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Phytochemical and antioxidant potential of *Bruguiera* sp. fruits revealed by LC-HRMS and conventional assays

ENDAH DWI HASTUTI[1,♥], SITI NUR HIDAYATI[2], ERMA PRIHASTANTI[1], MUHAMMAD LUQMAN HAKIM[1], SRI DARMANTI[1], SRI WIDODO AGUNG SUEDY[1]

[1]Department of Biology, Faculty of Science and Mathematics, Universitas Diponegoro. Jl. Prof. Soedarto, S.H., Semarang 50275, Central Java, Indonesia. Tel.: +62-24-7474754, ♥email: edh.hastuti@gmail.com

[2]Department of Biology, University of Middle Tennessee State. 1301 East Main St., Murfreesboro, Tennessee 37132, United States of America

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Abstract. *Hastuti ED, Hidayati SN, Prihastanti E, Hakim ML, Darmanti S, Suedy SWA. 2025. Phytochemical and antioxidant potential of* Bruguiera *sp. fruits revealed by LC-HRMS and conventional assays. Biodiversitas 26: 5714-5725.* Almost all mangrove fruits contain phytochemicals and nutrients, exhibiting varying levels of antioxidant activity that help them adapt to extreme environmental conditions. This study aims to investigate the phytochemical profile, nutrient composition, and antioxidant activity of *Bruguiera* sp. mangrove fruit through qualitative and quantitative analyses. Qualitative analysis was performed using High-Resolution Liquid Chromatography-Mass Spectrometry (LC-HRMS) to analyze the phytochemical profile. Quantitative analysis included determining nutrient composition using gravimetry, the Kjeldahl method, and the by-difference method. Secondary metabolites and pigments were analyzed using spectrophotometric analysis and High-Performance Liquid Chromatography (HPLC). Antioxidant activity was determined through the 2,2-diphenyl-1-picrylhydrazine (DPPH) assay. The results showed that *Bruguiera* sp. fruits contained lipids (28%), flavonoids (10%), alcohols (8%), carbohydrates (8%), and esters (8%) as the five most abundant groups of compounds that play a role in adaptation to a highly saline environment. In addition, its adaptability is also demonstrated by its high phenol concentrations (11.2% w/w) and significant levels of chlorophyll b (9.77 mg/g). The nutrient composition indicated a high carbohydrate content (79.21% w/w), carotenoids (17.61 µmol/g), and vitamin C (15.68 mg/kg). The integration of LC-HRMS with conventional methods improves the identification of bioactive compounds. Antioxidant analysis demonstrated very strong activity (0.19 ppm), indicating potential antioxidant activity. These findings indicate that the *Bruguiera* sp. fruit is a promising natural source of antioxidants with significant potential as a functional food and valuable medicinal source. The strong antioxidant properties of this fruit contribute to the prevention of diseases associated with oxidative stress and provide a sustainable nutritional alternative, especially in areas with limited access to nutritious foods.

Keywords: Carbohydrates, carotenoids, LC-HRMS, mangrove fruit, phenolic compounds

INTRODUCTION

The rising incidence of chronic diseases, including cancer and neurodegenerative disorders, has been closely linked to oxidative stress, a condition caused by an imbalance between Reactive Oxygen Species (ROS) production and antioxidant defense systems (Kitphati et al. 2024; Dhaou et al. 2025). Although synthetic antioxidants are commonly employed to neutralize ROS, concerns regarding their potential toxicity, bioaccumulation, and carcinogenic effects have prompted a global shift toward safer and natural alternatives (Haslina et al. 2023). Mangrove ecosystems offer a promising yet underexplored source of bioactive compounds with antioxidant properties. These plants have evolved to thrive under extreme conditions, such as high salinity, by producing diverse secondary metabolites that not only support stress tolerance but also exhibit therapeutic activities (Nizam et al. 2022; Sudhir et al. 2022).

Building on this foundation, mangroves have attracted attention for their medicinal and nutritional potential (Bibi et al. 2019). Many studies have discussed the phytochemical and dietary aspects of various mangrove species, such as *Avicennia marina* (Takarina et al. 2018; Govindhan 2024; Hastuti and Prihastanti 2025), *Bruguiera gymnorrhiza* (Analuddin et al. 2019; Acharya et al. 2020; Karim et al. 2020), *Sonneratia alba* (Dotulong et al. 2018; Analuddin et al. 2019), *Sonneratia caseolaris* (Basyuni et al. 2019), *Sonneratia apetala* (Yi et al. 2020), *Rhizophora* sp. (Nurzaman et al. 2018; Syahidah and Subekti 2019), and *Xylocarpus granatum* (Analuddin et al. 2019; Sahai et al. 2020).

Although there has been an increasing number of studies on mangrove leaves and bark, scientific research on mangrove fruits, especially those of the *Bruguiera* species, remains limited and fragmented. Few studies have analyzed the phytochemical content and antioxidant capacity of mangrove fruits, with *Bruguiera gymnorrhiza* occasionally appearing alongside species such as *X. granatum, S. alba, S. apetala,* and *Rhizophora* spp. (Analuddin et al. 2019; Yi et al. 2020; Riyadi et al. 2021; Sadeer et al. 2022; Mongdong et al. 2023; Rozirwan et al. 2023). This gap highlights the need for a comprehensive evaluation of

Bruguiera sp. fruit, particularly using an integrated and sensitive analytical platform.

Reliable and comprehensive analytical methods are essential for defining the bioactive components of mangrove fruit. Conventional analytical techniques, such as 2,2-diphenyl-1-picrylhydrazine (DPPH) (Mahmud et al. 2017; Riyadi et al. 2021; Khadeeja et al. 2022; Tung and Thuy 2022) and High-Performance Liquid Chromatography (HPLC) (Mahmud et al. 2017; Sadeer et al. 2020), have been widely used to explore phytochemical profiles, nutrient composition, and antioxidant activity. However, these approaches often face limitations in detecting low-abundance or structurally diverse compounds. Integrating these traditional approaches with advanced tools, such as Liquid Chromatography-High Resolution Mass Spectrometry (LC-HRMS), offers a more robust and comprehensive strategy. LC-HRMS provides high-resolution profiling, enabling the precise identification of both major and minor metabolites (do Amaral et al. 2021). Despite its promising phytochemical profile, scientific studies combining LC-HRMS with conventional assays to evaluate the *Bruguiera* sp. fruit remain limited. Such integrative analysis is not only scientifically valuable but also practically beneficial, offering a cost-effective and high-accuracy methodology for characterizing plant-derived bioactive compounds.

The primary objective of this study is to investigate the phytochemical profile, nutrient composition, and antioxidant activity of *Bruguiera* sp. fruit using an integrated analytical approach that combines conventional methods with advanced LC-HRMS. This research aims to fill the existing knowledge gap regarding the largely uncharacterized bioactive compounds in *Bruguiera* sp. fruit. By doing so, it promotes the valorization of mangrove fruits as a natural source of antioxidants and nutrients that can contribute to human health and nutrition.

