

Article

Production, Characterization, and Application of Palm Fruit (*Arenga pinnata* Merr.) Flour in Boba Pearls

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Abstract. Widely consumed food products can be strategically fortified with dietary fiber to enhance population-level fiber intake. This study examined the physicochemical and functional properties of palm fruit flour to determine its potential as a dietary fiber-enhancing substitute in tapioca-based boba. Initially, palm fruit flour was characterized for its physicochemical and functional properties. Afterwards, it was substituted for 20% of the tapioca in tapioca-based boba pearls and compared to a control (100% tapioca). Analyses of both the raw flour and the boba included its physicochemical and functional properties. Characterization of palm fruit flour showed a high water absorption capacity (8.79 mL/g) and whiteness degree (92.12%). Substituting 20% of the tapioca with palm fruit flour resulted in a product with a high dietary fiber content (20.73%), increased moisture content (68.46 ± 1.25), and a lowered caloric value (2.24 kcal). In conclusion, palm fruit flour is an effective ingredient for fortifying boba nutritionally, though it changes the texture, producing a softer product. Thus, it presents a potentially valuable approach for formulating novel functional foods for healthy consumers, offering a redefined sensory experience. This study is the first to evaluate palm fruit flour as a partial tapioca substitute for fiber-enriched boba production.

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Universitas Andalas. Padang, IndonesiaEmail : desniarti@ac.unand.ac.id**1. Introduction**

Dietary fiber consumption among Indonesian adolescents is critically inadequate, with over three-quarters consuming less than the WHO recommendation of 25–30 grams per day. Low fiber intake can impair gastrointestinal function, hinder gut microbiome development, and elevate the risk of chronic diseases such as obesity, diabetes, and cardiovascular disorders [1-3]. A study in Yogyakarta found that 98% of obese adolescents had inadequate fiber intake correlated with lower HDL cholesterol levels [4]. Similarly, research in Medan and Aceh Barat showed that low fiber consumption significantly increased the odds of overweight and obesity among adolescents [5-6]. These findings highlight the urgent need for acceptable and innovative dietary approaches to increase fiber intake among young populations.

Dietary fiber, consisting of indigestible and fermentable polysaccharides, is known for its physiological benefits in preventing obesity, diabetes, and cardiovascular disorders [7-9]. However, despite its recognized health importance, incorporating fiber into commonly consumed modern foods remains a challenge. Adolescents tend to prefer convenient and palatable products, such as boba—chewy tapioca pearls widely enjoyed in beverages and desserts [10]. Yet, conventional boba is low in fiber and high in amylopectin, which contributes elasticity but offers limited nutritional value [11]. Therefore, developing fiber-enriched boba formulations could be an effective way to promote higher fiber intake through familiar food items.

Palm fruit (*Arenga pinnata* Merr.) flour offers a promising local alternative for such formulations. It is rich in soluble dietary fiber, mainly galactomannan, a hydrocolloid polysaccharide valued for its gelling, thickening, and stabilizing properties [12-13]. With a galactomannan content of approximately 4.58% and a mannose-to-galactose ratio of 2:1–5:1, palm fruit flour also provides antioxidant and prebiotic benefits. Incorporating it into tapioca-based boba is expected to enhance fiber content while improving elasticity, chewiness, and textural quality [14].

Although fiber fortification has been explored in various foods—such as noodles, bakery products, and beverages—limited studies have examined palm fruit flour in starch-based systems like boba. Prior works using psyllium husk, oat bran, or konjac flour have not addressed this locally available ingredient, highlighting a gap and the novelty of applying indigenous fiber sources for functional food innovation.

Our preliminary findings showed that substituting 20% of tapioca flour with palm fruit flour achieved optimal sensory acceptance, balancing fiber enhancement with desirable texture. Similar substitution levels (15–25%) have been reported to maintain acceptable sensory qualities in other starchy foods such as cakes and cookies [15-16]. Thus, a 20% substitution level is considered practical to enrich boba nutritionally without compromising texture and consumer preference.

