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COMPARATIVE PHYSICOCHEMICAL CHARACTERIZATION OF TRADITIONAL HAND POUND RICE AND CONVENTIONALLY MILLED RICE

S u m m a r y

Background. Traditional rice processing methods preserve beneficial properties that are lost during conventional milling, potentially making them superior sources for bioplastic development. This study compares the physicochemical characteristics of traditional hand pound rice (THR) and conventionally milled rice (CMR). Poongar variety rice was processed using traditional hand-pounding and conventional milling methods. A comprehensive analysis included physical properties (dimensional characteristics, density, frictional properties, cooking properties), chemical composition (amylose, amylopectin, moisture content), functional characteristics (water absorption capacity, solubility index, hydration capacity, swelling power) and micronutrient content (iron, zinc, calcium, phosphorus).

Results and conclusions. THR exhibited significantly superior properties, including higher amylose content (28.64 ± 0.92 % vs. 24.35 ± 0.84 %), enhanced water absorption capacity (2.48 ± 0.11 g/g vs. 2.18 ± 0.09 g/g), greater swelling power (9.32 ± 0.42 g/g vs. 8.24 ± 0.35 g/g) and substantially higher micronutrient levels. THR also demonstrated better grain integrity with lower broken ratio (3.82 ± 0.42 % vs. 8.67 ± 0.95 %) and higher porosity (60.54 ± 1.85 % vs. 54.93 ± 1.62 %). Traditional hand-pounding preserves beneficial rice properties, particularly higher amylose content and superior functional characteristics that facilitate film formation.

Keywords: amylose content, bioplastic precursors, hand-pounding, sustainable materials, traditional rice processing

Introduction

The growing environmental concerns associated with conventional plastics have intensified research into sustainable alternatives, particularly bioplastics derived from

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renewable agricultural resources [14, 32]. Rice, being one of the world's most abundant cereal crops, represents a promising source for bioplastic development due to its high starch content and global availability [24, 39].

Traditional rice processing methods, particularly hand pounding, have been practiced for centuries and differ significantly from modern mechanical milling in their approach and outcomes [10, 27]. While conventional milling focuses on maximum bran removal and uniformity, traditional hand pounding employs minimal mechanical intervention, potentially preserving beneficial components and structural features that could enhance bioplastic properties [30, 34].

Starch, the primary component of rice, consists of amylose and amylopectin in varying ratios that significantly influence film-forming properties [18, 29]. Amylose, with its linear structure, contributes to intermolecular hydrogen bonding and film strength, while functional properties such as water absorption capacity and swelling power affect gelatinization behavior and film formation efficiency [19].

Previous studies focused primarily on conventionally processed rice for bioplastic applications, with limited attention to traditional processing methods [21, 25]. This gap in knowledge overlooks the potential advantages of traditional processing in preserving native starch properties and beneficial components that could enhance bioplastic performance.

The objective of this study was to conduct a comprehensive comparative analysis of the physicochemical characteristics of traditional hand pound rice (THR) and conventionally milled rice (CMR) to evaluate their relative suitability for sustainable bioplastic applications.

Materials and methods

Sample collection and preparation

Traditional hand pound rice (Poongar variety) was procured from M.G.S. Sankar, an organic farmer in Poolipatta, Sathankulam, Tirunelveli, Tamil Nadu (India). The rice was cultivated using organic farming practices and processed through traditional hand pounding with minimal mechanical intervention, thereby preserving the bran layer and essential micronutrients [10, 27]. Conventionally Milled Rice of the same variety was obtained from a local market in Tirunelveli district, having undergone standard mechanical milling operations including dehusking, polishing and whitening [30, 34].

Both samples were meticulously cleaned to remove foreign materials, broken grains, and impurities by manual sorting followed by sieving through a 2 mm mesh. The cleaned samples were stored in airtight high-density polyethylene (HDPE) containers at ambient temperature (25 ± 2 °C) and relative humidity of 65 ± 5 % until further analysis.

