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Effect of Traditional and Contemporary Cooking Techniques on the Nutritional Quality of Different Rice (Oryza sativa) Varieties: A Comparative Study

Research Article

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Abstract

Background: Rice (Oryza sativa) is a major staple food worldwide, and its nutritional quality is influenced by both rice variety and cooking method.

Methods: This study compared traditional cooking methods (open-vessel cooking, steaming and roasting followed by pressure cooking) with contemporary methods (pressure cooking and soaked pressure cooking) using white basmati, brown basmati and parboiled rice. Physical characteristics, proximate composition, nutrient retention and starch properties using standard analytical methods and analysed by one-way ANOVA ($p < 0.05$).

Results: Cooking method significantly influenced the physical, nutritional and starch properties of all rice varieties ($p < 0.05$). Pressure cooking produced the highest water uptake ratio (3.70), cooking yield (370%) and grain weight increase (270%) in white basmati rice. Brown basmati retained the highest dietary fibre (1.16 g/100 g) and ash (0.82 g/100 g), whereas parboiled rice exhibited the highest true density (1.90 g/cm³). Protein retention in open-vessel cooking of white basmati rice (105.72%), pressure cooking in brown basmati rice (96.20%) and roasting followed by pressure cooking in parboiled rice (175%). Roasted-pressure-cooked white basmati rice showed the lowest starch (45.45%) and total sugar (50.50%) contents. Light microscopy confirmed progressive starch gelatinization during cooking and greater retrogradation in soaked pressure-cooked rice after cooling.

Conclusion: The results demonstrated that both rice variety and cooking method significantly influenced cooking quality, nutrient retention and starch behaviour. Selecting an appropriate cooking method for each rice variety can improve the nutritional and functional quality of cooked rice, providing valuable guidance for consumers, nutritionists, and the food industry.

Keywords: Rice Cooking Methods; Nutrient Retention; Proximate Composition; Starch Gelatinization; Cooking Quality.

Introduction

Rice (*Oryza sativa*), one of the most cultivated cereal crops worldwide, is the staple diet for more than half of the world's population. It therefore represents an essential source for global food and nutritional security especially in Asia where it accounts for a huge part of the daily intake. As one of the world's largest producers and consumers of rice, India produces a range of varieties with varied culinary and nutritional properties. Because of its low cost, widespread availability, and versatility in food preparation, rice remains an essential food product for mankind and can fulfil an important share of global energy intake [**11**]. Rice mainly consists of carbohydrates which constitute 70-80% of dry weight primarily in the form of starch. It is thus a prominent source of dietary energy. Other major nutrients in rice include protein, which typically

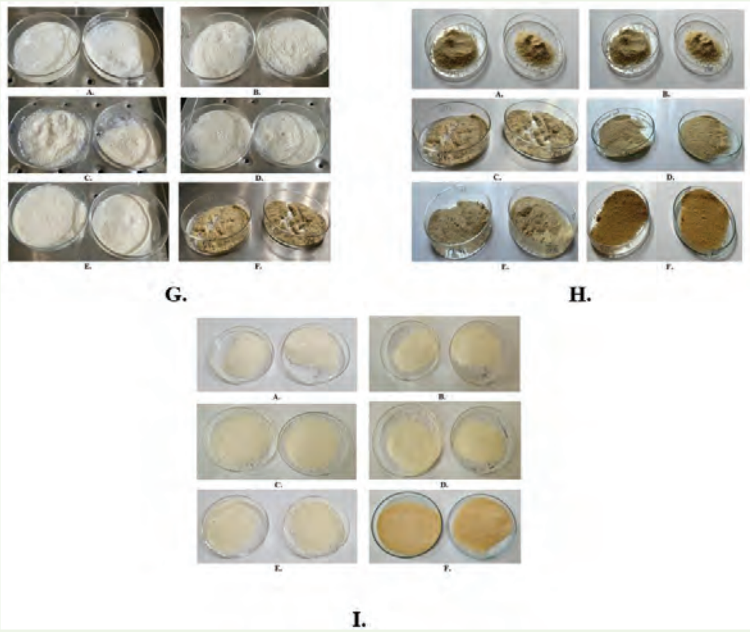

Figure 1: Moisture content profile of rice variety (G) white basmati rice [BRW], (H) brown basmati rice [BBR], (I) parboiled rice [PBR], in different cooking methods (A) Raw rice[T0], (B) Soaked pressure cooked [T1], (C) Pressure cooked [T2], (D) Open vessel cooked [T3], (E) Steamed [T4], (F) Roasted pressure cooked[T5].

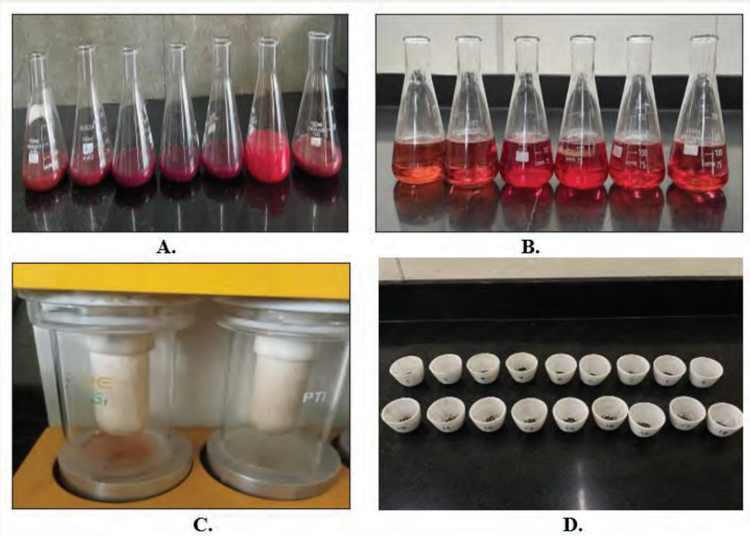

Figure 2: Nutritional analysis of samples (A)Starch, (B)Protein, (C)Fat, (D) Ash.

ranges from 6-8% (with a minimal amount of fat), followed by a small amount of fibre, vitamins, minerals, and diverse bioactive compounds. Nutritional composition varies by variety and by the type of processing applied to rice grain after harvest. However, brown rice (which contains bran and germ layers) has higher amounts of dietary fibre, B vitamins, vitamin E, magnesium, phosphorus, iron, zinc and antioxidant compounds such as phenolics compounds as compared to refined (polished) rice (which lacks these components due to their removal during polishing, i.e. Removing bran and germ layers), has more prolonged shelf life and is acceptable by consumers [6]. Moreover, the consumption of a rice-containing diet (more than a quarter of the dietary energy intake) has numerous health benefits, especially whole grain rice due to the present bioactive ingredients like dietary fibre, resistant starch and antioxidants, which reduce cardiovascular disease, diabetes Type 2 risk, improve lipid profile and gut health of human beings. They can also combat oxidative stress and inflammation due to their antioxidant content and are gluten-free; therefore, they are a choice for people with celiac

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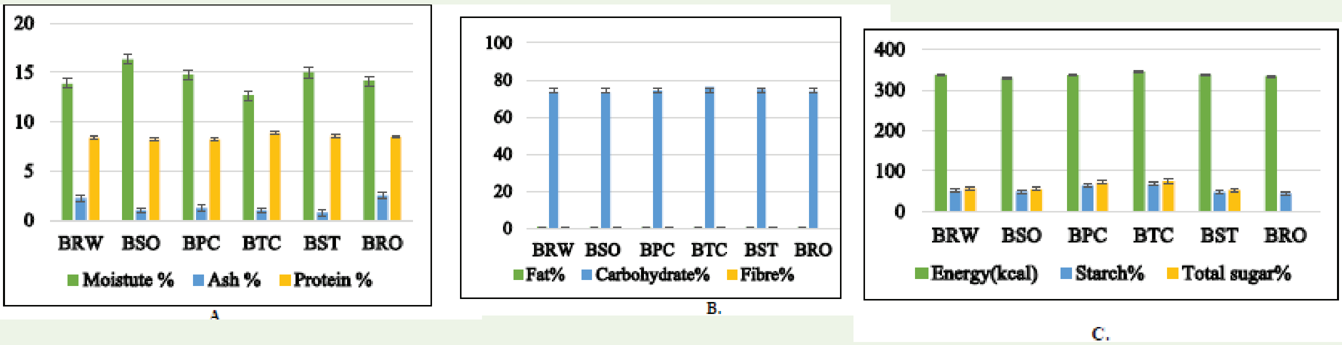

Figure 3: Effect of cooking methods on nutritional composition of white basmati rice *Raw white basmati rice (BRW), Open vessel cooking (BTC), pressure cooking (BPC), soaking followed by pressure cooking (BSO), steaming (BST), roasting followed by pressure cooking (BRO).

