Influence of Rice Processing Methods on Physicochemical Traits and Their Suitability for Bioplastic Fabrication

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Abstract

Traditional rice processing techniques retain several advantageous attributes that are often diminished during modern milling operations, potentially offering enhanced suitability for bioplastic production. The present investigation evaluates and compares the physicochemical properties of Traditional Hand-Pounded Rice (THR) and Conventionally Milled Rice (CMR) to determine their effectiveness as raw materials for bioplastic fabrication.

The Poongar rice variety was subjected to two processing approaches: traditional hand-pounding and conventional mechanical milling. A detailed characterization was carried out encompassing physical parameters (grain dimensions, density, frictional behavior, and cooking qualities), chemical composition (amylose, amylopectin, and moisture levels), functional properties (water absorption capacity, solubility index, hydration capacity, and swelling power), and micronutrient concentrations (iron, zinc, calcium, and phosphorus).

Results revealed that THR exhibited significantly enhanced characteristics, including higher amylose content (28.64 ± 0.92% compared to 24.35 ± 0.84%), improved water absorption capacity (2.48 ± 0.11 g/g versus 2.18 ± 0.09 g/g), increased swelling power (9.32 ± 0.42 g/g versus 8.24 ± 0.35 g/g), and markedly greater micronutrient retention. Additionally, THR demonstrated superior grain integrity, reflected by a lower percentage of broken grains (3.82 ± 0.42% compared to 8.67 ± 0.95%) and higher porosity (60.54 ± 1.85% versus 54.93 ± 1.62%).

Overall, traditional hand-pounding effectively preserves key structural and compositional attributes of rice that are advantageous for bioplastic synthesis, particularly elevated amylose levels and improved functional properties that support efficient film formation.

Keywords Amylose Content, Bioplastic Precursors, Hand-Pounding, Sustainable Materials, Traditional Rice Processing.

1. Introduction

Escalating environmental challenges associated with petroleum-based plastics have accelerated the search for sustainable and biodegradable alternatives, particularly bioplastics derived from renewable agricultural resources [1,2]. Among cereal crops, rice stands out as a

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highly promising candidate due to its widespread cultivation, global availability, and substantial starch content, which makes it suitable for polymer development [3,4].

Rice processing methods vary considerably, with traditional hand pounding representing an age-old technique that contrasts markedly with contemporary mechanical milling practices [5,6]. Modern milling systems are primarily designed to maximize bran removal and achieve grain uniformity, whereas traditional hand pounding involves minimal mechanical processing. This gentler approach may help retain valuable structural components and intrinsic biochemical properties that could positively influence bioplastic performance [7,8].

Starch, the principal constituent of rice, is composed of amylose and amylopectin in proportions that critically determine film-forming behavior [9,10]. The linear configuration of amylose promotes intermolecular hydrogen bonding, thereby enhancing film strength and structural integrity. Additionally, functional attributes such as water absorption capacity and swelling power play a vital role in starch gelatinization and the efficiency of film formation processes [11].

Existing research has predominantly emphasized conventionally milled rice as a raw material for bioplastic production, while traditional processing techniques remain comparatively underexplored [12,13]. This limited attention restricts understanding of how traditional methods may preserve native starch architecture and associated beneficial components that could improve bioplastic functionality.

Therefore, the present study aimed to undertake a comprehensive comparative evaluation of the physicochemical properties of Traditional Handpounded Rice (THR) and Conventionally Milled Rice (CMR) in order to assess their relative potential for sustainable bioplastic development.

2. Materials and Methods

2.1 Sample Collection and Preparation

Traditional Handpounded Rice (Poongar variety) was sourced from Mr. M.G.S. Sankar, an organic farmer located in Poolipatta, Sathankulam, Tirunelveli, Tamil Nadu. The crop was cultivated under certified organic farming practices and processed using the traditional hand-pounding method, which involves minimal mechanical action and facilitates retention of the bran layer along with associated micronutrients [5,6].

For comparison, Conventionally Milled Rice of the same Poongar variety was procured from a local retail market in Tirunelveli district. This sample had undergone standard mechanical milling procedures, including dehusking, polishing, and whitening processes typical of commercial rice processing systems [7,8].

