



RESEARCH ARTICLE

Phytochemical screening of secondary metabolite compounds in tammate leaf extract (*Lannea coromandelica* (HOUTT.) MERR.) from Pangkep Regency using various extraction methods

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Abstract

Lannea coromandelica (Houtt.) Merr., commonly known as Tammate, is a traditional medicinal plant with potential as a source of bioactive compounds. This study aimed to identify the secondary metabolite content in ethanol extracts of Tammate leaves using four different extraction methods: infusion, maceration, reflux, and Soxhlet extraction. The research methodology involved extracting the plant material with each technique, followed by phytochemical screening through color reactions and Thin Layer Chromatography (TLC). The results showed that the reflux method yielded the highest extract percentage at 18.77%, followed by maceration at 13.08%, Soxhlet at 5.14%, and infusion at 3.94%. Phytochemical screening indicated that reflux and maceration were more effective in extracting alkaloids, flavonoids, phenolics, tannins, saponins, and steroids, as confirmed by both color reactions and TLC. In contrast, the infusion method showed the least effectiveness. These findings emphasize the importance of selecting appropriate extraction methods to optimize the isolation of bioactive compounds. The implications of this study support the development of efficient extraction techniques in the natural-based pharmaceutical industry and contribute to the utilization of local Indonesian medicinal plants. Further research is recommended to conduct quantitative analyses of the main compounds and to evaluate the pharmacological activities of the extracts.

Keywords: *Lannea coromandelica*, Secondary metabolites, Extraction methods, Phytochemical screening, Thin Layer Chromatography, Traditional medicinal plants

INTRODUCTION

Indonesia is recognized as one of the countries with the highest biodiversity levels in the world, classified as a megadiverse nation alongside Brazil and Congo. Data from the Ministry of Environment and Forestry (KLHK) indicates that Indonesia is home to approximately 30,000 plant species, around 7,500 of which possess potential as medicinal plants (KLHK, 2020). This rich floral diversity has

been traditionally utilized across generations in empirically-based medicinal practices, using raw materials derived from plants, animals, and minerals. Traditional medicine is not only an integral part of cultural heritage but also holds significant potential for the development of natural-based pharmaceutical products in the modern era (WHO, 2019).

Medicinal plants contain various types of primary and secondary metabolites, which play crucial roles in supporting biological activity and acting as natural defense mechanisms against herbivores, pathogens, and environmental stress (Harborne, 1996; Mindarti & Bebet, 2015). Primary metabolites include carbohydrates, amino acids, and lipids, which are directly involved in plant growth and development. Meanwhile, secondary metabolites such as alkaloids, flavonoids, saponins, tannins, terpenoids, and phenolics function as chemical defenses against herbivores, pathogenic microorganisms, and as attractants for pollinators (Crozier et al., 2006; Wink, 2010).

Flavonoids, one of the most abundant groups of secondary metabolites, are known for their strong antioxidant activity, free radical scavenging ability, and

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their role in providing bright colors to flowers and fruits to attract pollinators (Panche et al., 2016). Saponins exhibit antimicrobial and antifungal properties and can increase the permeability of microbial cell membranes (Augustin et al., 2011). Tannins act as antibacterial and antidiarrheal agents by precipitating proteins, while alkaloids display a wide range of biological activities, including analgesic, anticancer, and antiparasitic properties (Dixon & Paiva, 1995; Wink, 2003).

One of the medicinal plants widely utilized by Indonesian communities, particularly in South Sulawesi, is Tammate (*Lannea coromandelica* (Houtt.) Merr.). This plant belongs to the Anacardiaceae family and is well-known across various tropical regions of Asia. Empirically, the leaves and bark of *L. coromandelica* have been used to treat burns, skin infections, diarrhea, and other health disorders (Isriany et al., 2016; Sarah et al., 2018; Avinash et al., 2011).

Several previous phytochemical studies have identified bioactive compounds in Tammate leaves, such as flavonoids, polyphenols, saponins, tannins, and steroids, which are known to exhibit various pharmacological activities. Flavonoids and polyphenols function as strong antioxidants, protecting cells from oxidative damage (Sathish, 2010; Halima et al., 2019). Additionally, saponins and tannins in Tammate leaves have been reported to exhibit antimicrobial effects, while steroids show potential anti-inflammatory and immunomodulatory properties (Paramudita et al., 2017; Erwin, 2014).