Physical properties analysis

Length, width and thickness: the dimensions of rice grains were measured using a digital caliper (Mitutoyo, Japan) with an accuracy of 0.01 mm following the method described by Mohsenin [29] and refined by Li et al. [23]. Twenty grains were randomly selected from each rice sample, and three measurements were taken for each dimension per grain to minimize measurement errors.

Length was measured along the longest axis from the base to the apex, width was measured as the maximum breadth perpendicular to the length axis, and thickness was measured as the maximum depth perpendicular to both length and width [23, 26].

Broken ratio: the broken ratio was determined by manually inspecting a 100 g sample of each rice type under standard lighting conditions (500 lux). Grains with less than 75 % of the intact grain length were classified as broken, following the definition provided by the Food and Agriculture Organization [13]. The broken ratio was calculated using the equation 1 described by Li [23] and Yadav & Jindal [41]:

$$Broken\ ratio\ (\%) = (Weight\ of\ broken\ grains / Total\ weight\ of\ sample) \times 100 \qquad \text{Eq. 1}$$

Sphericity: sphericity was calculated based on the three principal dimensions using the equation 2 proposed by Mohsenin [29] and validated by Kumar [20] and Sakai [35]:

$$Sphericity = (Length \times Width \times Thickness)^{1/3} \ / \ Length \qquad \text{Eq. 2}$$

Size: the geometric mean diameter was calculated using the equation 3 proposed by Kumar [20] and validated by Dalen [9]:

$$Size\ (mm) = (Length \times Width \times Thickness)^{1/3} \qquad \text{Eq. 3}$$

Volume: the volume was calculated assuming an ellipsoidal shape using the Equation 4 [4, 35]:

$$Volume(mm^3) = (\pi \ / \ 6) \times Length \times Width \times Thickness \qquad \text{Eq. 4}$$

Surface area: surface area was estimated using the equation 5 [4, 35]:

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

Density characteristics

The density of rice flour was determined using a specific gravity bottle method, as described by Mohsenin [29] and modified by Zareiforoush [42]. Bulk density was determined using the mass-volume relationship method described by Mohapatra and Bal [28] and refined by Zareiforoush [42], which is shown in figure 1.

Figure 1. Determination of bulk density; (a) measuring the solid density in milled rice, (b) measuring the solid density in hand pounded rice

Tapped density was determined using the method described by Bhattacharya [8] and modified by Zareiforoush [42]. True density was determined using the liquid displacement method with toluene, as described by Subramanian and Viswanathan [38] and validated by Qiu et al. [33]. Porosity was calculated using the relationship between bulk density and true density, as described by Mohsenin [29] and validated by Sakai et al. [35]:

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

Frictional properties

The coefficient of friction was determined using an inclined plane apparatus, as described by Adebowale [1] and refined by Bhat and Riar [6]. Three different surfaces were used: galvanized steel, plywood and glass. The angle of repose was determined using the static heap method, as described by Ghadge and Prasad [15] and validated by Bhat and Riar [6].

Cooking properties

Optimum cooking time was determined using the method described by Vidal et al. [40] and refined by Srikaeo et al. [36]. Water uptake ratio was determined using the method described by Bhattacharya and Sowbhagya et al. [37] and validated by Srikaeo et al. [36]. Thousand kernel weight: thousand-kernel weight (TKW) was determined by counting 1,000 whole grains using a seed counter (Numigral II, Chopin Technologies, France) and weighing them on an analytical balance (Shimadzu AUX220, Japan).

Chemical characteristics

Amylose content was determined using the iodine colorimetric method, as described by Juliano [17] and modified by Juliano and Perdon [18]. A calibration curve was prepared using potato amylose (Sigma-Aldrich, USA) as a standard, with concentrations ranging from 0 to 100 mg/100 cm^3. Amylopectin content was calculated by subtracting the amylose content from the total starch content, as described by Juliano and Perdon [18]:

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

Moisture content was determined using the oven-drying method according to AOAC Official Method 925.10 [3].