2. Method**2.1 Materials and Tools**

Palm fruit sourced from a local Batusangkar palm fruit production site and commercial tapioca flour procured from a wholesale store in Bungus Teluk Kabung, Padang. Chemicals used for analysis included distilled water, α -amylase, protease, acetone, celite, amyloglucosidase, phosphate buffer (pH 6), NaOH (Merck), HCl (Smartlab), ethanol, and Na_2CO_3 .

Equipment utilized in the study included aluminum and porcelain crucibles, desiccator, muffle furnace, oven, food dehydrator, texture analyzer (Brookfield), colorimeter (HunterLab Flex EZ

spectrophotometer), bomb calorimeter (CAL3K), Rapid Visco Analyzer (RVA 4500, Perten Instruments), Differential Scanning Calorimeter (DSC 4000, Perkin Elmer), and glassware.

2.2 Research Design

The research conduct of two phases:

Phase 1: Characterization of palm fruit flour. This phase involved the production and comprehensive analysis of flour made from palm fruit (*Arenga pinnata* Merr.).

Phase 2: Application in boba. This phase involved the development and evaluation of boba formulated with a blend of tapioca flour and palm fruit flour (80:20 w/w).

Analyses of product were performed in triplicate. Statistical analysis was conducted using Analysis of Variance (ANOVA) with a significance level of 5%. Differences among means were further tested using Duncan's New Multiple Range Test (DNMRT).

2.3 Research Implementation

2.3.1 Preparation of Palm Fruit Flour

The preparation of palm fruit flour used a modified method from [17]. The primary modification was the implementation of a flattening step (~0.5 cm thickness) post-soaking to ensure uniform and efficient drying. The process of palm fruit flour can be seen at Figure 1. Raw palm fruit obtained from palm trees. After boiling the raw fruit, the gelatinous kernels (kolang-kaling) were removed from their hard shells. The fresh fruits were then thoroughly washed with running water to remove impurities. Purification step involved soaking the fruits in distilled water for 48 h, with water changes every 24 h to leach out tannins and cyanogenic compounds. Afterward, the fruits were rinsed, drained, and flattened to a uniform thickness (~0.5 cm) to maximize surface area. The slices were dried using a food dehydrator (60°C for 12-13 h). Finally, the dried slices were ground and sieved through an 80-mesh sieve to obtain homogeneous flour for analysis.



Figure 1. Palm Fruit Flour Production Procedure

2.3.2 Preparation of Boba

The method was adapted from [18]. The ingredients were weighed according to the formulation. The tapioca flour was dissolved in water at room temperature. Then, in a preheated pan with a small amount of water, the palm fruit flour was added to the tapioca slurry and stirred until formed a dough. The dough was then kneaded and shaped into small (~1 cm diameter) balls. The shaped boba were boiled over low heat for 10 minutes, until they floated, which indicated that they were cooked. It was then drained and cooled.

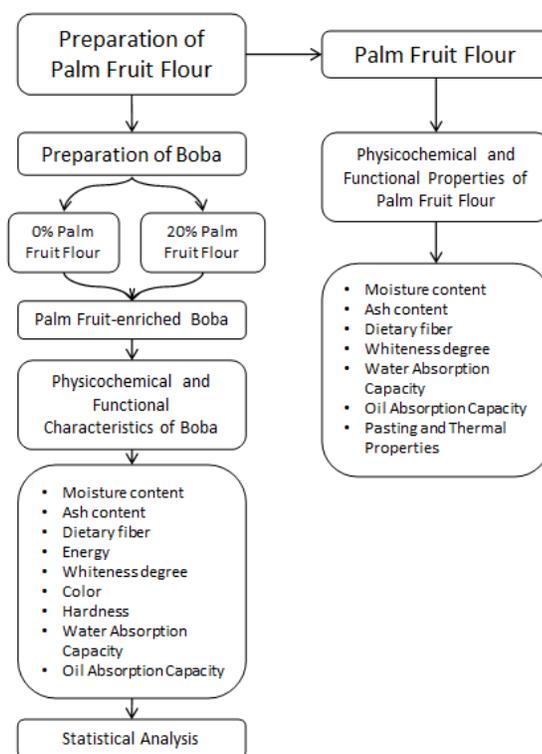


Figure 2. Experimental workflow of palm fruit-enriched boba production and subsequent analyses

2.3.3 Observations

Physicochemical Analysis

Moisture Content

Sample (3-5 g) was weighed in a pre-dried aluminum dish, then oven-dried at 105°C until constant weight [19]. Moisture content was calculated as:

$$\text{Moisture (\%)} = [(W1 - (W2 - W0)) / W1] \times 100\%$$

Where W0 = empty dish, W1 = initial weight, W2 = final weight.