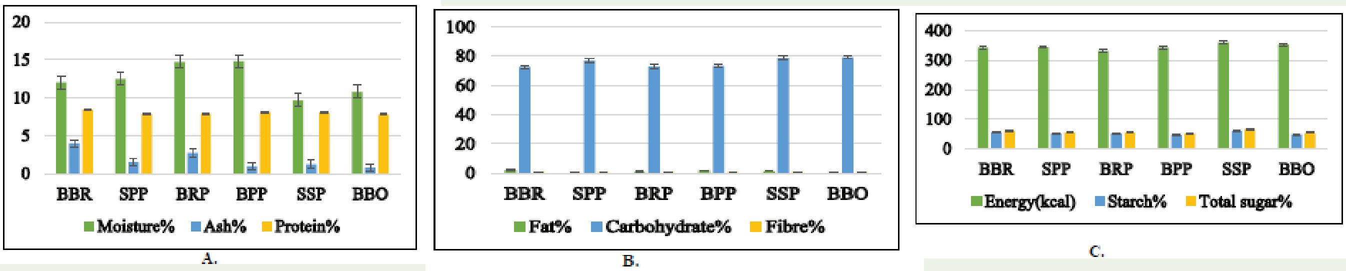

Figure 4: Effect of cooking methods on nutritional composition of brown basmati rice *Raw brown basmati rice (BBR), Open vessel cooking (BBO), pressure cooking (BPP), soaking followed by pressure cooking (SPP), steaming (SSP), roasting followed by pressure cooking (BRP).

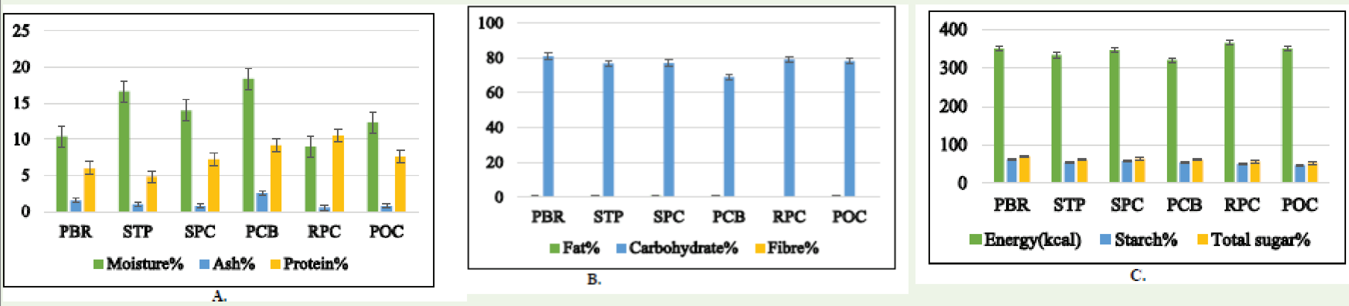

Figure 5: Effect of cooking methods on nutritional composition of parboiled rice *Raw parboiled rice (PBR), Open vessel cooking (POC), pressure cooking (PCB), soaking followed by pressure cooking (SPC), steaming (STP), roasting followed by pressure cooking.

disease and gluten-intolerance conditions [40]. With the widespread consumption of rice, domestic cooking techniques often influence the nutritional value and nutrient bioavailability in cooked rice. Soaking, boiling, steaming, pressure cooking, or absorption methods affect moisture uptake, gelatinisation, yield, and nutrient loss or retention. Cooking losses depend on the method used. Many B-vitamins and some minerals, being water-soluble, leach into the cooking water during boiling, especially if a large amount of water is used and it is wasted after boiling. Steam and pressure cooking require little or no water, which minimises nutrient losses, as these methods generally have shorter cooking times than simple boiling, soaking before boiling, or absorption cooking. In addition, cooking increases starch gelatinisation and protein digestibility, making foods more palatable, but it may also degrade heat-sensitive nutrients [33]. The aim of the present study is to determine differences in selected nutrient contents across selected varieties and compare their retention after using different household cooking methods. The results will help identify appropriate cooking methods for different rice varieties to retain or enhance nutrients, supporting better consumer health through informed choices and minimising deficiencies by adopting optimal cooking methods. Therefore, this study investigates the impact of different cooking techniques on retaining the selected nutritional components of chosen rice varieties.

Methodology

Procurement of Samples

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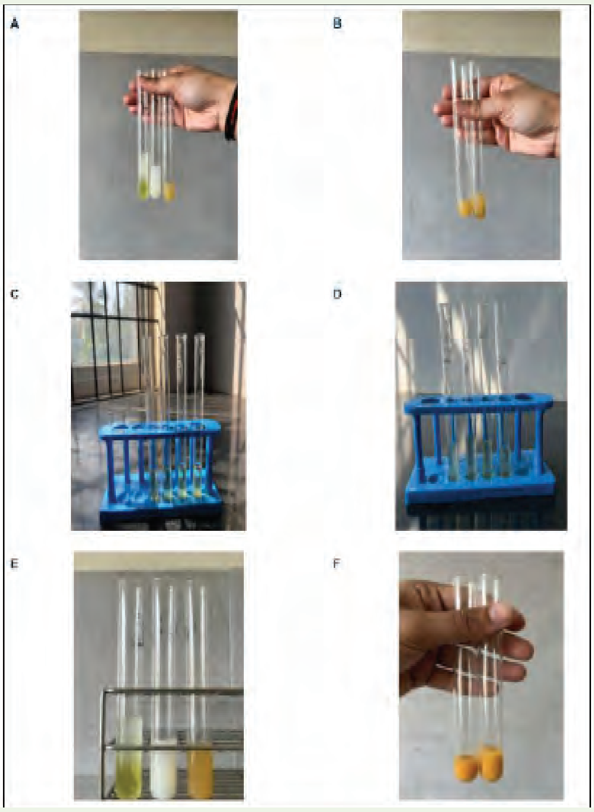

Figure 6: (A) (C) (E) Shows the qualitative test for selected vitamins (Thiamine, Riboflavin, and Niacin) in BRW, PBR, BBR respectively. (B) (D) (F) shows the qualitative test for anti-nutritional factors (Tannin and Phytate) in BRW, PBR, BBR respectively.

Three commercially available rice (*Oryza sativa)* varieties, namely parboiled rice, white basmati rice and brown rice, were selected for the study. The samples were purchased from a retail supermarket in Bengaluru, Karnataka, India, in their original sealed packages to ensure product quality and authenticity. All rice samples were procured from the same production batch to minimise batch-to-batch variation. After procurement, the samples were transferred to clean, labelled airtight containers and stored in a cool, dry place at room temperature (25 ± 2°C) until further processing.

Sample Preparation

Before cooking, the rice samples were manually sorted to remove broken grains, foreign materials, stones and other visible impurities. The cleaned samples were thoroughly washed with potable water to remove adhering dust and surface contaminants. A representative 100 g sample from each rice variety was weighed using a digital analytical balance (SIPLAB PG3100, India) with accuracy ±0.01 g and allocated to the respective cooking treatments.