Both rice samples were carefully cleaned to eliminate extraneous matter, broken grains, and other impurities through manual sorting, followed by sieving using a 2 mm mesh screen. The purified samples were then stored in airtight high-density polyethylene (HDPE) containers under controlled ambient conditions (25 ± 2°C; relative humidity 65 ± 5%) until subsequent physicochemical analysis.

2.2 Physical Properties Analysis

2.2.1 Grain Dimensions (Length, Width, and Thickness)

The dimensional characteristics of rice grains were determined using a digital caliper (Mitutoyo, Japan) with a precision of 0.01 mm, following the methodology outlined by Mohsenin [14] and subsequently refined by Li [15]. For each sample, twenty grains were randomly selected, and three independent measurements were recorded for each dimensional parameter per grain to ensure accuracy and minimize experimental error.

Grain length was measured along the principal longitudinal axis from the base to the apex. Width was recorded as the maximum lateral breadth perpendicular to the length axis, while thickness was measured as the maximum depth perpendicular to both the length and width axes [15,16].

Broken Ratio

The broken ratio was evaluated by manually examining a 100 g representative sample of each rice type under standardized illumination conditions (500 lux). Grains measuring less than 75% of the original intact grain length were categorized as broken, in accordance with the criteria established by the Food and Agriculture Organization [17]. The percentage of broken grains was calculated using Equation (1), as described by Li [15] and Yadav and Jindal [18].

$$Broken\ ratio\ (\%) = (Weight\ of\ broken\ grains / Total\ weight\ of\ sample) \times 100$$ Eqn (1)

Sphericity: The sphericity of the grains was computed using the three principal dimensions according to Equation (2), originally proposed by Mohsenin [14] and later validated by Kumar [19] and Sakai [20].

$$Sphericity = (Length \times Width \times Thickness)^{1/3}\ /\ Length$$ Eqn (2)

Size: The geometric mean diameter was determined according to Equation (3), originally proposed by Kumar [19] and later validated by Dalen [21].

$$Size\ (mm) = (Length \times Width \times Thickness)^{1/3}$$ Eqn (3)

Volume: Grain volume was estimated based on an assumed ellipsoidal shape according to Equation (4) [14,20].

$$Volume (mm^3) = (\pi\ /\ 6) \times Length \times Width \times Thickness$$ Eqn (4)

Surface Area: The surface area was determined according to Equation (5), based on the method reported by Mohsenin [14] and Sakai [20].

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$$Surface\ area\ (mm^2) = \pi \times (geometric\ mean\ diameter)^2 \qquad \text{Eqn (5)}$$

2.2.2 Density Characteristics

Density: Rice flour density was measured using a specific gravity bottle technique following the procedure outlined by Mohsenin [14] with modifications reported by Zareiforoush [23].

Bulk Density: The bulk density was measured according to the mass–volume relationship method proposed by Mohapatra and Bal [24] and subsequently refined by Zareiforoush [23], as presented in Figure 1.

Description: (a) Measuring the solid density in milled rice (b) Measuring the solid density in hand pounded rice

Figure 1. Determination of bulk density

Tapped Density: Tapped density was determined following the method described by Bhattacharya [25] and subsequently modified by Zareiforoush [23].

True Density: True density was measured using the liquid displacement method with toluene as the displacement medium, according to the procedure described by Subramanian and Viswanathan [26] and later validated by Qiu [27].

Porosity: Porosity was calculated using Equation (6), based on the relationship between bulk density and true density, as described by Mohsenin [14] and validated by Sakai [20].

$$Porosity(\%) = [1 - (bulk\ density/true\ density)] \times 100 \qquad \text{Eqn (6)}$$

2.2.3 Frictional Properties

Coefficient of Friction: The coefficient of friction was determined using an inclined plane apparatus following the method described by Adebowale [27] and subsequently refined by Bhat and Riar [28]. Measurements were conducted on three contact surfaces: galvanized steel, plywood, and glass.