Importantly, this research aligns with the United Nations Sustainable Development Goals (SDGs), particularly SDGs 2 and SDGs 12. This study supports the goal of ending hunger and achieving food security by exploring the potential of *Bruguiera* sp. fruit as a sustainable and alternative source of nutrition for coastal communities. By characterizing its nutrient density and antioxidant capacity, the research encourages diversification of local diets and contributes to enhancing food security and nutritional resilience. Optimal utilization of mangrove fruits promotes the sustainability of coastal resources based on biodiversity, reduces waste, and decreases dependence on synthetic antioxidants that may pose health risks.

MATERIALS AND METHODS

Plant material

The *Bruguiera* fruit samples were collected from the coastal region of Mangunharjo, Tugu, Semarang, Central Java, Indonesia, during the dry season in April. Specimens were taken from three mature trees to ensure the validity and reliability of the results. The fruits were sourced from the central part of each tree at a moderate level of ripeness to ensure the stability of fruit characteristics. Fruits with medium maturity are characterized by an increase in fruit size and the appearance of slight protuberances or protrusions, which indicate the gradual emergence of the hypocotyl. This process is also accompanied by changes in the color and texture of the fruit, which is not yet fully ripe, still green, with the emergence of other colors (Figure 1) (Sarno et al. 2018).

Sample preparation

The collected fruits were oven-dried and ground into powder. Extraction is performed by dissolving the crushed fruit sample in a specific solvent selected based on its polarity and compatibility. This aims to maximize the recovery of target phytochemicals and testing accuracy. Methanol is used in LC-HRMS analysis due to its ability to effectively extract various polar and semi-polar metabolites (Zuffa et al. 2025). Spectrophotometric tests targeting secondary metabolites, such as phenolics and pigments, use diethyl ether and acetone, respectively, because these solvents efficiently dissolve these classes of compounds (Boutaoui et al. 2018). HPLC samples are prepared using aqueous solvent injections to maintain chromatographic compatibility. Ethanol is chosen for DPPH antioxidant assays due to its ability to extract antioxidant compounds and maintain their activity (Rea-Martinez et al. 2020). Solvent selection and extraction methods are standardized across three replicates, except for LC-HRMS with two replicates, to minimize variability in phytochemical extraction and ensure reliable comparative analysis (Roy and Dutta 2021).

Procedures

Phytochemical profiling

Thermo Scientific™ Dionex™ Ultimate 3000 RSLCnano UHPLC, coupled with a Thermo Scientific™ Q Exactive™ High Resolution Mass Spectrometer, was employed to analyze the bioactive compounds in *Bruguiera* sp. fruit qualitatively. The analysis utilized Phenyl-Hexyl analytical column (100 mm × 2.1 mm). A total of 2.55 g of fruit was extracted in methanol and shaken with a vortex for 3 min. The mobile phase consisted of water with 0.1% formic acid (A) and acetonitrile with 0.1% formic acid (B) (Dwiyanti et al. 2023). A gradient technique was applied at a flow rate of 0,20 mL/minute. The gradient began with 5% mobile phase B, which was gradually increased to 60% over 13 minutes, and then held at 95% for 7 minutes. Then it returned to the initial condition (5% B) within 0.1 min, followed by column re-equilibration under these conditions until the end of the 30-min run. The solution was filtered through a 0.2 µm Millex filter and injected into the LC-HRMS system. Mass spectrometric analysis was performed in both positive and negative ionization modes using a Heated Electrospray Ionization (H-ESI) method. Compound identification was performed using Thermo Scientific™ Compound Discoverer software, which utilizes accurate mass measurements combined with MS/MS spectral matching to reference databases, such as mzCloud and ChemSpider.

Figure 1. *Bruguiera* sp. fruits

Analysis of secondary metabolites and pigments

Phytochemical analysis was conducted to identify and quantify bioactive compounds, including phenols, tannins, alkaloids, chlorophyll a, and chlorophyll b, present in *Bruguiera* sp. fruit. Several techniques were employed to assess phytochemicals, including spectrophotometry for the analysis of pigments and secondary metabolites, and HPLC for the quantification of vitamin C content.

The total phenolic content was measured using the spectrophotometric method. A total of 50 mg of sample was mixed with 0.5 mL of Folin-Ciocalteu reagent and 7.5 mL of distilled water, and then shaken. After 10 minutes, 1.5 mL of 20% sodium carbonate was added, the mixture was shaken, and it was then incubated for an additional 10 minutes. The final solution was diluted to 10 mL with distilled water, filtered, and diluted 25 times. Absorbance was measured at a wavelength of 760 nm. A detection wavelength of 760 nm was employed, corresponding to the absorbance maximum of the blue molybdenum-tungsten complex formed in the Folin-Ciocalteu reaction. This wavelength ensures optimal sensitivity while minimizing interference from non-phenolic compounds (Aleixandre-Tudo and du Toit 2018). A standard curve was prepared using 10 mg of gallic acid at concentrations of 100, 75, 50, 25, 10, 5, 2.5, 1, 0.5, and 0.2 ppm.

The total tannin content was measured using the spectrophotometric method. A total of 50 mg of sample was extracted with 10 mL of diethyl ether for 20 hours, followed by filtration and evaporation under reduced pressure. The resulting residue was dissolved in distilled water to a volume of 10 mL. 1 mL of the sample solution was combined with 0.1 mL of Folin-Ciocalteu reagent, mixed using a vortex. 2 mL of 20% sodium carbonate were added, followed by vortex mixing. Finally, the solution was diluted to a total volume of 10 mL. The absorbance was measured at 760 nm after a 30-minute incubation at room temperature. A standard curve was prepared using tannic acid solution, following the same procedure (Martins et al. 2021).

To determine the alkaloid content, 100 mg of the sample was extracted using hydrochloric acid and subsequently washed three times with 10 mL of chloroform, following neutralization with 0.1 N NaOH. Bromocresol Green (BCG) solution and phosphate buffer were added, and the mixture was stirred at 500 rpm for 15 minutes while being extracted with 5 mL of chloroform. The extraction process was repeated twice. The chloroform phase was evaporated using nitrogen gas and then redissolved in 5 mL of chloroform. The alkaloid content was measured at 470 nm, using 10 mg of quinine as the standard (Dey et al. 2025). This wavelength was selected based on the maximum absorbance (λmax) of the yellow-orange ion-pair complex formed between the alkaloid constituents and BCG under acidic conditions. The choice of λmax ensures optimal sensitivity and accuracy by minimizing baseline noise and maximizing signal intensity (Prajapati et al. 2024). Total phenols, tannins, and alkaloids were measured using the same formula, namely standard concentration (c) multiplied by the final volume of the solution (V) divided by the sample mass (m) (c × V/m).