Household Treatments Study Design

The present study evaluated six cooking treatments: untreated raw rice (T_0), soaking followed by pressure cooking (T_1), pressure cooking (T_2), open-vessel cooking (T_3), steaming (T_4), and roasting followed by pressure cooking (T_5). The cooking procedures were adapted from **[34]** with minor modifications. For the soaking treatment, rice samples were soaked in potable water at a 1:3 (w/v) rice-to-water ratio for 30 min at room temperature to ensure uniform hydration before cooking. Pressure cooking was carried out using a domestic pressure cooker with a 1:2.5 (w/v) rice-to-water ratio for 15 min (approximately three whistles). Open-vessel cooking was performed by boiling the rice in water at a 1:4 (w/v) ratio for 25–30 min until the grains became soft and fully cooked. Steaming was carried out in a household steam cooker for 30 min using pre-soaked rice. For the roasting treatment, rice grains were dry-roasted in a stainless-steel pan over a moderate flame (approximately 120–140°C) for 5 min with continuous stirring to prevent scorching. The roasted grains were subsequently pressure-cooked under the same conditions. The untreated raw rice served as the control throughout the study, as represented in (Table 1). After cooking, the rice samples were spread uniformly on stainless-steel trays and dried in a hot-air oven at 50–55°C until they reached a constant weight (approximately 18–24 h). The dried samples were cooled to room temperature in a desiccator to prevent moisture absorption. Each sample was then ground using a laboratory grinder and passed through a 60-mesh sieve to obtain a uniform particle size. The powdered samples were packed in airtight polyethene pouches, labelled and stored at ambient temperature until further physicochemical and nutritional analyses.

Chemicals and Reagents

All chemicals and reagents used in the study were of analytical reagent (AR) grade. Laboratory chemicals and consumables were procured from Vasa Scientific Pvt. Ltd., Bengaluru, India. Toluene was obtained from Fisher Scientific, India. Copper sulphate, sodium

Table 1: Experimental Treatments: Different cooking methods of *Oryza sativa.*

Treatments	Cooking Method	Parboiled Rice	White Basmati Rice	Brown Basmati Rice
T_0	Raw rice	PBR	BRW	BBR
T_1	Soaked Pressure	SPC	BSO	SPP
T_2	Pressure cooked	PCB	BPC	BPP
T_3	Open-vessel	POC	BTC	BBO
T_4	Steaming	STP	BST	SSP
T_5	Roasted pressure	RPC	BRO	BRP

Table 2: Physical characteristics of Rice (*Oryza sativa)* varieties.

Sample	Bulk density (g/ml)	True density (g/ml)	1000 kernel (g)
BRW	0.862	1.64	16.3
BBB	0.871	1.72	16.4
PBR	0.895	1.90	16.3

*Raw white basmati rice (BRW), Raw brown basmati rice (BBR), Raw parboiled rice (PBR).

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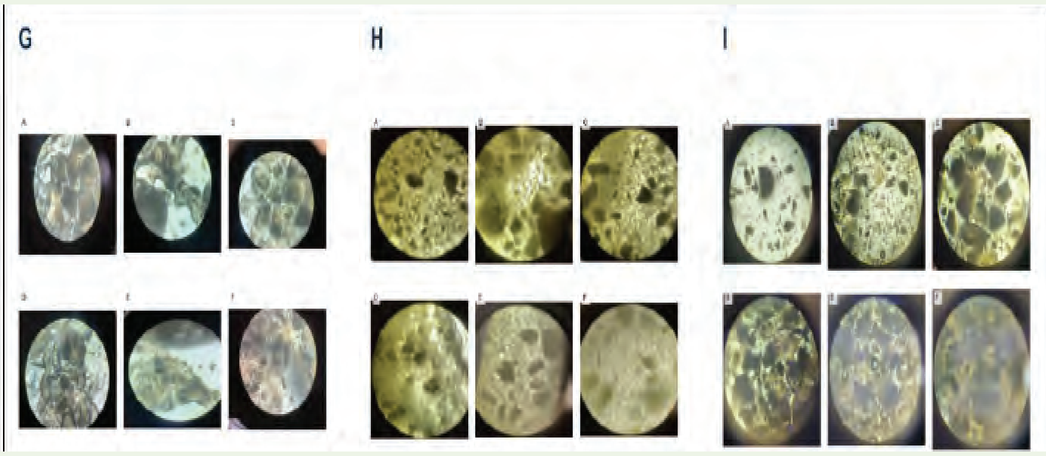

Figure 7: Microscopic observation of starch gelatinization in traditionally cooked rice grains (G) white basmati rice (BRW), (H) brown basmati rice (BBR), (I) parboiled rice (PBR), at progressive heating temperatures and after cooling. (A) 50°C. (B) 60°C. (C) 70°C. (D) 80°C. (E) 90°C. (F) starch granules after cooling.

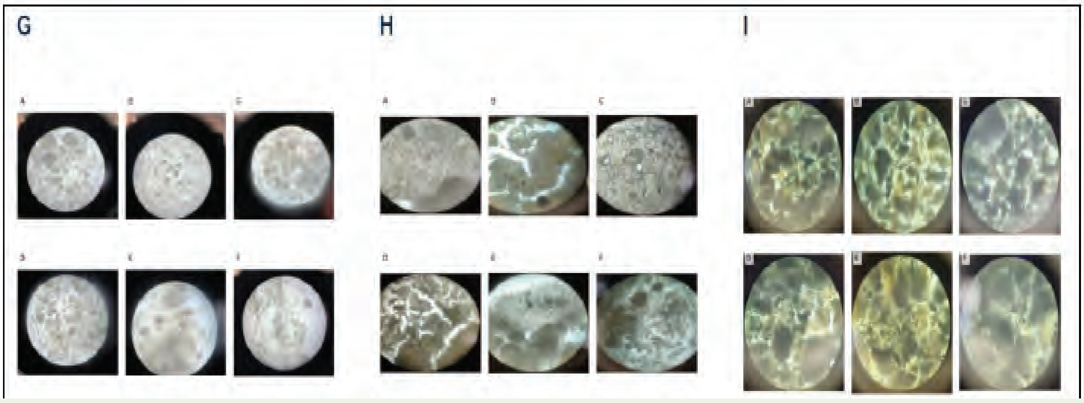

Figure 8: Microscopic observation of starch gelatinization in raw rice grains (G) white basmati rice (BRW), (H) brown basmati rice (BBR), (I) parboiled rice (PBR), at progressive heating temperatures and after cooling. (A) 50°C. (B) 60°C. (C) 70°C. (D) 80°C. (E) 90°C. (F) starch granules after cooling.

