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Effects of boiling and peeling treatments on the physicochemical properties of Durian (*Durio zibethinus*) seed flour

Durian (Durio zibethinus) Tohum Ununun Fizikokimyasal Özellikleri Üzerine Kaynatma ve Soyma İşlemlerinin Etkileri

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ABSTRACT

Durian (*Durio zibethinus*) seed flour represents an underutilized byproduct with significant potential for food applications. This study systematically evaluated how boiling and peeling pre-treatments affect the physicochemical properties of durian seed flour using a factorial completely randomized design with four treatments: boiled-peeled (BP), boiled-unpeeled (BUP), unboiled-peeled (UBP), and unboiled-unpeeled (UBUP). Results revealed that boiling significantly increased cohesiveness (Carr Index: 16.67% in BP vs 6.67% in UBUP) and thermal stability (peak temperature: 144.67°C in BP vs 26.87°C in UBUP) through starch gelatinization, while reducing flowability. Skin removal improved lightness (L* = 87.11 in UBP vs 60.02 in BUP) and flow properties. Unpeeled flours exhibited superior functional properties, with UBUP showing the highest water solubility (0.16%) and foam stability (94.44%), attributed to preserved seed coat polysaccharides and amphiphilic compounds. Thermal analysis confirmed boiling-induced structural stabilization, whereas unboiled-unpeeled flour displayed anomalous low transitions, suggesting enzymatic degradation. Color analysis aligned with consumer preferences, as peeled flours (UBP, BP) achieved higher lightness (L* > 83) compared to unpeeled counterparts (L* < 71). The study demonstrates that processing methods dictate flour functionality: peeled flours are optimal for visual quality and flowability, while unpeeled variants excel in foaming and solubility. These findings provide critical insights for tailoring durian seed flour production to specific applications, bridging the gap between agricultural waste valorization and functional ingredient development. Future research should explore protein isolation techniques and industrial-scale processing to fully exploit this sustainable resource.

Key Words: Boiling, Durian seed flour, Peeling

ÖZ

Durian (*Durio zibethinus*) tohumu unu, önemli potansiyele sahip ancak yeterince değerlendirilmemiş bir yan ürün olarak gıda uygulamaları açısından dikkate değerdir. Bu çalışma, haşlama ve kabuk soyma ön işlemlerinin durian tohumu ununun fizikokimyasal özellikleri üzerindeki etkilerini sistematik olarak değerlendirmiştir. Çalışmada, tamamen rastgeleleştirilmiş faktöriyel bir tasarım kullanılarak dört farklı işlem grubu incelenmiştir: haşlanmış-soyulmuş (BP), haşlanmış-soyulmamış (BUP), haşlanmamış-soyulmuş (UBP) ve haşlanmamış-soyulmamış (UBUP). Elde edilen sonuçlar, haşlama işleminin nişasta jelatinizasyonu yoluyla kohezyonu (Carr İndeksi: BP'de %16,67; UBUP'da %6,67) ve termal stabiliteyi (tepe sıcaklığı: BP'de 144,67°C; UBUP'da 26,87°C) önemli ölçüde artırırken akışkanlığı azalttığını ortaya koymuştur. Kabuk soyulması ise unun açıklığını (L = UBP'de 87,11; BUP'da 60,02) ve akış özelliklerini iyileştirmiştir. Soyulmamış unlar fonksiyonel özellikler açısından daha üstün bulunmuş, özellikle UBUP grubu en yüksek su çözünürlüğü (%0,16) ve köpük stabilitesi (%94,44) değerlerine ulaşmıştır. Bu durum, tohum kabuğunda korunan polisakkaritler ve amfipatik bileşiklere atfedilmektedir. Termal analiz, haşlamaya bağlı yapısal stabilizasyonu doğrularken, haşlanmamış-soyulmamış un düşük ve anormal geçiş sıcaklıkları göstermiş, bu durum enzimatik bozulmayı düşündürmektedir. Renk analizleri, tüketici tercihleriyle uyumlu olup, soyulmuş unların (UBP, BP) daha yüksek açıklık değerlerine (L > 83) ulaştığını, soyulmamış unların ise daha düşük değerlere (L < 71) sahip olduğunu göstermiştir. Bu çalışma, işleme yöntemlerinin unun fonksiyonelliğini belirlediğini ortaya koymaktadır: soyulmuş unlar görsel kalite ve akışkanlık açısından uygunken, soyulmamış unlar köpüklenme ve çözünürlük açısından daha üstündür. Elde edilen bulgular, durian tohumu ununun belirli uygulamalara uygun şekilde işlenmesine dair önemli bilgiler sunmakta ve tarımsal atıkların değerlendirilmesi ile fonksiyonel bileşen geliştirilmesi arasındaki boşluğu doldurmaya katkı sağlamaktadır. Gelecek çalışmaların, protein izolasyon teknikleri ve endüstriyel ölçekli işleme yöntemlerine odaklanarak bu sürdürülebilir kaynağın potansiyelini tam anlamıyla ortaya çıkarması önerilmektedir.