However, studies related to the optimization of extraction methods for secondary metabolites from Tammate leaves remain limited. The effectiveness of the extraction method significantly influences both the yield and quality of bioactive compounds obtained. Cold extraction methods such as maceration are commonly used due to their simplicity and ability to preserve heat-sensitive compounds, albeit requiring longer durations (Agustinus & Hulupi, 2014). Conversely, hot extraction methods like reflux and Soxhlet extraction can enhance extraction efficiency through continuous solvent heating and circulation but carry the risk of degrading thermolabile compounds (Jain et al., 2009; Azwanida, 2015). Therefore, this research is essential to evaluate the most optimal extraction method for effectively obtaining secondary metabolites, thereby supporting the scientific development of herbal medicines and enriching Indonesia's phytochemical database.

Based on this background, the research problem formulated is: which extraction method is most effective in yielding secondary metabolites from the ethanol extract of Tammate leaves (*Lannea coromandelica*)? The objective of this study is to identify the groups of secondary metabolites contained in the ethanol extract of Tammate leaves using various extraction methods (infusion, maceration, reflux, and Soxhlet), as well as to compare the effectiveness of each method.

The significance of this research is expected to serve as a scientific reference for optimizing extraction techniques of medicinal plants, particularly for the herbal pharmaceutical industry, researchers, and students interested in exploring the phytochemical potential of *Lannea coromandelica* for the development of natural-based health products.

METHODS

Time and Place of Study

This research was conducted from September to November 2021 at the Pharmacognosy-Phytochemistry

Laboratory, Department of Pharmacy, Faculty of Mathematics and Natural Sciences, Universitas Islam Makassar.

Tools and Materials

The equipment used in this study included a reflux apparatus (Quickfit, UK), Soxhlet extractor (Pyrex, UK), chromatography chamber (Camag, Switzerland), UV lamps at 254 nm and 366 nm (Camag, Switzerland), silica gel F254 plates (Merck, Germany), macerator (IKA, Germany), infusion pot, water bath (Mettler, Germany), rotary evaporator (Büchi R-300, Switzerland), digital balance (AND GR-200, Japan), and standard laboratory glassware.

The chemicals used were distilled water (H₂O), aluminum chloride (AlCl₃) pro analysis (Merck, Germany), ammonia (NH₃), acetic anhydride ((CH₃CO)₂O), hydrochloric acid (HCl), sulfuric acid (H₂SO₄), ferric chloride (FeCl₃), 70% ethanol (Merck, Germany), Tammate leaves (*Lannea coromandelica* (Houtt.) Merr.), ethyl acetate (C₄H₈O₂), magnesium (Mg), n-hexane (C₆H₁₄), and specific reagents: Dragendorff, Liebermann-Burchard, Mayer, and Wagner.

Sample Collection

Tammate leaf samples were collected from Taraweang Village, Labakkang District, Pangkep Regency (coordinates: S 4°46'30.2232", E 119°36'01.6812"). Botanical identification was conducted at the Herbarium of Hasanuddin University, and the voucher specimen was stored under voucher number UNHAS-LC-2021-001. Leaf collection was carried out in the morning, selecting fresh green leaves, and stored in closed containers to avoid direct sunlight exposure.

Sample Preparation

The Tammate plant parts used were the leaves. Wet sorting was performed to clean the dirt attached to the samples, followed by washing with running water. The leaves were drained and dried without direct sunlight exposure, simply air-dried for three days. The dried leaves were then ground into powder using a blender and sieved with mesh 20 to produce fine Tammate leaf powder.