Functional characteristics

Water absorption capacity (WAC) was determined using the method described by Beuchat [5] and modified by Oladunmoye et al. [31]. Water solubility index (WSI) was determined using the method described by Anderson et al [2] and refined by Oladunmoye et al. [31], which is shown in figure 2.

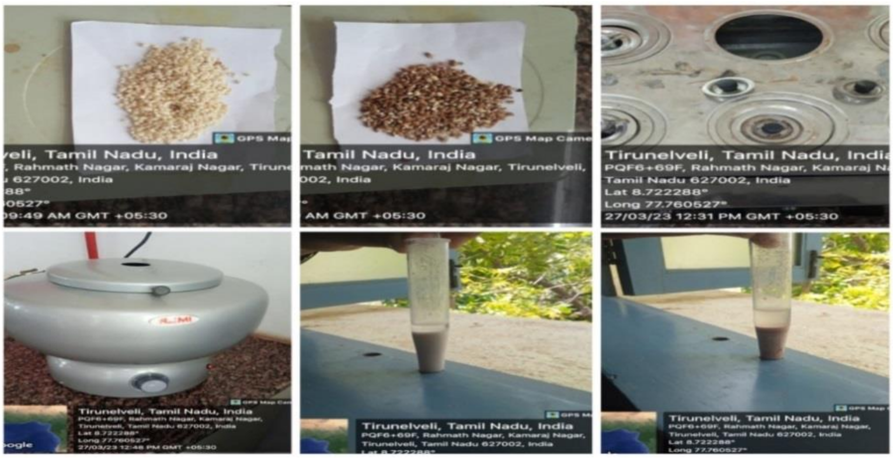

Figure 2. Determination of water solubility of rice

Hydration capacity was determined using the method described by Deshpande et al. [11] and validated by Sowbhagya et al. [37]. Swelling power was determined using the method described by Leach et al. [22] and modified by Oladunmoye et al. [31] and Sowbhagya et al. [39].

Micronutrient analysis

The rice samples were prepared for micronutrient analysis following the method described by Jiang et al. [16] and refined by Ebuehi and Oyewole [12]. Iron content was determined using the 1, 10-phenanthroline colorimetric method, as described by AOAC Official Method 944.02 [3] and validated by Jiang et al. [16]. Zinc content was determined using atomic absorption spectrophotometry, as described by AOAC Official Method 985.35 [3] and validated by Ebuehi and Oyewole [12]. Calcium content was determined using atomic absorption spectrophotometry, as described by AOAC Official Method 985.35 [3] and validated by Ebuehi and Oyewole [12]. Phosphorus content was determined using the molybdovanadate colorimetric method, as described by AOAC Official Method 965.17 [3] and validated by Jiang et al. [16].

Statistical analysis

All experiments were conducted in triplicate, and results were expressed as mean ± standard deviation. A statistical analysis was performed using independent t-tests to compare the properties of traditional hand pound rice and conventionally milled rice. A significance level of $p < 0.05$ was used for all statistical tests. Statistical analyses were conducted using SPSS software (version 25.0).

Results and discussion

Physical properties

THR exhibited significantly larger dimensions compared to CMR (Table 1). 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 ($p < 0.05$). These differences can be attributed to the preservation of the bran layer in THR due to minimal mechanical processing, as reported by Roy et al. [34].

The broken ratio was significantly lower in THR (3.82 ± 0.42 %) compared to CMR (8.67 ± 0.95 %). This substantial difference ($p < 0.001$) highlights the superior grain integrity of THR, which can be attributed to the traditional hand-pounding method that exerts less mechanical force on rice grains compared to conventional milling processes that employ abrasives [8]. Similar findings were reported by Li et al. [23], who observed that processing methods altered dimensional parameters, but had minimal effect on shape descriptors.

