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Characteristics of Cookies Made from Lindur Mangrove Flour Substitution

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ABSTRACT

Mangrove forests provide various economic opportunities for local communities, particularly through the utilization of mangrove resources. Among the various mangrove species in Lampung, lindur mangrove is one that has attracted attention due to its potential, not only as an ecological function but also as a sustainable food source. Flour produced from the lindur mangrove fruit can be used as a flour substitute in processed food products, such as cookies. This study seeks to examine the sensory and chemical properties of cookies incorporated with mangrove lindur flour at levels of 10%, 20%, 30%, 40%, and 50%. Cookies with a 20% substitution of mangrove lindur flour showed quite good acceptance in various sensory parameters. In terms of color, it provides a brighter color compared to higher substitution levels. The aroma of the cookies is preferred by the panelists, who also accepted the taste; additionally, the texture provides a crunchy sensation that the panelists enjoy. In terms of chemical characteristics, these cookies contain water content (4.40%), ash (1.12%), protein (9.74%), fat (14.43%), carbohydrates (70.32%), dietary fiber (9.92%), calories (523.87 kcal/100 g), phosphorus (71.51 mg/100 g), iron (1.30 mg/100 g), and calcium (57.41 mg/100 g).

1. INTRODUCTION

Mangrove ecosystems play a vital role in maintaining ecological balance and protecting coastal areas. In addition to their ecological functions, mangroves possess significant potential as alternative food resources that can contribute to food security (Sulistyowarni *et al*., 2020). One mangrove species that grows abundantly in the coastal areas of Lampung Province, particularly in Pesawaran Regency, is lindur (*Bruguiera gymnorhiza*). Lindur fruit contains carbohydrates, dietary fiber, and bioactive compounds with antioxidant activity (Amalia *et al*., 2022) making it a promising raw material for the production of nutritionally valuable flour (Rahman *et al*., 2021). Previous studies have demonstrated that lindur flour can be utilized as a functional food ingredient, particularly in the cookies production (Purwoko *et al*., 2023). Cookies formulated with lindur fruit flour exhibit good sensory properties and enhanced nutritional value due to their higher contents of dietary fiber, minerals, and bioactive compounds (Jariyah *et al*., 2024). Therefore, the incorporation of lindur fruit flour into cookie formulations represents a promising strategy for developing nutritious food products that may contribute to stunting prevention efforts.

Indonesia continues to face a significant stunting challenge, with a prevalence of 19.8% in 2024 (Kemenkes, 2025). One of the primary contributor to stunting is inadequate intake of energy, protein, and essential micronutrient among children. In this context, lindur flouroffers considerable potential as a locally available functional food ingredient to improve nutrition, particularly in coastal areas with abundant mangrove resources. Incorporating lindur flour into cookie formulations provides a nutritious, affordable, and environmentally sustainable food alternative that can support dietary improvement while promoting the utilization of indigenous resources.

Beyond its nutritional benefits, the development of mangrove flour-based cookies can generate important socio-economic and environmental impacts. Utilizing locally sourced lindur flour can stimulate the growth of small scale food industries, create employment opportunities for coastal communities, increase the value of local raw materials, and reduce dependence on imported food products. Moreover, processing mangrove fruit into flour extends its shelf life, facilitates storage and distribution, and promotes the utilization of underused natural resources, thereby reducing food loss and waste. These advantages are consistent with the growing global interest in sustainable, natural food ingredients and support the achievement of Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), by promoting food security, improved nutrition, and sustainable food systems. Consequently, this research contributes not only to nutritional improvement and local economic development but also to sustainable natural resource management and food diversification through the development of innovative regional food products based on local mangrove resources (Nirmagustina *et al*., 2024).

Previous studies have reported the potential use of lindur mangrove flour as a functional ingredient in cookie production, resulting in acceptable sensory characteristics and improved nutritional quality (Purwoko *et al*., 2023). However, information regarding the optimal substitution level of lindur flour and its effects on the proximate composition, dietary fiber content, mineral content, and overall sensory acceptability of cookies remains limited. In addition, studies evaluating the contribution of lindur flour to essential minerals associated with growth and development, such as calcium (Ca), iron (Fe), and phosphorus (P), are still scarce. Therefore, this study aimed to evaluate the effects of different levels of lindur mangrove flour substitution on the sensory characteristics, proximate composition, dietary fiber content, and mineral content of cookies. Unlike the study conducted by Purwoko *et al*. (2023) which primarily focused on the utilization of lindur flour in cookie production, the present study provides a more comprehensive assessment of both nutritional and sensory attributes to identify the most suitable formulation for the development of functional cookies. The relevance of this study to stunting prevention is associated with the nutritional potential of lindur flour. Stunting is a chronic nutritional problem closely related to inadequate intake of energy, protein, and essential micronutrients, particularly iron and calcium, during critical periods of growth. Lindur flour contains dietary fiber and various minerals that may enhance the nutritional value of food products. Therefore, its incorporation into cookies may contribute to the development of nutrient-dense food products that support efforts to improve dietary quality, especially among vulnerable populations. Although cookies alone cannot directly prevent stunting, the development of nutrient-rich food products may serve as a complementary strategy in stunting reduction programs and efforts to strengthen food security. Furthermore, the utilization of lindur mangrove flour may increase the added value of mangrove resources while supporting sustainable food diversification. Therefore, the findings of this study are expected to contribute not only to the development of innovative functional food products but also to broader efforts aimed at improving nutritional quality, food security, and community welfare.

2. RESEARCH METHODS

2.1. Materials and Tools

The equipment used in this study included a hammer mill for producing lindur mangrove flour, a slicer for sample preparation, a cabinet dryer for drying sliced lindur fruits, and a Tyler standard 80-mesh sieve to obtain a uniform flour particle size. Cookie preparation was carried out using a mixer, cooking pan, baking sheet, and baking oven. Chemical analyses were performed using an analytical balance, drying oven, desiccator, hot plate, muffle furnace, Soxhlet extraction apparatus, rotary evaporator, and bomb calorimeter. Mineral analyses were conducted using a UV-Vis spectrophotometer (HACH DR/2010, USA), X-Ray Fluorescence Spectrometer, FTIR spectrometer (ATR-FTIR mode, spectral range 4000–400 cm^{-1}) equipped with a diamond/ZnSe ATR crystal, burette, volumetric flasks, micropipettes, volumetric pipettes, porcelain crucibles, Erlenmeyer flasks, beakers, graduated cylinders, glass funnels, filter paper, and other standard laboratory glassware.

