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Full Length Research Article

Effectiveness of Different Extraction Techniques on the Yield and Antityrosinase Activity of Merbau (*Intsia bijuga* (Colebr.) Kuntze) Wood Extract

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ABSTRACT

This study employed various extraction techniques to determine the yield, phytochemical profile, and antityrosinase activity of merbau wood (*Intsia bijuga* (Colebr.) Kuntze) extracts. The extraction techniques consisted of two factors: the type of extraction methods (conventional maceration – CM, ultrasound-assisted extraction – UAE, and magnetic stirrer – MS) and the number of extraction repetitions (first repetition – F1, second repetition – F2, and third repetition – F3). The interaction of the extraction methods and the number of extractions affects the extraction yield, antityrosinase activity, and its phytochemical profile. Merbau wood extracted using the UAE-F1 extraction method resulted in the highest yield (13.38%). In contrast, the UAE-F3 extract showed the strongest antityrosinase activity (IC_{50} value of 1.548 ppm) and the highest total phenol content (692.86 mg/g AGE). Fourier transform infrared analysis of the F1 extract showed that all samples contained the same functional groups, namely C=C (1600–1475 cm^{-1}) and O-H (3800–3000 cm^{-1}), indicating structural similarity among the extracts. Merbau wood extraction using the UAE method, both in the first, second, and third extractions, produced the highest yield, antityrosinase activity, and total phenol content of the extract compared to the CM and MS extraction methods.

1. Introduction

Indonesia, a tropical country on the equator, experiences high-intensity exposure to the sun's ultraviolet (UV) rays, posing potential risks to human skin health. UV rays, although beneficial in vitamin D production at low intensities (Raymond-Lezman and Riskin 2023), can be carcinogenic to humans and have negative impacts, primarily due to the increased emissions of chlorofluorocarbons (CFCs), which cause ozone layer degradation (Lickley et al. 2020). Excessive UV exposure can lead to erythema, skin pigmentation, and an increased risk of skin cancer (Christensen et al. 2017; Lee et al. 2022; Solano 2020; Tang et al. 2024). The pigmentation was caused by simple pigments which were produced by only one enzyme tyrosinase oxidase or

tyrosinase and the pigment was blackish known as melanin. The enzyme tyrosinase catalyzes the oxidation of phenolic compounds (e.g., tyrosine) to quinones, which serve as precursors for melanin polymerization (Tahtaci et al. 2025). Tyrosinase inhibition is a promising strategy that prompts the investigation of skin-whitening methods. Inhibitors such as kojic acid and hydroquinone are frequently used in skin care products; however, they also have their own set of problems, including low bioavailability, mutagenicity, and irritation (Searle et al. 2021).

In recent years, natural compounds have been gaining interest as potential alternatives due to their multitude of bioactivities, such as antimicrobial (Shintawati et al. 2020) and antioxidant properties (Prayogo et al. 2023). Numerous studies have described tyrosinase-inhibiting substances derived from natural sources. For example, the phlorotannins extracted from *Sargassum horneri* using enzymatic and ultrasonic treatments had an IC_{50} value of 26.90 µg/mL (Tian et al. 2025). Strong tyrosinase inhibition was observed in the case of *Artocarpus heterophyllous* wood extract, with an IC_{50} value of 2 µM (Nguyen et al. 2016). These data have emphasized the interest in safer and stable natural melanogenesis inhibitors for application in cosmetics development. Concerning synthetic bleaching materials, merbau wood (*Intsia bijuga* (Colebr.) Kuntze) is more environmentally friendly than these industrial applications and is suitable for natural lightening. The extractive content, robidanol in 50% ethanol extract (E-50), exhibited potent antityrosinase activity (IC_{50} = 0.36 ppm), which was more active than kojic acid (IC_{50} = 31.33 ppm) (Sari et al. 2021). Merbau wood is a potential skin-lightening agent that can replace synthetic skin-lightening materials with side effects. Utilization of merbau wood waste, such as wood slabs, shavings, and powder which have often been burned, thrown away, and sold at low prices in West Manokwari District (Rianto et al. 2020), can be a solution that not only overcomes environmental problems but also increases the added value of the wood waste. With merbau wood production accounting for 46% of the total roundwood production in Papua during 2019–2020, 98% of which came from Papua's natural forests (FWI 2024), optimizing this wood waste is a very strategic move. As a particular class of wood that dominates national production by up to 84.4% (BPS 2022), merbau wood has commercial potential and contributes significantly to the innovation of natural materials. Combining previous research on utilizing waste to produce bioactive compounds (Galanakis et al. 2015) and the extensive ecology of merbau wood in Indonesia further underscores the urgency of the sustainable use of this wood.

The release of bioactive principles from natural resources is a crucial stage in the scope of research, development, and industrial applications. The extraction method chosen significantly influences the efficiency and quality of bioactive metabolites produced after the extractions (Zhang et al. 2022). The maceration, reflux, and soxhlet can be applied, but are problematic in the way that these methods require large amounts of solvent needed over a time-consuming period if we use conventional systems; long-term heating (it may also destroy bioactive compounds); and environmentally unfavourable processes (Daniels et al. 2020; Wu and Xi 2020). Therefore, green extraction technologies are becoming increasingly popular as they offer faster, more effective, and greener options by reducing the duration of the extraction process while decreasing the usage level of harmful solvents, leading to high energy efficiency and lower CO_2 generation compared to conventional methods (D'Alessandro et al. 2014). The list of pertinent solvent-free, environmentally friendly extraction methods includes microwave-assisted extraction, ultrasound-assisted extraction (UAE), supercritical fluid extraction, and infrared-assisted extraction (Chemat et al. 2020). Among these, the UAE stands out for its efficient method, which utilizes ultrasonic

waves to enhance mass transfer, disrupt cell matrices, and improve extraction efficiency through the cavitation process (Dimitrov et al. 2022; Khadhraoui et al. 2018; Stevanato and da Silva 2019).

Merbau wood is commonly harvested using traditional methods, as demonstrated by the research of Sari et al. (2021), where extraction was performed by soaking the material in various ethanol concentrations (E100, E75, E50, E25, and E0) for 24 hours. The process employed a material-to-solvent ratio of 1:10 and was repeated three times for each concentration. Although the extraction results showed significant antityrosinase potential, the method used still has shortcomings, namely limited efficiency and environmental impact. No study has evaluated the optimization of merbau wood extraction using modern extraction methods, such as those employed in the UAE. Additional studies are required to assess the yield, antityrosinase activity, phytochemical content, and functional groups of merbau wood extracts obtained through various extraction methods to develop a more efficient, environmentally friendly, and relevant approach for industrial applications.

2. Materials and Methods

2.1. Material Preparation

The materials used in this study were several merbau wood dishes with a diameter of 39–49 cm obtained from merbau trees growing in the Sinar Wijaya Group forest concession area in Papua. Other research materials were ethanol (Merck, Germany), distilled water, tyrosinase enzyme, pH 6.5 buffer, L-tyrosinase, ethanol, dimethyl sulfoxide (DMSO), kojic acid, 10% folin-cocalteu reagent (Merck, Germany), 7.5% Na_2CO_3, and gallic acid (Sigma Aldrich, USA). The tools used in this study were a Wiley mill, mesh screen (40–60 mesh), ultrasonic FS-150N, magnetic stirrer (Scilogex MS-H-S), digital scales, spatulas, funnels, aluminum foil, plastic wrap, jars, rotary evaporators, aluminum dishes, petri dishes, and vials, multiple well readers (ELISA), multiwell plates, eppendorf whatman 42, spatulas, micropipettes, vortex, incubators, and Fourier transform infrared (FTIR).

2.2. Raw Material Preparation

The raw material used was merbau heartwood (**Fig. 1**). The heartwood logs were first chopped into chips and dried in the sun for 3 days or until the wood chips were sufficiently dry to grind. After that, the wood chips were ground to obtain sawdust. The wood powder was then sieved using a 40–60 mesh sieve. The 40–60 mesh powder was then used as raw material for extraction. Before extraction, the moisture content was measured first. The moisture content of the powder was calculated by taking 2 g of the sample and drying it in an oven at a temperature of 100ºC until it reached a constant oven-dry weight. The determination of moisture content was carried out 3 times. The moisture content of the powder was calculated using Equation 1.

$$Moisture\ content = \frac{w_1 - w_2}{w_2} \times 100\% \quad (1)$$

where w_1 is the initial sample weight (g), and w_2 is the sample weight after being ovened (g).

2.3. Extraction

The extraction methods involved two main variables: the extraction methods (including conventional maceration (CM), magnetic stirring (MS), and ultrasound-assisted extraction (UAE))

and the number of extraction repetitions (first (F1), second (F2), and third (F3) repetitions). CM was a solvent immersion extraction method. The MS extraction method employed continuous stirring with a magnetic stirrer, whereas the UAE method utilized ultrasonic waves.

Fig. 1. Merbau wood logs.

2.3.1. Conventional extraction

Fig. 2 displays the maceration process of merbau simplicia powder. Up to 5 g of powder was placed in a closed container, soaked in 50 mL of 50% ethanol solvent (E50), and left for 24 hours with occasional stirring. The filtrate and residue are separated, and then the resulting residue is re-macerated with 50 mL of solvent using the same process. This process has been carried out 3 times. The extraction results are then filtered, and the filtrate is collected separately.