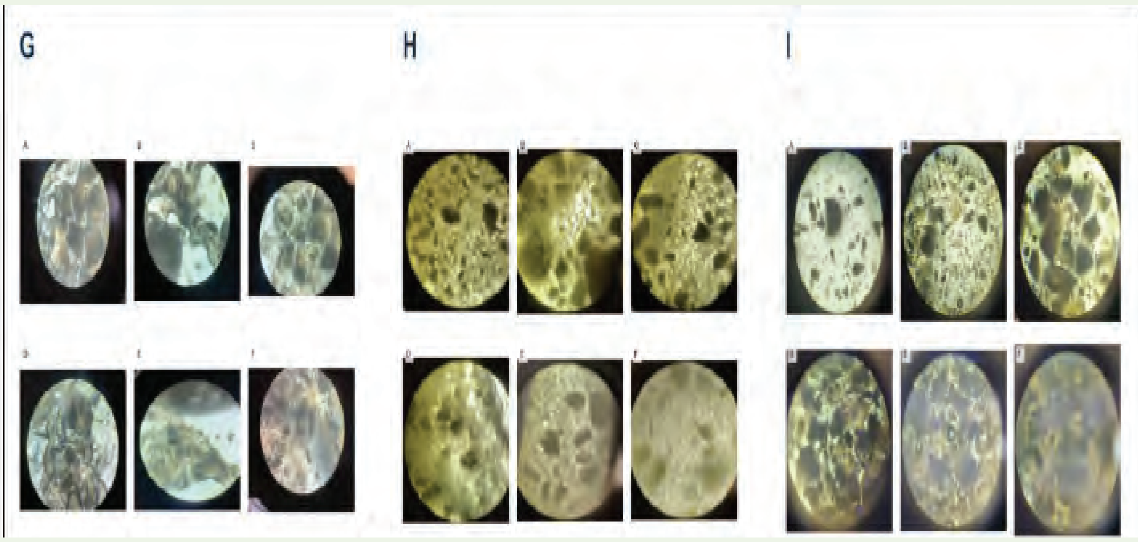

Figure 9: Microscopic observation of starch gelatinization in pressure cooked rice grains (G) white basmati rice (BRW), (H) brown basmati rice (BBR), (I) parboiled rice (PBR), at progressive heating temperatures and after cooling. (A) 50°C. (B) 60°C. (C) 70°C. (D) 80°C. (E) 90°C. (F) starch granules after cooling.

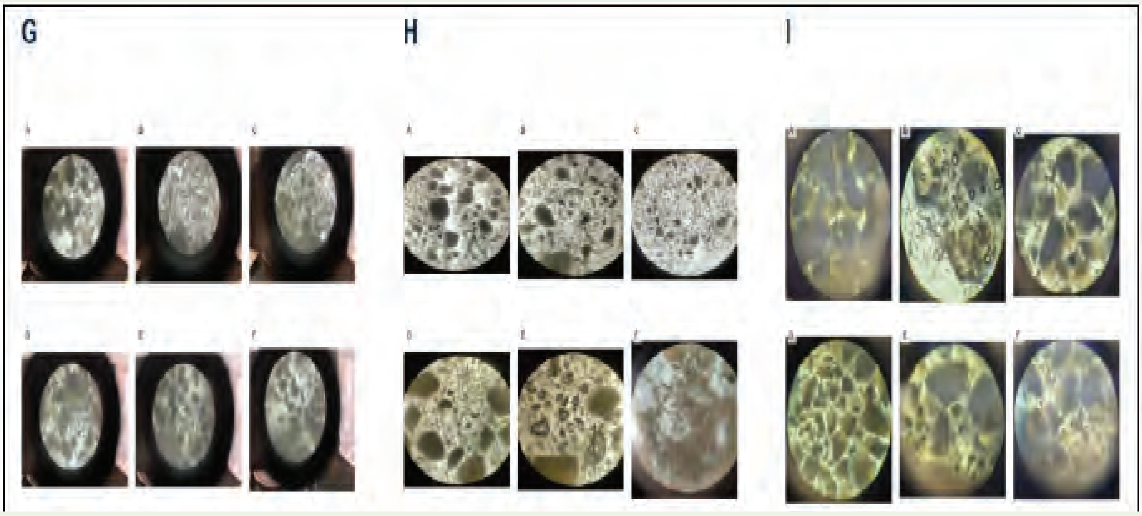

Figure 10: Microscopic observation of starch gelatinization in traditionally cooked rice grains (G) white basmati rice (BRW), (H) brown basmati rice (BBR), (I) parboiled rice (PBR), at progressive heating temperatures and after cooling. (A) 50°C. (B) 60°C. (C) 70°C. (D) 80°C. (E) 90°C. (F) starch granules after cooling.

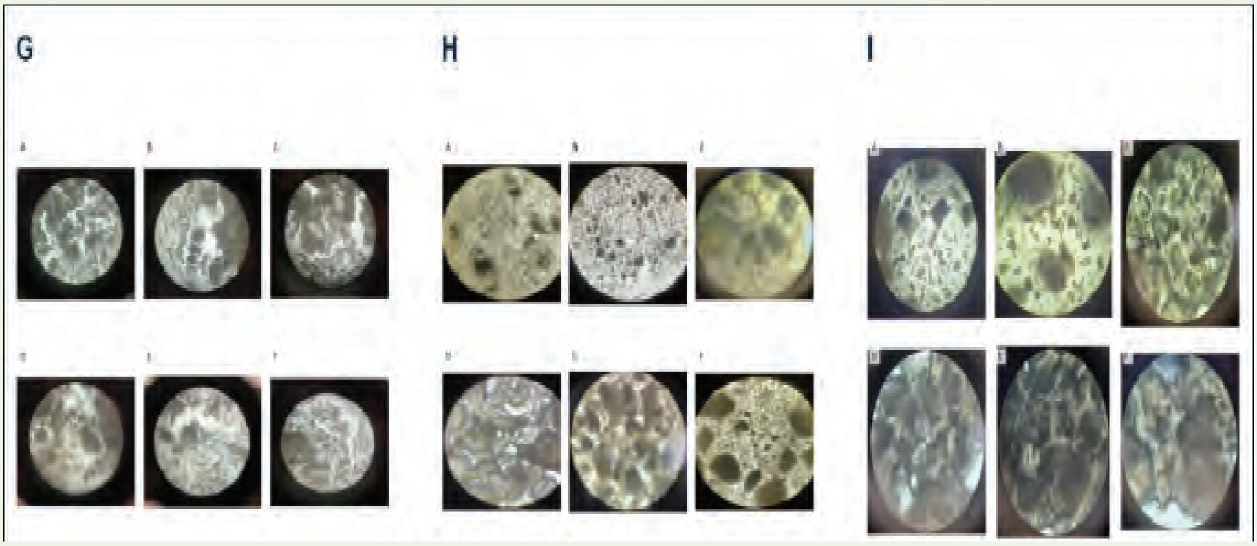

Figure 11: Microscopic observation of starch gelatinization in soaked followed by pressure cooked rice grains (G) white basmati rice (BRW), (H) brown basmati rice (BBR), (I) parboiled rice (PBR), at progressive heating temperatures and after cooling. (A) 50°C. (B) 60°C. (C) 70°C. (D) 80°C. (E) 90°C. (F) starch granules after cooling.

sulphate, sulphuric acid (H_2SO_4), sodium hydroxide (NaOH), boric acid, methyl red, hydrochloric acid (HCl), petroleum ether, ferric chloride and ethanol were purchased from S.D. Fine-Chem Ltd., Mumbai, India. Bromocresol green was procured from Rolex Chemical Industries, India. Distilled water was used throughout all experimental procedures.

Physical parameters

True density

True density was determined using the liquid displacement method described by [5]. Approximately 10 g of whole rice grains were accurately weighed using a calibrated analytical balance (SIPLAB PG3100, India) and immersed in a graduated cylinder containing a known volume of toluene. The increase in liquid volume was recorded as the sample's true volume.

$$\textbf{True density (g/ml)} = \frac{\text{Weight of sample(g)}}{\text{Volume of displaced toulene(ml)}}$$

