest products, essential oils are of particular economic significance. These volatile compounds, known for their distinct aroma and pharmacological properties, are extensively utilized across the pharmaceutical, cosmetic, food flavoring, and *green chemistry* sectors [1][2]. The growing global consumer demand for natural ingredients further underscores the urgency to optimize the exploration and utilization of Indonesian essential oil-producing flora.

One such highly valuable plant that is endemic to the region and widely cultivated is Cajuput (*Melaleuca leucadendra*). The leaves of this plant are the primary source of cajuput essential oil, which has been documented for its broad spectrum of bioactivities, including antiseptic, anti-inflammatory, and expectorant properties [3]. The therapeutic efficacy of the oil is primarily attributed to its major chemical constituents, notably 1,8-cineole (eucalyptol) and alpha-terpineol, with the concentration of 1,8-cineole often reported to be as high as 77.40% [4]. Furthermore, the essential oil's chemical profile can vary significantly depending on genetic factors, environmental conditions, and the specific extraction method employed [5].

To isolate the essential oil and other desired bioactive compounds efficiently from the plant matrix, the selection of the extraction technique is crucial [6]. The process of extraction is fundamental in chemical analysis, involving the separation of soluble constituents from the insoluble material using an appropriate liquid solvent. Soxhlet extraction remains a conventional benchmark method in laboratories for solid-liquid extraction. Its principle, which involves the continuous circulation of hot solvent, ensures exhaustive extraction and high yield efficiency while minimizing the total volume of solvent required [7][8]. Despite its efficiency, the Soxhlet method inherently involves



prolonged exposure to high temperatures, posing a risk of thermal degradation to heat-sensitive phytochemicals, such as certain polyphenols and flavonoids [9]

Beyond the method itself, the selection of the solvent is arguably the most critical variable that determines the final yield and the resulting chemical composition of the extract [10][11]. Solvent properties, including polarity, dictate the selective dissolution of target compounds. This research focuses on a crucial comparative study involving two distinct solvents with differing characteristics: 1. Ordinary Water: As a highly polar, inorganic, and environmentally benign solvent (*green solvent*), water is ideal for extracting highly polar, hydrophilic compounds. Its use is preferable from a sustainability standpoint. 2. Methanol: While also polar, methanol is an organic solvent that possesses a broader spectrum of dissolving power. It is highly effective in isolating semi-polar compounds, including many secondary metabolites, which often translates to a higher overall extraction efficiency compared to pure water for complex plant matrices [12].

This comparison is vital because the *M. leucadendra* extract comprises not only the volatile essential oils but also non-volatile secondary metabolites such as total phenolics and flavonoids [2][13]. These non-volatile compounds contribute significantly to the extract's antioxidant capacity and overall stability [14][15]. Comparative studies are essential to assess the efficiency of water versus methanol in isolating both the essential oil and these valuable bioactive compounds.

By performing a rigorous analysis using the Soxhlet method examining the trade-offs between the environmentally preferable water and the high-efficiency methanol this study seeks to address a critical gap in optimizing the processing protocol for *M. leucadendra*. Such optimization is key to enhancing the final product quality and increasing the economic viability of this sustainable Indonesian natural resource.

The specific objectives of this study are therefore established as follows to quantitatively analyze the essential oil content extracted from *Melaleuca leucadendra* leaves using the Soxhlet method and to evaluate and compare the efficiency of ordinary water and methanol as solvents based on the resulting essential oil yield and the co-extracted secondary metabolite compounds (total phenolics). The findings are anticipated to provide fundamental data for the development of a more efficient and quality-driven essential oil extraction process in the tropical resources industry.

## 2. Literature Review

The utilization of natural resources, particularly plants yielding essential oils, has become a core focus within the global pharmaceutical, cosmetic, and *green chemistry* sectors. Essential oils are complex, volatile, and oily fluids synthesized by plants via secondary metabolic pathways, primarily the mevalonate (MVA) and methylerythritol phosphate (MEP) pathways [1]. These compounds are generally classified as terpenoids specifically monoterpenes (C<sub>10</sub>) and sesquiterpenes (C<sub>15</sub>) [2] and phenylpropanoids. The significant commercial value of essential oils stems not only from their characteristic aroma but also from their broad spectrum of biological activities, encompassing antimicrobial, anti-inflammatory, and antioxidant properties, making them indispensable for various therapeutic and industrial applications [15].