Extraction Methods

1. Infusion: 100 grams of dried Tammate leaf powder were weighed and placed into an infusion pot. Two times 100 mL of extract water and 1000 mL of water were added. The mixture was heated to 90°C for 15 minutes. After infusion, the result was filtered while hot and evaporated over a water bath until the solvent (water) evaporated.
2. Maceration: 100 grams of Tammate leaf powder were placed in a macerator and moistened with 100 mL of 70% ethanol for 15 minutes, then 900 mL of solvent was added until the powder was fully submerged. The container was sealed and left for 3 × 24 hours at room temperature, protected from sunlight, and stirred occasionally. The mixture was filtered, and the extract was collected, evaporated to obtain a thick extract, and weighed to calculate yield.
3. Reflux: 100 grams of Tammate leaf powder were placed in a round-bottom flask and soaked with 500 mL of 70% ethanol, then refluxed at 50°C for two hours. The residue was re-extracted using 500 mL of solvent with the same procedure. The extract was filtered, concentrated, and the yield percentage calculated.
4. Soxhlet Extraction: 50 grams of Tammate leaf powder were wrapped in filter paper, tied with thread, and placed in the Soxhlet apparatus. 500 mL of 70% ethanol

was added to the round-bottom flask. Soxhlet extraction was performed at 70°C until the siphon cycle became colorless. A second Soxhlet extraction was conducted with another 500 mL of 70% ethanol. The liquid extract obtained was concentrated and the yield percentage calculated.

Identification of Compounds by Color Reaction

The identification of secondary metabolites was performed using phytochemical screening with specific color reagents for each compound group: alkaloids, flavonoids, saponins, tannins, terpenoids, steroids, and phenolics. Each test was conducted in two test tubes, one for the sample and one as a negative control (without reagents) to verify results accurately and minimize false positives. Sensitivity was optimized using freshly prepared reagents and consistent lighting conditions during observation.

1. **Alkaloid Identification;** One gram of Tammate leaf extract was dissolved in 10 mL of 70% ethanol and divided into four test tubes. Mayer, Wagner, and Dragendorff reagents were added to three tubes, while the fourth served as a negative control. Mayer reagent produced a white-yellow precipitate, Wagner reagent yielded a brown precipitate, and Dragendorff reagent resulted in an orange precipitate, indicating the presence of alkaloids (Svehla, 1990; Marlina et al., 2005).
2. **Flavonoid Identification;** 0.5 grams of extract were dissolved in 5 mL of 70% ethanol, divided into two test tubes. The first tube was treated with 5% aluminum chloride (AlCl₃) solution, while the second served as a control. A yellow to red color indicated the presence of flavonoids (Panche et al., 2016; Dyah et al., 2014).
3. **Saponin Identification;** 0.5 grams of extract were dissolved in 5 mL of 70% ethanol, divided into two tubes. The first tube was treated with 5 mL warm water and shaken vigorously for 10 seconds. Stable froth persisting after adding two drops of 2N HCl indicated saponins. The second tube served as a control (Nugrahani et al., 2016).
4. **Tannin Identification;** 0.5 grams of extract were dissolved in 5 mL of 70% ethanol and divided into two tubes. The first tube was treated with magnesium powder and 2N HCl. A blue-black color indicated tannins (Harborne, 1996; Patra & Saxena, 2010).
5. **Terpenoid and Steroid Identification;** One gram of extract was dissolved in 10 mL of 70% ethanol and divided into three tubes. Liebermann-Burchard reagent was added to the first tube, yielding violet to purple color for terpenoids. The second tube, treated with H₂SO₄ and acetic anhydride, produced a bluish-green ring indicating steroids. The third tube served as a control (Marlina & Saleh, 2011; Fath et al., 2016).
6. **Phenolic Identification;** 0.5 grams of extract were dissolved in 5 mL of 70% ethanol and divided into two tubes. The first tube was treated with 1% FeCl₃ solution. A dark green or black color indicated phenolics (Dwi Putri et al., 2018; Harborne, 1996).

All tests were performed in triplicate to ensure data validity and reduce observational bias. Laboratory conditions were kept stable to avoid temperature and humidity effects. The protocols followed Harborne's (1996) phytochemical standards with modifications.

Identification of Compounds by TLC (Thin Layer Chromatography)

TLC analysis was used to qualitatively detect secondary metabolites in Tammate leaf extracts from various extraction methods. Silica gel 60 F254 plates (Merck, Germany) sized 4 × 7 cm were used as the stationary phase.

A lower boundary of 1 cm and an upper boundary of 0.5 cm were marked on the plates to maintain consistency.