Angle of Repose: The angle of repose was measured using the static heap method as described by Ghadge and Prasad [29] and later validated by Bhat and Riar [28].

2.2.4 Cooking Properties

Optimum Cooking Time: Optimum cooking time was determined following the method described by Vidal [30] and subsequently refined by Srikaeo [31].

Water Uptake Ratio: The water uptake ratio was measured according to the procedure described by Bhattacharya and Sowbhagya [32] and later validated by Srikaeo [31].

Thousand Kernel Weight: Thousand-kernel weight (TKW) was determined by counting 1000 intact grains using a seed counter (Numigral II, Chopin Technologies, France) and weighing them with an analytical balance (Shimadzu AUX220, Japan).

2.3 Chemical Characteristics

2.3.1 Amylose Content

Amylose content was determined using the iodine colorimetric method following the procedure described by Juliano [33] and subsequently modified by Juliano and Perdon [9]. A standard calibration curve was constructed using potato amylose (Sigma-Aldrich, USA) as the reference standard, with concentrations ranging from 0 to 100 mg/100 mL.

2.3.2 Amylopectin Content

Amylopectin content was calculated using Equation (7) by subtracting the measured amylose content from the total starch content, according to the method described by Juliano and Perdon [9].

$$Amylopectin(\%) = 100 - amylose\ content(\%) \qquad \text{Eqn (7)}$$

2.3.3 Moisture Content

Moisture content was measured following the oven-drying procedure specified in AOAC Official Method 925.10 [34].

2.4 Functional Characteristics

2.4.1 Water Absorption Capacity

Water absorption capacity (WAC) was determined following the method described by Beuchat [40] and subsequently modified by Oladunmoye [36].

2.4.2 Water Solubility Index

Water solubility index (WSI) was measured according to the procedure described by Anderson [42] and later refined by Oladunmoye [36], as illustrated in Figure 2. The water solubility test was performed for both conventionally milled rice and traditional hand-pounded rice samples.

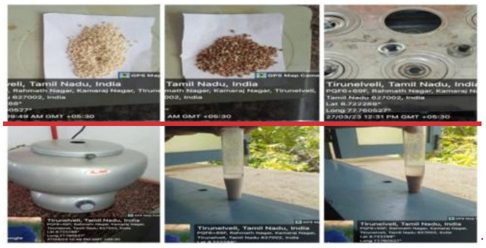

Figure 2. Determination of water solubility of rice

2.4.3 Hydration Capacity

Hydration capacity was determined using the method described by Deshpande [43] and subsequently validated by Sowbhagya [39].

2.4.4 Swelling Power

Swelling power was measured following the procedure described by Leach [45] and later modified by Oladunmoye [36] and Sowbhagya [39].

2.5 Micronutrient Analysis

2.5.1 Sample Preparation

Rice samples were prepared for micronutrient analysis according to the method described by Jiang [41] and subsequently refined by Ebuehi and Oyewole [42].

2.5.2 Iron Content

Iron content was determined using the 1,10-phenanthroline colorimetric method in accordance with AOAC Official Method 944.02 [34] and validated by Jiang [41].

2.5.3 Zinc Content

Zinc content was measured using atomic absorption spectrophotometry following AOAC Official Method 985.35 (AOAC, 2000) and validated by Ebuehi and Oyewole [42].

2.5.4 Calcium Content

Calcium content was determined using atomic absorption spectrophotometry as specified in AOAC Official Method 985.35 (AOAC, 2000) and validated by Ebuehi and Oyewole [42].

2.5.5 Phosphorus Content

Phosphorus content was determined using the molybdovanadate colorimetric method according to AOAC Official Method 965.17 [34] and validated by Jiang [41].

2.6 Statistical Analysis

All experiments were performed in triplicate, and the results are presented as mean ± standard deviation. Statistical comparisons between Traditional Handpounded Rice (THR) and Conventionally Milled Rice (CMR) were conducted using independent sample *t*-tests. A significance level of $p < 0.05$ was considered statistically significant for all analyses. Statistical computations were carried out using SPSS software (Version 25.0; IBM Corp., Armonk, NY, USA).