Ash Content

Samples (3–5 g) were incinerated in a muffle furnace at 600°C for 6 hours [14]. Ash content was determined using:

$$\text{Ash (\%)} = [(W2 - W0) / W1] \times 100\%$$

Where W0 = empty dish, W1 = initial weight, W2 = final weight.

Dietary Fiber

Samples (0.5 g) were enzymatically hydrolyzed using α -amylase, pepsin, and β -amylase under sequential incubations. Insoluble fiber was filtered, washed with ethanol and acetone, dried, and weighed. The remaining filtrate was precipitated using ethanol to isolate soluble fiber [19]. Total dietary fiber was calculated as:

$$\text{Dietary fiber (\%)} = \frac{\text{Final filter paper weight} - \text{Initial paper weight}}{\text{Sample weight}} \times 100\%$$

Color and Whiteness Degree

Color evaluation was performed using a ColorFlex EZ spectrophotometer (HunterLab) based on the Hunter L*, a*, b* color space. The instrument was calibrated with a white standard [20]. Whiteness was calculated using the equation:

$$\begin{aligned} \text{Whiteness} &= 100 - \sqrt{[(100 - L)^2 + a^2 + b^2]**} \\ \text{Hue angle (}^\circ\text{Hue)} &= \text{arctangent}(b/a)** \end{aligned}$$

Texture Measurement

Texture measurements were performed using a Brookfield Texture Analyzer [21]. Samples were placed on a flat surface and compressed once using a probe. The hardness value was expressed in N/cm² and calculated as follows:

$$\text{Hardness (N/cm}^2\text{)} = \frac{\text{Peak force (kg)} \times 9.8\text{m/s}^2}{\text{Probe area (cm}^2\text{)}}$$

Energy

Energy was determined using CAL3K-S Oxygen bomb calorimeter system following the guidelines from manual of DDS Calorimeters [22]. One gram of sample was combusted in a bomb calorimeter under 25 atm of oxygen. The temperature change was recorded to calculate metabolizable energy (ME):

$$\text{ME (kcal/g)} = \frac{(\text{Final temp} - \text{Initial temp}) \times \text{Bomb factor}}{\text{Sample weight}} \times 100\%$$

Oil Absorption Capacity

Sample of 1–3 g was mixed with 10 mL of vegetable oil, vortexed for 2 minutes, left for 15 minutes, and centrifuged at 3000 rpm for 25 minutes [23]. The supernatant was removed, and oil absorption was calculated as:

$$\text{OAC (mL/g)} = \frac{\text{Initial oil} - \text{Supernatant}}{\text{Sample weight}}$$

Water Absorption Capacity

Similar to the OAC procedure, 1–3 g of sample was mixed with 10 mL of distilled water, vortexed, rested, and centrifuged [23]. Water absorption was determined as:

$$\text{WAC (mL/g)} = \frac{\text{Initial water} - \text{Supernatant}}{\text{Sample weight}}$$

Pasting Properties

Pasting Properties were analyzed using a Rapid Visco Analyzer (RVA 4500, Perten Instruments). The testing profile was as follows: sample suspension (3.5 g total weight, 12% moisture basis) was held at 50°C for 1 min, heated to 95°C at a rate of 12 °C/min, held at 95°C for 2.5 min, cooled to 50°C at a rate of 12 °C/min, and held at 50°C for 2 min. The stirring speed was 160 rpm for the first 10 seconds followed by a constant 960 rpm [24].