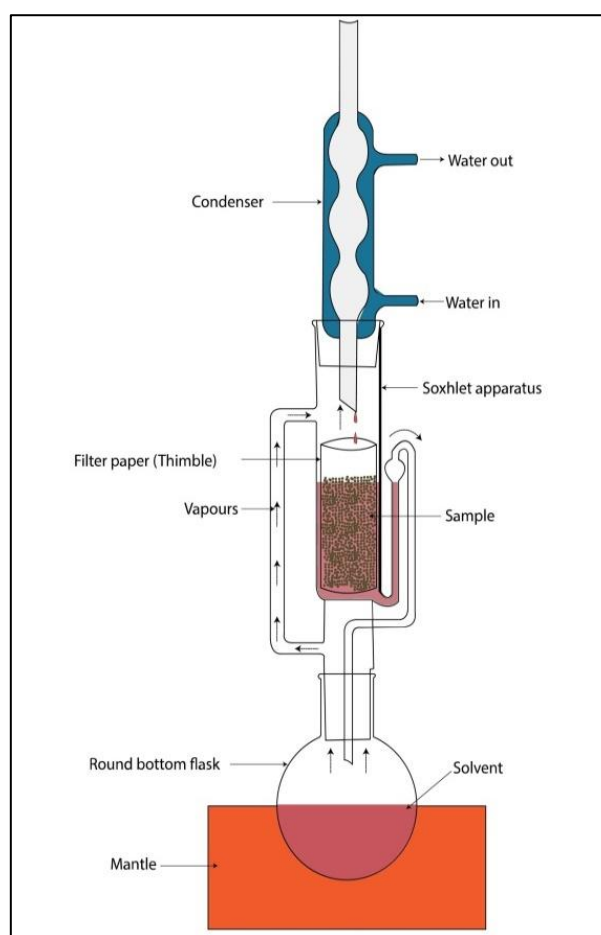
**Fig 1.** *Melaleuca leucadendra* leaves as the main raw material for essential oil extraction: *Melaleuca leucadendra* leaves exhibit an oblong to lanceolate morphology and serve as the primary storage location for essential oil sacs. The physical condition and drying process of the leaves critically determine the efficiency of subsequent extraction.

Cajuput (*Melaleuca leucadendra*) stands as a strategic commodity in tropical regions like Indonesia, where the oil extracted from its leaves

has been historically and widely used as an effective topical antiseptic, expectorant, and analgesic [3]. The quality and therapeutic efficacy of cajuput oil are predominantly governed by the concentration of its key active component, 1,8-cineole (*eucalyptol*). This monoterpene oxide imparts the characteristic camphoraceous scent and is responsible for the oil's primary therapeutic effects. Industrial and pharmacological standards typically require 1,8-cineole content to be maintained above 70% to ensure product efficacy and purity [4]. Optimal extraction methodologies are therefore required to maximize the yield and purity of this specific component while preserving the integrity of others, such as  $\alpha$ -terpineol and *p*-cymene.

The chemical composition of essential oils is highly susceptible to chemotype variation, meaning the concentration and ratio of active compounds are significantly influenced by environmental and geographic factors, including climate, soil composition, and altitude [5]. This inherent variability creates significant quality control challenges. Specifically, comparing locally sourced *Melaleuca leucadendra* leaves with imported raw material is essential. Imported leaves may originate from different geographic locations, possessing distinct chemotypes, and thus may yield significantly different essential oil concentrations and 1,8-cineole ratios [14]. This comparative study is critical to provide empirical data to the industry regarding which raw material source is the most stable and efficient for thermal extraction processes [16].

To effectively isolate these active compounds from the rigid plant cell matrix, Soxhlet extraction is often the preferred technique for achieving exhaustive extraction. The Soxhlet principle relies on a closed-loop mechanism involving the continuous cycling of heated, condensed, and purified solvent over the solid sample. This sustained, high-temperature washing process maintains a steep concentration gradient between the solvent inside the plant cells and the surrounding solvent, which maximizes the rate of mass transfer as governed by Fick's Law of Diffusion [7][8]. The high efficiency of the Soxhlet method makes it an ideal tool for this study, as it effectively standardizes the extraction completeness when comparing the two distinct raw material sources (local vs. imported) [6]. Nevertheless, the method's primary drawback is the prolonged exposure to elevated temperatures, which poses a considerable risk of thermal degradation to heat-sensitive phytochemicals, particularly various polyphenols and flavonoids [9][17].