Chlorophyll were quantified using spectrophotometric method. Initially, 0.1 g of mangrove fruit was crushed and subsequently extracted using 10 mL of 80% acetone. The wavelengths employed for the measurements were 645 nm and 663 nm. Chlorophyll a exhibits maximal absorbance at 663 nm due to its Qy transition in the red region of the spectrum. Chlorophyll b shows a λmax at 645 nm, reflecting a slight red shift caused by its formyl substitution at the C7 position of the chlorin ring. The spectrophotometer was calibrated with a blank solution. Cuvettes containing standard solutions and extracts of *Bruguiera* sp. fruit samples were measured at predetermined wavelengths. Each absorbance value was recorded (Musara et al. 2020). The pigment concentrations were calculated using the equations presented by Hendry and Grime (1993):

$$Chlorophyll\ A\ (mg/g) = \frac{(12{,}7x\ A663) - (2{,}69\ x\ A645)}{10}$$

$$Chlorophyll\ B\ (mg/g) = \frac{(22{,}9x\ A645) - (4{,}68\ x\ A663)}{10}$$

$$Total\ Chlorophyll\ (mg/g) = \frac{(8{,}02x\ A663) - (20{,}2\ x\ A645)}{10}$$

Nutrient composition

The composition of carbohydrate, proteins, fats, ash, water, carotenoids, and vitamin C content of *Bruguiera* sp. fruit was analyzed using Standard methods, including gravimetry, Kjeldahl, by-difference, and spectrophotometry methods (Egra et al. 2023).

The protein content was determined using the Kjeldahl method, which consists of destruction, distillation, and automatic titration. Destruction is carried out by weighing 1 g of the sample, then placing it in a Kjeldahl tube. K_2SO_4 3.5 g, $CuSO_4.5H_2O$ 0.1 g, and H_2SO_4 12 mL are added, then heated in an acid cabinet on the Automatic Digestion Unit instrument. The digestion product is transferred to a round-bottomed flask mounted on a distillation apparatus. Two boiling stones, 50 mL of 30% NaOH, and 100 mL of distilled water are added to the flask, and then the flask is sealed. The distillate is collected with 4% H_3BO_3 containing methyl red and BCG indicators. The flask is heated at ±100°C until the distillation droplets are neutral. The distillate is adjusted to exactly 100 mL, then titrated

with 0.2N HCl that has been standardized. A blank, consisting of 30% NaOH, distilled water, ammonia, and BCG indicator, is prepared using the same procedure without the sample. The protein content was calculated by applying a conversion factor (Sormin et al. 2024). The calculation of %N and %protein is done using the following formula:

$$\%N = \frac{14{,}007\ x\ (volume\ titran - volume\ blanko)\ x\ N\ x\ 100}{(1000\ x\ gram\ sampel)}$$

$$\%Protein = conversion\ factor\ x\ \%N$$

The fat content was measured using the gravimetric method. Samples (1-10 g) were homogenized with 50 mL of 4M HCl and Celite (2 g), rinsed to neutral pH, and then hydrolyzed with a BUCHI HydrolEx H-506 unit series. After that, 50 mL of distilled water at 50°C was added. The heating level was turned off, and then the lever was lowered, allowing the sample to be sucked into the filter glass. The sample was spread evenly on the filter glass, then 10 g of quartz sand was added. The filter glass containing the sample was dried in an oven at 100°C for 2 hours, placed in a beaker of known weight, and then 100 mL of a 1:1 (v/v) mixture of petroleum ether and diethyl ether solvent was added. The beaker was mounted on the BUCHI E-500 HE extraction unit and left until evaporation was complete (Jamarun et al. 2020). The calculation of %total fat is done using the following formula:

$$\%Total\ fat = \frac{(\text{weight of beaker} + \text{fat} - \text{weight of empty beaker})}{(\text{weight of sample})}\ x\ 100$$

Water and ash content were determined using gravimetric methods, which involved weighing the empty crucible (A). A homogeneous sample was weighed and placed in a porcelain crucible (B). The sample was heated in an oven at 105°C for 3 hours until a constant weight was achieved, and then it was finally placed in a desiccator to be weighed (C). The porcelain crucible was then sealed, placed in a furnace, and heated at 600°C for 8 hours until a constant weight was achieved. The porcelain crucible was then placed in a desiccator and weighed (D) (Klohmann and Padilla-Gamiño 2022). The calculation of water and ash content is done using the following formula:

$$\text{Water content} = \frac{(A + B) - C}{B}\ x\ 100\%$$

$$\text{Ash content} = \frac{(D - A)}{B}\ x\ 100\%$$

Carbohydrates were analyzed using the by-difference method. This method estimates the total carbohydrate content by subtracting the percentages of total protein, fat, water, and ash content from 100% (Dewi et al. 2025).

Carotenoids were quantified using spectrophotometric method. A total of 0.1 g of mangrove fruit was crushed and subsequently extracted using 10 mL of 80% acetone. The wavelengths employed for the measurements were 480 nm, 645 nm, and 663 nm. Carotenoids exhibit maximal absorbance in the blue-green region (Bednarczyk et al. 2019). The spectrophotometer was calibrated with a blank solution. Cuvettes containing standard solutions and extracts of *Bruguiera* sp. fruit samples were measured at predetermined wavelengths. Each absorbance value was recorded (Musara et al. 2020). The pigment concentrations were calculated using the equations presented by Hendry and Grime (1993) in Table 1.

The vitamin C content was analyzed using the HPLC method. A total of 200 mg of fruit powder was extracted using 1 mL of aqua pro injection solution, vortexed, then centrifuged. 1 mL of aqua pro injection was added to a test tube containing the residue, sonicated for 5 minutes, vortexed, and centrifuged. The filtrate was placed in a 10 mL volumetric flask. Repeat the steps 3 times. The filtrate was then diluted to 10 mL, filtered with a 0.45 µm filter, and subsequently diluted 10 times. Samples of 50 and 100 µL were injected into the HPLC. Standards of ascorbic acid were prepared from a solution containing 10 mg in 70% ethanol, resulting in a standard solution of 1.000 mg/L. Then, a series of dilutions was made to concentrations of 2, 4, 6, 8, 10, 25, 50 mg/L, and 20 µL was injected into the HPLC for calibration (Bansal et al. 2018).