Thermal Properties

Thermal Properties were analyzed using a Differential Scanning Calorimeter (DSC 4000, Perkin Elmer). Samples (~3 mg, dry basis) were weighed into aluminum pans, hydrated with distilled water (1:3 ratio), sealed, and equilibrated overnight. An empty pan was used as a reference. The scanning temperature range was from 20°C to 120°C at a heating rate of 10 °C/min [25].

3. Results and Discussion

3.1 Physicochemical and Functional Properties of Palm Fruit Flour

Characterization of palm fruit flour revealed its potential as a functional food ingredient (Table 1). Its low moisture content (5.73%) is essential for shelf stability and aligns with quality standards for flours. This result is well below the recommended maximum limit of 10-14% for safely storing flours because it helps minimize the risk of microbial development and biochemical deterioration [26]. The low moisture content, which was achieved through effective dehydrator drying, suggests that the flour has a long shelf life and good storage stability.

Table 1. Physicochemical Characteristic of Palm Fruit Flour

Analysis Component	Palm fruit flour
Moisture	5.73 %
Ash	1.22 %
Dietary fiber	1.97 %
Whiteness degree	92.12 %

The ash content (1.22%) was significantly lower than that of other fruit peel flours, affirming the effectiveness of the soaking purification process in eliminating mineral impurities. The moderately low value is common for fruit flours and indicates a high degree of purity with a small amount of inorganic impurities. It suggests that thorough washing and soaking effectively removed external contaminants. Analysis revealed a dietary fiber (1.97%), which was aligned with [27], that discovered a dietary fiber content of 2.60% in palm fruit. The slight variation is not anomalous but rather expected, reflecting the natural variability in fruit composition. A key finding was the exceptionally high whiteness degree of 92.12%, revealing a visually bright, neutral-colored powder, surpassing that of many alternative flours [28]. This significant functional advantage allows for the flour to be incorporated into products like boba without inducing undesirable color changes, thereby enhancing consumer acceptability. The flour's bright white color is likely a result of an effective soaking procedure during preparation. Soaking helps remove phenolic compounds and other substances that cause browning reactions, preserving the flour's pale color [29].

The functional properties (Table 2) revealed a high water absorption capacity (WAC = 8.79 mL/g), substantially greater than that of native tapioca starch. This can be attributed to its high content of hydrophilic polysaccharides, such as galactomannan [30]. High WAC is a favorable functional attribute because it improves the moisture retention, yield, viscosity, and shelf life of food products [31]. In contrast, the low oil absorption capacity (OAC = 1.16 mL/g) is likely due to the flour's low protein and lipid content, indicates a lower tendency to bind with nonpolar molecules. This property reduces greasiness in the final product [32-33].

Table 2. Functional Properties of Palm Fruit Flour

Functional Properties	Palm fruit flour
Water Absorption Capacity	8.79 mL/g
Oil Absorption Capacity	1.16 mL/g

3.2 Pasting and Thermal Properties of Palm Fruit Flour

The pasting and thermal properties (see Table 3) are crucial for understanding its application in thermally processed foods. Its remarkably low pasting temperature (37.37°C), compared to tapioca starch (typically >65°C), indicates an early onset of hydration and swelling [34]. This suggests that the galactomannan in palm flour hydrates readily and can affect the gelatinization dynamics of the starch blend in boba.

Table 3. Pasting and Thermal Properties of Palm Fruit Flour

Properties	Palm Fruit Flour
Final Viscosity	214 cP
Pasting Temperature	37.37 °C
Peak Temperature	118.33 °C
Conclusion Temperature	163.79 °C
ΔH (Enthalpy of gelatinization)	270.90 J/g
Peak Area	3034.08 (mJ)

The palm fruit flour exhibited a low final viscosity (214 cP), indicative of a limited capacity to form a cohesive gel post-cooling. This is attributed to its composition, where galactomannan inhibits starch chain reassociation (retrogradation) by competing for water and physically blocking polymer alignment [30],[35]. Consequently, this results in a softer gel texture and imparts improved shelf-stability by reducing syneresis and firming compared to pure starch systems [36].