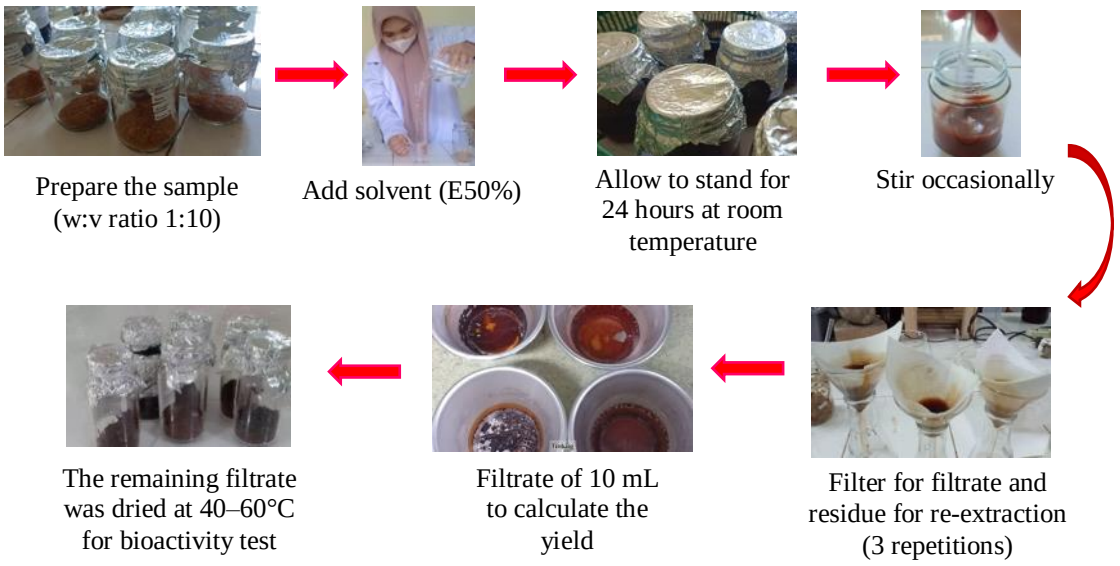

Fig. 2. The maceration process of merbau wood extract.

2.3.2. Ultrasonic-assisted extraction (UAE)

Fig. 3 shows the UAE process of merbau wood extract. Briefly, 5 g of merbau wood powder samples were extracted using the UAE method with E50 solvent, employing a material-to-solvent ratio of 1:10 (w/v). The mixture of merbau wood powder and solvent was subjected to ultrasonic waves for 45 minutes at an amplitude of 65%. The residue from the first sonication was re-

extracted with 50 mL of solvent with the same treatment. This extraction process was carried out 3 times. The extraction results were filtered, and the filtrate was collected separately (Widyasanti et al. 2018).

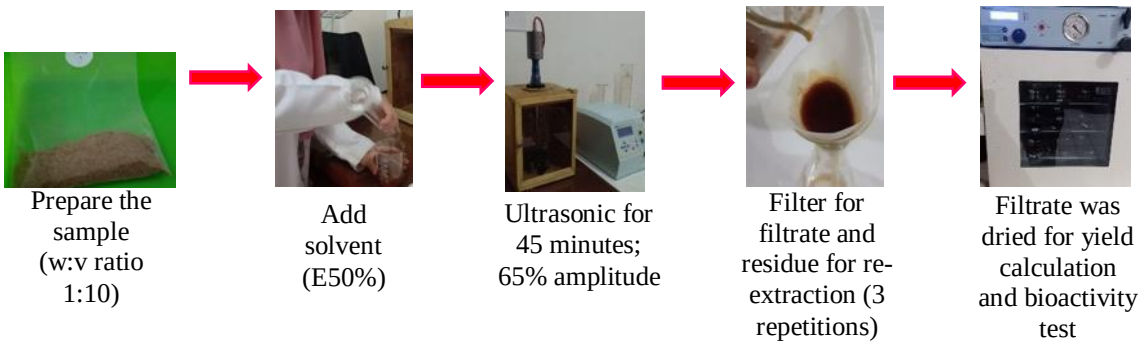

Fig. 3. Ultrasonic-assisted extraction process of merbau wood extract.

2.3.3. Magnetic stirrer extraction

Fig. 4 illustrates the magnetic stirrer (MS) extraction of merbau wood extract. The maceration process using 5 g of simplicia powder with a volume of solvent E50. The mixture was stirred using MS at 300 rpm for 45 minutes and 60 minutes. The mixture was further filtered to yield a filtrate and a residue, from which re-extraction was performed using an identical procedure. This step was performed three times. The filtered samples were washed for further analysis (Zaini et al. 2020).

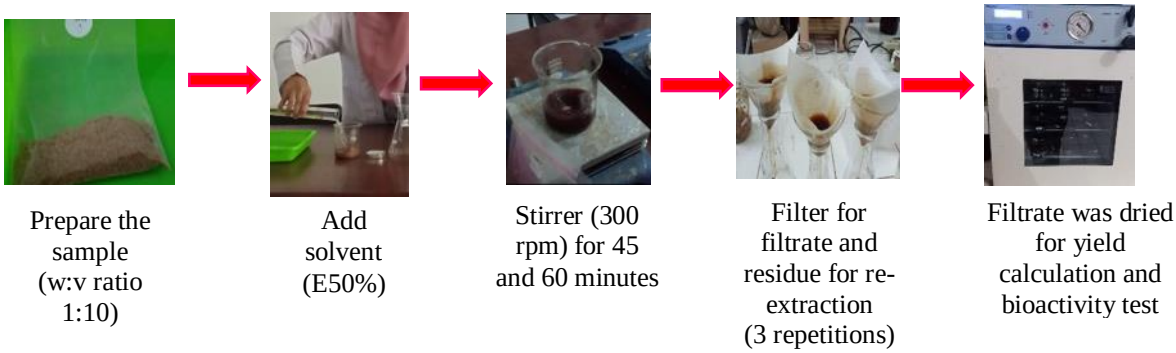

Fig. 4. Magnetic stirrer extraction process of merbau wood extract.

2.4. Determination of Extract Yield

Ten milliliters of each extracted filtrate were put into a petri dish and dried in an oven set at 100°C until the weight remained constant. The solvent was completely removed during this drying process, enabling precise measurement of the remaining extract mass. Equation 2 was then used to determine the extract's yield.

$$Yield\ Value\ (\%) = \frac{Furner\ dry\ weight\ of\ extract\ (g)}{Furner\ dry\ weight\ of\ powder\ (g)} \times 100 \quad (2)$$

2.5. Antityrosinase Activity Test

With minor adjustments made to meet the goals of this investigation, the assay was conducted utilizing the methodology outlined by Nerya et al. (2003). In a 96-well microplate, the

assay was prepared by sequentially adding 80 µL phosphate buffer solution (50 mM; pH 6.5), a substrate solution (40 µL of L-tyrosinase), 40 µL of L-tyrosinase enzyme solution, and a sample solution (40 µL). This assay used the monophenolase reaction. The range of extract concentrations was 0.98 to 62.50 parts per million. The absorbance of each reaction mixture at the maximum wavelength was measured using a microplate reader at the appropriate time after the reaction was thoroughly mixed and incubated for the required duration at the optimum temperature (25–30°C). The kojic acid, which acted as a positive control, the blank control, and the blank sample control underwent the same process. Due to its established efficacy as a tyrosinase inhibitor and its formulation stability in dermocosmetic applications, kojic acid was utilized as the positive control (Miyazawa and Tamura 2007). The percentage of tyrosinase inhibition activity was calculated using Equation 3.

$$\% \text{ Antityrosinase activity} = \frac{(A-B)-(C-D)}{(A-B)} \times 100\% \quad (3)$$

where *A* is the blank solution's absorbance, *B* is the blank control solution's absorbance, *C* is the sample solution's absorbance, and *D* is the sample control solution's absorbance.

2.6. Total Phenol Content Testing

The Folin-Ciocalteu method, as outlined by Chaudhuri and Ray (2020), was used to calculate the total phenolic content (TPC). 10 µL volumes of merbau wood extracts were made using the CM, MS, and UAE extraction methods. In a 96-well microplate, each sample was combined with 160 µL of distilled water, 10 µL of 10% Folin-Ciocalteu reagent, and 20 µL of 7.5% Na_2CO_3 solution. After thoroughly mixing the mixture, it was incubated for 30 minutes. A microplate reader was used to measure the absorbance at 750 nm after incubation to determine the amount of phenolic content. The total phenolic content of each extract was measured in milligrams of gallic acid equivalent (GAE) per gram of dry powder (mg GAE/g dry powder). A standard curve of gallic acid was prepared using five concentrations: 3.13, 6.25, 12.5, 25, 50, and 100 mg/L. Each extract was tested in triplicate.