The density characteristics of THR and CMR are presented in Table 2. THR exhibited significantly higher true density (1.47 ± 0.04 g/cm³) compared to CMR (1.42 ± 0.03 g/cm³), which can be attributed to the presence of the bran layer that contains dense lipid and protein components. Conversely, the bulk density was lower for THR

(0.58 ± 0.02 g/cm³) than CMR (0.64 ± 0.03 g/cm³), resulting in significantly higher porosity in THR (60.54 ± 1.85 %) compared to CMR (54.93 ± 1.62 %).

Table 1. Dimensional characteristics of traditional hand pound 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 [mm³]	14.53 ± 1.12	11.86 ± 0.94	4.31	< 0.001*
Surface area [mm²]	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

Table 2. Density characteristics of traditional hand pound 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 density differences have important implications for starch extraction and subsequent film formation. The higher porosity of THR facilitates, the better water penetration during cooking and gelatinization, potentially enhancing the extraction efficiency of starch and improving the homogeneity of the resultant film-forming solution [23]. Similar results were reported by Mohapatra and Bal [28], who found that higher porosity in rice enhances hydration rates and cooking quality.

The cooking properties of THR and CMR are presented 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 extended cooking time can be attributed to the presence of the bran layer, which acts as a hydrophobic barrier, reducing the rate of water penetration into the starch core [36].

Table 3. Cooking properties of traditional hand pound 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

The water uptake ratio was lower for THR (2.85 ± 0.12) compared to CMR (3.22 ± 0.15), which can be explained by the hydrophobic nature of the bran layer containing lipids that repel water, and the higher amylose content of THR forming more compact starch granules that limit water absorption [7].

Chemical characteristics

The chemical composition of THR and CMR is presented in Table 4. THR exhibited significantly higher amylose content (28.64 ± 0.92 %) compared to CMR (24.35 ± 0.84 %). Consequently, the amylopectin content was lower in THR (71.36 ± 0.92 %) compared to CMR (75.65 ± 0.84 %), resulting in higher amylose: amylopectin ratio for THR (0.40 ± 0.02) compared to CMR (0.32 ± 0.01).

Table 4. Chemical characteristics of traditional hand pound 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 higher amylose content in THR can be attributed to the preservation of the aleurone layer, which contains amylose-rich small starch granules that are typically removed during conventional milling and the minimal mechanical and thermal stress during hand pounding, which prevents amylose degradation [29]. Similar findings were reported by Wang et al. [39], who observed that traditional processing methods preserved the native starch structure better than modern mechanical milling.

The higher amylose content in THR is particularly advantageous for bioplastic film production, as amylose contributes to film formation through its linear chain structure, which allows for more efficient intermolecular hydrogen bonding and entanglement [18, 19].

Functional characteristics

The functional properties of THR and CMR are presented in Table 5. THR exhibited significantly higher water absorption capacity (WAC) (2.48 ± 0.11 g/g) compared to CMR (2.18 ± 0.09 g/g). This enhanced WAC can be attributed to the presence of hydrophilic components in the bran layer, such as proteins and dietary fibers, which have high water-binding capacity [36].

Table 5. Functional characteristics of traditional hand pound 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 lower water solubility index (WSI) (8.74 ± 0.38 %) compared to CMR (11.32 ± 0.46 %). The lower WSI of THR can be attributed to its higher amylose content, which forms more ordered crystalline regions that are less susceptible to leaching during heating [37]. The hydration capacity and swelling power were significantly higher for THR (1.65 ± 0.07 g/g and 9.32 ± 0.42 g/g respectively) compared to CMR (1.42 ± 0.06 g/g and 8.24 ± 0.35 g/g respectively). These findings align with the observations of Leach et al. [22] and Sowbhagya et al. [37], who reported that native, unmodified starch exhibits higher swelling power due to its intact granular structure.

Micronutrient analysis

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

The substantial differences in micronutrient content can be attributed to the retention of the bran layer in THR, which contains a significant proportion of these minerals. Conventional milling removes approximately 80 ÷ 90 % of the bran layer, resulting in substantial nutrient losses [12, 30]. These findings align with those of Jiang et al.