Mangrove lindur fruit from the Cuku Nyinyi Farmers Group in Pesawaran Regency, Lampung Province, served as the primary ingredient in this investigation. The following additional ingredients were purchased from Untung market in Bandar Lampung: tapioca flour (Gunung Agung brand), coconut milk (Kara brand), granulated sugar (Gulaku brand), palm sugar (Alkasari brand), salt (Refina brand), baking soda (Koepoe-Koepoe brand), margarine (Blueband brand), and chicken eggs. The chemicals used in this study included distilled water, ethanol (96%, technical grade), and Pro Analytic (PA) grade from Merck (Germany) including sulfuric acid (H_2SO_4), potassium sulfate (K_2SO_4), copper sulfate ($CuSO_4$), sodium hydroxide (NaOH), hydrochloric acid (HCl, 37%), petroleum ether, and other analytical-grade reagents used for proximate and mineral analyses.

2.2. Research Location

The research was conducted at the THP Laboratory and the Pastry Laboratory of Politeknik Negeri Lampung, BRIN Tanjung Bintang, and the PT Saraswanti Indo Genetech Laboratory in Bogor, West Java.

2.3. Preparation of Mangrove Lindur Flour and Cookies

Well ripe lindur fruits characterized by brown-colored peel were selected for this reseacrh. Each treatment used a total of 1 kilogram of fruit. Before processing, the chosen fruits were carefully cleaned and weighed. To make peeling easier and lessen antinutritional chemicals, the fruits were then cooked in water for 30 min at a fruit-to-water ratio of 1:3 (w/v). The fruits were then manually peeled. To speed up the drying process, the fruits were cut into small pieces (approximately 0.5–1.0 cm thick). To lower the tannin content and enhance the quality of the flour, the sliced fruits were soaked in water at a fruit-to-water ratio of 1:3 (w/v) for 48 h, with the soaking water being changed every 12 h. Following soaking, the samples were drained and dried at 50 °C in a cabinet dryer until the moisture content was about 12%. The dried lindur slices were then ground using a hammer mill and sieved through 80-mesh Tyler standard sieve to obtain a uniform particle size. The resulting flour was packaged and stored in airtight containers until further use in cookie production.

Cookies preparation was started with mixing 170 mL of thick coconut milk with 100 mL of water and 5 g of salt. The mixture was cooked at 70°C for 30 min, then cooled to room temperature. Next, prepare the dough: beat 50 g of eggs with a mixer until fluffy, then add 50 g of granulated sugar and 50 g of palm sugar. Mix in 50 g of margarine and 5 g of baking soda until thoroughly combined, and let the mixture rest for 12 h. Afterward, incorporate the base flour mixture (consisting of 200 g of a tapioca and mangrove lindur flour blend) following standard blending techniques. Finally, roll the dough to a thickness of 5 mm, place it on a baking sheet, and bake at 170 °C for 15 min.

2.4. Experimental Design

This study employed a single-factor experiment arranged in a completely randomized design (CRD) with three replications. The factor was the substitution level of lindur flour, consisting of five levels: 10% (L1), 20% (L2), 30% (L3), 40% (L4), and 50% (L5). The sensory data were analyzed using one-way analysis of variance (ANOVA) to determine whether different levels of lindur flour substitution significantly affected the sensory attributes of the cookies. When significant differences among treatments were observed ($p < 0.05$), Duncan's Multiple Range Test (DMRT) at the 5% significance level was conducted as a post-hoc test to compare treatment means and identify which substitution levels differed significantly from one another. The best formulation was selected based on the highest overall acceptability score and its statistical significance compared with the other treatments. The selected best formulation was subsequently analyzed for moisture content, ash content, protein content, fat content, dietary fiber, carbohydrate content, caloric value, mineral contents (P, Fe, and Ca), X-Ray Fluorescence Spectrometer, and Fourier Transform Infrared Spectroscopy (FTIR).

2.5. Sensory Analysis

The resulting cookies were evaluated by 25 untrained panelists consisting of undergraduate students from the Food Technology Study Program, Politeknik Negeri Lampung. A 5-point hedonic scale was used to determine the degree of liking, consisting of very dislike (1), dislike (2), neither like nor dislike (3), like (4), and very like (5). The quality attributes assessed were color, aroma, taste, texture, and overall acceptability.

2.6. Chemical Analysis

Chemical analysis was conducted to determine the proximate composition of cookies substituted with mangrove lindur flour. The analysis included moisture, ash, protein, fat, dietary fiber, and carbohydrate contents. All proximate analyses were performed according to the procedures described in the Official Methods of Analysis of AOAC International (AOAC, 2019).

A. Moisture content was determined according to the Official Method 925.10 with minor modifications. About 5 g of the sample (M_1) was placed in a clean, pre-dried, and pre-weighed crucible. The sample was dried in a preheated oven at 105 ± 2°C for 3 h. After drying, the dish containing the sample was transferred into a desiccator and cooled for 30 min to prevent moisture absorption from the surrounding environment. The dish and dried sample were then weighed (M_2). The moisture content (MC) in wet basis was calculated based using the following equation:

$$MC = \frac{M_1 - M_2}{M_1} \tag{1}$$

B. Ash content was determined using the dry ashing method in accordance with AOAC Official Method 923.03. Approximately 3 g of the oven dry sample (W_i) was placed in a clean, pre-dried, and pre-weighed crucible. The sample was incinerated in a muffle furnace at 550 ± 25°C for 6 h. After ashing, the crucible containing the ash was transferred into a desiccator, cooled for 30 min, and weighed (W_f). Ash content was calculated as the following:

$$Ash = (W_f / W_i) \times 100\% \tag{2}$$

C. Protein Content content was determined by the Kjeldahl method according to AOAC Official Method 979.09. About 1 g of sample was digested with concentrated H_2SO_4 and a catalyst tablet, followed by distillation with NaOH and titration of the liberated ammonia with standardized HCl. Protein content was calculated using a nitrogen-to-protein conversion factor of 6.25. Protein content was calculated using the following equation:

$$Protein\ content\ (\%) = \frac{(V_s - V_b) \times N_{HCl} \times 14.007 \times 6.25 \times 100}{m \times 100} \tag{3}$$

where V_s is volume of HCl used for sample titration (mL), V_b is volume of HCl used for blank titration (mL), NHCl is normality of HCl, m is weight of the sample (g), 14.007 is atomic weight of nitrogen, and 6.25 is nitrogen-to-protein conversion factor.