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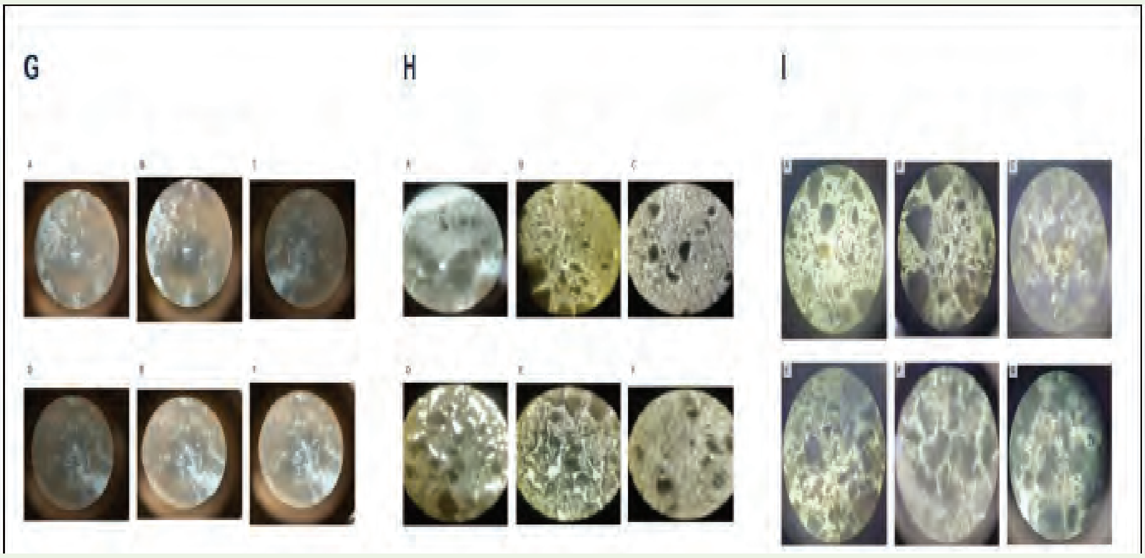

Figure 12: Microscopic observation of starch gelatinization in steamed rice grains (G) white basmati rice (BRW), (H) brown basmati rice (BBR), (I) parboiled rice (PBR), at progressive heating temperatures and after cooling. (A) 50°C. (B) 60°C. (C) 70°C. (D) 80°C. (E) 90°C. (F) starch granules after cooling.

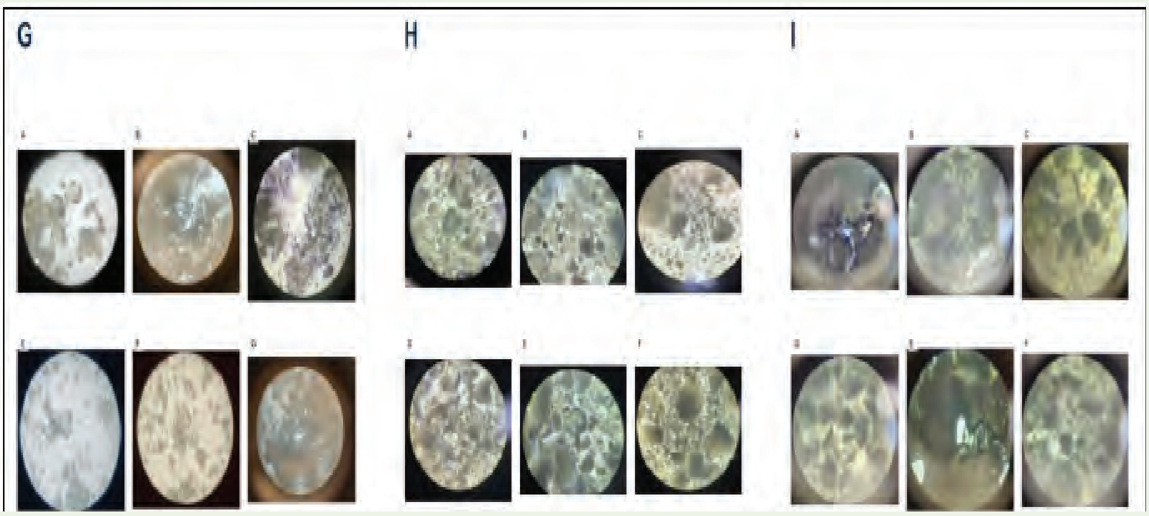

Figure 13: Microscopic observation of starch gelatinization in roasted followed by pressure cooked rice grains (G) white basmati rice (BRW), (H) brown basmati rice (BBR), (I) parboiled rice (PBR), at progressive heating temperatures and after cooling. (A) 50°C. (B) 60°C. (C) 70°C. (D) 80°C. (E) 90°C. (F) starch granules after cooling.

Bulk Density

Bulk density was determined according to **[28].** A clean, dry 100 mL graduated cylinder was filled with rice grains without tapping or compaction. The weight of the grains occupying the known volume was recorded and bulk density was calculated as the ratio of sample weight to bulk volume.

$$\textbf{Bulk density (g/ml)} = \frac{\text{Weight of sample (g)}}{\text{Bulk Volume of the sample (ml)}}$$

1000 kernel weight

Thousand-kernel weight was determined as described in **[18]** One thousand healthy, unbroken rice kernels were manually counted and weighed using a calibrated analytical balance (SIPLAB PG3100, India) with an accuracy of 0.001g used to assess grain size and physical quality.

Nutrient Retention

Nutrient retention was evaluated by comparing the total nutrient content of processed and raw rice samples on a weight basis. The retention percentage was calculated by dividing the total nutrient content of the processed sample by that of the raw sample, then multiplying by 100. This parameter was used to assess the effectiveness of processing in preserving nutritional quality according to **[35]**

Nutrient Retention (%) $= \frac{\text{Total nutrient in processed sample}}{\text{Total nutrient in raw sample}} \times 100$

Cooking Yield

Cooking yield was determined by measuring the weight gain after cooking and was expressed as a percentage. It reflects the ability of rice grains to absorb and retain water during cooking and serves as an important indicator of cooking quality and processing efficiency as per **[2].**

Cooking Yield (%) $= \frac{\text{Weight of cooked sample}}{\text{Weight of raw same}} \times 100$

Percentage Increase in Weight

Percentage increase in weight was used to evaluate the water absorption and swelling behaviour of rice grains during cooking. The parameter was calculated as the difference between final and initial weights expressed as a percentage. Higher values indicate greater hydration and improved cooking performance evaluated by **[19].**

Percentage Increase in Weight (%) $= \frac{\text{Final weight} - \text{Initial weight}}{\text{Initil Weight}} \times 100$

Nutritive analysis

The nutritional composition of the rice (*Oryza sativa)* samples was determined using standard **[4]**. Moisture content was determined by the hot-air oven method using a Servewell HAO 18.8 hot-air oven (Servewell Instruments Pvt. Ltd., India). Protein content was estimated by the Kjeldahl method **[4]** using a KELPLUS DISTYL EM digestion and distillation system (Pelican Equipments, India) with a nitrogen conversion factor of 6.25. Crude fat was determined by the Soxhlet extraction method **[4]** using a SOCS PLUS 04B solvent extraction system (Pelican Equipment, India). Crude fibre was analysed using a FIBRA PLUS FES 4 fibre estimation system (Pelican Equipments, India) according to **[4],** while ash content was determined by incineration in a Servewell DTC 508 muffle furnace (Servewell Instruments Pvt. Ltd., India) following **[4]**. Total carbohydrate content was calculated by difference as described by **[38]**, and the energy value was estimated using the Atwater conversion factors (4 kcal/g for protein, 4 kcal/g for carbohydrate and 9 kcal/g for fat). Total sugars and starch were determined using the Lane–Eynon titrimetric method **[4].**

Phytochemical Test

Qualitative Analysis

Qualitative screening of selected vitamins and antinutritional compounds was carried out using standard fluorescence- and colour-based methods. Fresh extracts were prepared from 5 g of powdered rice using appropriate analytical-grade reagents. The extraction mixture was shaken for 30 min, filtered through Whatman No. 1 filter paper, and analysed immediately. All determinations were performed in triplicate.

Thiamine (Vitamin B_1)

Thiamine was qualitatively determined using the fluorescence method described by **[8]**. The sample extract was prepared using 0.1 N hydrochloric acid and examined under an ALPHA LINEAR UV Transilluminator (Model 2222 V-TT, Alpha Linear Instruments, India) at 365 nm. The appearance of characteristic blue fluorescence was considered indicative of thiamine.

Riboflavin (Vitamin B_2)

Riboflavin was qualitatively identified following the method reported by **[14]**. The prepared extract was examined under an ALPHA LINEAR UV Transilluminator (Model 2222 V-TT, Alpha Linear Instruments, India) at 365 nm. The development of a characteristic yellowish-green fluorescence confirmed riboflavin presence.