2.7. Fourier Transform Infra-Red (FTIR) Analysis

FTIR spectroscopy is a type of infrared spectroscopy that analyzes spectral results. FTIR testing aims to determine the content of compounds and chemical bonds in the extract. The test was carried out three times. The measurement results are presented as a frequency spectrum, which is further analyzed using a correlation table. The sample is a solid extract of the thick filtrate dried at 40–60°C.

2.8. Data Analysis

The study employed a factorial experimental design within a completely randomized design framework, incorporating two factors (4 × 3). The first factor is the extraction method with four levels, namely conventional maceration (CM), 45-minute stirer maceration (MS45), 60-minute stirrer maceration (MS60), and ultrasonic (UAE). The second factor is the repetition of extraction with three levels, namely the first filtrate (F1), the second filtrate (F2), and the third filtrate (F3). Each combination of treatments was repeated three times. Testing was conducted using the Duncan post hoc test to determine if the results of the analysis of variance (ANOVA) had a significant

effect at a 5% significance level. The Duncan post hoc test was only performed on the best samples from the interaction plot results. The responses analyzed were yield, IC_{50} value, and total phenol content, as shown in **Table 1**.

Table 1. Coding of yield response, IC_{50} value, and total phenol from the influence of extraction methods and extraction repetition

Extraction methods	Extraction repetition		
	1 (F1)	2 (F2)	3 (F3)
Conventional maceration (CM)	CM-F1	CM-F2	CM-F3
Magnetic stirrer 45 minutes (MS45)	MS45-F1	MS45-F2	MS45-F3
Magnetic stirrer 60 minutes (MS60)	MS60-F1	MS60-F2	MS60-F3
Ultrasound-assisted extraction (UAE)	UAE-F1	UAE-F2	UAE-F3

3. Results and Discussion

3.1. Extraction's Yield

The sample yield was critical for estimating the amount of extract collected during the extraction procedure. The yield was also related to a sample's active compound; if the yield was high, the content of active compounds was also elevated (Hasnaeni et al. 2019). Singh et al. (2017) confirm this claim by stating that the high yield achieved indicates a highly active chemical. The MW extraction yield ranges from 13.37% to 1.79% (**Fig. 5**). Analysis of variance revealed that the interaction between extraction method and repetition had a significant influence on yield (α = 0.05). **Fig. 5** shows how the extraction method and the number of repeats on the yield. The first filtrate had the highest yield for all four extraction methods.

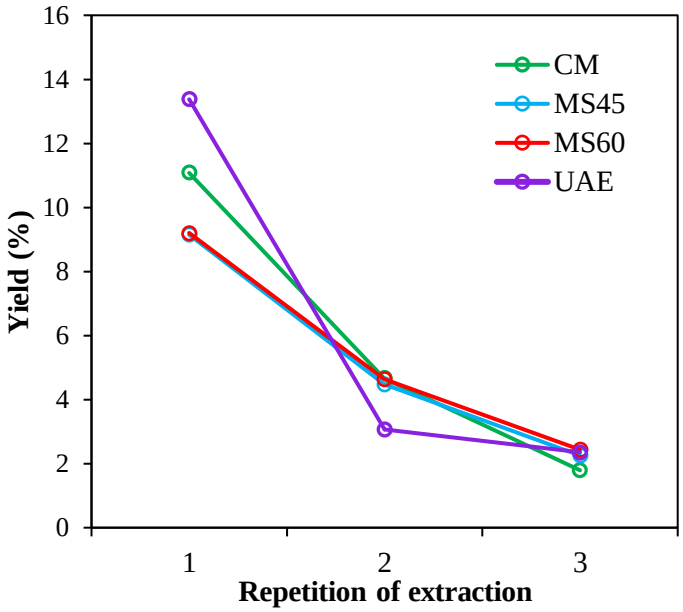

Fig. 5. Interaction between method and repetition of extractions on yield.

The four extraction methods reveal that the yield value falls as the number of extractions increases (**Fig. 5**). This result shows that the first extraction (F1) removed the most active chemicals. During extraction, the solvent penetrates the plant cell wall and enters the cell cavity, containing active chemicals. The concentration gradient between the solution within the cell and

the surrounding solvent causes the active chemicals, part of the more concentrated solution, to be ejected from the cell (Hasnaeni et al. 2019). Furthermore, the solvent used to extract metabolite chemicals from plants was more effective, as molecules were obtained based on their similarity in polarity to the solvent. This enables the extraction of the first filtrate, which includes several active chemicals. The Duncan post hoc test on the four best merbau extracts, specifically the first filtrate, revealed that UAE-F1 extraction produced the highest yield of merbau wood and differed considerably from the other extraction procedures, followed by CM-F1, MS60-F1, and MS45-F1. However, MS60-F1 and MS45-F1 extraction procedures produced consistent results (**Fig. 6**).

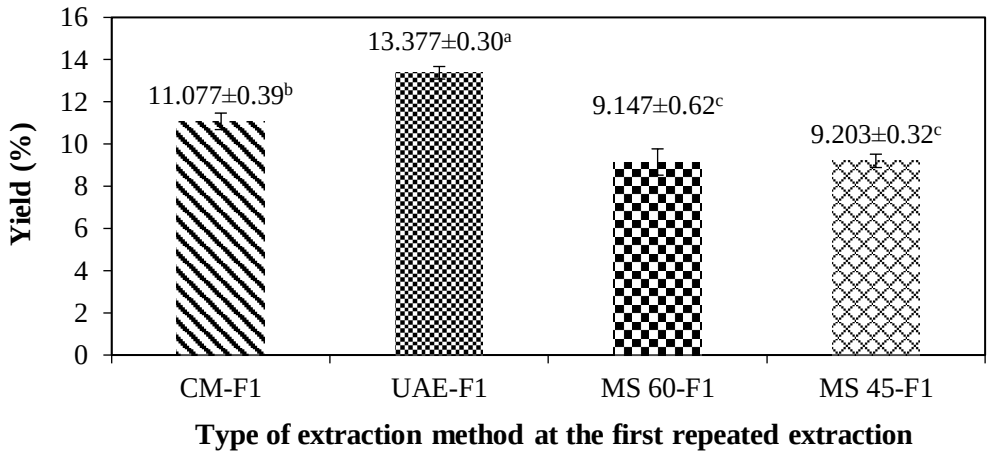

Fig. 6. Histogram of merbau wood extract yield based on the extraction method at the first repeated extraction (different letters indicate different yield values based on the Duncan post hoc test).

Budiastra et al. (2021) found that UAE extraction provided a greater yield value (16.38%) than traditional Extraction (10.80%). This information is further corroborated by the findings of Familasari et al. (2023). UAE extracts bidara laut (*Strychnos lucida*) heartwood at a higher yield (7.39%) than conventional Extraction (6.62%). Another study by Panjaitan and Meze (2023) found that the UAE approach can yield better outcomes (11.6–32.1%) compared to traditional methods (11.5–20.0%). This is because the UAE approach can physically damage the walls and membranes of biological plant cells, resulting in smaller particles. This impact increases the extracted solvent's penetration into the cell material, eventually boosting the mass transfer rate in cell tissue and promoting the transfer of secondary metabolite chemicals from cells to the solvent (Muller et al. 2015). The amount of active material produced during the extraction determines the yield value. The percentage yield figure is crucial for determining the amount of extract produced during the extraction process. The yield data is also associated with the active chemicals in the sample; a higher yield value implies that the sample includes more active compounds (Nur and Mulawarman 2022). Despite using the same extraction procedure, the extraction yield in this study differs from that in previous investigations. This is because the species and wood genus impact extraction yield in addition to the extraction process, according to Andianto et al. (2024).

3.2. Antityrosinase Activity

The method's validity was confirmed by assessing kojic acid as a positive control through comparison of its IC_{50} value obtained with the IC_{50} value from the results of literature studies (**Fig. 7**). Widely recognized for its efficacy as a whitening compound, kojic acid was employed as the

positive control, additionally owing to its notable stability in cosmetic products (Lee et al. 2023; Saeedi et al. 2019). In this tyrosinase enzyme inhibition test, four solutions were evaluated: the extract solution, the kojic acid/extract control solution, the blank solution, and the blank control solution. The blank solution is free from either kojic acid or extract inhibition. The control solution was a correction factor that did not involve the addition of enzymes or substrates. The assessment of tyrosinase inhibitory activity is based on the compound's capacity to prevent dopachrome formation, which results from the enzymatic reaction between L-DOPA and tyrosinase. Inhibition is reflected by a decrease in color intensity, quantified spectrophotometrically at 510 nm using a microplate reader. This device measures absorbance by passing light of a defined wavelength through the sample-containing well and detecting the intensity of the transmitted light. The resulting absorbance values were subsequently employed to determine the inhibition levels of reactions involving L-DOPA and L-tyrosine.