D. Fat content was determined by Soxhlet extraction using petroleum ether (40–60°C) in accordance with AOAC Official Method 920.39. Approximately 2 g of sample (W_0) was extracted for 6 h. The solvent was removed by rotary evaporation, and the residue was dried (W_1) at 105 °C for 30 min before weighing. Fat content was calculated using the following equation:

$$\text{Fat} = (\text{W1} / \text{W0}) \times 100\% \tag{4}$$

where W_1 is weight of the extracted fat after solvent evaporation (g), and W is weight of the sample (g).

E. Dietary fiber content was analyzed by the enzymatic–gravimetric method according to AOAC Official Method 991.43. Approximately 1 g of sample was sequentially treated with α-amylase, protease, and amyloglucosidase. The residue was filtered, washed with ethanol and acetone, dried to constant weight, and corrected for residual protein and ash. dietary fiber content was calculated using the following equation:

$$Dietary\ fiber\ content = \frac{R - P - A - B}{W} \times 100\% \tag{5}$$

where R is weight of dried residue (g), P is weight of protein in the residue (g), A is weight of ash in the residue (g), B is blank correction (g), and W is weight of the sample (g)

F. Carbohydrate content was calculated by difference, following the proximate analysis approach recommended in AOAC procedures. Carbohydrate (%) was obtained as: Carbohydrate (%) = 100 − [Moisture + Ash + Protein + Fat + Dietary Fiber]. All values are expressed as percentages on the same basis.

G. Calories. Caloric value was determined for the selected cookie formulation to evaluate its potential contribution to daily energy intake. The calorific value was measured using a Parr 6400 Automatic Isoperibol Calorimeter.

2.6.1. Minerals Analysis

A. Phosphorus (P) Content. Phosphorus content was determined using the phosphovanadomolybdate colorimetric method after wet digestion of the samples with concentrated H_2SO_4 and H_2O_2, according to Lauer *et al*. (2026). The absorbance of the yellow phosphovanadomolybdate complex was measured at the maximum wavelength using a UV–Visible spectrophotometer (UV-1900i, Shimadzu Corporation, Japan). The phosphorus content was calculated using a phosphorus standard calibration curve.

B. Iron (Fe) content was determined using the thiocyanate colorimetric method after dry ashing of the samples, according to Lauer *et al*. (2026). Ferric ions in the sample extract were reacted with ammonium thiocyanate to form a red ferric thiocyanate complex. The absorbance was measured at 510 nm using a UV–Visible spectrophotometer (UV-1900i, Shimadzu Corporation, Japan). The iron content was calculated using an iron standard calibration curve.

C. Calcium (Ca) content was determined by complexometric titration using the standardized Na_2EDTA (disodium ethylenediaminetetraacetate). The titration was conducted at pH 12–13 using murexide as the indicator. The endpoint was identified by a color change from pink to purple. The calcium content was calculated based on the volume and concentration of Na_2EDTA consumed during titration (Lauer *et al*., 2026).

2.6.2. X-Ray Fluorescence Analysis (XRF) Analysis

Elemental composition was analyzed using an Epsilon 3 energy-dispersive X-ray fluorescence spectrometer (PANalytical B.V., the Netherlands). Measurements were performed under an air atmosphere using the Omnian standardless analysis mode. The excitation conditions were 40 kV and 375 µA with an Ag filter, 4 kV and 2,000 µA without a filter, 5 kV and 3,000 µA with a Ti filter, 15 kV and 1,000 µA with an Al-200 filter, and 40 kV and 375 µA with a Cu-500 filter. Elemental concentrations were quantified using the fundamental parameter method incorporated into the instrument software. The results were expressed as percentages for major elements and mg/kg for trace elements (Marguí *et al*., 2024).

2.6.3. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

Fourier transform infrared spectroscopy analysis was performed using a Nicolet iS5 FTIR spectrometer equipped with an attenuated total reflectance accessory (Thermo Fisher Scientific, USA). The spectra of the dried and finely ground cookie samples were recorded at room temperature over the wavenumber range of 4,000–400 cm^{-1}. The resulting spectra were used to identify the principal functional groups and evaluate molecular interactions associated with the substitution of mangrove lindur flour in the cookie formulations (Workman Jr., 2024).

3. RESULTS AND DISCUSSION

Figure 1 is presented to provide visual evidence of the transformation of lindur mangrove fruit into flour and its application in cookie products. Figure 1A shows the fresh lindur mangrove fruit (*Bruguiera gymnorhiza*) used as the main raw material in this study. This image confirms the type and physical form of the mangrove fruit before processing. Figure 1B shows the lindur mangrove flour produced after sorting, boiling, soaking, drying, milling, and sieving. This flour served as the substitute ingredient in the cookie formulation. Figure 1C shows the appearance of cookies made with different levels of lindur mangrove flour substitution, namely 10% (L1), 20% (L2), 30% (L3), 40% (L4), and 50% (L5). The visual differences among the cookies support the sensory discussion, particularly regarding color and texture. As the substitution level increased, the cookies tended to become darker and showed more visible surface cracks.

3.1. Sensory Properties

The research results of the mangrove lindur flour cookies, which were made in five treatments, were tested for acceptability through hedonic sensory analysis on 25 panelists for color, aroma, taste, texture, and overall acceptability.

Figure 1. Visual description of the raw material, intermediate product, and final cookie products: (A) fresh lindur mangrove fruit used in this study, (B) lindur mangrove flour, and (C) cookies formulated with different levels of lindur mangrove flour substitution: 10% (L1), 20% (L2), 30% (L3), 40% (L4), and 50% (L5).

Table 1. Effect of lindur flour substitution on the sensory properties of the cookies

Mangrove Lindur Flour Substitution	Parameters*				
	Color	Aroma	Taste	Texture	Overall Acceptance
10%	3.87±0.15^{b}	4.00±077^{c}	3.81±0.50^{c}	3.92±0.77^{c}	4.04±0.75^{b}
20%	4.08±0.44^{bc}	4.07±0.23^{c}	4.01±0.44^{c}	3.96±0.50^{c}	4.17±0.34^{b}
30%	3.60±0.23^{b}	3.49±0.53^{b}	3.41±0.23^{b}	3.63±0.09^{b}	3.81±0.88^{ab}
40%	3.43±0.12^{b}	3.11±0.81^{a}	3.13±0.17^{a}	3.51±0.23^{ab}	3.57±0.16^{a}
50%	3.13±0.28^{a}	3.01±0.20^{a}	3.05±0.39^{a}	3.35±0.45^{a}	3.28±0.07^{a}

Note: *data coloum with different superscripts are significantly different ($p < 0.05$)