3. Results and Discussion

3.1 Physical Properties

3.1.1 Dimensional Characteristics

Traditional Handpounded Rice (THR) exhibited significantly greater grain dimensions compared to Conventionally Milled Rice (CMR) (Table 1). Grain length (7.21 ± 0.18 mm vs. 6.84 ± 0.15 mm), width (2.18 ± 0.09 mm vs. 2.02 ± 0.08 mm), and thickness (1.75 ± 0.07 mm vs. 1.62 ± 0.06 mm) were all significantly higher in THR ($p < 0.05$).

The observed differences are likely attributable to the retention of the bran layer and outer structural components in THR, resulting from minimal mechanical processing. In contrast, conventional milling removes substantial portions of the bran and surface layers, leading to reduced grain dimensions, as previously reported by Roy [8].

Table 1. Dimensional characteristics of traditional handpound rice (thr) and conventionally milled rice (cmr)

Parameter	THR	CMR	t-value	p-value
Length (mm)	7.21 ± 0.18	6.84 ± 0.15	3.87	0.002*
Width (mm)	2.18 ± 0.09	2.02 ± 0.08	3.12	0.007*
Thickness (mm)	1.75 ± 0.07	1.62 ± 0.06	3.25	0.005*
Broken Ratio (%)	3.82 ± 0.42	8.67 ± 0.95	-8.73	<0.001*
Sphericity	0.47 ± 0.02	0.46 ± 0.02	0.89	0.384
Size (mm)	3.17 ± 0.08	2.95 ± 0.07	4.94	<0.001*
Diameter (mm)	3.52 ± 0.10	3.28 ± 0.09	4.17	0.001*
Volume (mm^3)	14.53 ± 1.12	11.86 ± 0.94	4.31	<0.001*

Surface Area (mm^2)	31.58 ± 1.58	27.37 ± 1.30	5.02	<0.001*
Aspect Ratio	0.30 ± 0.01	0.30 ± 0.01	0.3	0.768

*Significant at p<0.05 level

The broken grain percentage was significantly lower in THR (3.82 ± 0.42%) compared to CMR (8.67 ± 0.95%), indicating superior grain integrity in traditionally processed rice ($p < 0.001$). This marked difference may be attributed to the gentler nature of the hand-pounding process, which applies reduced mechanical stress relative to conventional milling systems that rely on abrasive forces for bran removal [8]. Similar observations were reported by Li [15], who noted that processing methods significantly influenced dimensional attributes while exerting minimal impact on grain shape descriptors.

3.1.2 Density Characteristics

The density-related properties of THR and CMR are summarized in Table 2. THR demonstrated a significantly higher true density (1.47 ± 0.04 g/cm³) compared to CMR (1.42 ± 0.03 g/cm³), which may be associated with the retention of the bran layer containing relatively dense lipid and protein constituents.

In contrast, THR exhibited a lower bulk density (0.58 ± 0.02 g/cm³) than CMR (0.64 ± 0.03 g/cm³). The combined effect of higher true density and lower bulk density resulted in significantly greater porosity in THR (60.54 ± 1.85%) compared to CMR (54.93 ± 1.62%). This increased porosity may influence hydration behavior and film-forming characteristics during bioplastic production.

Table 2. Density characteristics of traditional handpound rice (thr) and conventionally milled rice (cmr)

Parameter	THR	CMR	t-value	p-value
Density (g/cm³)	1.37 ± 0.03	1.33 ± 0.03	2.35	0.031*
Bulk Density (g/cm³)	0.58 ± 0.02	0.64 ± 0.03	-3.87	0.002*
Tapped Density (g/cm³)	0.65 ± 0.02	0.69 ± 0.02	-3.32	0.004*
Solid Density (g/cm³)	1.42 ± 0.03	1.38 ± 0.03	2.24	0.037*

True Density (g/cm³)	1.47 ± 0.04	1.42 ± 0.03	2.28	0.034*
Porosity (%)	60.54 ± 1.85	54.93 ± 1.62	5.42	<0.001*

*Significant at p<0.05 level

These differences in density characteristics have important implications for starch extraction and subsequent film formation. The higher porosity observed in THR may promote enhanced water penetration during cooking and gelatinization, thereby improving starch release and increasing the uniformity of the resulting film-forming solution [15]. Comparable findings were reported by Mohapatra and Bal [24], who demonstrated that increased porosity in rice grains contributes to improved hydration kinetics and cooking performance.