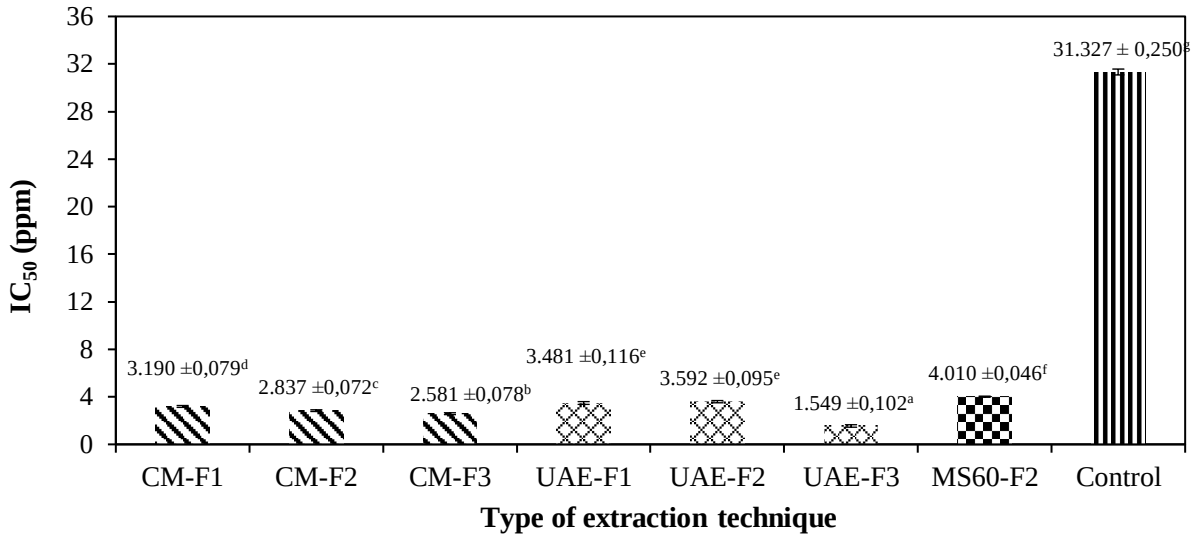

Fig. 7. The relationship between the type of extraction technique (method and repetition of extraction) and the IC_{50} value of merbau wood extracts (different letters indicate different yield values based on the Duncan post hoc test).

The antityrosinase activity of MW extract ranges from 15.11% to 1.54%. The analysis of variance at a 5% significance level on the IC_{50} value of the extract reveals a significant interaction effect of the extraction method and extraction repetition on antityrosinase activity, as indicated by the IC_{50} value. **Fig. 8** illustrates the interaction between the extraction method and the number of repetitions on the IC_{50} value. The best merbau wood extract results with the highest antityrosinase activity (lowest IC_{50} value) were UAE-F3 (1.55 ppm), followed by CM-F3 extract (2.58 ppm), CM-F2 (2.84 ppm), CM-F1 (3.190 ppm), UAE-F1 (3.48 ppm), UAE-F2 (3.59 ppm), and MS60-F2 (4.01 ppm). In the control sample, the concentration of kojic acid was 42.98 ppm. All extraction methods using UAE, CM, MS45, MS60, and repeated F1, F2, and F3 extractions yielded lower IC_{50} values than those of kojic acid. This indicates that merbau extract has stronger antityrosinase activity than kojic acid.

The more extraction repetitions in the CM and UAE methods, the stronger the antityrosinase activity of merbau wood extract; however, in the MS45 and MS60 methods, the antityrosinase activity decreased (**Fig. 8**). This is likely due to the MS45 and MS60 methods. However, continuous stirring was carried out, and the extraction time was only 45 to 60 minutes, so the

solvent had not penetrated optimally into the cell wall. The bioactivity of an extract is also influenced by the extraction method used. Because it directly affects the extraction process of phytochemical compounds in plants. Differences in extraction methods can also result in interactions between solvents and soluble compounds with the same polarity properties, where the same polarity properties of phytochemical compounds are observed with solvents. The polarity properties of phytochemical compounds that are similar to those of the solvent will create an interaction of attraction and repulsion (Yabalak et al. 2020). However, the IC_{50} value of merbau wood extract in all treatments showed stronger antityrosinase activity than kojic acid (31.33 ppm) (**Fig. 7**). Kojic acid is a synthetic brightening cosmetic ingredient widely used as a whitener to date (Kang et al. 2024; Risal 2020).

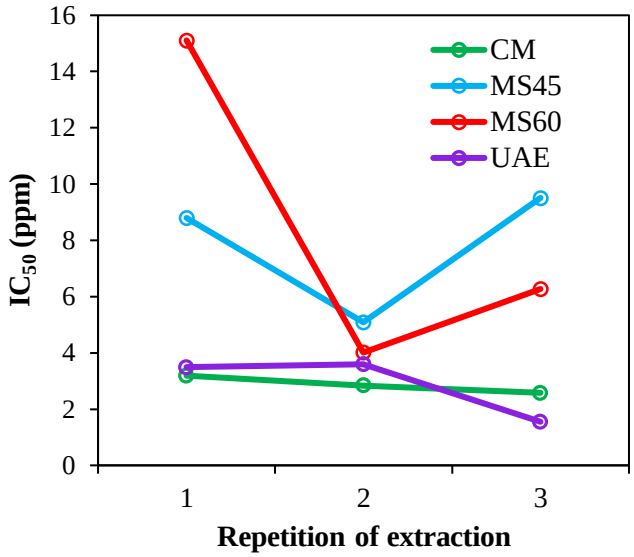

Fig. 8. Interaction between method and repetition of extractions on antityrosinase activity.

The Duncan post hoc test on the best extraction results showed that all extraction methods produced significantly different IC_{50} values, but in UAEF1 and UAEF2, they were not substantially different (**Fig. 7**). The UAEF3 method produced an extract with the lowest IC_{50} value, indicating that the extract had the strongest antityrosinase activity compared to other extraction methods and repetitions. The UAE method can increase the activity of an extract by extracting efficacious substances with higher antityrosinase activity. This is achieved through ultrasonic waves, which break down cell walls in the extract as it passes through the material medium, causing pressure and shear forces from solvent molecules. The study by Wardatun et al. (2024) found that the quercetin content of extracts from *Clitoria ternatea* L., obtained through ultrasound-assisted extraction (UAE), was significantly higher than that from maceration. The UAE method employed ultrasonic waves to form cavitation bubbles, which acted as mechanical forces to break the cell wall and promote the release and dissolution of active compounds in the solvent (Manzoor et al. 2021).

Tyrosinase is the primary enzyme in melanogenesis which generates melanin. Melanosome is a cytoplasmic organelle that synthesizes melanin, found in various parts of the human body, such as in the skin cells and hair follicles (Serre et al. 2018). Eumelanin and pheomelanin are the two primary forms of melanin produced by melanocytes in the skin's epidermal layer. Eumelanin is the type of melanin that helps create darker skin, whereas pheomelanin helps create lighter skin

(Del Bino et al. 2018). Tyrosinase-related protein-1 (TRP-1), tyrosinase, and TRP-2 are the enzymes essential to melanin synthesis. Melanogenesis is the complex process of synthesising melanin (Pillaiyar et al. 2017). Tyrosinase catalyzes the oxidation of L-tyrosine to dopaquinone, which controls the first two steps of melanin synthesis (Xue et al. 2023). Tyrosinase transforms L-tyrosine into 3,4-dihydroxyphenylalanine (L-DOPA) in the first stage. Tyrosinase oxidizes L-DOPA to dopaquinone (DQ) at the second stage. A crucial step in the biosynthesis of melanin is the DQ reaction (Djafarou et al. 2023; Lee et al. 2023; Zargaham et al. 2023). Intramolecular cyclization of this DQ compound yields leucodopachrome (cyclodopa) and indoline. Before this product is reoxidized back into DQ, a redox cycle between leucodopachrome and DQ, which acts as a substrate for tyrosinase, creates the dopachrome and L-DOPA substrates. TRP-2 (dopachrome tautomerase) ultimately breaks down dopachrome to catalyze a reaction that produces dihydroxyindole and dihydroxyindole-2-carboxylic acid; subsequent oxidations facilitate the conversion into eumelanins. TRP-1 facilitates the transformation of DHICA into eumelanin. Simultaneously, the previously generated DQ undergoes transsulfuration to create pheomelanin (after first being transformed once more into glutathionyldopa by the addition of cysteine or suitation) (Pillaiyar et al. 2017).

3.3. Total Phenolic Content

Phenolic compounds or flavonoids were identified as secondary metabolites that acted as essential components in plants that have antioxidant activity based on the redox properties, number, and position of free OH groups contained in flavonoids (Aryal et al. 2019; Molole et al. 2022). Plant extracts contained hydroxyl groups that facilitated the scavenging of free radicals. This total phenol test aims to measure the phenolic content of merbau wood extracts using the Folin-Ciocalteu method, employing various extraction methods and repetition. The Folin-Ciocalteu method has several advantages, including the use of simple instruments, no need for expensive reagents, ease of use, and rapid results. The results were reported in gallic acid equivalents (GAE) per gram of dry extract weight. (Ford et al. 2019). The total phenol of MW extract ranged from 692.86 mg GAE/g to 404.76 mg GAE/g. The analysis of variance at the 5% significance level on the total phenol content of the extract showed that the extraction method and the extraction repetition affected the extract's total phenol content.