Sensory evaluation in Table 1 shows differences in panelist acceptance among cookies with varying lindur flour substitutions. For color, cookies with 10–20% substitution (3.87–4.08) were significantly preferred over 40–50% substitutions (3.43–3.13), reflecting a darker color at higher flour levels. Aroma scores were highest at 10–20% (4.00–4.07) and declined significantly at 40–50% (3.11–3.01). Taste followed a similar trend, with 10–20% substitution preferred over higher levels. Texture values also decreased at higher substitutions, while overall acceptance peaked at 10–20% (4.04–4.17) and was lowest at 50% (3.28). These results indicate that cookies with low-level lindur flour substitution are more acceptable to consumers, while higher substitution levels negatively affect sensory attributes. This is likely influenced by the phenolic content in mangrove flour, which causes a darker color (Amalia *et al*., 2022). This color change can impact consumer acceptance, as darker colors are often associated with lower quality in processed products. The Maillard reaction and caramelization during the roasting process significantly influence this color reduction. These reducing sugars react with the free amino groups of proteins during high-temperature baking, forming brown melanoidin pigments that give the cake its darker hue. Sugar caramelization also yields brown melanoidin pigments. Therefore, adjusting the proportion of mangrove flour in the product must take this color effect into account, especially to attract consumer interest. Furthermore, the fiber in mangrove flour plays a role in influencing the final color of the product, as it can absorb a significant portion of the color and alter its intensity. Therefore, it is important to consider the composition of the raw materials and the roasting technique used to achieve the desired color balance in the final product. Statistical results showed significant differences in aroma, with 10% and 20% substitutions giving higher values compared to the 30% to 50% treatments, which demonstrated a clear decrease (the lowest at 50%). This difference indicates that at lower flour substitutions, the aroma was more acceptable. This decrease in aroma may be due to volatile compounds in mangrove lindur flour, such as tannins, which alter the product's aroma character. The main ingredients in cookie aroma are aroma compounds such as aldehydes, esters, and ketones, which can change based on the raw ingredients and processing techniques.

While the aroma produced by mangrove lindur flour can be a distinguishing factor, for some consumers, it may need to be further adjusted to be more acceptable. One solution is to adjust the composition of mangrove lindur flour and other ingredients to maintain a balanced aroma. Previous research also shows that adjusting the amount of binding and sweetening agents can enhance the aroma's acceptability. With the right approach, the unique aroma of mangrove lindur flour can become a market-acceptable added value. In terms of taste parameters, there were significant differences between treatments. The 10% and 20% treatments provided higher taste scores compared to the higher treatments (30%, 40%, and 50%), which tended to show a decrease (the lowest at 50%), indicating that the substitution of lindur mangrove flour affected the taste of the product. According to this, customers prefer more recognizable flavors and are less swayed by the stronger or more unique aromas of substitutes, even while mangrove flour substitution has functional advantages (Afifah *et al*., 2021). This decrease in taste is likely due to the bitter or astringent taste produced by bioactive compounds in mangrove flour, such as tannins (Amalia *et al*., 2022). We can address this unpopular taste at high proportions by adjusting the ratio of mangrove flour to other ingredients to balance the taste. Research by Rahman *et al*. (2021) showed that reducing the content of bioactive ingredients in mangrove lindur flour can reduce the bitter taste and increase consumer acceptance. Therefore, the use of additional ingredients such as palm sugar or a more neutral binder can help improve the flavor balance of the product. On the other hand, despite a decrease in flavor at high proportions, mangrove lindur flour still has outstanding potential as a highly nutritious functional food ingredient. Product development that considers the balance of flavor and nutritional benefits is key to ensuring optimal product acceptance in the market.

In terms of texture parameters, although there was a decrease, the differences between treatments were not significant. The 10% to 30% treatments showed better values, while the 40% and 50% treatments tended to be lower, but the differences between the treatments were not very striking. This is due to changes in the dough structure due to the addition of fiber from mangrove lindur flour, which can cause the texture to become more brittle or dense (Rahman *et al*., 2021). Furthermore, dietary fiber makes cookies firmer by decreasing their porosity (Kamal-Eldin *et al*., 2020). On the other hand, cookies F1 and F2, which had more cassava starch, had a crispier and lighter texture. According to Puspita *et al*. (2019), such behavior is consistent with the characteristics of cassava starch, which is high in amylopectin- dominated starch and produces a more delicate structure when baked. A correlation between substitution levels and cookie texture preferences has also been found in research on local flour substitutions, such as modified purple sweet potato flour: the more substitutions used, the more the texture structure changes (e.g., becoming crispier or softer) in comparison to control cookies, which influences panelists' evaluation of overall texture sensation (Khamassi *et al*., 2025). The results showed that cookies with lindur flour substitution were most preferred at the 20% level. Overall product acceptance differed significantly between treatments. Cookies with 10% and 20% substitution scored the highest, while 30%, 40%, and 50% substitution showed significant declines, with the lowest score at 50% substitution. This indicates that the higher the percentage of lindur flour substitution, the lower the level of consumer acceptance. This finding aligns with previous research showing that changes in sensory quality due to variations in ingredient composition can influence panelists' approval levels for cookies with alternative flour substitutions impacted. Practically, consumers prefer cookies with low substitution because the balance of taste, aroma, color, and texture is more in line with their expectations (Purwoko *et al*., 2023). The decline in acceptance at high substitution reflects the negative effects that consumers dislike. To address this, the proportion of lindur flour, dominant flavor and aroma, and texture of cookies need to be optimized to maintain crispiness and a pleasant experience.

3.2. Chemical Properties

Product quality is not only assessed objectively, but also has a subjective dimension determined through human judgment, or better known as sensory properties. Therefore, the determination of the best formulation is based on the results of sensory property observations. Based on the results of the sensory evaluation, cookies with 10% and 20% mangrove lindur flour substitution were equally accepted by consumers, but the 20% formulation was selected for chemical analysis because it showed a slightly higher overall score and provided an optimal balance between taste, aroma, color, and texture. These best cookies were then chemically analyzed as shown in Table 2. The results of the chemical analysis showed that the water content of the lindur flour substituted cookies was 4.40%, still below the maximum limit of 5.00% according to SNI 01-2973:1992 (BSN, 1992), for wheat flour-based cookies.