Niacin (Vitamin B_3)

Niacin was assessed using the ferric chloride colour reaction described by **[12]**. Mix approximately 2 mL of the extract with 1 mL of 1% analytical-grade ferric chloride solution. The formation of a light yellow to brownish colour indicated the presence of niacin.

Phytate

Phytate was evaluated following the method of **[29]**. Treat about 2 mL of the extract with 1% ferric chloride solution and allow it to stand for 5 min. The formation of a cream-coloured precipitate indicated phytate presence.

Tannins

Tannins were determined according to **[30]** 2 mL of the extract was treated with 2-3 drops of 1% ferric chloride solution. The appearance of a blue-black or greenish-black colour retained for 2 min confirmed the presence of tannin.

Gelatinization and microscopic examination

The gelatinization behaviour of rice starch was evaluated according to **[16]** with slight modifications. Approximately 1 g of powdered rice sample was dispersed in 10 mL of distilled water and heated gradually from 50°C to 90°C on a hot plate with continuous stirring. Observations were recorded at 50, 60, 70, 80, and 90°C to monitor starch granule swelling, viscosity development and paste formation. Complete gelatinization was confirmed by the formation of a homogeneous viscous paste. For microscopic examination, a small quantity of the gelatinized sample was mounted on a clean glass slide, covered with a coverslip, and examined using a compound light microscope (LABMED, INDIA) at 400× magnification.

Retrogradation and microscopic examination

Retrogradation was assessed following the procedure described by **[26]**. The gelatinized starch samples were cooled to room temperature, transferred to airtight containers and stored at 3–5°C for 24 h to promote starch molecular reassociation. Following storage,

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Table 3: Effect of cooking methods on the nutritional composition of white basmati rice Oryza sativa (mean ± SD).

Variables	BRW	BTC	BPC	BSO	BST	BRO	Total	P value
Moisture%	13.89±0.18	12.67±0.09	14.79±0.18	16.33±0.29	15±0.09	14.15±0	14.48±1.18	<0.001**
Energy (kcal)	337.42±4.3	345.22±0.28	336.82±4.04	330.62±1.24	338.22±0.96	334.68±0.08	337.16±4.93	0.015*
Carbohydrate%	73.72±0.53	76.31±0.06	74.3±0.2	73.31±0.33	74.88±0.22	74.03±0.01	74.42±1.04	<0.001**
Ash%	2.25±0.35	1±0	1.25±0.35	1±0	0.75±0.35	2.5±0	1.46±0.72	0.002**
Fat%	1±0.71	0.5±0	0.75±0.35	0.5±0	0.5±0	0.5±0	0.63±0.31	0.567
Protein%	8.39±0.01	8.87±0.01	8.22±0.02	8.23±0.02	8.55±0.02	8.52±0.03	8.46±0.23	<0.001**
Fiber%	0.75±0.02	0.65±0.02	0.67±0.03	0.63±0.02	0.32±0.02	0.3±0.02	0.55±0.19	<0.001**
Starch%	51.53±0.32	67.64±0.19	64.53±0.25	49.73±0.32	48.29±0.45	45.45±0.64	54.53±8.8	<0.001**
Total sugar %	57.25±0.35	75.15±0.21	71.7±0.28	55.25±0.35	53.65±0.49	50.5±0.71	60.58±9.78	<0.001**

* Moderately significant (P value:0.01<P ≤ 0.05), ** Strongly significant (P value: P≤0.01), Raw white basmati rice (BRW), Open vessel cooking (BTC), pressure cooking (BPC), soaking followed by pressure cooking (BSO), steaming (BST), roasting followed by pressure cooking (BRO).

Table 4: Effect of cooking methods on the nutritional composition of brown basmati rice Oryza sativa (mean ± SD).

Variables	BBR	SPP	BRP	BPP	SSP	BBO	Total	P value
Moisture%	12.04±0.18	12.48±0.27	14.73±0.09	14.83±0.19	9.67±0	10.8±0	13.17±1.97	<0.001**
Energy (kcal)	342.53±0.72	343.75±1.09	332.37±2.5	342.32±2.52	361±2.12	353.07±1.41	345.84±9.55	<0.001**
Carbohydrate%	72.67±0.18	76.92±0.54	72.91±0.97	73.5±0.16	78.86±1.06	79.34±0.35	75.7±2.95	<0.001**
Ash%	4±0	1.5±0	2.75±0.35	1±0	1.25±0.35	0.75±0.35	1.88±1.21	<0.001**
Fat%	2±0	0.5±0	1±0.71	1.75±0.35	1.5±0.71	0.5±0	1.21±0.69	0.050+
Protein%	8.46±0	7.9±0.27	7.93±0	8.14±0	8.02±0	7.8±0	8.04±0.24	0.008**
Fiber%	0.83±0	0.7±0.02	0.68±0	0.78±0.02	0.7±0	0.8±0	0.75±0.06	<0.001**
Starch%	56.39±0.45	51.53±0.32	51.39±0.51	47.07±0.25	61.02±0.25	48.51±0.13	52.65±4.96	<0.001**
Total sugar %	62.65±0.49	57.25±0.35	57.1±0.57	52.15±0.07	67.8±0.28	53.9±0.14	58.48±5.55	<0.001**

\+ Suggestive significance (P value: 0.05<P<0.10), *Moderately significant (P value:0.01<P ≤ 0.05), ** Strongly significant (P value: P≤0.01); Raw brown basmati rice (BBR), Open vessel cooking (BBO), pressure cooking (BPP), soaking pressure cooking (SPP), steaming (SSP), roasting followed by pressure cooking (BRP).

Table 5: Effect of cooking methods on the nutritional composition of parboiled rice *Oryza sativa* (mean ± SD).

Variables	PBR	STP	SPC	PCB	RPC	POC	Total	**P value**
Moisture%	10.42±0.04	16.65±0.38	13.96±0.64	18.35±0.35	8.95±0.33	12.3±1.34	13.77±3.32	<0.001**
Ash%	1.5±0	1±0.71	0.75±0.35	2.5±0.71	0.5±0	0.75±0.35	1.17±0.78	0.034*
Fat%	0.75±0.35	0.75±0.35	1±0	0.75±0.35	0.5±0	0.75±0.35	0.75±0.26	0.704
Protein%	6±0.62	4.82±0.62	7.25±0.71	9.19±0.62	10.5±0.62	7.57±0.45	7.43±2.35	<0.001**
Carbohydrate%	80.93±0.3	76.76±0.06	77.05±0.29	69.1±0.08	79.25±0.95	78.25±0.19	76.89±3.93	<0.001**
Fiber%	0.4±0.02	0.35±0.02	0.46±0.02	0.35±0.02	0.3±0	0.38±0	0.37±0.05	<0.001**
Energy (kcal)	349.71±1.94	333.03±0.47	346.18±3.99	319.91±6.01	365.24±1.33	349.99±5.73	344.01±15.2	<0.001**
Starch %	62.78±0.95	54.68±0.95	57.38±0.95	54.45±0.64	50.63±0.32	47.03±0.32	54.49±5.21	<0.001**
Total sugar%	69.75±1.06	60.75±1.06	63.75±1.06	60.5±0.71	56.25±0.35	52.25±0.35	60.54±5.79	<0.001**

* Moderately significant (P value:0.01<P ≤ 0.05), ** Strongly significant (P value: P≤0.01); Raw parboiled rice (PBR), Open vessel cooking (POC), pressure cooking (PCB), soaking followed by pressure cooking (SPC), steaming (STP), roasting followed by pressure cooking (RPC).

the gel structure was examined under a compound light microscope (LABMED, INDIA) with 400× magnification.