Antioxidant activities

Antioxidant activity of *Bruguiera* sp. fruit was tested using the 2,2-diphenyl-1-picrylhydrazine (DPPH) assay. This wavelength corresponds to the maximum absorbance (λmax) of the stable free radical 2,2-diphenyl-1-picrylhydrazyl in its unreacted form, which exhibits a deep violet coloration due to extensive π-π-electron conjugation within its aromatic and nitro-substituted structure (Ionita 2021). The sample (0.1 mL) was added to 1 mL of a 0.4 mM DPPH solution and diluted with ethanol to a final volume of 5 mL. The mixture was then incubated for 30 minutes in a dark room. The absorbance of the samples was measured to calculate the radical scavenging activity at 517 nm. The calculation of %inhibition is done using the following formula:

$$\%inhibition = \left(\frac{Acontrol - Asample}{Acontrol}\right) x\ 100\%$$

The IC_{50} value, which represents the concentration of the sample required to inhibit 50% of DPPH radical activity, was determined by plotting a regression curve of concentration versus percentage inhibition (Sadeer et al. 2023). IC_{50} value obtained for the standard (Maryam et al. 2023). The categories of antioxidant activity strength according to Susiloningrum and Sari (2021) are categorized into very strong (IC_{50}<50 ppm), strong (IC_{50} 51-100 ppm), moderate (IC_{50} 101-150 ppm), weak (IC_{50}>151 ppm), and inactive (IC_{50}>500 ppm).

Data analysis

Data analysis was performed using descriptive methods for the evaluation of phytochemical profile, secondary metabolites, pigments, nutrient composition, and antioxidant activity of *Bruguiera* sp. fruit. The phytochemicals identified by LC-HRMS were categorized and compared with known compounds using reference data from the PubChem and Human Metabolome Databases (HMDB).

RESULTS AND DISCUSSION

Phytochemical profile

Based on LC-HRMS analysis of *Bruguiera* sp. fruit, a total of 50 chemical compounds were identified (Table 1). Compound identification was carried out by matching mass spectra with the mzCloud and ChemSpider databases. All detected compounds showed a match in mzCloud, while 41 compounds were additionally confirmed through ChemSpider. Further classification was conducted using information from the PubChem and Human Metabolome Database (HMDB).

Among the identified metabolites, lipids and flavonoids were the most dominant chemical groups. Fourteen lipid-related compounds (28%) were identified, followed by five flavonoids (10%). In addition, the extract also contained other groups of bioactive compounds, including, four alcohols (8%), four carbohydrates (8%), four esters (8%), two organic acids (4%), two amines (4%), two amino acids (4%), two carboxylic acids (4%), two nucleic acids (4%), one phenol (2%), one tannin (2%), one alkaloid (2%), and several compounds belonging to minor categories (Figure 2).

A high peak area in LC-HRMS chromatograms indicates compounds with a high relative abundance. Among 50 identified metabolites in Table 1, hexadecanoic acid (7.72 × 10^9 g/mol), 2-hydroxybutanedioic acid (3.40 × 10^9 g/mol), (E)-3-(3,4-dihydroxyphenyl)prop-2-enoic acid (2.54 × 10^9 g/mol), (1R,3R,4S,5R)-3-[(E)-3-(3,4-dihydroxyphenyl)prop-2-enoyl]oxy-1,4,5-trihydroxycyclohexane-1-carboxylic acid (2.46 × 10^9 g/mol), 1S,3R,4R,5R)-1,3,4-trihydroxy-5-[(E)-3-(4-hydroxyphenyl)prop-2-enoyl]oxycyclohexane-1-carboxylic acid (1.39 × 10^9 g/mol), and 6-methylquinoline (1.26 × 10^9 g/mol) exhibited the first largest peak areas, suggesting that these metabolites are predominant in the sample matrix. Lower-abundance constituents, including N-[(2-thiophen-2-yl-1,3-thiazol-4-yl)methyl]benzamide (6.70 × 107 g/mol) and (2R)-4-methyl-2-[[(2S)-1-phenylmethoxycarbonylpyrrolidine-2-carbonyl]amino]pentanoic acid (6.47 × 10^7 g/mol), were also detected, reflecting the sample's chemical diversity.

Secondary metabolites and pigments

The concentrations of phenols, tannins, and alkaloids in *Bruguiera* sp. fruit, as determined using spectrophotometry, are listed in Table 2. The *Bruguiera* sp. fruit contains a high chlorophyll b (9.77 mg/g), followed by chlorophyll a (6.57 mg/g).

The results indicate that the concentration of phenols in *Bruguiera* sp. fruit is higher than tannins and alkaloids. The LC-HRMS analysis also revealed five flavonoid compounds, such as 2-(3,4-dihydroxyphenyl)-5-hydroxy-7-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl)oxan-2-yl]oxychromen-4-one, 2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl]oxychromen-4-one, 5,7-dihydroxy-2-(4-hydroxyphenyl)-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl]oxychromen-4-one, 3,5,7-trihydroxy-2-(4-hydroxyphenyl)chromen-4-one, and (2R,3S)-2-(3,4-dihydroxyphenyl)-3,4-dihydro-2H-chromene-3,5,7-triol. In addition, (E)-3-(3,4-dihydroxyphenyl)prop-2-enoic acid was detected as a phenol, 6-methylquinoline as an alkaloid, and benzene-1,2,3-triol as a tannin (Table 3).

Nutrient composition

Bruguiera sp. fruit contains carbohydrates, protein, fat, ash, and water (Table 4). Carbohydrates were the most abundant, with a concentration of 79.21% w/w, as supported by the presence of four compounds identified by LC-HRMS. The lipid group contained highly abundant compounds found in *Bruguiera* sp. fruit, as determined by LC-HRMS results, totaling 14 compounds (Table 1). These compounds include hexadecanoic acid, (Z)-docos-13-enamide, nonanedioic acid, (Z)-9,12,13-trihydroxyoctadec-15-enoic acid, (Z)-octadec-9-enamide, 2-methylpropanedioic acid, oleoyl-L-α-lysophosphatidic acid, (2S,3S)-2-amino-3-methylpentanoic acid, (10E,12E,14E,16S)-16-hydroxy-9-oxooctadeca-10,12,14-trienoic acid, (9E,11E)-13-hydroperoxyoctadeca-9,11-dienoic acid, (10E,12E)-9-hydroxyoctadeca-10,12-dienoic acid, (E)-3-phenylprop-2-enoic acid, 9-oxo-10(E), (9E,12E)-11-oxooctadeca-9,12-dienoic acid, and 3-(4-hydroxyphenyl)prop-2-enoic acid. Additionally, two amino acid compounds were also detected. The carotenoid and vitamin C contents in the fruit are 17.61 µmol/g and 15.68 mg/kg (Table 4).

Antioxidant activity

The antioxidant activity of *Bruguiera* sp. fruit was measured quantitatively using the DPPH assay, which determines the ability of fruit extracts to neutralize free radicals. The fruit showed a very low IC_{50} (Inhibitory Concentration 50%) value of 0.19 ppm, indicating that only 0.19 parts per million of extract is needed to inhibit 50% of DPPH radical activity, demonstrating strong antioxidant potential.