Anahtar Kelimeler: Kaynatma, Durian Tohumu Unu, Soyma

Introduction

Durian (*Durio zibethinus*), widely regarded as "The King of Fruits," holds significant agricultural and economic importance in Indonesia. Despite its popularity, the fruit's edible portion constitutes only 20–35% of its total weight, with the remaining 65–80% consisting of rind (60–75%) and seeds (5–15%) (Lestari et al., 2024). These byproducts are predominantly discarded as organic waste, representing both an environmental concern and a lost opportunity for resource utilization. Notably, durian seeds contain substantial nutritional value, with compositions of 54.90% water, 3.40% protein, 1.58% ash, 1.32% fat, and 18.92% starch (Srianta et al., 2012). While minimal efforts have been made to repurpose seeds as animal feed, their potential as a functional food ingredient remains underexplored. Converting durian seeds into flour presents a viable strategy to mitigate waste while enhancing their commercial value.

The production of durian seed flour involves sequential processing steps—washing, peeling, boiling, drying, and grinding—each of which may influence the final product's quality. Previous studies have demonstrated the successful incorporation of durian seed flour into various food products, including biscuits (Verawati and Yanto, 2019), bread (Humaira and Faisal, 2023), and noodles (Wibawani et al., 2023), suggesting its potential for broader food and beverage applications. However, the physicochemical properties of the flour are highly dependent on pretreatment methods, particularly boiling and peeling.

Boiling, for example, has been demonstrated to modify essential characteristics of flour. Cahyani and Hakim (2017) reported higher flour yields from unboiled seeds, whereas Amon et al. (2014) observed that boiling significantly modified moisture content, reducing sugars, crude fat, and phenolic compounds in taro flour. The boiling pretreatment was selected due to its role in starch gelatinization, protein denaturation, and antinutrient reduction, which simultaneously enhance the flour's functional properties (Ma et al., 2011). Similarly, peeling reduces seed mass, directly affecting flour yield. Despite these findings, no comprehensive study has evaluated the combined effects of boiling and peeling on durian seed flour's physicochemical properties, leaving a critical gap in optimizing processing techniques.

This study addresses this gap by systematically examining how different combinations of boiling (with/without) and peeling (with/without) influence durian seed flour's yield, nutritional profile, and functional quality. By elucidating the interactions between these pretreatment variables, the research aims to establish optimal processing conditions that maximize flour quality and economic viability. The findings will contribute to sustainable waste optimization strategies while expanding the utilization of durian by products in the food industry.

Material and Methods

The main ingredient used in making flour is durian seeds from ripe and fresh durian (Figure 1). Durian was obtained from farmer or community plantations in Desa Batee Meucanang, Labuhan Haji, South Aceh.

Figure 1. Durian and the seed

This study applied a Factorial Completely Randomized Design (CRD) with two main factors and two treatment levels, each of which was tested in three replications. The two main factors in this study were peeling of durian seed skin (with/without) and boiling of durian seed (with/without). Therefore, there were four samples in every replication, they were BP (boiled, peeled), BUP (boiled, unpeeled), UBP (unboiled, peeled), and UBUP (unboiled, unpeeled).

Preparation of Durian Seed Flour

Preparation of flour is shown by Figure 2. The initial stage in durian seed flour production involved manual sorting, wherein seeds were selected based on specific quality criteria: dense and fresh seed flesh, absence of pest damage, and free from rot. Following sorting, the peeling stage was conducted exclusively for the peeled and unpeeled samples, wherein the outer seed coat—unsuitable for flour production—was removed. Subsequently, the seeds underwent washing to eliminate surface contaminants. This process entailed soaking the seeds in clean water for 15 minutes to dissolve residual mucilage, followed by thorough rinsing under running water.