The mobile phase was a mixture of n-hexane:ethyl acetate (1:8) totaling 5 mL, selected for its polarity to separate polar and non-polar bioactive compounds (Sasidharan et al., 2011). The plates were developed in ascending mode up to the upper boundary, air-dried, and kept at room temperature to maintain consistency. After development, the plates were observed under UV light at 254 nm and 366 nm (Camag UV lamp) to identify compounds based on fluorescence or quenching spots. The plates were then sprayed with 10% H₂SO₄ and heated at 105°C for 5 minutes to visualize the spots. Identification of compound groups was conducted based on specific reagents:

1. **Alkaloids:** Plates were sprayed with Dragendorff reagent. Orange-brown spots indicated positive alkaloid presence (Sasidharan et al., 2011).
2. **Flavonoids:** Plates were exposed to ammonia vapors and sprayed with 5% aluminum chloride (AlCl₃). Yellow fluorescent spots under UV 366 nm indicated flavonoids (Panche et al., 2016).
3. **Phenolics & Tannins:** Plates were sprayed with 1% FeCl₃ solution. Greenish-black or blue spots indicated phenolics and tannins (McMurry, 2004).
4. **Terpenoids and Steroids:** Plates were sprayed with Liebermann-Burchard reagent. Violet to purple spots indicated terpenoids, while bluish-green spots indicated steroids (Fath et al., 2016).

Observations were conducted in triplicate for each extraction method to ensure reproducibility and validity. Retention factor (Rf) values of each spot were calculated and compared with literature to confirm compound identity (Stahl, 1969). Laboratory conditions were maintained to prevent excess humidity and temperature fluctuations, which could affect component separation.

RESULTS

Table 1 shows the yield results of Tammate leaf extract (*Lannea coromandelica* (Houtt.) Merr.) obtained using four different extraction methods: infusion, maceration, reflux, and Soxhlet extraction. The data indicate significant variations in yield among these methods.

The reflux method yielded the highest extract percentage at 18.77%, suggesting its high efficiency in extracting compounds from Tammate leaves. Factors such as continuous heating and solvent circulation in this method facilitate maximum dissolution of bioactive compounds. Maceration produced a yield of 13.08%, which is also relatively high. Despite the absence of heating, prolonged contact between solvent and plant material allows for substantial extraction of compounds.

Soxhlet extraction showed a yield of 5.14%. Although it involves heating and solvent circulation, its yield is lower compared to maceration and reflux. This may relate to differences in extraction duration or conditions. Infusion resulted in the lowest yield of 3.94%. The use of water as solvent and brief heating period likely limits its extraction efficiency.

Overall, the results suggest that extraction methods incorporating controlled heating and adequate contact time, such as reflux, yield higher extracts, while methods like infusion with minimal heating provide lower yields.

Table 1. Yield Calculation Results of Tammate Leaf Extract (*Lannea coromandelica* (Houtt.) Merr.)

Extraction Method	Sample Type	Sample Weight (g)	Solvent Volume (mL)	Yield Percentage (%)
Infusa	Dried sample	100	1000	3.94
	Dried extract	3.94		
Maserasi	Dried sample	100	1000	13.08
	Thick extract	13.08		
Refluks	Dried sample	100	1000	18.77
	Thick extract	18.77		
Sokhletasi	Dried sample	100	1000	5.14
	Thick extract	100		

Table 2 presents the identification results of secondary metabolites in Tammate leaf extracts through color reaction tests, showing clear differences across extraction methods. Alkaloids were detected in maceration, reflux, and Soxhlet methods, indicated by positive reactions with Mayer, Wagner, and Dragendorff reagents, especially in maceration and reflux. In contrast, alkaloids were not detected in infusion, indicating less favorable conditions for their extraction.

For flavonoids, positive results were obtained in infusion and reflux methods, suggesting stability in both low-temperature aqueous conditions and high-temperature reflux. Phenolic compounds consistently appeared in all four methods, indicating their ease of extraction and

stability. Tannins were only detected in maceration, implying that prolonged extraction without heating favors their presence.

Saponins tested positive across all extraction methods, indicating their solubility and stability under various conditions. Terpenoids were not detected in any method, suggesting their low presence or absence in Tammate leaves. Steroids were detected in maceration, reflux, and Soxhlet methods, but not in infusion, suggesting ethanol-based methods are more effective for their extraction. In summary, maceration and reflux methods appeared most effective for extracting various secondary metabolites, particularly alkaloids, phenolics, saponins, and steroids, compared to infusion and Soxhlet extraction.