Fig. 9 shows the interaction between the extraction method and the repetition of Extraction on the total phenol. Based on the results of these data, UAE-F3 is an extract with the highest total phenol content, followed by the CM-F3, MS60-F3, and MS45-F3. Among the four extraction methods, it was observed that the total phenol values decreased with an increasing number of extractions. This is a result of the removal process, which causes the solvent to enter all cell cavities, leading to swelling. If the swelling exceeds a certain limit, it will burst. Plant cell walls and vacuole fluids are rich in phenolic compounds, to which the plant owes its capacity for decay resistance. For F1 to F3, the higher total phenol yield from the UAE method may be due to ultrasonic waves that can damage and disrupt the cell wall structure, resulting in looser contact between solvent particles and the three-dimensional matrix of plant materials, thereby increasing the penetration level of solvents into the plant material. This underlies the increase in the mass transfer rate in cell tissue, facilitating the transfer of secondary metabolite compounds from cells to the solvent (Manzoor et al. 2019). This study's results between yield and total phenol showed no positive correlation. The high yield may have a sizable primary metabolite content

(polysaccharides, proteins, lipids) and reduce the percentage of secondary metabolite components that are bioactive compounds (Simić et al. 2016). Primary metabolites, such as carbohydrates and proteins, can be dissolved in an 80% ethanol solvent (López-Perea et al. 2019), whereas lipids are difficult to dissolve in polar solvents (Silve et al. 2018).

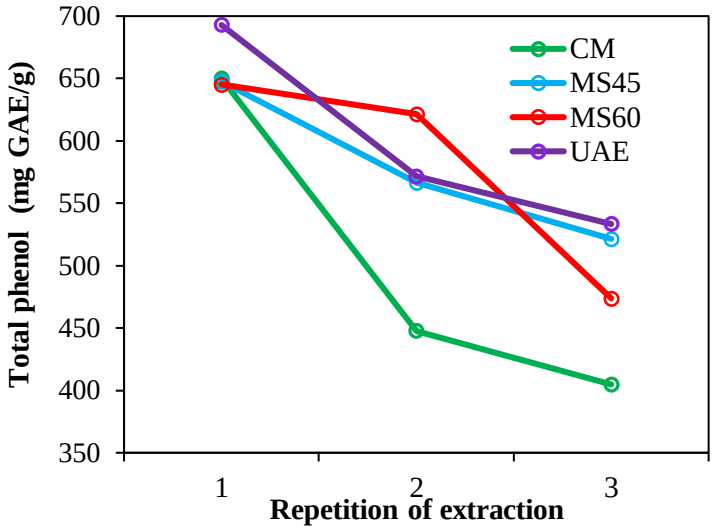

Fig. 9. Interaction plot between method and repetition of extractions on total phenol content of merbau wood extracts.

The Duncan post hoc test on the best extraction results, specifically the third repetition, showed that the total phenolics in the merbau wood extract obtained using the UAE method were the highest and significantly different from those of other extraction methods. In contrast, the extracts with the CM, MS60, and MS45 methods were uniform (**Fig. 10**). This indicates that Extraction with the help of ultrasonic waves has a higher efficiency level than CM and MS Extraction because, with less UAE extraction time, it can produce higher levels of total phenol than other extraction processes. A rarefaction cycle occurred during the ultrasonic extraction method, increasing the shear force of the liquid medium. In this cycle, cavitation bubbles form on the surface of the natural material. During the compression cycle, these cavitation bubbles collapse, creating several physical effects. The effects include shockwaves, microjets, and turbulence. These effects caused damage to natural material particles, allowing the natural material to release its active substances into the solvent and reduce particle size (Chemat et al. 2017). The extraction procedure and solvent were responsible for dissolving endogenous compounds from plants (Molole et al. 2022). The extraction method was the first factor that affected the total phenolic content. The ultrasonic method employed the principle of ultrasonic waves, which increased the temperature to break down cell walls more effectively than other extraction methods. The second factor was temperature. High or low temperatures can affect the effectiveness of the extraction process and the solubility of phenolic compounds; the higher the temperature used, the higher the amount of phenolic compounds that can be dissolved because high temperatures can damage cell wall elements so that more phenolic compounds are extracted (Benmanseur et al. 2025; Oroian et al. 2020). Therefore, the CM and MS extracts were prepared at room temperature, and the cell wall breakdown process is slower than that of the UAE extract. Additionally, the extraction solvent also influenced the total phenolic content of the extract. Due to their hydroxyl

groups, phenolic compounds exhibit enhanced solubility in polar organic solvents. Therefore, the use of ethanol-water solvents in this study was appropriate.

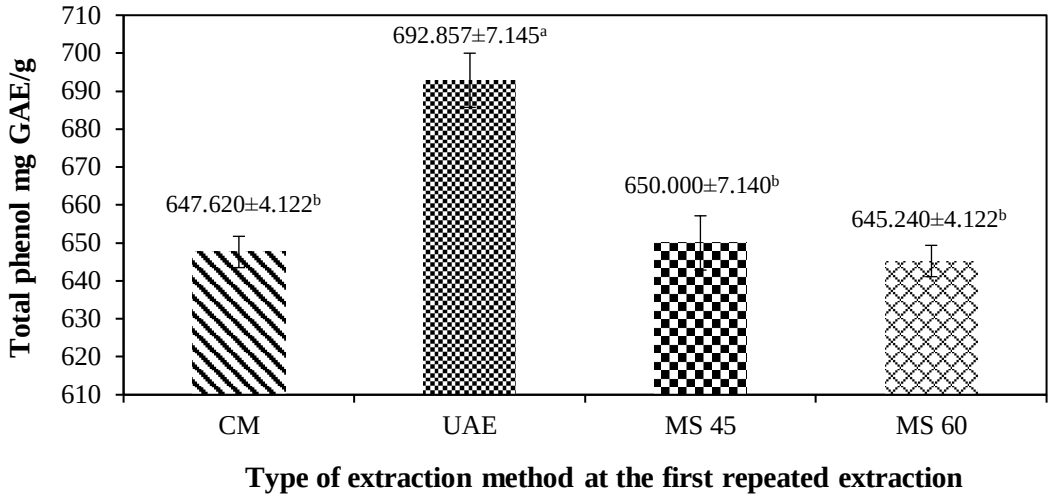

Fig. 10. Histogram of the total phenol in merbau wood extract from the first repeated extraction results of four different extraction methods (different letters indicate different yield values based on the Duncan post hoc test).

3.4. FTIR Analysis

The identification of merbau wood extracts from four distinct extraction procedures, as illustrated in **Fig. 11**, using a Fourier transform infrared (FTIR) spectrophotometer, offers information about the principal chemicals present in each extract. The spectral data of the four types of extracts, obtained using varied extraction procedures, exhibit the same absorption band patterns, with the absorption peaks varying slightly. The data are in line with the research by Rafi et al. (2025), which showed that the FTIR spectra of various maceration, sonication, and refluxing extraction methods of merbau wood were similar, but had different absorbance and peak intensities at some wavenumbers. The spectrum data reveal the functional groups at each extract's absorption peak. The confirmed functional groups provide information on the chemical profile and bioactivity of the final extract. The typical merbau wood extract absorption band peaks at wavenumbers 3345 cm^{-1} to 3287 cm^{-1}, representing the hydroxyl bond functional group (OH). The overall phenolic content of each sample will also have to be calculated using the absorption band of the hydroxyl group. Phenolic compounds, such as flavonoids, are important constituents of cosmetic preparations, as they have the potential to act as antioxidants and inhibit tyrosinase, thereby preventing the harmful effects of solar radiation. The presence of a hydroxyl group can indicate high antityrosinase activity in merbau wood extract (Sari et al. 2021).

Furthermore, the absorption band at 1620 cm^{-1} to 1509 cm^{-1} indicates the existence of an aromatic ring (C=C), whereas 1456 cm^{-1} to 1028 cm^{-1} indicates the presence of an ether group in each sample. The OH bond and aromatic ring functional group seen in the absorption band in **Fig. 11** are attributed to resorcinol, which is usually generated by conjugating the OH group with one aromatic ring C=C. The research by Malik et al. (2020) served as the basis for these conclusions. Each sample type has a different functional group content, affecting the resulting band's intensity. The intensity of each spectrum's high absorption band positively correlates with the composition of its functional groups. When compared to other extracts made using different methods, the merbau wood extract made using the UAE extraction method has the highest absorption intensity,

according to the absorption band results in **Fig. 11**. This confirms the yield data that has been reported, which shows that the UAE method of merbau wood extraction yields the highest yield when compared to other extraction methods.