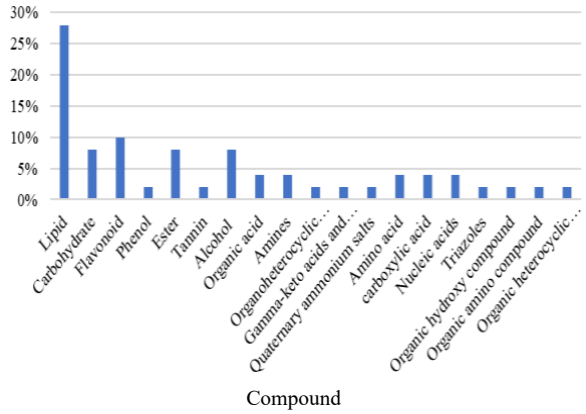

Figure 2. Abundant of compound groups in *Bruguiera* sp. fruits

Table 1. Bioactive compound content of *Bruguiera* sp. fruit

Name	Formula	Annot. source: mzCloud search	Annot. source: ChemSpider search	Calc. MW	RT [min]	Area (Max.)	Group area: F1	Group area: F2	Group
Hexadecanoic Acid	$C_{16}H_{32}O_2$	Invalid mass	No match	273.2662	12.97	7715697020	7715697020		Lipid
2-hydroxybutanedioic acid	$C_4H_6O_5$	Invalid mass	No results	134.0203	1.186	3404444373		3404444373	Organic acid
2-aminooctadecane-1,3,4-triol	$C_{18}H_{39}NO_3$	Full match	Full match	317.2922	13.146	2762169803	2762169803		Amines
(E)-3-(3,4-dihydroxyphenyl)prop-2-enoic acid	$C_9H_8O_4$	Full match	Not the top hit	180.042	4.811	2537737398	2537737398		Phenols
(1R,3R,4S,5R)-3-[(E)-3-(3,4-dihydroxyphenyl)prop-2-enoyl]oxy-1,4,5-trihydroxycyclohexane-1-carboxylic acid	$C_{16}H_{18}O_9$	Full match	Full match	354.0945	4.797	2462934732	2059594601	2462934732	Alcohol
1S,3R,4R,5R)-1,3,4-trihydroxy-5-[(E)-3-(4-hydroxyphenyl)prop-2-enoyl]oxycyclohexane-1-carboxylic acid	$C_7H_{12}O_6$	Full match	Full match	192.0625	1.159	1385140101		1385140101	Alcohol
6-Methylquinoline	$C_{10}H_9N$	Full match	Not the top hit	143.0733	5.788	1264826874	1264826874		Alkaloid
(Z)-docos-13-enamide	$C_{22}H_{43}NO$	Full match	No results	337.3338	22.515	944337789	944337789		Lipid
(1r,3R,4s,5S)-4-{[(2E)-3-(3,4-dihydroxyphenyl)prop-2-enoyl]oxy}-1,3,5-trihydroxycyclohexane-1-carboxylic acid	$C_{16}H_{18}O_9$	Full match	Not the top hit	354.0946	3.906	842844209	842844209		Alcohol
2-oxopentanedioic acid	$C_5H_6O_5$	Invalid mass	Invalid mass	146.0207	1.184	613037545		613037545	Gamma-keto acids and derivatives
nonanedioic acid	$C_9H_{16}O_4$	Invalid mass	Invalid mass	188.1039	9.621	569547710	10327625	569547710	Lipid
2-hydroxyethyl(trimethyl)azanium	$C_5H_{13}NO$	Full match	No results	103.0999	1.121	528135433	528135433		Quaternary ammonium salts
(2R)-piperidine-2-carboxylic acid	$C_6H_{11}NO_2$	Full match	Not the top hit	129.0789	1.167	331381954	331381954		Amino acids, peptides, and analogues
(Z)-9,12,13-trihydroxyoctadec-15-enoic acid	$C_{18}H_{34}O_5$	Full match	Partial match	330.2402	12.209	258049444		258049444	Lipid
(2R,3S,4R,5R)-2,3,4,5,6-pentahydroxyhexanal	$C_6H_{12}O_6$	Invalid mass	No match	226.0682	1.178	250016273		250016273	Carbohydrate
dodecyl hydrogen sulfate	$C_{12}H_{26}O_4S$	Full match	No results	266.1549	15.542	248503631		248503631	Ester
5-(hydroxymethyl)furan-2-carbaldehyde	$C_6H_6O_3$	Full match	Partial match	126.0318	1.579	247433816	247433816		Alcohol
(Z)-octadec-9-enamide	$C_{18}H_{35}NO$	Full match	Partial match	281.2715	20.018	243708135	243708135		Lipid
benzene-1,2,3-triol	$C_6H_6O_3$	Full match	Full match	126.0317	1.148	234348354	234348354		Tannins and galloyl derivatives
2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluorooctanoic acid	$C_8HF_{15}O_2$	Full match	Full match	413.973	14.212	210263614		210263614	Carboxylic acid
2-methylpropanedioic acid	$C_4H_6O_4$	Invalid mass	No results	118.0253	1.795	176470411		176470411	Lipid
Oleoyl-L-α-lysophosphatidic acid	$C_{21}H_{41}O_7P$	Full match	Full match	436.2584	17.901	165911142	62482155.9	165911142	Lipid
2-(3,4-dihydroxyphenyl)-5-hydroxy-7-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl)oxan-2-yl]oxychromen-4-on	$C_{21}H_{20}O_{11}$	Full match	Not the top hit	448.0998	9.204	160576142	43655694.2	160576142	Flavonoids
(2S,3S)-2-amino-3-methylpentanoic acid	$C_6H_{13}NO_2$	Full match	Not the top hit	131.0946	1.657	153866752	153866752		Lipid
2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-3-	$C_{27}H_{30}O_{16}$	Full match	Full match	610.1524	8.287	133296130	43795142.5	133296130	Flavonoids