The moisture content of the mangrove lindur flour substitute cookies is the same as that of wheat flour cookies, meaning it is still within safe limits. The proper drying process for mangrove lindur flour will help reduce water activity in the dough, thereby extending shelf life and maintaining product quality.Water is an important component in food ingredients that affects food quality. The amount of water can affect the rate of food spoilage due to microbiological, chemical, and enzymatic processes. According to Plustea *et al*. (2024), a low moisture content in a food ingredient is one factor that can extend its shelf life. Besides water content, a product's durability is also determined by its equilibrium moisture content (EMC), which is the water content of a material in balance with water

Table 2. Chemical properties of lindur flour

Parameters	Contents	
	Analysis Results	SNI Standard*
Moisture contents (%)	4.40 ± 0.07	Max. 5
Ash contents (%)	1.12 ± 0.03	Max. 1.6
Protein contents (%)	9.74 ± 0.06	Min. 9
Fat contents (%)	14.43 ± 0.31	Min. 9.5
Dietary fiber contents (%)	9.92 ± 0.16	Min. 0.5
Carbohydrate contents (%)	70.32 ± 0.26	Min. 70
Calories (kcal/100 g)	523.87 ± 0.92	Min. 400

*Source: SNI 01-2973-1992 (BSN, 1992)

water content of the surrounding air. This attribute is one factor that determines how well a material can be dried under certain environmental conditions (with a certain water activity) and can be used as a benchmark for the development of microorganisms that cause damage or decay during storage. Lower moisture content is associated with improved shelf life, as microbial activity and enzymatic reactions can be suppressed (Ali *et al*., 2020).

The measured ash content in cookies made with mangrove lindur flour (1.12%) indicates the amount of minerals in the product, which can be an indicator of additional nutrition from the use of local ingredients. Ash is the mineral residue left after organic materials are burned, and its presence reflects the presence of minerals such as calcium, phosphorus, or iron. The high ash content in the product indicates that the use of mangrove lindur flour results in a moderate mineral content while still contributing to nutrition. Relevant international studies on alternative flour-based cookies show that formulations incorporating local flours or agro-byproducts still produce reasonable ash levels without compromising the sensory quality of the final product. Research by Plustea *et al*. (2024) on gluten-free cookies using okara and rice flour showed that the addition of functional ingredients did not cause significant differences in ash content but provided additional nutritional benefits without compromising panelist acceptance.

The protein content of the selected mangrove lindur flour substitute cookies, with a 20% mangrove lindur flour substitution, was 9.74%. Protein is a source of amino acids containing the elements C, H, O, and N. The difference between protein and fat and carbohydrates lies in the N content, which none of them has. The primary function of protein is to form new tissue and maintain existing tissue. Protein also regulates various body processes by forming regulatory substances. Protein sources can be obtained from local food sources. The protein content of cookies substituted with 20% mangrove lindur flour is 9.74%. This protein comes not only from the lindur flour, but also partly from the eggs in the dough. Based on the recipe, 50 g of eggs contain approximately 12% protein, thus contributing approximately 6 g of protein per batch of cookies. If the total cookie weight is approximately 300 g, the protein from the eggs contributes approximately 20% of the total protein, while the remainder comes from the lindur flour and the main flour. This shows that although the lindur flour contributes protein, eggs remain the second main protein source in the dough. Neither fat nor protein is a quality requirement for cookies. However, their presence can complement their nutritional value. Protein is an essential component in body tissue formation and metabolic function, so it is important to increase or supplement it with other protein-rich ingredients to ensure a more nutritionally balanced final product. Mangrove lindur flour contributes its protein content, although it is still lower than the main flour component, such as wheat flour. Research by Owheruo *et al*. (2024) showed that cookie products using a combination of nut-based flour and wheat flour experienced an increase in protein content of up to 11.31–15.23% without sacrificing sensory quality. This finding confirms that increasing the protein component in cookies substituted with mangrove lindur flour can be achieved through an appropriate combination of ingredients to achieve higher nutritional value while maintaining sensory properties, especially the taste and texture characteristics accepted by consumers. Aworh (2023) also reported that the substitution of local flours in cookies generally does not reduce total protein content. Protein plays an important role in nutritional contribution and in forming cookie texture through interactions with starch and fat.

The fat content in selected cookies made with mangrove lindur flour is 14.43% (higher than in standard wheat flour cookies). Fat is an essential nutrient for health and a more effective source of energy than carbohydrates and protein. One gram of fat yields 9 kcal, while carbohydrates and protein only yield 4 kcal per gram. The crude fat content was analyzed using the Soxhlet extraction method. The Soxhlet method uses the principle of extracting fat with hexane as a solvent. After the solvent is evaporated, the fat can be weighed and its percentage calculated. Fat also plays a crucial role in the final texture of cookies, helping to produce a chewy texture and a better mouthfeel than non-fat products. The fat content in cookies made with a mangrove lindur flour substitute supports sensory characteristics such as rich flavor and softness without excessively increasing the energy load. Functionally, fat works together with starch and protein in the dough to form a stable network so that the product is neither too brittle nor too rigid when consumed. The fat content of cookies made with 20% mangrove lindur flour is 14.43%, higher than cookies made with regular wheat flour. Most of the fat in the dough comes from margarine, which is used as a binding agent and to create a crispy texture and rich flavor. Besides margarine, eggs also contribute a small amount of fat to the dough, as 50g of eggs contain approximately 10% fat. Mangrove flour itself contains a low fat content (approximately 1–2% on a dry basis), so its contribution to the total fat content of cookies is relatively small and insignificant compared to primary fat sources like margarine. Fat in cookies serves not only as a nutrient but also plays a role in forming a stable dough network with starch and protein, ensuring the final product is neither too brittle nor too tough. Research by Ristanti & Asrar (2025) on cookie formulations varied with functional flours and also found that variations in flour composition can significantly affect fat content while remaining within acceptable consumer limits. In the study, cookie formulations with the addition of alternative flours showed changes in fat content related to the functional and sensory qualities of the product without reducing panelist acceptance. Waziiroh *et al*. (2023) reported that non-gluten materials with denser fiber structures tend to reduce fat retention in bakery products. This phenomenon is also supported by Wibowo *et al*. (2024), who emphasized that products with lower fat content are increasingly preferred as they are considered healthier.