Statistical Analysis

The experiment was conducted, with each treatment analysed in triplicate. Results are presented as mean ± standard deviation. Statistical analysis was performed using IBM SPSS Statistics version 22.0. Differences among treatments were evaluated by one-way analysis of variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) test for pairwise comparisons. Statistical significance was accepted at $p < 0.05$. Microsoft Excel 2021 (Microsoft Corporation, Redmond, WA, USA) was used exclusively for data tabulation and graphical presentation.

Result

Comparative cooking characteristics of Rice (*Oryza sativa)*

The cooking characteristics of raw white basmati rice (BRW), raw brown basmati rice (BBR) and raw parboiled rice (PBR) differed markedly among the cooking methods (**Table 3).** Overall, water uptake ratio, cooked weight, cooking yield and percentage increase in weight followed similar trends across all treatments. During soaking (T_1), BBR showed the highest hydration capacity, with the highest

Table 6: Pairwise comparison of the nutritional composition of white basmati rice Oryza sativa under different cooking methods.

Variables	BRW	BTC	BPC	BSO	BST	BRO
Moisture (%)	Compare	0.003**	0.012*	<0.001**	0.004**	0.651
Ash (%)	Compare	0.128	1.000	0.200	0.999	0.867
Fat %	Compare	0.001**	0.407	0.705	0.044*	0.868
Protein (%)	Compare	0.018*	0.049*	0.018*	0.007**	0.902
Carbohydrates (%)	Compare	0.652	0.962	0.652	0.652	0.652
Energy (kcal)	Compare	<0.001**	0.001**	0.001**	0.001**	0.004**
Fiber%	Compare	0.036*	0.130	0.016*	<0.001**	<0.001**
Starch%	Compare	<0.001**	<0.001**	0.026*	0.001**	<0.001**
Total sugar%	Compare	<0.001**	<0.001**	0.026*	0.001**	<0.001**

* Moderately significant (P value:0.01<P ≤ 0.05), ** Strongly significant (P value: P≤0.01); Raw white basmati rice (BRW), Open vessel cooking (BTC), pressure cooking (BPC), soaking followed by pressure cooking (BSO), steaming (BST), roasting followed by pressure cooking (BRO).

Table 7: Pairwise comparison of the nutritional composition of brown basmati rice Oryza sativa under different cooking methods.

Variables	BBR	SPP	BRP	BPP	SSP	BBO
Moisture (%)	Compare	0.428	<0.001**	<0.001**	<0.001**	0.002**
Ash (%)	Compare	0.981	0.012*	1.000	<0.001**	0.010*
Fat %	Compare	0.005**	0.999	0.789	0.001**	<0.001**
Protein (%)	Compare	<0.001**	0.018*	<0.001**	<0.001**	<0.001**
Carbohydrates (%)	Compare	0.087+	0.315	0.989	0.843	0.087+
Energy (kcal)	Compare	0.015*	0.020*	0.154	0.045*	0.007**
Fiber%	Compare	<0.001**	<0.001**	0.030*	<0.001**	0.271
Starch%	Compare	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
Total sugar%	Compare	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**

+ Suggestive significance (P value: 0.05<P<0.10), * Moderately significant (P value:0.01<P ≤ 0.05), ** Strongly significant (P value: P≤0.01 Raw brown basmati rice (BBR), Open vessel cooking (BBO), pressure cooking (BPP), soaking followed by pressure cooking (SPP), steaming (SSP), roasting followed by pressure cooking (BRP).

Table 8: Pairwise comparison of the nutritional composition of parboiled rice Oryza sativa under different cooking methods.

Variables	PBR	STP	SPC	PCB	RPC	POC
Moisture (%)	Compare	0.003**	0.154	0.001**	0.021*	0.891
Ash (%)	Compare	0.867	0.604	0.357	0.357	0.604
Fat %	Compare	1.000	0.942	1.000	0.942	1.000
Protein (%)	Compare	1.000	0.049*	0.003**	<0.001**	0.029*
Carbohydrates (%)	Compare	0.001**	0.001**	<0.001**	0.057+	0.006**
Energy (kcal)	Compare	0.166	0.087+	0.166	0.011*	0.942
Fiber%	Compare	0.036*	0.931	0.002**	0.049*	1.000
Starch%	Compare	<0.001**	0.003**	<0.001**	<0.001**	<0.001**
Total sugar%	Compare	<0.001**	0.003**	<0.001**	<0.001**	<0.001**

+ Suggestive significance (P value: 0.05<P<0.10),* Moderately significant (P value:0.01<P ≤ 0.05), ** Strongly significant (P value: P≤0.01); Raw parboiled rice (PBR), Open vessel cooking (POC), pressure cooking (PCB), soaking followed by pressure cooking (SPC), steaming (STP), roasting followed by pressure cooking (RPC).

water uptake ratio (2.92 mL), while PBR showed the lowest (2.41 mL). Pressure cooking (T_2) produced the highest hydration and cooking performance among all treatments, with BRW recording the maximum water uptake ratio (3.70 mL), cooked weight (370 g), cooking yield (370%) and percentage increase in weight (270%). Under open-vessel cooking (T_3), PBR demonstrated the greatest hydration, with a water uptake ratio of 3.16 mL, whereas BBR recorded the lowest value (2.20 mL). A similar pattern emerged during steaming (T_4), where BRW showed superior cooking characteristics, followed by PBR, while BBR showed comparatively lower hydration. In contrast, roasting (T_5) favoured BBR, which recorded the highest water uptake ratio (3.42 mL), cooked weight (342 g), cooking yield (342%) and percentage increase in weight (242%).

Physical characteristics of Rice (*Oryza sativa)*

The physical characteristics of the rice varieties, including bulk density, true density and thousand-kernel weight, are presented in Table 2. Bulk density varied slightly among the rice varieties, ranging from 0.862 to 0.895 g/cm³. PBR recorded the highest bulk density (0.895 g/cm³), followed by BBR (0.871 g/cm³) and BRW (0.862 g/cm³). A similar trend was observed for true density, with PBR exhibiting the highest value (1.90 g/cm³), followed by BBR (1.72 g/cm³) and BRW

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Table 9: Retention (%) of protein, fat and fibre in different rice *Oryza sativa* varieties following various cooking methods.

Sample	Protein (%)			Fat (%)			Fiber (%)		
	BRW	BBR	PBR	BRW	BBR	PBR	BRW	BBR	PBR
T_1	98.09	93.3	120.8	50	25	133.3	84	84.3	115
T_2	97.97	96.2	153.16	75	87.5	100	89.3	93.9	87.5
T_3	105.72	92.1	129.16	50	25	100	86.6	96.3	95
T_4	101.90	94.7	80.3	50	75	100	42.6	84.2	87.5
T_5	101.54	93.7	175	50	50	66.6	40	81.9	75

*Raw white basmati rice (BRW), Raw brown basmati rice (BBR), Raw parboiled rice (PBR); Soaked pressure (T_1), Pressure cooked (T_2), Open vessel cooked (T_3), Steamed (T_4), roasted pressure (T_5).

(1.64 g/cm^3). In contrast, thousand-kernel weight varied only slightly among the rice varieties. BBR recorded the highest thousand-kernel weight (16.4 g), whereas BRW and PBR exhibited similar values (16.3 g).