The high peak and conclusion temperatures (118.33°C and 163.79°C, respectively) demonstrate exceptional thermal stability. This is a critical functional advantage because the flour's components remain stable under high-shear and high-temperature cooking conditions, preventing breakdown and ensuring consistent viscosity [37-38]. This high thermal stability is a significant functional advantage, making palm fruit flour ideal for high-temperature processing [38]. The high enthalpy of gelatinization ($\Delta H = 270.90$ J/g) suggests that melting crystalline structures requires significant energy, possibly because a robust starch-galactomannan matrix requires more heat to dissociate [39].

The enthalpy of gelatinization refers to the endothermic amount of energy absorbed when the crystalline and molecular structure of starch is disrupted [39]. The large peak area of 3,034.08 mJ was consistent with the high energy required for this process. The DSC thermogram (Figure. 2) confirms a single, sharp endothermic peak representative of this coordinated melting process.

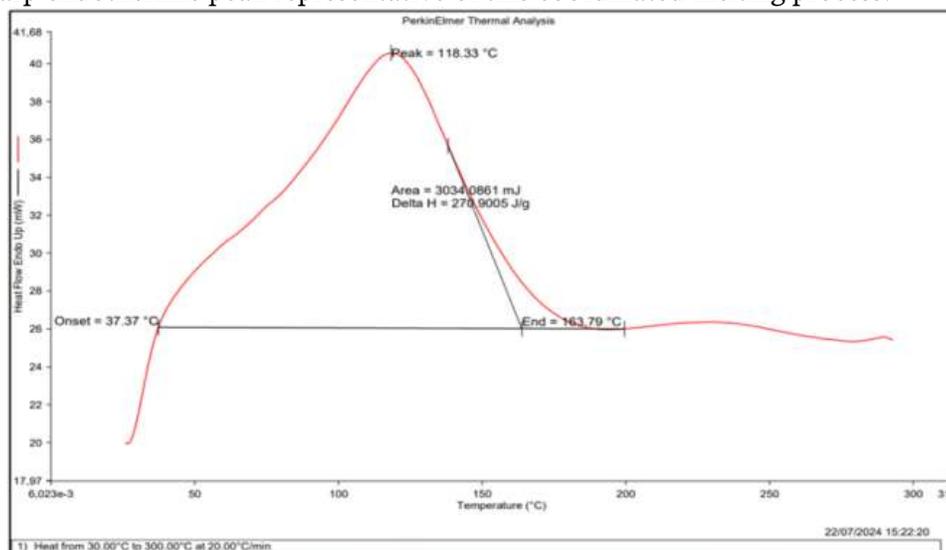


Figure 3. DSC Thermograms of Palm Fruit Flour

3.3 Physicochemical and Functional Characteristics of Boba

The substitution of 20% tapioca flour with palm fruit flour induced significant and transformative changes in the boba's properties (Table 4). Statistical analysis confirmed that the differences in hardness, color, moisture, and WAC were significant ($p < 0.05$), while differences in ash and OAC were not ($p > 0.05$).

Table 4. Physical, Chemical, and Functional Characteristics of Boba

Analysis component	A	B
Hardness (N/cm ²)	64.22 ± 0.43 ^b	24.01 ± 0.98 ^a
Color (°Hue)	266.39 ± 0.19 ^b (blue)	262.62 ± 0.11 ^a (blue)
Moisture (%)	59.04 ± 1.62 ^a	68.46 ± 1.25 ^b
Ash (%)	0.16 ± 0.18	0.33 ± 0.27
Energy (kcal)	2.65	2.24
Dietary fiber (%)	-	20.73
Water absorption (ml/g)	0.34 ± 0.16 ^a	0.60 ± 0.12 ^b
Oil absorption (ml/g)	0.22 ± 0.11	0.31 ± 0.21

Note: means in the same row with different superscript letters are significantly different ($p < 0.05$).

The most pronounced effect was on texture. The hardness of Sample B (24.01 N/cm²) was significantly lower than Sample A (64.22 N/cm²). This reduction of over 60% is not just a difference, but a fundamental textural modification. The galactomannan in palm flour competes for water and physically interferes with starch chain association, likely inhibiting the formation of a continuous, rigid amylopectin network and resulting in a significantly softer and more cohesive gel. Their presence hinders retrogradation, or the recrystallization of starch molecules during cooling, resulting in more stable starch gels that retain texture over time [40-42].