**Fig 2.** Schematic diagram of the Soxhlet extraction apparatus: The Soxhlet apparatus comprises a round-bottom flask (A), a thimble or sample chamber (B), and a condenser (C). The cyclic action of the heated solvent ensures efficient extraction, but the prolonged heat exposure must be considered when evaluating the stability of thermolabile compounds.

Beyond methodology, the selectivity of the solvent is the single most critical factor determining extraction efficiency [10]. Solvent polarity, quantified by its dielectric constant ( $\epsilon$ ), dictates the range of compounds it can effectively dissolve. This research focuses on the comparative analysis between Ordinary Water ( $\epsilon = 78.5$ ) and Methanol ( $\epsilon = 33.0$ ). Water, being highly polar and an environmentally

favorable *green solvent*, is strictly selective for highly hydrophilic compounds. However, its efficacy is limited for semi-polar compounds like monoterpenoids. Conversely, Methanol, a polar organic solvent, exhibits a wider dissolving power spectrum. Its moderate polarity enables it to interact with compounds ranging from highly polar to semi-polar. This broader efficiency, often detailed using Hansen Solubility Parameters (HSP), generally results in higher total extract yields from complex botanical matrices compared to pure water [12]. The study will empirically test if methanol's wider solubility provides a significant advantage over water in the co-extraction of both the essential oil and other key bioactive compounds.

**Table 1** Differences in solvent capability (polarity) in extracting compounds from the cellular matrix

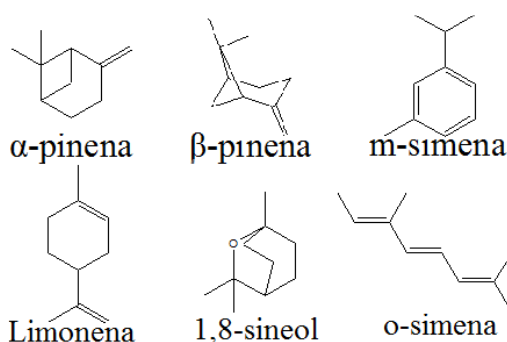
Solvent	Chemical Formula	Boiling Point	Dielectric Constant	Density
<b>Non – Polar Solvents</b>				
Hexane	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	69 °C	2.0	0.655 g/mL
Benzene	C <sub>6</sub> H <sub>6</sub>	80 °C	2.3	0.879 g/mL
Toluene	C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>	111 °C	2.4	0.867 g/mL
Diethyl ether	CH <sub>3</sub> CH <sub>2</sub> OCH <sub>2</sub> CH <sub>3</sub>	35 °C	4.3	0.713 g/mL
Chloroform	CHCl <sub>3</sub>	61 °C	4.8	1.498 g/mL
Ethyl acetate	CH <sub>3</sub> C(O)OCH <sub>2</sub> CH <sub>3</sub>	77 °C	6.0	0.894 g/mL
<b>Polar Aprotic Solvents</b>				
Hexane	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub>	69 °C	2.0	0.655 g/mL
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<b>Polar Protic Solvents</b>				
Acetic acid	CH <sub>3</sub> C(O)OH	118 °C	6.2	1.049 g/mL
n-Butanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> OH	118 °C	18	0.810 g/mL
Isopropanol (IPA)	CH <sub>3</sub> CH(OH)CH <sub>3</sub>	82 °C	18	0.785 g/mL
n-Propanol	CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> OH	97 °C	20	0.803 g/mL
Ethanol	CH <sub>3</sub> CH <sub>2</sub> OH	79 °C	30	0.789 g/mL
Methanol	CH <sub>3</sub> OH	65 °C	33	0.791 g/mL
Formic acid	H–C(O)OH	100 °C	58	1.21 g/mL
Water	H–O–H	100 °C	80	1.000 g/mL

This schematic illustrates the difference in interaction between water (small, highly polar molecules) which is selective for hydrophilic compounds, and methanol (possessing both hydroxyl and non-polar carbon chain segments) which can extract semi-polar compounds like terpenoids and polyphenols.