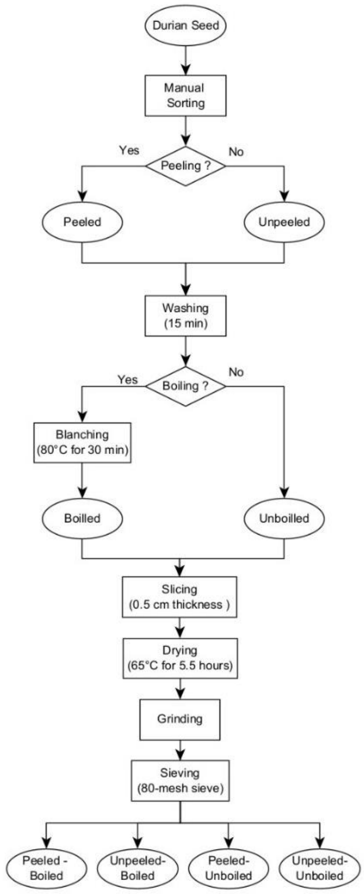

Figure 2. Durian seed flour processing

For the boiled and unboiled samples, the washed seeds were subjected to blanching at 80°C for 30 minutes (Wibawani et al., 2023). After blanching, the seeds were sliced uniformly to a thickness of 0.5 cm to optimize the subsequent drying and milling processes. The sliced seeds were then dried in an oven at 65°C for 5.5 hours (Lisa et al., 2015) to reduce moisture content and enhance shelf stability. The dried slices were pulverized using a mechanical grinder, and the resulting powder was sieved through an 80-mesh sieve to ensure particle uniformity and a fine flour consistency.

Measurement of Physical Properties

In order to find out the physical properties of durian seed flour, the density, Carr index, Hausner ratio, angle of repose, and flowability were measured. Bulk density was determined according to the method described by Puteri et al. (2017). Durian seed flour was placed into a 10 ml graduated cylinder. Then, the 10 ml flour was weighted. The bulk density was calculated by dividing the sample weight by the sample volume. For the tapped density, the cylinder was mechanically tapped for 30 times. The tapped density was calculated by dividing the sample weight by the sample volume after tapping. Carr index and Hausner ratio were calculated from bulk and tapped density (Nani and Krishnaswamy, 2021) by using equations (1) and (2).

$$\text{Carr index} = \frac{\text{tapped density - bulk density}}{\text{tapped density}} \times 100 \qquad (1)$$

$$\text{Hausner ratio} = \frac{\text{tapped density}}{\text{bulk density}} \qquad (2)$$

Flow rate and angle of repose were determined according to the method described by Khan and Saini (2016). A glass funnel was attached to a stand at a distance of 10 cm above a table surface. Durian seed flour (30 g) was poured through the funnel to create a heap, the height and diameter were then measured. The flow rate was measured by using stopwatch. In order to determine the angle of repose, the anti-tangent of radius and height was calculated.

Measurement of Functional Properties

The solubility in water and swelling power were assessed according to the method described by Kusumayanti et al. (2025). To measure the solubility, 0.5 g of the sample was heated in 10 mL of distilled water at 60°C for 30 minutes without agitation. The samples were then centrifuged at 1600 rpm for 10 minutes. Subsequently, 5 mL of the supernatant was collected, dried, and weighed. Percentage of solubility was calculated by dividing weight of dried supernatant to the weight of sample (dry basis). For swelling power, the sample (0.1 g) was heated in 10 mL of distilled water at 60°C for 30 minutes with continuous agitation. Subsequently, the samples were centrifuged at 1600 rpm for 15 minutes, and the weight of the sedimented portion was recorded. Swelling power was calculated by dividing weight of sediment to the weight of sample (dry basis).