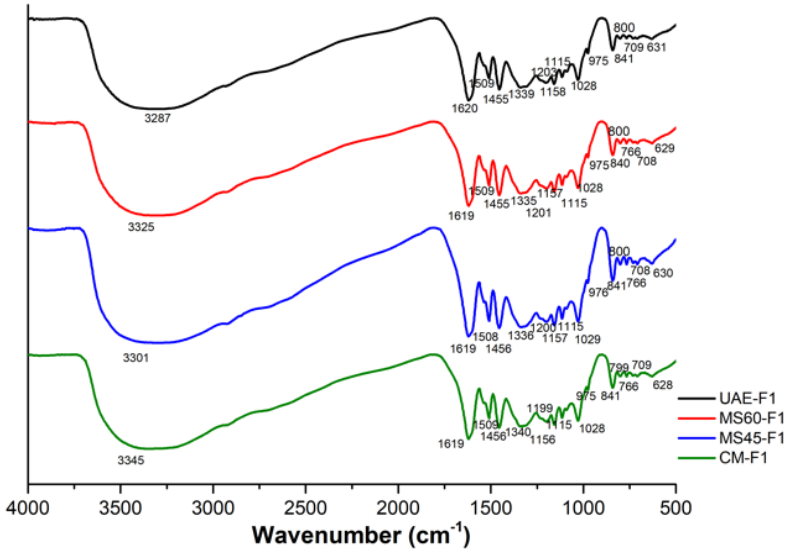

Fig. 11. FTIR spectrum of merbau extract from first repeated extraction (F1) treatment and UAE, MS60, CM, and MS45 extraction methods.

3.5. The Correlation among Parameters

Pearson correlation analysis was used to evaluate the relationship between the yield, antityrosinase activity, and total phenol variables of the studied samples. Based on the analysis results (**Fig. 12**), a robust and statistically significant positive correlation exists between yield and total phenol. This result indicates that the higher the total phenol content in the sample, the higher the yield value produced.

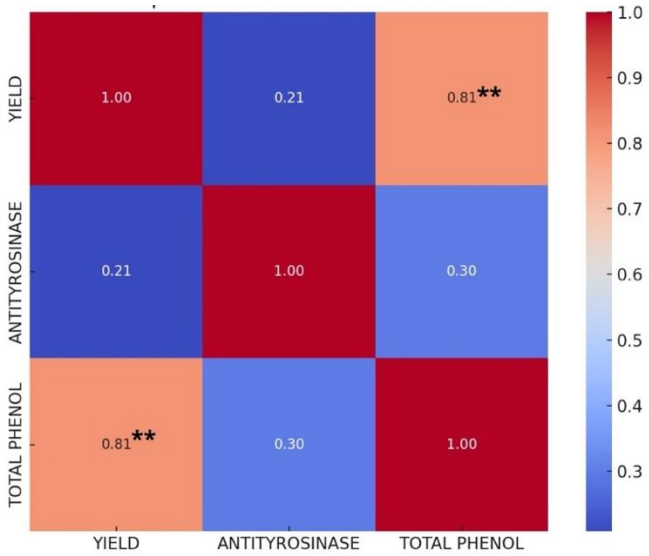

Fig. 12. Pearson's correlation heatmap between variables.

Previous studies have stated a positive correlation between yield and total phenolics (Rosales-Castro et al. 2015). There was a weak, nonsignificant association between yield and antityrosinase activity. It suggests that yield changes are not linear to changes in antityrosinase

activity. Yields persist because the compounds within them do not completely inhibit the tyrosinase enzyme. Although the expected correlation between total phenols and antityrosinase activity was weakly positive (and insignificant), this is consistent with what could be inferred from tyrosine, given that even its inhibition is driven by putatively present polyphenolic molecules. This finding aligns with earlier studies that suggest a positive correlation between total phenols and bioactivity (Turker and Isleroglu 2021).

4. Conclusions

The interaction between extraction methods and repetitions significantly impacted the yield, antityrosinase activity, and total phenol content of the merbau wood extracts. The highest yield of merbau wood extract was the UAE extract in the first repetition extraction (F1). The more repetitions of extraction that were carried out, the lower the yield of the extract. The highest antityrosinase and total phenol values in the merbau wood extract were found in the UAE-F3 extract. The FTIR spectrum revealed that all extracts contained the same functional groups, specifically O-H (3800–3000 cm^{-1}) and C=C (1600–1475 cm^{-1}). Based on the yield, antityrosinase activity, and total phenol, the extraction requirements to produce prospective merbau wood extract for further development are extraction using the ultrasonic method and repeated extraction up to the third filtrate. These findings provide valuable information on effective wood extractive methods that produce good antityrosinase activity, which can be applied to the cosmetic or pharmaceutical industries.

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Author Contributions

R.A.L.S.: Methodology, Software, Investigation, Resources, Data Curation, Writing—Original Draft Preparation, Writing—Review and Editing, Project Administration; U.D.S.: Conceptualization, Methodology, Software, Validation, Resources, Data Curation, Supervision, Funding Acquisition; R.K.S.: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Resources, Writing—Original Draft Preparation, Writing—Review and Editing, Supervision, Funding Acquisition; M.W.: Methodology, Writing—Original Draft Preparation, Visualization; M.A.A.: Methodology, Formal Analysis, Resources, Writing—Review and Editing, Visualization, Project Administration; M.A.R.L.: Methodology, Validation, Formal Analysis, Writing—Review and Editing, Supervision, Funding Acquisition; M.W.N.: Investigation.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Declaration of Generative AI and AI-Assisted Technologies in the Manuscript Preparation

Not applicable.

References

Andianto, Wahyudi, I., Sari, R. K., Pari, G., and Prayogo, Y. H. 2024. Phytochemical Profile of *Rhizophora apiculata*, *Bruguiera gymnorhiza*, and *Bruguiera cylindrica* for Wood Identification. *Jurnal Sylva Lestari* 12(2): 435–444. DOI: 10.23960/jsl.v12i2.884

Aryal, S., Baniya, M. K., Danekhu, K., Kunwar, P., Gurung, R., and Koirala, N. 2019. Total Phenolic Content, Flavonoid Content and Antioxidant Potential of Wild Vegetables from Western Nepal. *Plants* 8(4): 96. DOI: 10.3390/plants8040096

Benmanseur, A., Tacherfiout, M., Benguerba, Y., and Zahra, F. 2025. Optimization of Ultrasound Phenolic Extraction from *Erica multiflora* Leaves using Response Surface Methodology and Artificial Neural Networks. *Journal of Applied Research on Medicinal and Aromatic Plants* 45(1): 100627. DOI: 10.1016/j.jarmap.2025.100627

BPS. 2023. *Statistics of Forestry Production*. Badan Pusat Statistik, Jakarta, Indonesia.

Budiastra, I. W., Mardjan, S. S., and Azis, A. A. 2021. Pengaruh Amplitudo Ultrasonik dan Waktu Ekstraksi terhadap Rendemen dan Mutu Oleoresin Pala. *Jurnal Keteknikan Pertanian* 8(2): 45–52. DOI: 10.19028/jtep.08.2.45-52

Chaudhuri, A., and Ray, S. 2020. In Vitro Free Radical Scavenging Activities of Aerial Parts' Aqueous Extract and Extract Fractions of *Ampelocissus Latifolia* (Roxb.) Planch in Relation to Total Phenolics and Flavonoid Contents. *Journal of King Saud University - Science* 32(1): 732–739. DOI: 10.1016/j.jksus.2018.12.006

Chemat, F., Rombaut, N., Sicaire, A. G., Meullemiestre, A., Fabiano-Tixier, A. S., and Abert-Vian, M. 2017. Ultrasound-Assisted Extraction of Food and Natural Products. Mechanisms, Techniques, Combinations, Protocols, and Applications. A Review. *Ultrasonics Sonochemistry* 34: 540–560. DOI: 10.1016/j.ultsonch.2016.06.035

Chemat, F., Vian, M. A., Fabiano-Tixier, A. S., Nutrizio, M., Jambrak, A. R., Munekata, P. E., Munekata, P. E. S., Lorenzo, J. M., Barba, F. J., Binello, A., and Cravotto, G. 2020. A Review of Sustainable and Intensified Techniques for Extraction of Food and Natural Products. *Green Chemistry* 22(8) 2325–2353. DOI: 10.1039/c9gc03878g

Christensen, L., Suggs, A., and Baron, E. 2017. Ultraviolet Photobiology in Dermatology. *Ultraviolet Light in Human Health, Diseases and Environment* 996: 89–104. DOI: 10.1007/978-3-319-56017-5_8

Daniels, K. D., Park, M., Huang, Z., Jia, A., Flores, G. S., Lee, H. K., and Snyder, S. A. 2020. A Review of Extraction Methods for the Analysis of Pharmaceuticals in Environmental Waters. *Critical Reviews in Environmental Science and Technology* 50(21): 2271–2299. DOI: 10.1080/10643389.2019.1705723

Del Bino, S., Duval, C., and Bernerd, F. 2018. Clinical and Biological Characterization of Skin Pigmentation Diversity and Its Consequences on UV Impact. *International Journal of Molecular Sciences* 19(9): 2668. DOI: 10.3390/ijms19092668

Dimitrov, K., Pradal, D., Vauchel, P., Fabiano-Tixier, A.-S., and Chemat, F. 2022. Ultrasounds Technology to Recover Polyphenols. *Technologies to Recover Polyphenols from AgroFood By-products and Wastes* 201–223. DOI: 10.1016/b978-0-323-85273-9.00010-7

Djafarou, S., Mermer, A., Barut, B., Yılmaz, G. T., Amine Khodja, I., and Boulebd, H. 2023. Synthesis and Evaluation of the Antioxidant and Anti-tyrosinase Activities of Thiazolyl Hydrazone Derivatives and Their Application in the Anti-browning of Fresh-cut Potato. *Food Chemistry* 414: 135745. DOI: 10.1016/j.foodchem.2023.135745