[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl]oxychromen-4-one									
(10*E*,15*Z*)-9,12,13-trihydroxyoctadeca-10,15-dienoic acid	$C_{18}H_{32}O_5$	Full match	Full match	328.2245	11.798	127478134		127478134	Lipid
bis(3,5,5-trimethylhexyl) benzene-1,2-dicarboxylate	$C_{26}H_{42}O_4$	Full match	Partial match	418.3076	23.898	126487311	126487311		Ester
bis(2-ethylhexyl) benzene-1,2-dicarboxylate	$C_{24}H_{38}O_4$	Full match	Full match	390.2764	23.324	124572496	124572496		Ester
(2R,3S)-2,3,4-trihydroxybutanoic acid	$C_4H_8O_5$	Invalid mass	Invalid mass	136.0363	1.143	120620326		120620326	Carbohydrate
β-D-Glucopyranuronic acid	$C_6H_{10}O_7$	Full match	Full match	194.0418	1.146	117064281		117064281	Carbohydrate
7H-purin-6-amine	$C_5H_5N_5$	Full match	Partial match	135.0544	1.159	111481633	111481633		Nucleic acids
6-methyl-5H-[1,2,4]triazolo[4,3-b]pyridazin-8-one	$C_6H_6N_4O$	Invalid mass	No results	150.0517	1.176	108795054		108795054	Triazoles
5,7-dihydroxy-2-(4-hydroxyphenyl)-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl]oxychromen-4-one	$C_{27}H_{30}O_{15}$	Full match	Full match	594.1576	8.783	108297738	45931934	108297738	Flavonoids
tetradecyl hydrogen sulfate	$C_{14}H_{30}O_4S$	Full match	Full match	294.1861	17.131	106348147		106348147	Ester
5-methyl-1H-pyrimidine-2,4-dione	$C_5H_6N_2O_2$	Full match	Full match	126.0429	2.443	102486334	102486334		Nucleic acids
(9E,11E)-13-hydroperoxyoctadeca-9,11-dienoic acid	$C_{18}H_{32}O_4$	Invalid mass	No match	294.2191	17.616	91992438.4	91992438.4		Lipid
(E)-3-(1H-indol-3-yl)prop-2-enoic acid	$C_{11}H_9NO_2$	Full match	Full match	187.0632	4.427	91058501	91058501		Organic acid
cyclopropane-1,2,3-tricarboxylic acid	$C_6H_6O_6$	Invalid mass	No match	174.0153	1.205	89507180.1		89507180.1	Carboxylic acids
(2R,3S,4S,5R,6R)-2-(hydroxymethyl)-6-[(2R,3S,4R,5R)-4,5,6-trihydroxy-2-(hydroxymethyl)oxan-3-yl]oxyoxane-3,4,5-triol	$C_{12}H_{22}O_{11}$	Invalid mass	No results	364.0978	1.124	87831675.7	87831675.7		Carbohydrate
2-phenylethanamine	$C_8H_{11}N$	Full match	Full match	121.0892	3.185	84978242.4	84978242.4		Amines
2-hydroxyacetic acid	$C_2H_4O_3$	Invalid mass	No results	76.01472	1.448	81620516.2		81620516.2	Organic hydroxy compound
(10E,12E)-9-hydroxyoctadeca-10,12-dienoic acid	$C_{18}H_{32}O_3$	Full match	Partial match	296.2345	17.138	79912895.1		79912895.1	Lipid
4-phenylaniline	$C_{12}H_{11}N$	Full match	Partial match	169.089	7.632	77526985.2	77526985.2		Organic amino compound
(E)-3-phenylprop-2-enoic acid	$C_9H_8O_2$	Full match	Full match	148.0518	9.798	74752819.2		74752819.2	Lipid
(10E,12E)-9-oxooctadeca-10,12-dienoic acid	$C_{18}H_{30}O_3$	Full match	Not the top hit	294.2191	17.713	73616677.2	73616677.2	10741385.6	Lipid
3,5,7-trihydroxy-2-(4-hydroxyphenyl)chromen-4-one	$C_{15}H_{10}O_6$	Full match	Full match	286.0472	9.821	71640561.3	71640561.3		Flavonoids
3-(4-hydroxyphenyl)prop-2-enoic acid	$C_9H_8O_3$	Full match	Full match	164.0472	6.33	68423563.1	68423563.1		Lipid
(2R,3S)-2-(3,4-dihydroxyphenyl)-3,4-dihydro-2H-chromene-3,5,7-triol	$C_{15}H_{14}O_6$	Full match	Full match	290.0787	6.612	67955808.5	19920730.9	67955808.5	Flavonoids
N-[(2-thiophen-2-yl-1,3-thiazol-4-yl)methyl]benzamide	$C_{15}H_{12}N_2OS_2$	Invalid mass	No results	322.0153	1.711	66960942.9	66960942.9		Organic heterocyclic compound
(2R)-4-methyl-2-[[(2S)-1-phenylmethoxycarbonylpyrrolidine-2-carbonyl]amino]pentanoic acid	$C_{11}H_{20}N_2O_3$	Full match	Partial match	228.1471	1.168	64676945.8	64676945.8		Amino Acids, Peptides, and Proteins

Discussion

Phytochemical profiling

Qualitative analysis using LC-HRMS showed that flavonoids and lipids were the dominant groups of compounds in *Bruguiera* sp. fruit (Figure 1). These findings are consistent with those of previous studies by Dahibhate et al. (2022), which reported that these two groups were also the main components in *B. gymnorrhiza* fruit. The diversity of these two groups of compounds is related to the ecological adaptation and unique biochemical composition of mangrove plants (Budiyanto et al. 2022). Meanwhile, GC-MS results for *A. marina* indicate that the most abundant compounds originate from the phenol group, which is also crucial in adaptation mechanisms (Wonggo et al. 2024). Among the identified metabolites, hexadecanoic acid (7.72×10^9 g/mol) and 2-hydroxybutanedioic acid (3.40×10^9 g/mol) were the most abundant, indicating the combined importance of primary metabolic processes and secondary metabolite-mediated defense mechanisms. 2-hydroxybutanedioic acid plays a central role in the Tricarboxylic Acid (TCA) cycle, contributing to energy production, pH regulation, and osmotic adjustment. These compounds are essential for stress tolerance in extreme coastal environments (Pott et al. 2019).

Bruguiera sp. also responds to high-salinity environmental conditions by exhibiting high lipid diversity, which helps maintain cell integrity (Analuddin et al. 2019; Yoon et al. 2021). Additionally, it is also associated with the antimicrobial potential of plants, which has allelopathic control effects on forest organisms and the degradation of polycyclic aromatic hydrocarbons (Fudyma et al. 2019). Other minor compounds, including 2-oxopentanedioic acid, may enhance the bioactive potential through antioxidant, antimicrobial, or anti-inflammatory properties (Analuddin et al. 2019; Saragih et al. 2020). This diversity of chemical compounds is not only relevant for meeting the nutritional needs of coastal communities but also holds promise for bioprospecting and the development of functional foods (Singh 2020).

The 6-methylquinoline is a unique potential compound in *Bruguiera* sp. fruit. This compound has not been widely documented in recent chemical profiling studies (Yami et al. 2020). Several phytochemical investigations have extensively documented the presence of alkaloids, flavonoids, phenols, terpenoids, and other secondary metabolites, but 6-methylquinoline remains explicitly absent from these profiles. It highlights that 6-methylquinoline may be either an extremely rare or novel constituent in the genus, warranting further targeted studies (Muhtadi et al. 2025; Tanod et al. 2025).

The ecological significance of nitrogen-containing heterocyclic compounds, such as quinoline derivatives, likely relates to their role in chemical defense mechanisms against microbial pathogens and oxidative stress caused by tidal fluctuations. Quinoline alkaloids are well-known for their antioxidant, antimicrobial, and anti-inflammatory properties, which may contribute to the survival and ecological success of mangroves in harsh environments. The discovery of methylquinoline in *Bruguiera* fruits would thus provide new insights into the species' chemical diversity and potential applications in drug discovery (Luo et al. 2024).