Foaming capacity and stability were determined according to the method described by Puteri et al. (2017). The sample solution (60 mL, 5% w/v) was homogenized for 1 minute. The solution was then placed in a 100 mL graduated cylinder and the foam volume was recorded. In addition, the foam stability was obtained as the percentage of foam volume retained after 10 minutes. The foaming capacity was expressed using Equation (3).

$$\text{Foaming capacity } (\%) = \frac{\text{volume after homogenization- initial volume}}{\text{initial volume}} \times 100\% \qquad (3)$$

Color Analysis

The color profile of the sample was interpreted by Hunter Lab using a Chromameter (Konica, Minolta CR-300, Tokyo, Japan). The L* value represents lightness ranging from 0 to 100 (white). The a* value represents red (+) to green (-), while the b* value represents yellow (+) to blue (-) (Puteri et al., 2017). Moreover, the value of ΔE (total color difference to reference or black) was also calculated using Equation (4). The ΔL, Δa, and Δb values represent the differences in lightness, red–green, and yellow–blue color components, respectively, relative to the reference sample (black).

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \qquad (4)$$

Measurement of Protein Solubility

Protein solubility was measured to quantify the percentage of soluble protein using the Lowry method with modification (Dent et al., 2024). Protein supernatants were diluted tenfold and hydrolyzed in 2 N NaOH at 100 °C for 10 minutes prior to the addition of the complex-forming reagent and the Folin–Ciocalteu phenol reagent. The absorbance of sample was measured at 750 nm using a UV-VIS spectrophotometer (Optizen Alpha, KLAB, South Korea). The result was compared with a calibration curve prepared using bovine serum albumin (BSA).

Measurement of Thermal Properties

The thermal properties were observed by using Differential Scanning Calorimetry (Mettler Toledo). The onset, peak, and endset temperature were saved to analyse the gelatinization behavior of sample.

Statistical Analysis

The data of analyses were processed with Analysis of Variance by using the RStudio (Version 2024.12.1+563) software package. The data that had a significant effect on the observation variables were further tested using Duncan's Multiple Range Test (DMRT) at a 95% confidence level (α = 0.05).

Table 1. Physical properties of durian seed flour with different treatment[1]

Parameters	Treatment			
	BP[2]	BUP[3]	UBP[4]	UBUP[5]
Bulk Density ($g\ ml^{-1}$)	0.56±0.01	0.56±0.01	0.57±0	0.57±0.01
Tapped Density ($g\ ml^{-1}$)	0.68±0.02	0.65±0.05	0.62±0.02	0.61±0.03
Carr Index	16.67±2.89a	13.33±5.77ab	8.33±2.89b	6.67±2.89b
Hausner Ratio	1.2±0.04a	1.16±0.08ab	1.09±0.03b	1.07±0.03b
Angle of Repose (°)	23.17±2.82a	20.30±1.83ab	19.57±3.54ab	16.26±2.01b
Flow rate (s)	5.09±1.2b	6.06±0.02b	5.06±0.49b	9.36±2.47a

[1]Different letters indicate significant differences among samples within the same row ($p < 0.05$). Data are means ± standard deviation. [2]Boiled and peeled. [3]Boiled and unpeeled. [4]Unboiled and peeled. [5]Unboiled and unpeeled.

Results and Discussion

Physical Properties

The results demonstrate significant differences in the flow properties and cohesiveness of durian seed flour across pre-treatment methods, while density parameters remain stable (Table 1). This phenomenon can be explained by the unique physicochemical characteristics of durian seed starch. The higher Carr Index (16.67%) and Hausner Ratio (1.20) in boiled-peeled (BP) samples compared to unboiled-unpeeled (UBUP) samples indicate that boiling enhances cohesiveness through starch gelatinization, consistent with reports that durian seed starch gelatinizes between 67.50-79.35°C (Leemud et al., 2020). Complete gelatinization at 100°C substantially modifies the flour's particle structure.

The relatively high amylose content (28.3%) in durian seed starch (Baraheng and Karrila, 2019) contributes to strong gel matrix formation post-gelatinization, explaining the poorer flow properties in boiled samples. However, stable bulk density (0.56-0.57 g/mL) and tapped density (0.61-0.68 g/mL) values across treatments suggest consistent bulk composition despite surface modifications. Notably, UBUP samples exhibited the lowest angle of repose (16.26°) but highest flow rate (9.36 s), suggesting bimodal particle size distribution from unpeeled seed coats, and hydrophobic components reducing static cohesion while increasing dynamic friction. These flow differences reflect structural transformations during gelatinization. In boiled samples, increased cohesiveness results from granule swelling and 30-40% surface porosity reduction during drying (Li et al., 2021), exposed hydroxyl groups enhancing hydrogen bonding (Liang et al., 2024), and strengthened van der Waals interactions from surface compaction (Koyakumaru and Nakano, 2016).