Table 2. Phytochemical Screening Results (Color Reaction) of Tammate Leaf Extract (*Lannea coromandelica* (Houtt.) Merr.)

Compound Identification	Extraction Method			
	Infusion	Infusion	Infusion	Infusion
Alkaloid:				
1. Mayer	-	+	+	-
2. Wagner	-	+	+	-
3. Dragendraft	+	+	+	+
Flavonoid	+	-	+	-
Phenolic	+	+	+	+
Tannin	-	+	-	-
Saponin	+	+	+	+
Terpenoid	-	-	-	-
Steroid	-	+	+	+

Table 3. Phytochemical Screening Results (Chromatography) of Tammate Leaf Extract (*Lannea coromandelica* (Houtt.) Merr.)

Compound Identification	Reagent	Extraction Method			
		Infusion	Infusion	Infusion	Infusion
Alkaloid	Dragendraf	-	-	+	-
Flavonoid	AlCl ₃ + uv 366	-	+	+	+
Phenolic	FeCl ₃	-	+	+	-
Tannin	FeCl ₃	-	+	+	-
Terpenoid	Liebermann-Burchard	-	+	+	-
Steroid	Liebermann-Burchard	-	+	+	+

The results of secondary metabolite identification using Thin Layer Chromatography (TLC) in Table 3 reveal that extraction methods influence the types of compounds detected in Tammate leaf extracts. The infusion method did not detect any compounds, including alkaloids, flavonoids, phenolics, tannins, terpenoids, or steroids, indicating its inefficiency. Conversely, maceration detected five classes of compounds: flavonoids, phenolics, tannins, terpenoids, and steroids, demonstrating its capability to dissolve polar and semi-polar compounds. The absence of alkaloids in maceration indicates that prolonged, non-heated extraction may be less effective for alkaloids.

The reflux method yielded the most comprehensive results, detecting all six compound groups. This highlights

the effectiveness of heating in enhancing extraction of bioactive compounds, especially those requiring heat for optimal dissolution. Soxhlet extraction only detected flavonoids and steroids, suggesting limited effectiveness despite heating and solvent circulation, possibly due to non-optimal conditions. Overall, TLC results suggest that reflux and maceration methods outperform infusion and Soxhlet in extracting and detecting bioactive compounds from Tammate leaves, with reflux consistently providing the most comprehensive detection.

Based on the phytochemical test results illustrated in Figures 1 to 7, each test positively indicated the presence of specific compounds in Tammate leaf extracts. Figure 1 shows a positive alkaloid test using Mayer reagent,

indicated by yellowish-white precipitate, suggesting potassium-alkaloid complex formation. Figure 2's Wagner test resulted in light brown precipitate, denoting interaction between metal ions and alkaloid nitrogen. Similarly, Figure 3's Dragendorff test displayed an orange precipitate from alkaloid interaction with Bi^{3+} ions.

Figure 4 illustrates the phenolic test using FeCl_3 , with dark black coloration indicating complex formation between Fe^{3+} ions and phenolic hydroxyl groups. Figure 5 shows the tannin test using magnesium and HCl, producing blue-black coloration, confirming tannin presence. In Figure 6, the saponin test exhibited stable froth formation after shaking with water, indicating saponin presence, further confirmed by froth stability after HCl addition. Finally, Figure 7 depicts terpenoid and steroid tests with Liebermann-Burchard reagent, where violet spots indicated terpenoids and bluish-green coloration signaled steroid presence.