3.1.3 Cooking Properties

The cooking properties of THR and CMR are summarized in Table 3. THR exhibited a significantly longer optimum cooking time (20.42 ± 0.82 min) compared to CMR (16.75 ± 0.65 min). This prolonged cooking duration is likely associated with the retention of the bran layer in THR, which acts as a semi-permeable, hydrophobic barrier that slows water diffusion into the starch matrix [31].

Table 3. Cooking properties of traditional handpound rice (thr) and conventionally milled rice (cmr)

Parameter	**THR**	**CMR**	**t-value**	**p-value**
Optimum Cooking Time (min)	20.42 ± 0.82	16.75 ± 0.65	7.89	<0.001*
Water Uptake Ratio	2.85 ± 0.12	3.22 ± 0.15	-4.46	<0.001*
Thousand Kernel Weight (g)	26.38 ± 0.73	23.45 ± 0.65	6.69	<0.001*

*Significant at p<0.05 level

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The water uptake ratio was significantly lower in THR (2.85 ± 0.12) compared to CMR (3.22 ± 0.15). This reduction may be attributed to the hydrophobic characteristics of the retained bran layer in THR, which contains lipids that impede water absorption. Additionally, the higher amylose content in THR may promote the formation of more compact and organized starch granule structures, thereby restricting water penetration [32].

3.2 Chemical Characteristics

The chemical composition of THR and CMR is presented in Table 4. THR demonstrated a significantly higher amylose content (28.64 ± 0.92%) than CMR (24.35 ± 0.84%). Correspondingly, amylopectin content was lower in THR (71.36 ± 0.92%) compared to CMR (75.65 ± 0.84%), resulting in a greater amylose-to-amylopectin ratio for THR (0.40 ± 0.02) relative to CMR (0.32 ± 0.01).

Table 4. Chemical characteristics of traditional handpound rice (thr) and conventionally milled rice (cmr)

Parameter	THR	CMR	t-value	p-value
Amylose Content (%)	28.64 ± 0.92	24.35 ± 0.84	7.92	<0.001*
Amylopectin Content (%)	71.36 ± 0.92	75.65 ± 0.84	-7.92	<0.001*
Amylose: Amylopectin Ratio	0.40 ± 0.02	0.32 ± 0.01	7.4	<0.001*
Moisture Content (%)	11.82 ± 0.45	12.67 ± 0.52	-2.94	0.009*

*Significant at p<0.05 level

The elevated amylose content observed in THR may be attributed to the retention of the aleurone layer, which contains small starch granules enriched in amylose that are often removed during conventional milling. Furthermore, the minimal mechanical and thermal stress associated with traditional hand pounding likely reduces structural degradation of amylose, thereby preserving its native integrity [9]. Comparable observations were reported by Wang [3], who demonstrated that traditional processing methods better maintained the native starch architecture compared to modern mechanical milling techniques.

The higher amylose concentration in THR is particularly beneficial for bioplastic film development. Due to its predominantly linear molecular structure, amylose facilitates stronger intermolecular hydrogen bonding and chain entanglement, resulting in improved film cohesion, mechanical strength, and structural stability [10,11].

3.3 Functional Characteristics

The functional properties of THR and CMR are summarized in Table 5. THR demonstrated a significantly higher water absorption capacity (WAC) (2.48 ± 0.11 g/g) compared to CMR (2.18 ± 0.09 g/g). This enhanced WAC may be attributed to the retention of hydrophilic constituents within the bran layer, including proteins and dietary fibers, which possess substantial water-binding capacity [36].

The presence of these components likely increases the availability of polar sites for water interaction, thereby improving hydration behavior and potentially facilitating better dispersion and gelatinization during film-forming processes.