The number of compounds found in different samples may vary. This may differ from the results of other studies in various regions, both in terms of the number of compounds and the dominance of metabolite groups, such as the results obtained by Dahibhate et al. (2022), who obtained 60 compounds from *B. gymnorrhiza* leaves. This may be a result of sampling in habitats with higher salt levels or more extreme environmental exposure, where the tendency to accumulate protective compounds, such as phenols, flavonoids, and alkaloids, is usually higher (Nugraha et al. 2023).

Table 2. Phenol, tannin, and alkaloid, chlorophyll a, chlorophyll b, and total chlorophyll content of *Bruguiera* sp. fruit

Parameter	Concentration
Phenol (% w/w)	11.22±0.35
Tannin (% w/w)	8.89±0.25
Alkaloid (% w/w)	0.03±0.00
Chlorophyll a (mg/g)	6.57±1.73
Chlorophyll b (mg/g)	9.77±3.29
Total chlorophyll (mg/g)	5.11±1.41

Table 3. Phytochemical compounds identified in *Bruguiera* sp. fruit using LC-HRMS analysis

Compound group	Compound name
Flavonoid	• 2-(3,4-dihydroxyphenyl)-5-hydroxy-7-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl)oxan-2-yl]oxychromen-4-one • 2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl]oxychromen-4-one • 5,7-dihydroxy-2-(4-hydroxyphenyl)-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl]oxychromen-4-one • 3,5,7-trihydroxy-2-(4-hydroxyphenyl)chromen-4-one • (2R,3S)-2-(3,4-dihydroxyphenyl)-3,4-dihydro-2H-chromene-3,5,7-triol
Phenol	(E)-3-(3,4-dihydroxyphenyl)prop-2-enoic acid
Alkaloid	6-methylquinoline
Tannin	benzene-1,2,3-triol

Table 4. Carbohydrate, protein, fat, ash content, and water content in *Bruguiera* sp. fruit

Parameter	Concentration
Carbohydrate (% w/w)	79.21±0.20
Protein (% w/w)	3.25±0.33
Fat (% w/w)	0.22±0.02
Ash content (% w/w)	2.38±0.27
Water content (% w/w)	10.89±4.17
Carotenoids (µmol/g)	17.61±3.35
Vitamin C (mg/kg)	15.68±1.13

Secondary metabolites and pigments

The spectrophotometry analysis showed that the phenolic compounds were the most abundant phytochemicals in *Bruguiera* sp. fruit (Table 2). The result of spectrophotometry methods, when integrated with LC-HRMS, essentially confirms the abundance of phenolic compounds in mangrove fruit, albeit through different mechanisms. Spectrophotometry provides an overview of total phenols, while LC-HRMS offers further details on phenol compounds. This finding aligns with the study of Sadeer et al. (2020), which compared *B. gymnorrhiza* with other mangrove species, such as *A. marina* and *R. apiculata*, and reported that *B. gymnorrhiza* had higher phenol concentrations.

Phenolic and flavonoid compounds exhibit potent antioxidant activity, which helps reduce oxidative stress by neutralizing free radicals. They have also shown potential in treating neurodegenerative diseases through various mechanisms (Şahin et al. 2025). (E)-3-(3,4-dihydroxyphenyl) prop-2-enoic acid, as a phenolic compound, was detected in *Bruguiera* sp. fruit (Table 3). (E)-3-(3,4-dihydroxyphenyl) prop-2-enoic acid is a potent antioxidant that mitigates oxidative stress by neutralizing free radicals and has demonstrated potential in the treatment of neurodegenerative illnesses, including Parkinson's and Alzheimer's, by decreasing neuronal inflammation and oxidative stress (Cizmarova et al. 2020; Goyal et al. 2025).

The detected flavonoids included 2-(3,4-dihydroxyphenyl)-5-hydroxy-7-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl) oxan-2-yl]oxychromen-4-one, 2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R, 4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl] oxan-2-yl]oxychromen-4-one, 5,7-dihydroxy-2-(4-hydroxyphenyl)-4-oxo-4H-chromen-3-yl-6-O-(6-deoxyhexopyranosyl)hexopyranoside, kaempferol, and catechin (Table 3). 2-(3,4-dihydroxyphenyl)-5-hydroxy-7-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl) oxan-2-yl]oxychromen-4-onehas also demonstrated potential in Alzheimer's disease treatment by elevating lipidation-associated protein levels and diminishing amyloid-beta levels in the brain (Cao et al. 2024). 2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[(2R,3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl]oxychromen-4-one is a potent antioxidant that helps scavenge free radicals, thereby protecting cells from oxidative stress. It also has anti-inflammatory properties, which benefit conditions such as chronic venous insufficiency and hemorrhoids (Patel and Patel 2019; Bidzhieva and Chiriapkin 2023). 3,5,7-trihydroxy-2-(4-hydroxyphenyl)chromen-4-one is recognized for its anticancer properties, which involve inhibiting the proliferation of cancer cells and inducing apoptosis. It also has cardioprotective effects by reducing the risk of heart disease. Like other flavonoids, 3,5,7-trihydroxy-2-(4-hydroxyphenyl)chromen-4-one exhibits strong antioxidant and anti-inflammatory activity, contributing to its therapeutic potential in various inflammatory diseases. Additionally, (2R,3S)-2-(3,4-dihydroxyphenyl)-3,4-dihydro-2H-chromene-3,5,7-triol is widely recognized for its benefits to cardiovascular health, including the ability to lower cholesterol levels and improve vascular function (Patel and Patel 2019).

The tannin compound detected was benzene-1,2,3-triol. Benzene-1,2,3-triol has been shown to protect against influenza. The virus causes lung damage by triggering the NRF2-PPAR--HO-1 signaling pathway. This activation helps reduce excessive proinflammatory responses and abnormal cell death, demonstrating its potential as a therapeutic agent for influenza (Zhou et al. 2024). The presence of alkaloids, such as 6-Methylquinoline, further supports the potential of *Bruguiera* sp. as a source of bioactive compounds with diverse therapeutic properties. The compound belongs to a broader class of quinoline derivatives, which are known for their diverse biological activities, including anticancer, antimalarial, antimicrobial, and anti-inflammatory properties, making them valuable in drug development (Kushwaha 2024).

The combination of flavonoids, phenolics, tannins, and alkaloids enhances the antioxidant capacity of *Bruguiera* sp. fruit, making it a potent source for therapeutic applications targeting oxidative stress and inflammation (Sadeer et al. 2020; Audah and Anisa 2024). Hydroxyl groups in flavonoids, tannins, and alkaloids play a crucial role in their ability to neutralize highly reactive free radicals that can damage biological molecules (Al-Mamary and Moussa 2021). Hydroxyl groups combat free radicals primarily through hydrogen atom transfer mechanisms. The presence of multiple hydroxyl groups enhances electron delocalization (Platzer et al. 2022).