Familasari, S., Sari, R. K., Syafii, W., Carolina, A., Cahyaningsih, U., and Sa'diah, S. 2023. Ultrasound-Assisted Extraction of Antimalarial Compounds from the Bidara Laut (*Strychnos ligustrina*) Heartwood. *Jurnal Sylva Lestari* 11(3): 360–369. DOI: 10.23960/jsl.v11i3.682

Ford, L., Theodoridou, K., Sheldrake, G. N., and Walsh, P. J. 2019. A Critical Review of

Analytical Methods Used for the Chemical Characterisation and Quantification of Phlorotannin Compounds in Brown Seaweeds. *Phytochemical Analysis* 30(6): 587–599. DOI: 10.1002/pca.2851

FWI. 2024. *Stop Tebang Pilih Tindak Industri Pengolahan Kayu di Papua Barat Daya.* <https://fwi.or.id> (Sept. 05, 2024)

Galanakis, C. M., Barba, F. J., and Prasad, K. N. 2015. Cost and Safety Issues of Emerging Technologies against Conventional Techniques. *Food Waste Recovery: Processing Technologies and Industrial Techniques* 279–294 DOI: 10.1016/b978-0-12-800351-0.00014-6

D'Alessandro, L. G., Dimitrov, K., Vauchel, P., and Nikov, I. 2014. Kinetics of Ultrasound Assisted Extraction of Anthocyanins from *Aronia melanocarpa* (Black Chokeberry) Wastes. *Chemical Engineering Research and Design* 92(10): 1818–1826. DOI: 10.1016/j.cherd.2013.11.020

Hasnaeni, Wisdawati, and Usman, S. 2019. The Effect of Extraction Method on Yield Value and Phenolic Content of Beta-Beta. *Galenika Journal of Pharmacy* 5(2): 175–182. DOI: 10.22487/j24428744.2019.v5.i2.13149

Kang, M., Choi, Y., and Byeon, S. 2024. Stability, Release, and Tyrosinase Inhibition Behaviors of Kojic Acid Encapsulated in the Interlayer Space of Layered Yttrium Hydroxide. *Applied Clay Science* 260(8): 107547. DOI: 10.1016/j.clay.2024.107547

Khadhraoui, B., Turk, M., Fabiano-Tixier, A. S., Petitcolas, E., Robinet, P., Imbert, R., Maâtaoui, M. El, and Chemat, F. 2018. Histo-Cytochemistry and Scanning Electron Microscopy for Studying Spatial and Temporal Extraction of Metabolites Induced by Ultrasound. Towards Chain Detexturation Mechanism. *Ultrasonics Sonochemistry* 42: 482–492. DOI: 10.1016/j.ultsonch.2017.11.029

Lee, J., Park, Y. J., Jung, H. J., Ullah, S., Yoon, D., Jeong, Y., Kim, G. Y., Kang, M. K., Kang, D., Park, Y., Chun, P., Chung, H. Y., and Moon, H. R. 2023. Design and Synthesis of (Z)-2-(Benzylamino)-5-benzylidenethiazol-4(5H)-one Derivatives as Tyrosinase Inhibitors and Their Anti-Melanogenic and Antioxidant Effects. *Molecules* 28(2): 1–27. DOI: 10.3390/molecules28020848

Lee, S. A., Lee, D., Kang, M., Kim, S., Kwon, S. J., Lee, H. S., Seo, H. R., Kaushal, P., Lee, N. S., Kim, H., Lee, C., and Kwon, J. 2022. BAP1 Promotes the Repair of UV-Induced DNA Damage via PARP1-Mediated Recruitment to Damage Sites and Control of Activity and Stability. *Cell Death and Differentiation* 29(12): 2381–2398. DOI: 10.1038/s41418-022-01024-w

Lickley, M., Solomon, S., Fletcher, S., Velders, G. J. M., Daniel, J., Rigby, M., Montzka, S. A., Kuijpers, L. J. M., and Stone, K. 2020. Quantifying Contributions of Chlorofluorocarbon Banks to Emissions and Impacts on the Ozone Layer and Climate. *Nature Communications* 11(1): 1380. DOI: 10.1038/s41467-020-15162-7

López-Perea, P., Guzmán-Ortiz, F. A., Román-Gutiérrez, A. D., Castro-Rosas, J., Gómez-Aldapa, C. A., Rodríguez-Marín, M. L., Falfán-Cortés, R. N., González-Olivares, L. G., and Torruco-Uco, J. G. 2019. Bioactive Compounds and Antioxidant Activity of Wheat Bran and Barley Husk in the Extracts with Different Polarity. *International Journal of Food Properties* 22(1): 646–658. DOI: 10.1080/10942912.2019.1600543

Malik, J., Santoso, A., and Ozarska, B. 2020. Polymerized Merbau Extractives as Impregnating Material for Wood Properties Enhancement. *IOP Conference Series: Materials Science and*

Engineering. DOI: 10.1088/1757-899x/935/1/012021

Manzoor, M. F., Hussain, A., Sameen, A., Sahar, A., Khan, S., Siddique, R., Muhammad, R., and Xu, B. 2021. Ultrasonics Sonochemistry Novel Extraction, Rapid Assessment and Bioavailability Improvement of Quercetin : A Review. *Ultrasonics Sonochemistry* 78: 105686. DOI: 10.1016/j.ultsonch.2021.105686

Manzoor, M. F., Zeng, X., and Rahaman, A. 2019. Combined Impact of Pulsed Electric Field and Ultrasound on Bioactive Compounds and FT-IR Analysis of Almond Extract. *Journal of Food Science and Technology* 56: 2355–2364. DOI: 10.1007/s13197-019-03627-7

Miyazawa, M., and Tamura, N. 2007. Inhibitory Compound of Tyrosinase Activity from the Sprout of Polygonum Inhibitory Compound of Tyrosinase Activity from the Sprout of *Polygonum hydropiper* L. (Benitade). *Biological and Pharmaceutical Bulletin* 30(3): 595–597. DOI: 10.1248/bpb.30.595

Molole, G. J., Gure, A., and Abdissa, N. 2022. Determination of Total Phenolic Content and Antioxidant Activity of *Commiphora mollis* (Oliv.) Engl. Resin. *BMC Chemistry* 16(1): 1–11. DOI: 10.1186/s13065-022-00841-x

Muller, C. D., Abu-orf, M., Blumenschein, C. D., and Novak, J. T. 2015. A Comparative Study of Ultrasonic Pretreatment and an Internal Recycle for the Enhancement of Mesophilic Anaerobic Digestion. *Water Environment Research* 81(12): 2398–2410. DOI: 10.2175/106143009X407311

Nerya, O., Vaya, J., Musa, R., Izrael, S., Ben-Arie, R., and Tamir, S. 2003. Glabrene and Isoliquiritigenin as Tyrosinase Inhibitors from Licorice Roots. *Journal of Agricultural and Food Chemistry* 51(5): 1201–1207. DOI: 10.1021/jf020935u

Nguyen, H. X., Nguyen, N. T., Nguyen, M. H. K., Le, T. H., Do, T. N., Hung, T. M. and Nguyen, M. T. T. 2016. Tyrosinase Inhibitory Activity of Flavonoids from *Artocarpus heterophyllous*. *Chemistry Central Journal* 10(1): 4–9. DOI: 10.1186/s13065-016-0150-7

Nur, Y., and Mulawarman, U. 2022. Aktivitas Antioksidan Ekstrak Kulit Batang Kenitu (*Chrysophyllum cainito* L.) dengan Dua Metode Ekstraksi. *Proceedings of the 8th Mulawarman Pharmaceuticals Conferences* 8–13. DOI: 10.25026/mpc.v8i1.296

Oroian, M., Ursachi, F., and Dranca, F. 2020. Ultrasound-Assisted Extraction of Polyphenols from Crude Pollen. *Antioxidants* 9(4): 322. DOI: 10.3390/antiox9040322

Panjaitan, R. S., and Meze, F. M. 2023. Variations of Extraction Methods, Phytochemical Screening, and Toxicity Test of Methanol *Eucheuma cottonii* Extract. *Indonesian Journal of Pharmaceutical Research* 3(2): 8–20. DOI: 10.1515/jcim-2012-0015

Pillaiyar, T., Manickam, M., and Namasivayam, V. 2017. Skin Whitening Agents: Medicinal Chemistry Perspective of Tyrosinase Inhibitors. *Journal of Enzyme Inhibition and Medicinal Chemistry* 32(1): 403–425. DOI: 10.1080/14756366.2016.1256882

Prayogo, Y. H., Batubara, I., Sari, R. K., Egra, S., Yamauchi, K., Mitsunaga, T., and Syafii, W. 2023. Chemical Constituent of *Acacia auriculiformis* Wood Extractives and Their Antioxidant Activity. *Jurnal Sylva Lestari* 11(3): 370–381. DOI: 10.23960/jsl.v11i3.753