Dietary fiber is a crucial nutritional component, playing a role in improving digestive health and helping prevent chronic diseases such as diabetes and heart disease. Cookies using a 20% substitution of mangrove lindur flour have a higher fiber content compared to cookies made with regular wheat flour. These cookies contain 9.92% dietary fiber, indicating that mangrove lindur flour can be a good source of fiber. The dietary fiber in these cookies not only benefits digestion but can also slow glucose absorption in the body, which is very beneficial for regulating blood sugar levels. Research by Grzelczyk *et al*. (2025) revealed that cookies with high fiber content can help reduce the risk of type 2 diabetes and regulate carbohydrate and fat metabolism. With its higher fiber content, cookies made from mangrove lindur flour have the potential to provide additional benefits for consumers at risk of or already suffering from metabolic diseases. Furthermore, dietary fiber also promotes a longer feeling of fullness, helps control appetite, and prevents excessive calorie consumption. The increased fiber content in these cookies affects the product's texture and consistency. Cookies containing mangrove lindur flour tend to have a softer and lighter texture, in line with the preferences of consumers seeking low-calorie, fiber-rich products. According to Kamil *et al*. (2023), increasing dietary fiber from local flours can provide functional benefits, including lowering the glycemic index of bakery products.

Mangrove lindur flour substitute cookies contain 70.32% carbohydrates. This indicates that mangrove lindur flour cookies have a carbohydrate content close to the minimum level found in wheat flour cookies, or even slightly higher. Therefore, based on their nutritional content, mangrove lindur-flour substitute cookies are suitable as an alternative food ingredient. Carbohydrates consist of the elements C, H, and O. The ratio of hydrogen to oxygen is generally 2:1. In its simplest form, the general formula for carbohydrates is $C_nH_{2n}O_n$. The primary function of carbohydrates is to provide energy for the body. The amount of carbohydrates in cookies made with mangrove lindur flour is crucial. Research on cookies made with mangrove lindur flour shows that the use of lindur flour in ready-to- eat food formulations can affect the carbohydrate profile and other components related to the functional aspects of the food. This phenomenon is important because carbohydrates are the main source of energy in cookies, but the presence of components such as dietary fiber and resistant starch is often associated with a lower glycemic index and better metabolic health benefits compared to simple carbohydrates. Resistant starch is a fraction of complex carbohydrates that is not easily digested and therefore functions as soluble fiber with prebiotic effect. Moko *et al*. (2024) further noted that complex carbohydrates from resistant starch can help regulate blood glucose, improve gut health, and enhance lipid metabolism. Thus, the increase in carbohydrate content, particularly from resistant starch, strengthens the functional value of these cookies as a healthy food product.

The calorie or energy value of cookies is crucial to consider in a diet because it indicates how much energy consumers will obtain from the product. Cookies with a 20% substitute of mangrove lindur flour had an average energy value of 394.05 kcal/100 g. Cookies with a more moderate energy value offer benefits for those monitoring their calorie intake. Research by (Varghese *et al*., 2022) found that cookies containing higher-fiber, lower-calorie additives offer a healthier option for consumers seeking a calorie-controlled snack alternative. By using mangrove lindur flour, which contains high fiber components and complex carbohydrates, cookies made with mangrove lindur flour have a lower calorie value, thus reducing the risk of weight gain and metabolic disorders related to excess calories (Grzelczyk *et al*., 2025).

3.3. Minerals Content

Mineral analysis in food ingredients aims to identify and measure the content of various essential minerals in food, such as phosphorus (P), iron (Fe), and calcium (Ca). These minerals play a vital role in maintaining physiological functions in the body, such as bone and tooth formation, red blood cell production, and supporting the immune system.

By knowing the mineral content in food ingredients, it is possible to assess the nutritional quality of the food consumed by the public. Mineral analysis also helps meet the standards and regulations applied to food product nutrition labels. Therefore, mineral analysis is a crucial aspect in quality control and the development of highly nutritious food products (AlJuhaimi *et al*., 2025). Furthermore, mineral analysis also aims to determine the mineral levels in food ingredients to support efforts to prevent nutritional deficiencies associated with mineral deficiencies. For example, iron deficiency can cause anemia, while calcium deficiency can increase the risk of osteoporosis. Mineral analysis enables the development of fortified food products that can be used to increase mineral intake in the daily diet. Therefore, with information on the mineral content of food, governments and health institutions can design more effective nutritional interventions and educate the public about consuming foods with a balanced mineral content. The best cookies were subjected to mineral analysis as presented in Table 3.

Table 3. Mineral content of lindur flour

Parameters	Contents (mg/100g)
Phosphorus (P)	71.51±0.03
Iron (Fe)	1.30±0.17
Calcium (Ca)	57.45±0.09

Calcium is an essential mineral that plays a role in bone formation, muscle contraction, and enzyme function. Cookies can provide calcium, but the source is highly dependent on the raw materials used, as white wheat flour typically has a lower mineral content than other substitutes or more mineral-rich whole flours (Martínez-Martínez *et al*., 2023). Cookies made with 20% mangrove lindur flour had 57.45 mg of calcium per 100 g, or 574.5 ppm. This means that they did contain some calcium, but not as much as milk or dairy products, which are known to be high in calcium. However, when compared with scientific articles on conventional cookies, this value suggests that substituting local ingredients has the potential to increase mineral content compared to wheat flour, which often loses minerals through bleaching and milling. The presence of calcium in cookies is also influenced by the interaction of other components in the dough, such as dietary fiber and phytic acid, which can bind minerals and reduce their availability. Martínez-Martínez *et al*. (2023) stated that phytic acid in bakery products can inhibit calcium absorption in the digestive tract, so increasing total calcium levels does not necessarily increase its bioavailability. Selecting substitute ingredients such as mineral-rich mangrove lindur has the potential to increase the calcium content of cookies, and this aligns with the trend in food nutrition research using alternative flours to improve the mineral profile of modern bakery products. Research on composite flour indicates that the inclusion of non-wheat flours can enhance the mineral content of processed foods in comparison to wheat flour controls. Practically, the calcium content of 574.5 ppm in cookies with 20% substitution of mangrove lindur flour indicates a higher nutritional value compared to cookies made with wheat flour, due to the use of mineral-rich substitutes.

Phosphorus is a macromineral essential for energy metabolism, DNA formation, and cell membrane function. Phosphorus is often found in protein- and grain-containing foods and can be increased through the use of alternative flours or pseudocereals in the dough. The cookies with 20% mangrove lindur flour had a phosphorus content of 71.51 mg/100g, which is very high for a baked good. Phosphorus is a common mineral in many foods, like nuts and seeds, that are often used as flour substitutes. Research on other bakery products has shown that substituting conventional flour with other ingredients, such as taro and sweet potatoes, often increases the content of minerals, such as phosphorus, in the final product. This effect is demonstrated in a study of the incorporation of taro flour into biscuits, which increased the mineral content compared to a wheat flour control. Phosphorus often associates with protein and other phytonutrients in flour substitutes, so in addition to adding nutritional value, it can also enhance the product's functional value. The phosphorus content in cookies made with 20% mangrove lindur flour is higher than in cookies made with wheat flour, so the use of mangrove lindur has the potential to provide a significant mineral contribution. In the context of a healthy diet, phosphorus is a mineral necessary for the body's physiological functions, indicating that 20% mangrove lindur substitute cookies are not only a source of energy but also an important mineral source that can help meet daily needs, although a balance with calcium is necessary for bone health.