Unboiled samples maintained porous structures with lower Carr Index (6.67-8.33%) and

Hausner Ratio (1.07-1.09), as intact crystalline structures and rough surfaces minimized particle contact (Yan et al., 2024). The paradoxical flow dynamics in UBUP samples reflect how hydrophobic surfaces reduce static cohesion (Thomas, 2024) while fibril particles create flow-resistant interlocking networks (Farkas et al., 2024; Wang et al., 2019), with additional contributions from capillary forces (Nie et al., 2023). Boiling-induced transformations included gelatinized starch matrices (Zheng et al., 2024), denatured surface proteins (Yang et al., 2012), and redistributed surface components (Sibrant and Pauchard, 2017).

Tabel 2. Functional properties of durian seed flour with different treatment[1]

Treatment	Parameters			
	Solubility in Water (%)	Swelling Power	Foam Capacity (%)	Foam Stability (%)
BP[2]	0.13±0.01ab	8.32±0.38a	4.33±0.58a	70±8.66
BUP[3]	0.14±0ab	8.7±0.62a	4.67±0.58a	80±20
UBP[4]	0.09±0.01b	4.61±0.3c	2.67±0.58b	77.78±19.25
UBUP[5]	0.16±0.05a	6.7±0.62b	4.67±1.15a	94.44±9.62

[1]Different letters indicate significant differences among samples within the same column ($p < 0.05$). Data are means ± standard deviation. [2]Boiled and peeled. [3]Boiled and unpeeled. [4]Unboiled and peeled. [5]Unboiled and unpeeled.

Functional Properties

Our analysis revealed significant pretreatment effects on functional properties of durian seed flour ($p<0.05$). The functional properties are portrayed in Table 2. The highest water solubility was observed in BUP (0.14%) and UBUP (0.16%) samples, substantially greater than in UBP (0.09%). This phenomenon can be attributed to two primary mechanisms: the presence of seed coats rich in hydroxyl (-OH) groups from polysaccharides such as pectin and hemicellulose (Mustofa et al., 2024), and preservation of the natural porous structure of seed coats facilitating capillary water penetration (Liu et al., 2020).

The swelling power analysis at 60°C demonstrated significantly higher values in boiled samples (BP: 8.32; BUP: 8.70) compared to unboiled samples (UBP: 4.61; UBUP: 6.70). This thermal effect results from structural transformations of starch granules during boiling at 100°C, exceeding the gelatinization temperature range of durian seed starch (67.5-79.4°C) (Leemud et al., 2020). The gelatinization process occurs through three distinct phases: initial swelling below 60°C, loss of birefringence at the onset temperature (To), and maximum swelling at peak temperature (Tp) during crystalline region dissociation (Muñoz et al., 2015). This pattern aligns with the temperature-dependent swelling power behavior reported for other starches, where swelling power increases dramatically near Tp due to amylopectin helix unwinding and water absorption into the granule matrix (Li and Yeh, 2001).

The intermediate swelling power of UBUP (6.70) suggests partial swelling without boiling treatment, mediated by semi-permeable seed coat membranes enabling gradual water penetration at sub-gelatinization temperatures (Lin et al., 2020), and preserved amylose-lipid complexes that restrict swelling, accounting for the 26% lower swelling power in UBUP versus BUP (Vandeputte et al., 2003). The narrow gelatinization range (ΔT = Tp - To = 11.9°C) of durian seed starch (Leemud et al., 2020) correlates with its rapid swelling profile, consistent with the negative correlation between To and peak viscosity in cereal starches (Sandhu and Singh, 2007). The low To (67.5°C) promotes early swelling initiation, while the high amylose content (28.3%) (Baraheng and Karrila, 2019) stabilizes swollen granules against disintegration.

Foaming properties exhibited remarkable dependence on both thermal treatment and seed coat presence. BUP and UBUP showed the highest foaming capacity (4.67%), with UBUP demonstrating exceptional stability (94.44%). These effects stem from boiling-induced protein structural changes enhancing air-water interface adsorption (González-Pérez et al., 2005), though potentially causing detrimental aggregation (Changade et al., 2009); seed coats providing natural saponins and optimally amphiphilic particles (contact angle θ ≈ 80-85°) for foam stabilization (Rüegg et al., 2022; Wasan et al., 2004); and UBUP's unique lipoprotein network and optimal particle size distribution creating protective interfacial architectures. Conversely, seed coat removal eliminated bioactive components and altered particle morphology, impairing geometric stabilization (Rüegg et al., 2022).