The functional quality of the *M. leucadendra* extract must be measured beyond the volatile essential oil content. The co-extraction of non-volatile secondary metabolites, primarily Total Phenolics and Flavonoids, is critical. These polyphenols act as potent natural antioxidants, essential for stabilizing the essential oil against oxidative degradation and contributing significantly to the extract's therapeutic potential [2][13]. Total Phenolic Content (TPC), quantified using the Folin-Ciocalteu assay, serves as the standard proxy for assessing the antioxidant capacity of the extract [15].

To accurately validate the solvent and raw material comparison, precise quantitative analytical methods are indispensable. The primary essential oil component, 1,8-cineole, must be measured using a chromatographic technique, typically Gas Chromatography-Mass Spectrometry (GC-MS). GC-MS allows for simultaneous identification and quantification of volatile components based on their unique retention times and mass fragmentation patterns. This method is crucial to ensure that the extracted essential oil from both local and imported leaves meets the required purity and compositional standards [4]. Furthermore, TPC determination is performed using the spectrophotometric Folin-Ciocalteu method. This assay relies on the reduction of a phosphomolybdate-phosphotungstate complex by phenolic hydroxyl groups under alkaline conditions, yielding a blue product whose absorbance is measured, typically at 765 nm. This result is then converted using a gallic acid calibration curve, providing reliable quantitative data on the extract's antioxidant potential [15].





**Fig 3.** Chemical Structure of 1,8-Cineole (*Eucalyptol*) : 1,8-cineole, a monoterpene oxide with molecular formula  $C_{10}H_{18}O$ , serves as the marker for the quality and bioactivity of *Cajuput* oil. Its semi-polar structure explains why its solubility is significantly influenced by the choice of solvent, such as Methanol compared to Water.

This research carries significant implications for green chemistry and industrial optimization. The potential success of using water as a solvent in Soxhlet extraction would offer an environmentally friendly alternative, reducing operational costs and eliminating the need for toxic organic solvents [18]. Although water is the ideal green solvent, its limited efficacy for semi-polar terpenoids often leads industries to rely heavily on organic solvents. Furthermore, the current knowledge gap lies in the lack of empirical data that simultaneously integrates all three variables: high-temperature Soxhlet extraction, the Water vs. Methanol comparison, and the critical Local vs. Imported raw material variation. Previous studies typically focus on only one or two variables. By testing the complex interactions between geographic origin and solvent selection, this research aims to fill this gap, providing a comprehensive basis for recommending the most efficient extraction protocol for both quantitative essential oil yield and the quality of non-volatile bioactive extracts, ensuring a scientifically-guided approach to raw material sourcing.

### 3. Material and Method

#### 3.1 Plant Material Collection and Preparation

The raw material consisted of *Melaleuca leucadendra* leaves obtained from two distinct geographical sources: (1) Local material, which was collected from Bakungan Purwajaya Village, Loa Janan District, Kutai Kartanegara Regency, East Kalimantan, Indonesia ; and (2) Imported commercial material. The sampling was conducted using a purposive methodology, selecting only mature, undamaged leaves. Plant authenticity was verified and confirmed by botanists at the Mulawarman University Herbarium. Subsequently, the collected leaves were thoroughly washed with distilled water, air-drained, and subjected to mechanical grinding to produce a fine, uniform powder (simplicia).

#### 3.2 Chemical and Reagent

All reagents employed in this study were of analytical grade specifications. The key chemicals included methanol (>99.8% Merck), distilled water, magnesium metal, concentrated hydrochloric acid (37% Merck), potassium hydroxide (>85% Merck), Folin-Ciocalteu reagent (Sigma-Aldrich), anhydrous sodium carbonate (99.5% Merck), and gallic acid standard (>98%, Sigma-Aldrich). A 1% gelatin solution containing sodium chloride was also prepared for tannin identification.

#### 3.3 Soxhlet Extraction Procedure

The extracts of *Melaleuca leucadendra* leaves, prepared using the Soxhlet method with both water and methanol solvents at two different solvent-to-sample ratios (1:4 and 1:6 w/w), were utilized for this analysis. Prior to TPC and LC-MS analysis, a precise amount of the dried extract (0.8 g) was accurately dissolved in 10 mL of methanol and homogenized in a 25 mL volumetric flask.