Iron is a mineral that plays an important role in hemoglobin formation, oxygen transport, and other metabolic functions. 20% mangrove lindur flour substitute cookies have an iron content of 13.0 ppm (1.30 mg/100 g), which is a positive mineral contribution, although relatively lower compared to other functional ingredients such as nuts that have higher Fe levels in bakery products when used as a substitute. The iron content of around 13 ppm in cookies made with 20% mangrove lindur flour can contribute to meeting daily iron needs, especially when consumed with other food sources that increase Fe absorption, such as vitamin C, so that the potential nutritional function of these cookies is more optimal than cookies made from wheat flour.

3.4. Integration X-Ray Fluorescence Analysis (XRF) and Principals Component Analysis (PCA)

Mineral analysis in cookies was initially performed using X-ray Fluorescence (XRF) to obtain a rapid, non-destructive, multi-element profile of the samples. XRF is widely applied in food analysis because it allows simultaneous detection of major and trace elements with minimal sample preparation and without chemical digestion. The XRF results in this study revealed the presence of major minerals such as Ca, P, K, and Mg, as well as trace elements including Fe, Zn, Cu, Mn, and Cr. However, univariate interpretation of XRF data is limited because it only describes individual element concentrations without considering inter-element relationships (Figure 2). Therefore, the dataset was further analyzed using Principal Component Analysis (PCA) as a chemometric approach to reduce dimensionality and explore multivariate patterns.

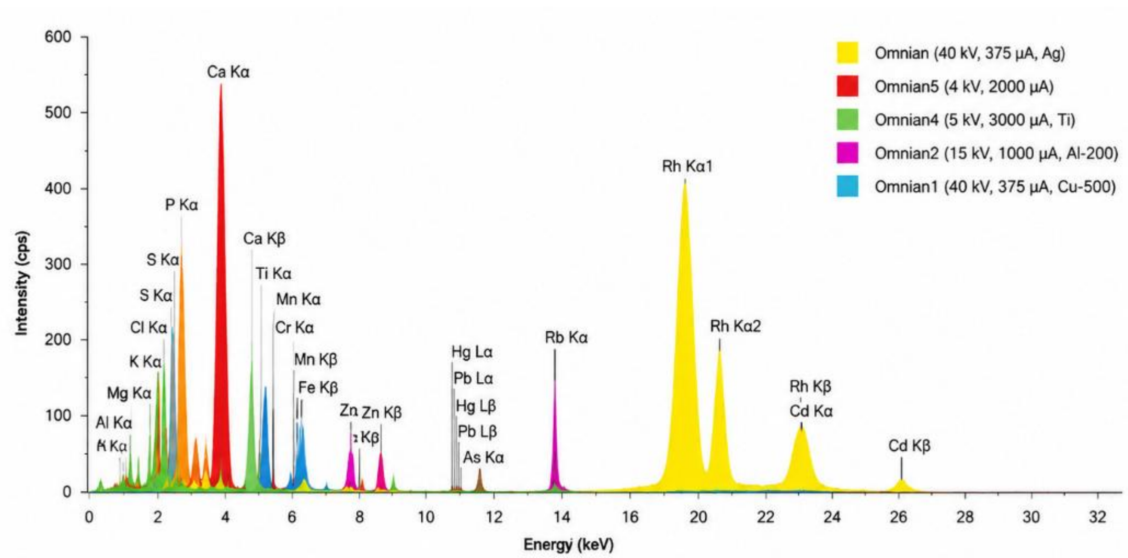

Figure 2. XRF Spectrum and detected elements in cookies with 20% lindur mangrove flour substitution. [Note: cps = counts per second; keV = kilo electron volt].

The PCA results (Figure 3) indicated that the dataset could be reduced into two principal components (PC1 and PC2), which explained more than 70% of the total variance. PC1 was strongly associated with macro minerals such as Ca, P, K, and Mg, indicating their dominant contribution to overall sample variability. PC2 was mainly influenced by trace elements such as Fe, Zn, Cu, Mn, and Cr, which reflect secondary variability related to minor compositional differences and processing conditions. The PCA score plot showed clear clustering among samples based on elemental profiles and excitation conditions. This indicates that mineral composition is not randomly distributed, but structured according to the formulation and measurement conditions. Such clustering behavior confirms that XRF-derived elemental data contain meaningful multivariate patterns that can be effectively interpreted using PCA. In addition, the loading plot revealed positive correlations among Fe, Zn, Cu, and Mn, suggesting that these elements may share similar sources or exhibit similar behavior during processing. In contrast, Ca and P showed different loading directions, indicating their dominant role in defining the macro-mineral structure of the cookies. Overall, the integration of XRF and PCA provides a more comprehensive interpretation compared to single-element analysis. While XRF provides quantitative elemental composition, PCA reveals relationships among variables and identifies dominant patterns in the dataset. This combined approach strengthens the interpretation that substitution of mangrove lindur flour not only increases mineral content but also produces a distinct and structured mineral profile in in the final product.

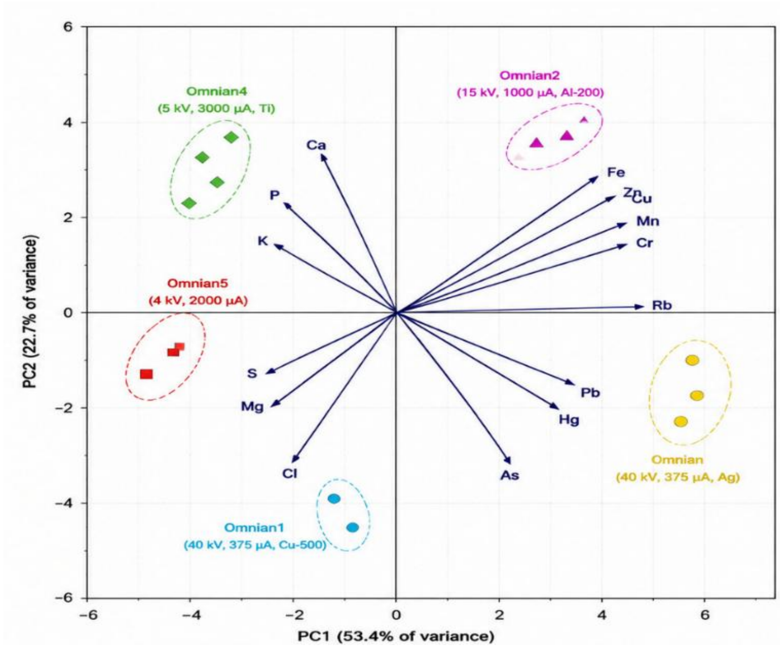

Figure 3. Principal Component Analysis (PCA) Biplot of XRF Data From Cookies with 20% Lindur Mangrove Flour Substitution Under Different Excitation Conditions. Notes: Each point represents one excititation condition, arrows indicate the direction and strength of element loadings. PC1 = principal component 1; PC2 = principal component.