Table 5. Functional characteristics of traditional handpound rice (thr) and conventionally milled rice (cmr)

Parameter	THR	CMR	t-value	p-value
Water Absorption Capacity (g/g)	2.48 ± 0.11	2.18 ± 0.09	4.95	<0.001*
Water Solubility Index (%)	8.74 ± 0.38	11.32 ± 0.46	-9.78	<0.001*
Hydration Capacity (g/g)	1.65 ± 0.07	1.42 ± 0.06	5.69	<0.001*
Swelling Power (g/g)	9.32 ± 0.42	8.24 ± 0.35	4.67	<0.001*

*Significant at $p<0.05$ level

THR exhibited a significantly lower water solubility index (WSI) (8.74 ± 0.38%) compared to CMR (11.32 ± 0.46%). The reduced WSI in THR may be associated with its higher amylose content, which promotes the formation of more ordered and compact crystalline regions that are less prone to solubilization and leaching during thermal processing [39].

Hydration capacity and swelling power were significantly greater in THR (1.65 ± 0.07 g/g and 9.32 ± 0.42 g/g, respectively) than in CMR (1.42 ± 0.06 g/g and 8.24 ± 0.35 g/g, respectively). These findings are consistent with the observations of Leach [40] and Sowbhagya [39], who reported that native, minimally processed starch exhibits enhanced swelling behavior due to the preservation of its intact granular architecture.

3.4 Micronutrient Analysis

The micronutrient composition of THR and CMR is presented in Table 6. THR contained significantly higher concentrations of all analyzed micronutrients (iron, zinc, calcium, and phosphorus) compared to CMR, with the most pronounced differences observed for iron and zinc.

Table 6. Micronutrient content of traditional handpound rice (thr) and conventionally milled rice (cmr)

Micronutrient (mg/kg)	THR	CMR	t-value	p-value
Iron	28.42 ± 1.35	8.76 ± 0.48	28.13	<0.001*
Zinc	22.86 ± 0.98	10.42 ± 0.52	23.95	<0.001*
Calcium	142.68 ± 6.75	78.34 ± 3.85	17.14	<0.001*
Phosphorus	2854.32 ± 98.65	1245.67 ± 56.78	30.76	<0.001*

*Significant at p<0.05 level

The pronounced differences in micronutrient content can be attributed to the retention of the bran layer in THR, which is a major reservoir of essential minerals. Conventional milling typically removes approximately 80–90% of the bran fraction, leading to significant nutrient depletion [7,42]. These observations are consistent with the findings of Jiang [41], who reported that traditional processing methods preserve substantially higher micronutrient levels compared to modern mechanical milling systems.

4. Conclusion

This comprehensive comparative investigation demonstrates that Traditional Handpounded Rice (THR) exhibits superior physicochemical and functional characteristics for bioplastic applications when compared to Conventionally Milled Rice (CMR). The advantages of THR can be summarized as follows:

1. **Enhanced film-forming potential:** The significantly higher amylose content (28.64% vs. 24.35%) and improved amylose-to-amylopectin ratio enhance intermolecular hydrogen bonding and structural cohesion, contributing to stronger and more stable film matrices.

2. **Improved processing functionality:** Greater water absorption capacity, increased swelling power, and superior hydration behavior promote efficient gelatinization and improved homogeneity of film-forming solutions.

3. **Superior structural characteristics:** Lower broken grain percentage and higher porosity reflect improved grain integrity and favorable processing attributes that may enhance starch extraction efficiency.

4. **Added nutritional value:** Significantly higher levels of iron, zinc, calcium, and phosphorus provide additional functional benefits, particularly for the development of edible or nutritionally enriched bioplastic films.

Overall, the retention of key structural, compositional, and functional attributes in THR—achieved through minimal mechanical intervention—presents a compelling rationale for integrating traditional rice processing methods into sustainable bioplastic development strategies.

This study not only reinforces the material advantages of traditionally processed rice but also bridges traditional agricultural practices with contemporary green material technologies. Future research should focus on translating these superior physicochemical properties into measurable improvements in bioplastic film performance, including mechanical strength, barrier properties, and biodegradability.

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