#### 3.4 Total Phenolic Content (TPC) Determination

The Total Phenolic Content (TPC) was quantified colorimetrically using the established **Folin-Ciocalteu assay**. A 2 mL aliquot of the methanolic extract solution was mixed with 0.4 mL of the Folin-Ciocalteu reagent and allowed to stand for an initial 8 minutes. Subsequently, 4 mL of a 7 % sodium carbonate solution was introduced, and the final volume was adjusted to 10 mL with distilled water. The mixture was then incubated for 2 hours at ambient temperature in the dark to ensure complete color development. The absorbance was recorded at a maximum wavelength of  $\lambda = 760$  nm using a UV-Vis spectrophotometer (Model specified in the full paper). A calibration curve was generated using standard gallic acid solutions (2, 4, 6, and 8 ppm). The TPC was calculated from the linear regression of the standard curve and expressed as milligrams of gallic acid equivalents per gram of extract (mg GAE/g). All determinations were performed in triplicate [19].



### 3.5 LC-MS Analysis

Preparation of Gallic Acid Standard Solution Quantitative analysis for Total Phenolic Content (TPC) was based on a standard curve generated using Gallic Acid. A stock solution of 1000 ppm Gallic Acid in 96% methanol was prepared and then diluted to a working stock of 50 ppm. Subsequent calibration standards were prepared at 4, 6, and 8 ppm. To each standard, 7% Na<sub>2</sub>CO<sub>3</sub> solution was added and thoroughly homogenized. The Na<sub>2</sub>CO<sub>3</sub> addition is crucial as it generates the alkaline medium required for the reduction of the Folin-Ciocalteu reagent by the phenolic hydroxyl groups in the samples [20]. The final volume was adjusted to 10 mL with sterile aquadest, and the standards were incubated for 2 hours at room temperature. The determination of Total Phenolic Content by Spectrophotometry was done at 760 nm. For the TPC quantification, 0.8 g of the cajuput leaf extract was accurately weighed into a 25 mL volumetric flask, dissolved in 10 mL of methanol, homogenized, and diluted. A 2 mL aliquot of this processed solution was taken, treated with 0.4 mL of Folin-Ciocalteu Reagent, briefly shaken, and allowed to stand for 8 minutes. Following this, 4 mL of Na<sub>2</sub>CO<sub>3</sub> solution was added and homogenized. The mixture was brought up to a final volume of 10 mL with aquadest and incubated for 2 hours at room temperature. The absorbance was then measured at 760 nm to determine the TPC relative to the Gallic Acid standard curve. LC/MS Analysis. The LC/MS technique was utilized as an advanced method to identify and quantify specific non-volatile secondary metabolite compounds. This process provides a detailed chemical fingerprint, separating complex mixtures (LC) before structural confirmation and quantification based on the mass-to-charge ratio (MS). This analysis is essential for comparing the selective extraction efficiency of methanol versus aquadest for individual bioactive constituents.

## 4. Result and Discussion

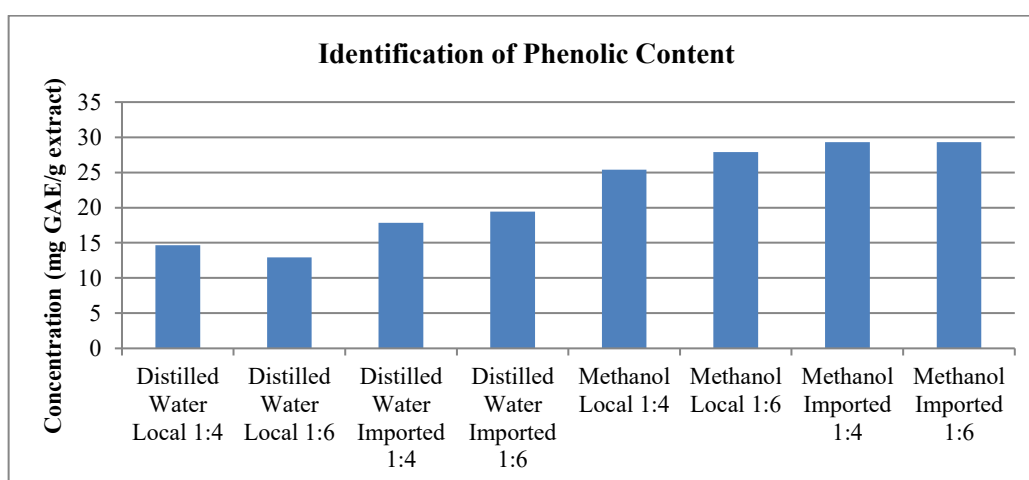
The essential oil extraction from cajuput leaves (*Melaleuca leucadendra*) in this experiment aims to compare the effectiveness of two types of solvents, namely distilled water and methanol, in the extraction process. This comparison was conducted to determine the more optimal solvent for extracting the active compounds from the cajuput leaves. The effectiveness of each solvent was demonstrated through a series of both qualitative and quantitative tests, which included the identification of bioactive compounds such as flavonoids as well as the analysis of total phenolic content using spectrophotometry and the testing of secondary metabolite compounds.