3.5. Fourier Transform Infrared Spectroscopy (FTIR) Analysis

FTIR analysis was used to identify functional groups and molecular interactions in cookies with 20% mangrove lindur flour substitution. The FTIR spectrum showed several characteristic absorption bands associated with carbohydrates, proteins, and lipids in the cookie matrix (Figure 4).

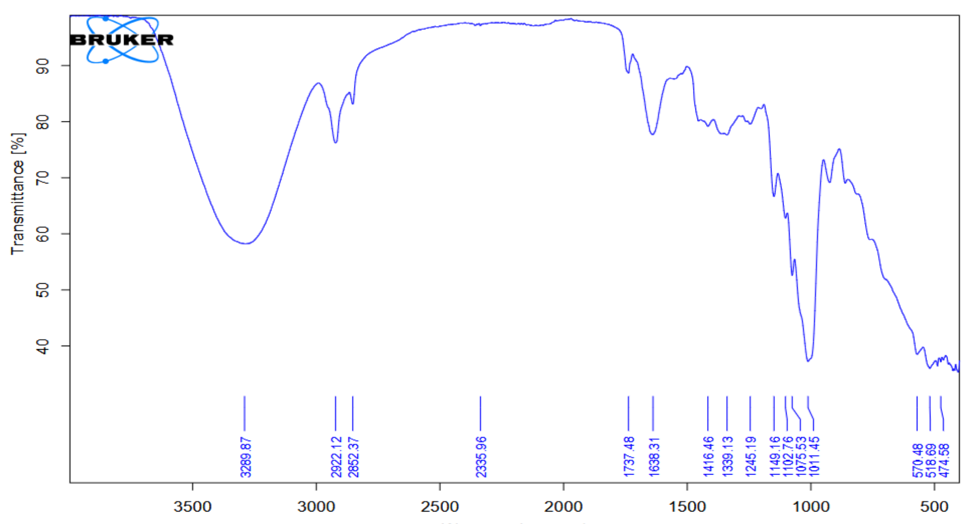

Figure 4. FTIR spectrum of cookies with 20% mangrove lindur flour substitution.

FTIR analysis of cookies with 20% mangrove lindur flour substitution revealed the presence of major functional groups including O–H, C–H, C=O, and C–O/C–O–C (Derksen *et al*., 2023). These functional groups represent the main biochemical components of the cookie matrix, namely carbohydrates, proteins, lipids, and bound water. This indicates that the final product consists of a complex biomolecular system formed during the baking process. X-ray fluorescence (XRF) analysis further identified the presence of both macro and trace elements in the sample, including Ca, P, K, Mg, Fe, Zn, Mn, and Cu. These results confirm that the substitution of mangrove lindur flour contributes not only organic compounds but also a diverse mineral profile in the final product, enhancing its nutritional value at the micronutrient level. However, XRF data alone provides only univariate information and does not capture relationships among elements. Therefore, principal component analysis (PCA) was applied to explore multivariate patterns in the mineral composition. The PCA results reduced the dataset into two principal components (PC1 and PC2), which explained most of the total variance. PC1 was mainly associated with macro minerals such as Ca, P, K, and Mg, indicating their dominant role in defining the overall mineral structure of the cookies. In contrast, PC2 was influenced by trace elements such as Fe, Zn, Cu, and Mn, reflecting minor compositional variations within the samples. This pattern shows that mineral distribution is structured rather than random. When FTIR and XRF results are interpreted together, a link between organic functional groups and mineral elements can be observed. Functional groups such as C–O and C–O–C from polysaccharides may interact with minerals like Ca and Mg through physical association or complex formation within the food matrix. These interactions can influence the structural stability and texture of the final product. The integration of FTIR, XRF, and PCA demonstrates that cookies with 20% mangrove lindur flour substitution exhibit a complex and well-structured food matrix composed of interacting organic and inorganic components. FTIR provides molecular-level structural information, XRF describes elemental composition, and PCA reveals multivariate relationships among minerals. Together, these techniques confirm that mangrove lindur flour substitution modifies not only nutritional composition but also the structural organization of the final product (Pasieczna-Patkowska *et al*., 2025).

4. CONCLUSION

Cookies with 10% and 20% mangrove lindur flour substitution were both moderately accepted by panelists, with sensory scores ranging from slightly like to like. The 20% formulation was selected for chemical analysis as it provided the best balance of taste, aroma, color, and texture. Chemical analysis showed that cookies with 20% mangrove lindur flour contained water (4.40%), ash (1.12%), protein (9.74%), fat (14.43%), carbohydrates (70.32%), and dietary fiber (9.92%). These values indicate a nutritionally balanced product that provides energy (523.87 kcal/100 g) and essential minerals, including phosphorus (71.51 mg/100 g), iron (1.30 mg/100 g), and calcium (57.45 mg/100 g).

AUTHOR CONTRIBUTION

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
TY	✓	✓	✓	✓		✓		✓	✓		✓			
OR	✓			✓	✓		✓	✓		✓		✓	✓	✓
NK	✓						✓			✓		✓		
Sur	✓	✓					✓			✓		✓		
Zuk	✓	✓		✓			✓			✓		✓		

C: Conceptualization; M: Methodology; So: Software; Va: Validation; Fo: Formal Analysis; I: Investigation; D: Data Curation; R: Resources; O: Writing - Original Draft; E: Writing - Review & Editing; Vi: Visualization; Su: Supervision; Fu: Funding Acquisition; P: Project Administration

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION

Not applicable. The authors did not use any generative AI tools or services in the preparation of this manuscript. All content is entirely the intellectual work of the authors.

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