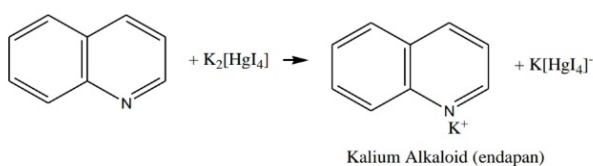


Figure 1. Mayer's Test Reaction (McMurry, 2004)

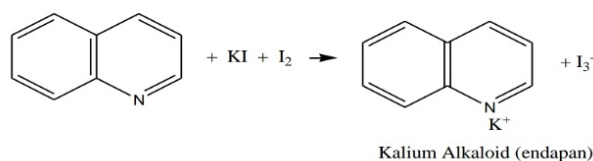


Figure 2. Wagner's Test Reaction (Marliana et al., 2005)

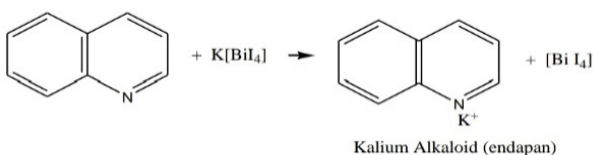


Figure 3. Dragendorff's Test Reaction (Miroslav, 1971)

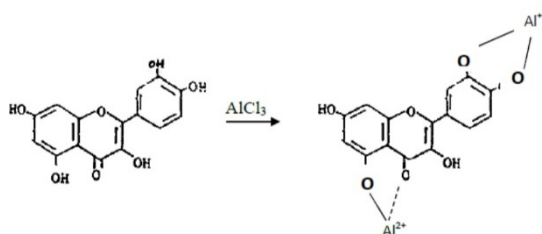


Figure 4. Formation of Aluminum Chloride Complex Compound (Dyah et al., 2014)

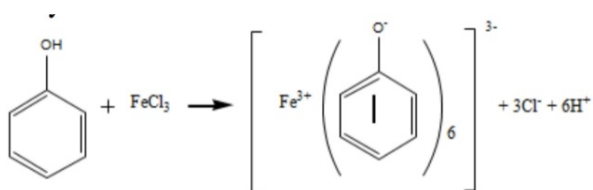
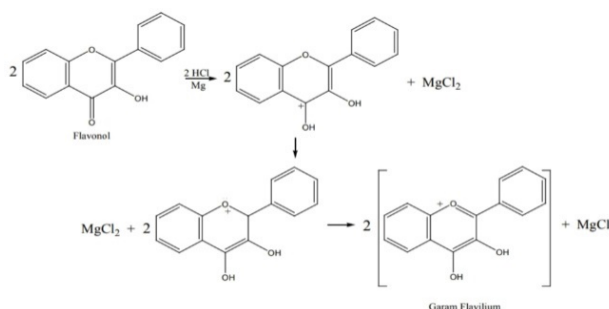
Figure 5. Phenol Reaction with FeCl_3 (Dwi Putri et al., 2018)

Figure 6. Reaction of Magnesium Metal and HCl (Septyangsih, 2010)

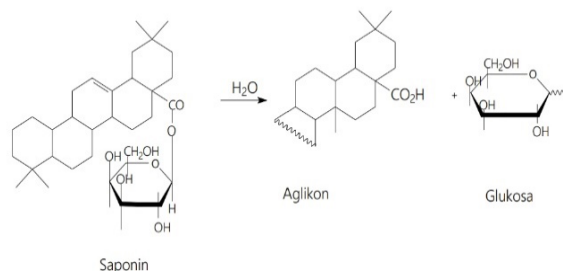


Figure 7. Saponin Reaction with Water (Marliana et al., 2005)

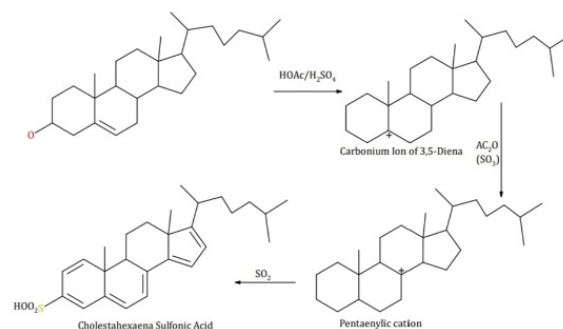


Figure 8. Terpenoid and Steroid Test Reaction (Marliana & Saleh, 2011)

Overall, the results of the phytochemical tests using color reactions indicate that the Tammate leaf extract contains various secondary metabolite compounds, such as alkaloids, flavonoids, phenolics, tannins, saponins, terpenoids, and steroids, although the intensity and effectiveness vary depending on the extraction method used.