### 4.1 Identification of Phenolic Content in Cajuput Leaf Extracts

Based on the results of the phenolic content test presented in Table 2 and Figure 4, the cajuput leaf extracts indicated the presence of phenolics across all samples. However, the resulting phenolic intensity varied depending on the solvent type, leaf source, and solvent ratio. These results can be observed through the total phenolic concentrations obtained.

**Table 2.** Results of Phytochemical Screening Test (Phenolic Identification)

No	Type of Leaf	Solvent	Extraction Ratio	Absorbance (ABS)	Concentration (mg GAE/g extract)	Phenolic Indication
1	Water	Local	1:4	0.742	14.68	Moderate
			1:6	0.645	12.92	Low
		Imported	1:4	0.890	17.83	Moderate
			1:6	0.967	19.42	Moderate-High
2	Methanol	Local	1:4	1.265	25.40	High
			1:6	1.386	27.91	High
		Imported	1:4	1.520	28.93	High
			1:6	1.533	29.29	High



**Fig. 4** Results of Phytochemical Screening Test (Flavonoid Identification)



Figure 4 clearly shows that the methanol solvent consistently yielded higher phenolic concentration values compared to the distilled water solvent. The local leaf extract processed with methanol at a solvent ratio of 1:6 produced a significantly greater phenolic concentration, namely 27.91 mg GAE/g, when compared to the distilled water solvent at the same ratio, which yielded a concentration of only 2.92 mg GAE/g.

The same trend was observed in the imported leaves, where methanol extracted a higher amount of phenolics compared to distilled water. The phenolic concentrations in the imported leaves at ratios of 1:4 and 1:6 were 29.30 mg GAE/g and 29.29 mg GAE/g respectively. These values are significantly higher than those obtained using the distilled water solvent, which resulted in lower phenolic concentrations at the corresponding solvent ratios, specifically 17.38 mg GAE/g and 19.42 mg GAE/g}, respectively.

The test results in Table 2 and Figure 4 demonstrate that the methanol solvent is highly effective in extracting phenolic compounds. This is attributed to the superior polarity of methanol in dissolving phenolic compounds compared to distilled water. The 1:6 solvent ratio generally yielded a lower number of phenolic compounds compared to the 1:4 ratio. The type of cajeput leaf also influenced the resulting phenolic concentration, with imported cajeput leaves producing a higher phenolic content than the local cajeput leaf type.

### 4.2 Identification of Secondary Metabolite Compounds in Cajeput Leaves

Based on the secondary metabolite compound content test results presented in Table 3 and Figure 5, the cajeput leaf extracts indicate that extraction using the methanol solvent yielded optimal absorbance, consequently resulting in a higher phenolic concentration, particularly at the 1:6 ratio. The imported leaf type, when extracted with methanol at the 1:6 concentration, produced an average of 22.6791 mg GAE/g, which is the highest sample concentration value compared to the other samples. Conversely, the distilled water solvent yielded a lower phenolic concentration, even though its absorbance value was relatively high. This outcome suggests that although the extract compounds were capable of absorbing light at the specified wavelength, not all components contained within the sample were phenolic compounds.