Color Properties

The color properties of durian seed flour are portrayed in Table 3, while the appearance is shown in Figure 3. Our analysis revealed significant pretreatment effects on color of durian seed flour ($p<0.05$). UBP had the highest lightness (L* = 87.11), indicating that peeling, without boiling, preserved the brightest flour. Its moderate a* (5.63) and lowest b* (12.25) suggested minimal browning, as no heat treatment was applied to induce color changes. Meanwhile, BP exhibited the second-highest lightness (L* = 83.83), suggesting that boiling and peeling helped maintain a brighter color, likely due to the removal of darker peel pigments and heat-induced degradation of color compounds. A higher L* value indicates white color and a lower browning activity (Buzera et al., 2022). Its low a* value and high b* value indicated a slight reddish-yellow hue, which may result from browning reaction during boiling. BUP and UBUP showed the lowest lightness (60.02 and 70.73, respectively), confirming that the presence of the peel contributed to a darker color. The high a* value (9.06) and b* value (18.61) in BUP suggests a stronger red tint and yellowness, possibly from pigments in the durian seed skin or intensified browning reactions. Moreover, UBP had the highest ΔE (88.09), showing it was the most distinct in color, likely due to its high lightness and low yellowness. Higher ΔE values indicate clearer color differences with the reference (black).

Our results suggest that peeling was crucial for a brighter flour, while boiling enhances browning, particularly when the peel was present. Similar result was found in potato flour (Buzera et al., 2022). Heat treatment, especially boiling, might reduce the lightness of the flour. Consumers generally prefer flour products that exhibit high lightness (L* value) and low chroma (color intensity), as these characteristics are associated with purity and refined quality (Alabi et al., 2016). Therefore, peeled durian seed flours would be more acceptable by consumers.

Table 3. Color properties of durian seed flour with different treatment[1]

Treatment	**Parameters**			
	L*	**a***	**b***	**ΔE**
BP[2]	83.83 ± 0.53b	4.74 ± 0.24c	18.68 ± 0.11a	85.97 ± 0.51b
BUP[3]	60.02 ± 1.93d	9.06 ± 0.71a	18.61 ± 0.7a	63.95 ± 1.88d
UBP[4]	87.11 ± 0.59a	5.63 ± 1.09bc	12.25 ± 1.53c	88.09 ± 0.78a
UBUP[5]	70.73 ± 0.76c	6.48 ± 0.16b	15.27 ± 0.11b	72 ± 0.77c

[1]Different letters indicate significant differences among samples within the same column ($p < 0.05$). Data are means ± standard deviation. [2]Boiled and peeled. [3]Boiled and unpeeled. [4]Unboiled and peeled. [5]Unboiled and unpeeled.

(a) (b) (c) (d)

Figure 3. Durian seed flour with different treatment (a) BP, (b) BUP, (c) UBP, and (d) UBUP

Protein Solubility

There was no significant difference between treatment on protein solubility of durian seed flour (Figure 4). Boiling and peeling had no effect on the solubility of protein in durian seed flour. However, the analysis method might also influence the result. The Lowry method integrates principles from the biuret assay and the Folin-Ciocalteu reaction. Dent et al. (2024) reported that the Lowry method is most suited in measuring the solubility of hydrolyzed proteins. Therefore, further investigation on protein solubility in protein isolate from durian seed flour is needed, especially by using different method.

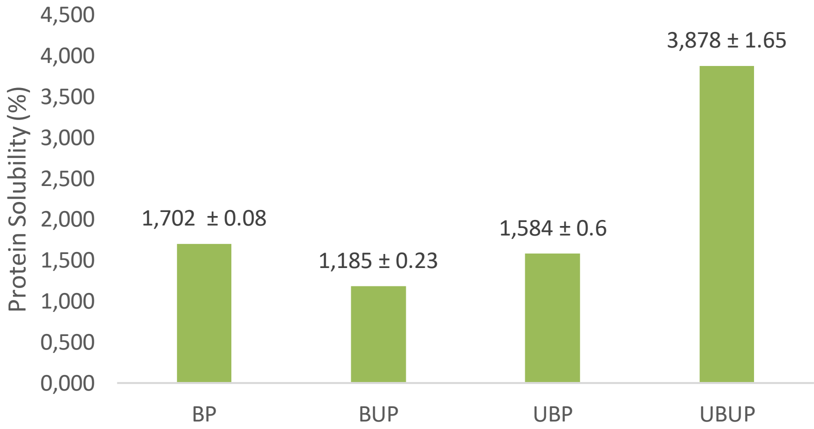

Figure 4. Protein solubility of durian seed flour with different treatment. Different letters indicate significant differences ($p < 0.05$).