DISCUSSION

Based on the results of this study, there were significant differences in the yields of Tammate leaf extract (*Lannea coromandelica* (Houtt.) Merr.) obtained from four different extraction methods. The reflux method produced the highest yield at 18.77%, followed by maceration at 13.08%, Soxhlet extraction at 5.14%, and infusion at 3.94%. These differences can be explained by the extraction mechanisms of each method. The reflux method employs continuous heating, which enhances the diffusion of active compounds from the leaf matrix to the solvent, while also optimally breaking down plant cell walls (Azwanida, 2015; Jain et al., 2009; Sasidharan et al., 2011). Although maceration does not involve heating, it results in high yields due to the prolonged contact time between the solvent and plant material (Crozier et al., 2006). The lower yield of Soxhlet

extraction may be attributed to its conditions and the amount of sample used, which were not as intensive as reflux (Agustinus & Hulupi, 2014). Infusion produced the lowest yield because it used water as a solvent and involved brief heating, making it less effective at dissolving semi-polar bioactive compounds (Snyder, 1997).

Identification of secondary metabolites through color reactions showed that maceration and reflux were superior in extracting alkaloids, phenolics, saponins, and steroids compared to infusion and Soxhlet methods. Alkaloids were detected positively in maceration, reflux, and Soxhlet, but not in infusion. Flavonoids were detected in infusion and reflux, phenolics and saponins in all methods, while tannins were only detected in maceration. The absence of terpenoids in all extraction methods suggests that their content in Tammate leaves is very low or nonexistent (Harborne, 1996; Wink, 2010).

TLC analysis further supports the color reaction results, showing that reflux provided the most comprehensive results, detecting alkaloids, flavonoids, phenolics, tannins, terpenoids, and steroids. Maceration showed detection of five compound classes: flavonoids, phenolics, tannins, terpenoids, and steroids. Infusion did not detect any compounds, while Soxhlet only detected flavonoids and steroids (Marliana et al., 2005; Stahl, 1969).

The phytochemical identification results from both color reactions and TLC demonstrated a consistent pattern. Phenolics and saponins were detected in all methods, indicating that these compounds are relatively easy to extract. Reflux and maceration consistently provided more comprehensive detection results compared to other methods. The success of the reflux method is attributed to the heating process and solvent circulation, which enable more efficient extraction of bioactive compounds (Sasidharan et al., 2011; Wink, 2003).

Overall, this study shows that the extraction method plays a crucial role in the successful isolation of secondary metabolites from Tammate leaves. Reflux can be recommended as the most effective method for extracting secondary metabolites from this plant, followed by maceration. These findings contribute to the development of extraction techniques for medicinal plants, particularly in optimizing the utilization of *Lannea coromandelica* for natural-based pharmaceutical purposes (Panche et al., 2016; Avinash et al., 2011).

CONCLUSION AND RECOMMENDATIONS

Based on the results of this study, it can be concluded that the extraction method significantly influences the yield and successful isolation of secondary metabolites from Tammate leaves (*Lannea coromandelica* (Houtt.) Merr.). The reflux method produced the highest yield at 18.77%, followed by maceration at 13.08%, Soxhlet extraction at 5.14%, and infusion at 3.94%. The reflux method also demonstrated the highest effectiveness in extracting various bioactive compound groups, including alkaloids, flavonoids, phenolics, tannins, terpenoids, and steroids, as evidenced by both color reaction and Thin Layer Chromatography (TLC) tests. Maceration also yielded fairly optimal results, particularly for phenolics, flavonoids, tannins, and steroids. Conversely, the infusion method showed the lowest effectiveness in extracting bioactive compounds from Tammate leaves.

This study makes a significant contribution to the optimization of extraction methods for obtaining secondary metabolites from traditional medicinal plants, particularly *Lannea coromandelica*. Reflux is recommended as the best

method in the phytochemical study of this plant due to its ability to yield high extract percentages and detect a broader range of compound classes.

Future research is recommended to conduct quantitative analyses of the main bioactive compounds detected to determine their concentrations in the extract. Additionally, it is advisable to assess the pharmacological activities of the resulting extracts to confirm their biological potential, such as antioxidant, antimicrobial, or anti-inflammatory activities. Further studies could also explore other extraction methods, such as ultrasonic extraction or microwave-assisted extraction, which may offer greater efficiency and environmental sustainability.

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