Rafi, M., Sari, R. K., Wientarsih, I., Wulansari, L., Kautsar, A., Karomah, A. H., and Septaningsih, D. A. 2025. Antioxidant Activity and Metabolite Profiling of Intsia Bijuga Using Different Extraction Methods. *AIP Conference Proceedings* 3166(4): 020007-1-020007-8. DOI: 10.1063/5.0236655

Raymond-Lezman, J. R., and Riskin, S. I. 2023. Benefits and Risks of Sun Exposure to Maintain Adequate Vitamin D Levels. *Cureus* 15(5): e38578. DOI: 10.7759/cureus.38578

Risal, Y. 2020. Analisis Kemometrik Senyawa Inhibitor Tirosinase menggunakan Spektrofotometer IR (FTIR). *Majalah Farmasi dan Farmakologi* 24(2): 59–62. DOI: 10.20956/mff.v24i2.10610

Rianto, R., Wahyudi, and Dony, A. D. 2020. Potensi dan Pemanfaatan Limbah Gergajian pada Stand Kayu di Distrik Manokwari Barat. *Jurnal Kehutanan Papuasia* 5(1): 33–41. DOI: 10.46703/jurnalpapuasia.vol5.iss1.111

Rosales-Castro, M., Honorato-Salazar, J. A., Reyes-Navarrete, M. G. and González-Laredo, R. F. 2015. Antioxidant Phenolic Compounds of Ethanolic and Aqueous Extracts from Pink Cedar (*Acrocarpus fraxinifolius* Whight & Arn.) Bark at Two Tree Ages. *JWCT* 35(4): 270–279. DOI: 10.1080/02773813.2014.946619

Saeedi, M., Eslamifar, M., and Khezri, K. 2019. Kojic Acid Applications in Cosmetic and Pharmaceutical Preparations. *Biomedicine and Pharmacotherapy* 110(11): 582–593. DOI: 10.1016/j.biopha.2018.12.006

Sari, R. K., Prayogo, Y. H., Sari, R. A. L., Asidah, N., Rafi, M., Wientarsih, I., and Darmawan, W. 2021. *Intsia bijuga* Heartwood Extract and its Phytosome as Tyrosinase Inhibitor, Antioxidant, and Sun Protector. *Forests* 12(12): 1792. DOI: 10.3390/f12121792

Searle, T., Al-Niaimi, F., and Ali, F. R. 2021. Hydroquinone: Myths and Reality. *Clinical and Experimental Dermatology* 46(4): 636–640. DOI: 10.1111/ced.14480

Shintawati, S., Rina, O., and Ermaya, D. 2020. Sifat Antimikroba dan Pengaruh Perlakuan Bahan Baku terhadap Rendemen Minyak Sereh Wangi (Antimicrobial Properties and Effects of Raw Material Treatments on Citronella Oil Yield). *Jurnal Sylva Lestari* 8(3): 411. DOI: 10.23960/jsl38411-419

Serre, C., Busuttil, V., and Botto, J. M. 2018. Intrinsic and Extrinsic Regulation of Human Skin Melanogenesis and Pigmentation. *International Journal of Cosmetic Science* 40(4): 328–347. DOI: 10.1111/ics.1246

Silve, A., Papachristou, I., Wüstner, R., Sträßner, R., Schirmer, M., Leber, K., Guo, B., Interrante, L., Posten, C., and Frey, W. 2018. Extraction of Lipids from Wet Microalga *Auxenochlorella protothecoides* using Pulsed Electric Field Treatment and Ethanol-Hexane Blends. *Algal Research* 29: 212–222. DOI: 10.1016/j.algal.2017.11.016

Simić, V. M., Rajković, K. M., Stojičević, S. S., Veličković, D. T., Nikolić, N., Lazić, M. L., and Karabegović, I. T. 2016. Optimization of Microwave-Assisted Extraction of Total Polyphenolic Compounds from Chokeberries by Response Surface Methodology and Artificial Neural Network. *Separation and Purification Technology* 160(2): 89–97. DOI: 10.1016/j.seppur.2016.01.019

Singh, M., Pandey, N., Agnihotri, V., Singh, K. K., and Pandey, A. 2017. Antioxidant, Antimicrobial Activity and Bioactive Compounds of B*ergenia ciliata* Sternb: A Valuable Medicinal Herb of Sikkim Himalaya. *Journal of Traditional Chinese Medical Sciences* 7(2): 152–157. DOI: 10.1016/j.jtcme.2016.04.002

Solano, F. 2020. Photoprotection and Skin Pigmentation: Melanin-Related Molecules and Some Other New Agents Obtained from Natural Sources. *Molecules* 25(7): 1–18. DOI: 10.3390/molecules25071537

Stevanato, N., and da Silva, C. 2019. Ultrasound-assisted Extraction using Ethanol as Solvent and Assessment of its Potential for Ester Production. *Industrial Crops and Products* 132(12): 283–291. DOI: 10.1016/j.indcrop.2019.02.032

Tahtaci, H., Ozcan, I., Hamdi, A., Erdogan, T., and Kisa, D. 2025. 1,2,4-Triazole-derived Oxime

Ether Derivatives: Synthesis, Characterization, in Vitro Tyrosinase Inhibition Properties and in Silico Studies. *Journal of Molecular Structure* 1323(1): 140722. DOI: 10.1016/j.molstruc.2024.140722

Tang, X., Yang, T., Yu, D., Xiong, H., and Zhang, S. 2024. Current Insights and Future Perspectives of Ultraviolet Radiation (UV) Exposure: Friends and Foes to the Skin and Beyond the Skin. *Environment International* 185: 108535. DOI: 10.1016/j.envint.2024.108535

Tian, Y., Deng, D., Luo, H., He, M. and Wang, S. 2025. Ultrasonic Assisted Enzymatic Extraction, Structural Characterization, and Tyrosinase Inhibition Mechanism of Phlorotannins from *Sargassum horneri*. *Algal Research* 88(11): 104038. DOI: 10.1016/j.algal.2025.104038

Turker, I., and Isleroglu, H. 2021. Optimization of Extraction Conditions of Bioactive Compounds by Ultrasonic-Assisted Extraction from Artichoke Wastes. *Acta Chimica Slovenica* 68(3): 658–666. DOI: 10.17344/acsi.2021.6679

Wardatun, S., Ahyar, A. Z., and Nining, E. 2024. Comparison of Maceration and Ultrasound-Assisted Extraction Method in Determining Quercetin Content of *Clitoria ternatea* L. *Jurnal Ilmiah Farmasi* 14(1): 36–43. DOI: 10.33751/jf.v14i1.10043

Widyasanti, A., Aryadi, H., and Rohdiana, D. 2018. Pengaruh Perbedaan Lama Ekstraksi Teh Putih dengan menggunakan Metode Microwave Assisted Extraction (Mae). *Jurnal Teknologi Pertanian Andalas* 22(2): 165. DOI: 10.25077/jtpa.22.2.165-174.2018

Wu, K., and Xi, J. 2020. Mechanochemical-Assisted Extraction of Platycodin D from the Roots of *Platycodon grandiflorum* with Solid Alkalis. *Industrial Crops and Products* 145: 112026. DOI: 10.1016/j.indcrop.2019.112026

Xue, S., Li, Z., Ze, X., Wu, X., He, C., Shuai, W., Marlow, M., Chen, J., Scurr, D., Zhu, Z., Xu, J., and Xu, S. 2023. Design, Synthesis, and Biological Evaluation of Novel Hybrids Containing Dihydrochalcone as Tyrosinase Inhibitors to Treat Skin Hyperpigmentation. *Journal of Medicinal Chemistry* 66(7): 5099–5117. DOI: 10.1021/acs.jmedchem.3c00012

Yabalak, E., Emire, Z., Adıgüzel, A. O., Könen Adıgüzel, S., and Gizir, A. M. 2020. Wide-Scale Evaluation of *Origanum munzurense* Kit Tan and Sorger using different Extraction Techniques: Antioxidant Capacity, Chemical Compounds, Trace Element Content, Total Phenolic Content, Antibacterial Activity and Genotoxic Effect. *Flavour and Fragrance Journal* 35(4): 394–410. DOI: 10.1002/ffj.3574

Zaini, M., Hidriya, H., and Japeri, J. 2020. Aktivitas Antioksidan Ekstrak Etanol *Muntingia calabura* dengan Variasi Laju Pengadukan menggunakan Macerator-Magnetic Stirrer (M-MS). *Jurnal Pharmascience* 7(2): 27. DOI: 10.20527/jps.v7i2.9037

Zargaham, M. K., Ahmed, M., Akhtar, N., Ashraf, Z., Abdel-Maksoud, M. A., Aufy, M., and Nadeem, H. 2023. Synthesis, in Silico Studies, and Antioxidant and Tyrosinase Inhibitory Potential of 2-(Substituted Phenyl) Thiazolidine-4-Carboxamide Derivatives. *Pharmaceuticals* 16(6): 1–15. DOI: 10.3390/ph16060835

Zhang, H., Yuan, Y., Zhu, X., Xu, R., Shen, H., Zhang, Q., and Ge, X. 2022. The Effect of Different Extraction Methods on Extraction Yield, Physicochemical Properties, and Volatile Compounds from Field Muskmelon Seed Oil. *Foods* 11(5): 721. DOI: 10.3390/foods11050721