Table 3. Secondary Metabolite Content Test Results using the LC/MS Method

No	Solvent	Type of Leaf	Extraction Ratio	Average Test Concentration (ppm)			Average Absorbance (ABS)			Average Concentration (mg GAE/g)	Average Standard Deviation
				2	4	6	2	4	6		
1	Water	Local	1:4	30.1203	29.5731	6.4105	1.532	1.4985	0.1193	22.0346	0.1032
			1:6	27.8815	26.9963	5.8201	1.4124	1.3668	0.1059	20.2333	0.0945
		Imported	1:4	29.3753	28.4827	6.2136	1.5380	1.4833	0.1121	21.3572	0.1018
			1:6	26.7312	25.8499	5.6112	1.3725	1.3308	0.1023	19.3971	0.0912
2	Methanol	Local	1:4	9.1432	8.0111	31.5237	0.2883	0.2015	1.6123	16.226	0.0613
			1:6	30.8125	29.2376	6.4253	1.5982	1.5116	0.1238	22.1585	0.0992
		Imported	1:4	8.8306	7.628	30.0799	0.2734	0.216	1.5815	15.5128	0.0597
			1:6	31.4138	30.0252	6.5984	1.6636	1.5902	0.1311	22.6791	0.1037

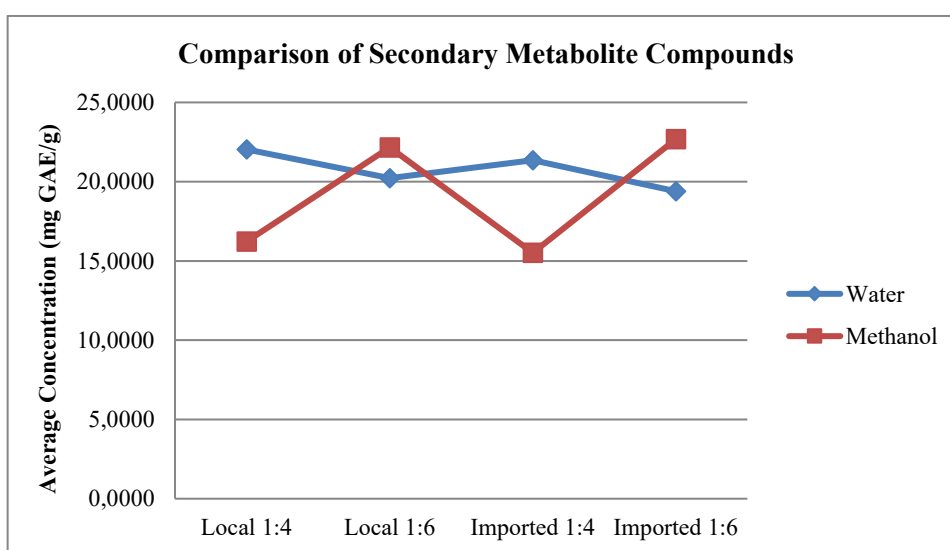


Fig. 5 Secondary Metabolite Compound Content Test Results



The comparison of leaf sources also significantly affects the concentration of secondary metabolite compounds present in the extract. Imported leaf types tend to produce a higher concentration of secondary metabolite compounds compared to the local cajeput leaves, especially when extracted using the methanol solvent. The standard deviation across all samples was relatively low, specifically less than 0.11, indicating that the test repetitions were relatively stable and the obtained data is reliable.

## 5. Conclusion

The findings of this study confirm that all cajeput leaf extracts contain flavonoids, tannins, and other secondary metabolites, though the intensity varies significantly based on the solvent type, leaf source, and ratio. The imported cajeput leaves consistently exhibited a higher content of bioactive compounds than the local leaves, evidenced by the deeper color intensity in the assays. In terms of efficiency, the methanol solvent consistently proved to be more effective than distilled water across the parameters (total phenolics). Methanol's superior performance is attributed to its optimal polarity, which allows it to thoroughly dissolve polar and semi-polar compounds such as flavonoids and tannins. Specifically, methanol produced the highest phenolic concentration when used with imported leaves at both 1:4 and 1:6 ratios. Furthermore, the 1:6 solvent ratio often maximized the extraction yield for flavonoids and tannins, demonstrating that the combination of imported leaves, methanol solvent, and a 1:6 ratio provides the most optimal condition for extracting the highest content of secondary metabolite compounds.

## Acknowledgement

The authors gratefully acknowledge the Faculty of Engineering and Chemical Engineering Department, Universitas Mulawarman, for providing laboratory facilities and technical support. Special appreciation is extended to the laboratory staff for their assistance throughout the experimental work.

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