[16], who reported that traditional processing methods preserved significantly higher levels of micronutrients compared to conventional milling.

Table 6. Micronutrient content of traditional hand pound 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

Conclusions

This comprehensive comparative analysis demonstrates that traditional hand pound rice possesses superior physicochemical properties for bioplastic applications compared to conventionally milled rice. Key advantages include:

1. Enhanced film-forming potential: higher amylose content (28.64 % vs. 24.35 %) and superior amylose: amylopectin ratio provides better intermolecular bonding capacity.
2. Improved processing characteristics: higher water absorption capacity, enhanced swelling power and better hydration properties facilitate superior gelatinization and film formation.
3. Better structural integrity: lower broken ratio and higher porosity indicate superior grain quality and processing characteristics.
4. Enhanced nutritional value: substantially higher micronutrient content adds value to potential bioplastic applications, particularly for edible films.

The preservation of these beneficial properties in traditional hand pound rice through minimal mechanical intervention presents a compelling case for utilizing traditional processing methods in sustainable bioplastic development. These findings establish a strong foundation for preferring THR over CMR as a raw material source for environmentally friendly bioplastic applications.

This research contributes to the growing body of knowledge on sustainable material development and highlights the potential of traditional agricultural processing methods in modern green technology applications. Future research should explore the translation of these superior properties into enhanced bioplastic film characteristics and performance.

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PORÓWNAWCZA CHARAKTERYSTYKA FIZYKOCHEMICZNA TRADYCYJNIE RĘCZNIE OBRABIANEGO I KONWENCJONALNIE MIELONEGO RYŻU

S t r e s z c z e n i e

Wprowadzenie. Tradycyjne metody przetwarzania ryżu zachowują korzystne właściwości, które są tracone podczas konwencjonalnego mielenia, co potencjalnie czyni go potencjalnym surowcem do trzymywania bioplastików. W niniejszym badaniu porównano właściwości fizykochemiczne tradycyjnego ryżu obrabianego ręcznie (THR) i ryżu konwencjonalnie mielonego (CMR). Ryż odmiany Poongar przetworzono tradycyjnymi metodami ręcznego tłuczenia i mielenia konwencjonalnego. Kompleksowa analiza obejmowała właściwości fizyczne (wymiary, gęstość, właściwości cierne, właściwości kulinarne), skład chemiczny (amyloza, amylopektyna, zawartość wilgoci), właściwości funkcjonalne (zdolność absorpcji wody, wskaźnik rozpuszczalności, zdolność hydratacji, zdolność pęcznienia) oraz zawartość mikroskładników (żelazo, cynk, wapń, fosfor).

Wyniki i wnioski. THR wykazał znacząco lepsze właściwości, w tym wyższą zawartość amylozy (28,64 ± 0,92 % w porównaniu z 24,35 ± 0,84 %), zwiększoną zdolność absorpcji wody (2,48 ± 0,11 g/g w porównaniu z 2,18 ± 0,09 g/g), większą siłę pęcznienia (9,32 ± 0,42 g/g w porównaniu z 8,24 ± 0,35 g/g) i znacznie wyższy poziom mikroskładników odżywczych. THR wykazał również lepszą integralność ziarna z niższym wskaźnikiem złamania (3,82 ± 0,42 % w porównaniu z 8,67 ± 0,95 %) i wyższą porowatość (60,54 ± 1,85 % w porównaniu z 54,93 ± 1,62 %). Tradycyjne, ręczne tłuczenie ryżu pozwala zachować korzystne właściwości ryżu, w szczególności wyższą zawartość amylozy i lepsze właściwości funkcjonalne, które ułatwiają tworzenie filmu.

Słowa kluczowe: zawartość amylozy, prekursory bioplastików, ręczne tłuczenie, materiały zrównoważone, tradycyjne przetwarzanie ryżu.