This alleviates a common consumer complaint about the excessive chewiness of traditional boba. Both boba samples exhibited hue angles within the blue spectrum (A: 266.39°; B: 262.62°). While the difference is small, it is statistically significant ($p < 0.05$). The slightly lower hue angle of the palm-fortified boba (sample B) indicates a subtle shift toward violet, consistent with the addition of a non-starch ingredient containing trace amounts of pigments or phenolic compounds [43]. The significant increase in moisture content in Sample B (68.46%) is due to the transfer of the palm flour's high WAC to the final product. The fiber matrix acts as a sponge, binding water more readily and producing a moister, less rubbery pearl. This is visually apparent in Figure 4, where Sample B appears more translucent and moist. From a nutritional standpoint, the addition of 20.73% dietary fiber to Sample B is a breakthrough, as it transforms a high-glycemic food into a fiber-enriched one. This directly addresses the public health issue of low fiber intake. Despite the small reduction in caloric content (2.24 kcal vs. 2.65 kcal), it is consistent with the partial replacement of digestible starch with non-digestible fiber [44].

Furthermore, boiling and processing promoted resistant starch formation, which acts similarly to dietary fiber and further reduces caloric content [45]. The significantly higher water absorption capacity (WAC) of Sample B (0.60 mL/g) indicates the direct transfer of hydration functionality from palm fruit flour to the boba matrix. Retained hydration functionality explains the product's higher moisture content and softer texture. The robust fiber network effectively plasticizes the gel. In contrast, the modest increase in oil absorption capacity (OAC) indicates that the fiber-starch composite matrix is slightly more porous, capable of physically trapping a greater volume of oil.

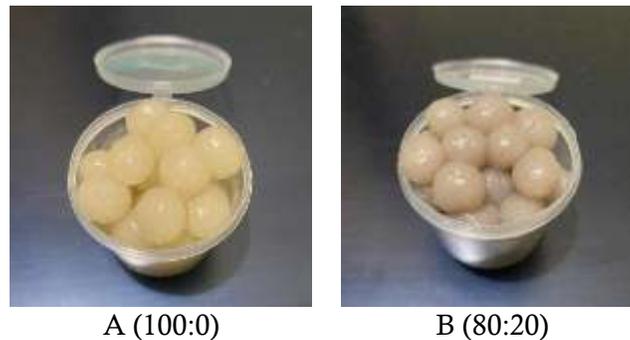


Figure 4. Boba Produced from Formulations

As shown in Figure 4, the visual characteristics of the boba pearls provide clear morphological evidence of the profound impact caused by the 20% palm fruit flour substitution. The control boba (A), made from 100% tapioca flour, has the typical opaque, chalky white appearance resulting from a dense network of light-scattering swollen starch granules characteristic of a pure amylopectin gel. In comparison, the fortified boba (B) has a noticeably more translucent and glossy surface. This increased translucency indicates a more hydrated and continuous gel phase where light dispersion is reduced. This study introduces the strategic utilization of underutilized palm fruit flour as a novel dietary fiber source for the functional modification of boba pearls. The innovation lies in achieving nutritional enhancement (a significant increase in fiber), textural modification (substantial softening), and utilizing a local agricultural byproduct simultaneously. These findings provide a sustainable, viable strategy for developing healthier versions of popular staple foods and addressing the critical issue of low fiber intake, particularly among younger demographics.

4. Conclusion

In conclusion, this study establishes palm fruit flour as a novel, multifunctional ingredient for enhancing the nutrition and texture of boba pearls. The flour's inherent properties, including high whiteness, exceptional water-binding capacity, and unique thermal stability, enable its successful integration. The 20% substitution strategy yielded a transformative outcome: nutritionally fortified boba with 20.73% dietary fiber and significantly softer texture (a >60% reduction in hardness). This research provides a scientifically grounded, sustainable strategy for utilizing an underutilized crop to address public health challenges. It offers a model for creating healthier versions of popular staple foods without compromising their functional properties.

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