Bruguiera sp. fruit contains various pigments that work together to enhance its antioxidant activity. Research findings indicate that *Bruguiera* sp. fruit has a high concentration of chlorophyll b, measuring 9.77 mg/g (Table 2). High chlorophyll b is a form of adaptation of mangroves to their environment. Chlorophyll b plays crucial role in enhancing light absorption efficiency and providing photoprotection under high-light conditions (Simkin et al. 2022).

Nutrient composition

The proximate content of *Bruguiera* sp. fruit showed a high carbohydrate (79.21% w/w), followed by water content (10.89% w/w) and protein (3.25% w/w) (Table 4). It is supported by LC-HRMS results that detected the presence of (2R,3S,4R,5R)-2,3,4,5,6-pentahydroxyhexanal, (2R,3S)-2,3,4-trihydroxybutanoic acid, β-D-Glucopyranuronic acid, and (2R,3S,4S,5R,6R)-2-(hydroxymethyl)-6-[(2R,3S,4R,5R)-4,5,6-trihydroxy-2-(hydroxymethyl)oxan-3-yl]oxyoxane-3,4,5-triol as part of the carbohydrates (Table 1). Carbohydrates

are needed in large quantities as the primary source of energy in extreme environments (Sudhir et al. 2022). One species of the genus *Bruguiera*, namely *B. gymnorrhiza*, has been proven to be suitable for processing into sweet cookies, but it requires considerable processing to remove the bitter taste of its tannins (Afifah et al. 2021).

Despite relatively low protein concentration, two amino acid compounds that make up proteins were identified in the LC-HRMS results, namely (2R)-piperidine-2-carboxylic acid and (2R)-4-methyl-2-[[(2S)-1-phenylmethoxycarbonylpyrrolidine-2-carbonyl]amino]pentanoic acid (Table 1). These compounds have a significant impact on lipid metabolism and other metabolic pathways (Zhang et al. 2025). The fruits have high lipid diversity (Figure 2). Several lipid compounds, including hexadecanoic acid and nonanedioic acid, play a role in human health. Hexadecanoic acid has potential as an anti-tumor agent by inducing apoptosis in cancer cells, inhibiting proliferation, and enhancing the efficacy of chemotherapy. These effects have been observed in various cancers, including liver and colon cancer (Wang et al. 2023). Nonanedioic acid is widely used in dermatology due to its anti-inflammatory, antimicrobial, and anti-keratinization properties. It is effective in treating conditions, such as acne vulgaris, rosacea, and hyperpigmentation disorders, including melasma and chloasma (Feng et al. 2024). Nonanedioic acid also prevents and treats Non-Alcoholic Fatty Liver Disease (NAFLD) and steatohepatitis (Kahn et al. 2019). However, despite the low concentrations of protein and fat, *Bruguiera* sp. fruits still have high potential as a food source because they are not assessed based on only these two parameters (Devi et al. 2019).

Research findings indicate that *Bruguiera* sp. fruit has a high concentration of carotenoids at 17.61 µmol/g (Table 2). This finding is consistent with the results of Britton and Khachik (2009), who classify a carotenoid level of more than 0.037 µmol/g as a very high content. High concentrations of carotenoids also serve as a form of defense for mangroves against oxidative stress in their growing environment (Priyanto and Rimba 2023). Carotenoids possess antioxidant properties, functioning as single oxygen reducers due to the conjugated bonds present in their carbon chains. Additionally, carotenoids provide protective effects against degenerative diseases, including cancer and cardiovascular diseases (Luo et al. 2024). This finding aligns with Hidayati et al. (2023), who reported that the *B. gymnorrhiza* fruit contains elevated levels of carotenoids (2.63 µmol/g).

Vitamin C is one of the important nutrients in food. It acts as a water-soluble antioxidant by neutralizing free radicals and reducing ROS (Combs and McClung 2022). The results of this study indicate that *Bruguiera* sp. fruit had a very high content of vitamin C (15.68 mg/kg) (Table 3), which is relatively higher than that reported by Hosen et al. (2020), who found 11.4 mg/kg. This discrepancy may be attributed to differences in growing locations. According to Phillips et al. (2018), vitamin C levels can vary significantly within the same plant species, due to various factors including harvest maturity, environmental conditions, and post-harvest handling.

Antioxidant activity

The antioxidant capacity of *Bruguiera* sp. fruit was evaluated using the DPPH assay, revealing a robust efficacy in free radical scavenging, as demonstrated by the low IC_{50} value of 0.19 ppm. A reduced IC_{50} value signifies that a smaller quantity of the fruit extract is required to attain a 50% decrease in DPPH radical activity (Rozirwan et al. 2024). The results correspond with the findings of Hidayati et al. (2023), which indicated that *B. gymnorrhiza* fruit has higher antioxidant activity compared to other mangrove species, including *R. apiculata* and *A. marina*. The antioxidant capacity indicates that the fruit may significantly contribute to the protection against diseases associated with oxidative stress (Audah and Anisa 2024). The *Bruguiera* sp. fruit also demonstrated lower IC_{50} values in the DPPH assay when compared to other tropical plants known for their antioxidant qualities (guava and dragon fruit) (Budiyanto et al. 2022) and ascorbic acid (12.36 ppm) (Maryam et al. 2023). This discovery identifies *Bruguiera* sp. fruit as a potent source of antioxidants compared to other mangrove and tropical fruits, as well as common antioxidants. Several compounds also contribute to the antioxidant activity of *Bruguiera* sp. fruits, such as flavonoids, phenols, and tannins (Nugraha et al. 2023).

This study shows that *Bruguiera* sp. fruit has very strong antioxidant activity and high carbohydrate content, making it a potential staple food source, especially for coastal communities with limited access to nutritious food supplies. Suzery et al. (2025) stated that mangrove-derived products rich in antioxidant compounds can help prevent degenerative diseases and strengthen the immune system, especially in regions with limited access to nutritious food sources. Conserving mangrove ecosystems is crucial for biodiversity and achieving the SDGs, especially for food security and protection from coastal damage (Hosen et al. 2020; Darmadi et al. 2021). These ecosystems need to be conserved so that they can provide sustainable benefits, alleviating poverty and improving nutrition and public health.

In conclusion, research results show that *Bruguiera* sp. fruit is a rich source of nutrients containing various bioactive compounds, including lipids, carbohydrates, flavonoids, phenolics, carotenoids, and vitamin C. The very low IC_{50} value (0.19 ppm) indicates significant antioxidant potential. This fruit not only serves as a valuable source of nutrients but also shows potential as a therapeutic agent, particularly in protecting against diseases associated with oxidative stress. Cultivation and consumption of this fruit can contribute to improved food security and health outcomes in coastal communities and those vulnerable to climate change. To maximize these benefits, future research should investigate the bioavailability, safety, and synergistic effects of the fruit's phytochemical compounds, as well as the development of sustainable cultivation and harvesting methods that support both local livelihoods and ecological conservation.

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