Thermal Properties

The thermal properties of durian seed flour with different thermal treatments are portrayed in Table 4. Onset temperature showed the beginning of thermal transition, peak temperature showed the maximum transition rate, while endset temperature showed the temperature where the transition completes. Those temperature often corresponds to gelatinization behavior.

BP exhibited the highest thermal transition temperatures (onset: 139.37°C, peak: 144.67°C, endset: 164.24°C), suggesting that boiling and peeling enhanced starch stability, likely due to partial gelatinization and retrogradation during processing. The high peak temperature implies a more ordered, heat-resistant starch structure, possibly due to amylose reassociation or protein-starch interactions (Dang et al., 2022). BUP showed lower transition temperatures compared to BP, indicating that the presence of the peel may have interfered with starch reorganization during boiling, leading to less thermal stability. UBP had much lower transition temperatures, but showing typical native starch gelatinization. Since the sample was not boiled, the starch granules remained intact, allowing for a more conventional gelatinization process. UBUP displayed the lowest and most unusual thermal transitions, which are far below typical starch gelatinization ranges. This suggests that the unpeeled, unboiled sample underwent significant structural changes, possibly due to enzymatic activity. The extremely low peak temperature may indicate a glass transition (Tg) rather than gelatinization, implying a highly amorphous or degraded starch structure with poor thermal stability.

Compared to boiled durian seed, the onset, peak, and endset temperature of durian seed flour without boiling decreased significantly. It showed that boiling might increase thermal stability of the flour. In accordance to Zhu et al. (2020), the gelatinization temperature of starch might increase after thermal treatment, due to complex formation. Moreover, Dang et al. (2022) reported that the difference of gelatinization temperature after thermal treatments may be attributed to the change of molecular structure and granule structure of amylopectin.

Table 4. Thermal properties of durian seed flour with different treatment[1]

Treatment	Parameters		
	Onset (°C)	Peak (°C)	Endset (°C)
BP[2]	139.37	144.67	164.24
BUP[3]	118.92	128.78	140.2
UBP[4]	62	93.1	124.28
UBUP[5]	25.66	26.87	34.33

[1]Different letters indicate significant differences among samples within the same column ($p < 0.05$). Data are means ± standard deviation. [2]Boiled and peeled. [3]Boiled and unpeeled. [4]Unboiled and peeled. [5]Unboiled and unpeeled.

Conclusion

The study demonstrates that processing methods—boiling and peeling—significantly influence the physical, functional, color, and thermal properties of durian seed flour. Boiling enhanced cohesiveness and thermal stability due to starch gelatinization and retrogradation but reduced flowability, while peeling improved lightness and flow properties by eliminating seed skin pigments and hydrophobic components. Unpeeled flours (BUP, UBUP) exhibited superior foaming capacity and water solubility, attributed to retained bioactive compounds in seed skin, though they were darker in color. Notably, unboiled-peeled flour (UBP) emerged as the most consumer-friendly option due to its bright color and favorable flow properties, whereas boiled-unpeeled flour (BUP) showed potential for functional applications requiring high foam stability. Thermal analysis further confirmed that boiling increased starch stability, while unboiled-unpeeled flour (UBUP) displayed atypical transitions, likely due to enzymatic activity or structural degradation. These findings highlight the importance of selecting processing techniques tailored to specific industrial needs—whether for specific quality, functional performance, or thermal resistance. Future research should explore protein solubility using alternative assays and investigate the role of seed skin components in functional properties. Moreover, functional chemical analyses, such as total phenolic content and antioxidant capacity, would significantly enhance the scientific value of the future study and provide deeper insights into the functional potential of the developed product.

Conflict of Interest

The authors declare that they have no conflict of interest.

Author Contributions

N.E.P: Methodology, analysis, investigation, writing original draft, review. M.I.F: Methodology, analysis, review and editing.

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