Nutritional Analysis

The nutritional composition of white basmati rice (BRW), brown basmati rice (BBR) and parboiled rice (PBR) was significantly influenced by the cooking methods Tables 4–6. In white basmati rice, moisture content increased significantly ($p < 0.001$), reaching the highest value after soaking followed by pressure cooking (BSO; 16.33 ± 0.29%). Open-vessel cooking (BTC) resulted in the highest carbohydrate (76.31 ± 0.06%), protein (8.87 ± 0.01%), starch (67.64 ± 0.19%) and total sugar (75.15 ± 0.21%) contents, all of which differed significantly from the other treatments ($p < 0.001$). The raw sample had the highest ash content (2.25 ± 0.35%; $p = 0.002$), whereas cooking did not significantly affect fat content ($p = 0.567$). Fibre content varied significantly ($p < 0.001$), with the highest value observed in the raw sample (0.75 ± 0.02%). Among the brown basmati rice samples, pressure cooking (BPP) produced the highest moisture content (14.83 ± 0.19%; $p < 0.001$). Open-vessel cooking (BBO) recorded the highest carbohydrate content (79.34 ± 0.35%; $p < 0.001$), while steaming (SSP) resulted in the highest starch (61.02 ± 0.25%) and total sugar (67.80 ± 0.28%) contents ($p < 0.001$). The highest protein content among the cooked samples was observed after pressure cooking (8.14 ± 0.00%; $p = 0.008$). The raw sample contained significantly higher ash (4.00 ± 0.00%; $p < 0.001$), fat (2.00 ± 0.00%; $p = 0.050$) and fibre (0.83 ± 0.00%; $p < 0.001$) than the processed samples. In parboiled rice, pressure cooking (PCB) resulted in the highest moisture content (18.35 ± 0.35%; $p < 0.001$). The raw sample retained the highest carbohydrate (80.93 ± 0.30%), starch (62.78 ± 0.95%) and total sugar (69.75 ± 1.06%) contents, with all three parameters showing significant differences among the cooking treatments ($p < 0.001$). Roasting recorded the highest protein content, followed by pressure cooking (RPC; 10.50 ± 0.62%; $p < 0.001$). Ash content also differed significantly ($p = 0.034$), with the raw sample showing the highest value (1.50 ± 0.00%), whereas fat content remained statistically unchanged across all treatments ($p = 0.704$). Fibre content varied significantly ($p < 0.001$), with the raw sample retaining the highest value (0.40 ± 0.02%). Comparisons with the traditional method of cooking as shown in (Tables 7–9) supported the ANOVA results and showed that moisture, protein, starch and total sugar were the nutritional components most consistently influenced by the cooking methods ($p < 0.05$). In comparison, carbohydrate, ash, and fat showed fewer significant differences among treatments, with fat remaining relatively stable regardless of cooking method ($p > 0.05$). Collectively, these findings indicate that the effect of cooking on nutrient composition depends on both rice variety and processing method.

Nutrient retention

Protein retention in BRW ranged from 97.97–105.72%, with the highest value recorded after open-vessel cooking T_3) 105.72%, whereas BBR showed a narrower range 92.10–96.20%, with maximum retention following pressure cooking (T_2) 96.20%. PBR showed the greatest variation (80.3–175%), with the highest protein retention after roasting, followed by pressure cooking (T_5) at 175%. Fat retention ranged from 50–75% in BRW and 25–87.5% in BBR, while PBR showed the highest retention 66.6–133.3%, with maximum retention after soaking followed by pressure cooking (T_1) 133.3%. Fibre retention ranged from 40–89.3% in BRW, 81.9-96.3% in BBR and 75–115% in PBR. The highest fibre retention was observed in BBR after open-vessel cooking (T_3) 96.3% and in PBR after soaking pressure cooking (T_1) 115%. Overall, PBR showed greater retention of protein and fat, whereas BBR retained comparatively higher fibre across the cooking treatments.

Qualitative test

The qualitative analysis of thiamine, riboflavin, niacin, tannin and phytate in white basmati rice (BRW), brown basmati rice (BBR) and parboiled rice (PBR) revealed that these compounds were not detected under the conditions of the qualitative assay, as depicted in (Figure 4). All three rice varieties exhibited negative (–) results for each parameter and no qualitative differences were observed among the samples.

Gelatinization and Retrogradation

Microscopic examination revealed progressive gelatinization of

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starch granules in white basmati rice (BRW), brown basmati rice (BBR) and parboiled rice (PBR) with increasing temperature. In the raw samples (T_0), starch granules remained intact at **50-60°C**, exhibited initial swelling at **70°C**, and became extensively gelatinized with disruption of the granular structure at **80–90°C**. Among the cooking methods, soaked pressure cooking (T_1) and pressure cooking (T_2) produced more pronounced swelling and disruption of starch granules than steaming (T_4) and open-vessel cooking (T_3), which showed comparatively gradual structural changes. In contrast, roasting followed by pressure cooking (T_5) delayed starch swelling and resulted in partially fused starch granules. Following cooling, the gelatinized starch underwent retrogradation, characterised by the reassociation of starch molecules into aggregated structures. The most pronounced retrogradation was observed in soaked pressure-cooked (T_1) samples, followed by pressure-cooked (T_2) samples, both showing dense, continuous starch matrices. Steamed (T_4) and open-vessel cooked (T_3) samples showed moderate reassociation with comparatively loose starch matrices, whereas roasting followed by pressure cooking (T_5) produced a less compact structure with irregular starch aggregates.

Discussion

Comparative cooking characteristics of Rice (*Oryza sativa)*

In the current investigation, rice variety and cooking method significantly influenced rice cooking quality ($p < 0.05$). Among cooking techniques, pressure cooking (T) yielded the highest water uptake ratio, cooked weight, cooking yield, and per cent increase in weight, particularly for white basmati rice (BRW). The high temperature and pressure environment increased the migration rate of moisture from grain outer layers towards endosperm and promoted starch gelatinization leading to increased cooking yield and improved grain expansion. This is consistent with other studies **[21]**, which concluded that pressure cooking enhances the water absorption capacity of rice grain, increases volume, and improves rice grain quality after cooking. Starch gelatinisation controls water diffusion through the kernel, and the extent of gelatinisation strongly influences hydration kinetics and, subsequently, cooked rice texture **[37]**. Because water moves more easily through the endosperm than through layers like the bran, swelling volume with an appropriate degree of hydration improves cooking quality. Various rice varieties behaved differently due to variation in grain microstructure, hardness and other physicochemical factors **[15]**. Grain morphology, which is closely associated to cooking behaviour is one major criterion for classifying rice. White basmati rice attained higher hydration properties in pressure cooking (T) and steam cooking (T), most likely due to polished nature of grain that favours the fast movement of moisture inside, because loss of bran-rich outer layer offers less impediment to moisture diffusion to endosperm and consequently enhance hydration behaviour during cooking. Some similar reports indicate that polished rice had faster water absorption capacity in contrast with intact grain **[20]**. Besides that high amylose content in rice varieties caused higher cooking loss and lesser increased weight. Also generally accepted knowledge is low in hardness grain take water fast during cooking and lead to soft cooked grain whereas for the high harder grain take water very slow and result into better texture. But parboiled rice (PBR) gave the best hydration in open pot cooking (T), which illustrates their relatively dense grain microstructure may need high heating treatment to achieve sufficient moisture penetration rate. Since gelatinization and retrogradation take place during parboiling reduces the movement of water. In a recent study **[39]**, found that due to the loss of structure during heat- gelatinized starch formation and movement through the grain limits in parboiling causing in increasing grain density and altering hydration during cooking. Recent reviews highlighted, parboiled rice also exhibits lower water absorption due to higher extent of starch gelatinization than refined (polled) rice grain structure because starch has been partially gelatinized causing structure is dense. Brown basmati rice (BBR) demonstrated better hydrated grain values in case of pre-soaking (T) and by roasting followed by pressure cooking (T), where pre-soaking helped in facilitating moisture transfer through the bran and the roasting process possibly leads the outer kernel to have increased permeability and allows better moisture movement from the grain during the following pressure-cooking stage.

Physical characteristics of Rice (*Oryza sativa)*

The physical characteristics of the rice varieties differed according to grain type and processing history. Parboiled rice (PBR) exhibited the highest bulk density and true density, indicating a denser grain matrix than that of white basmati rice (BRW) and brown basmati rice (BBR). This behaviour is associated with the hydrothermal treatment during parboiling, which induces starch gelatinization followed by retrogradation, resulting in a more compact internal structure and enhanced grain integrity. Similar findings were reported by **[22]**, which showed that parboiling improves structural compactness, increases grain hardness, and reduces grain breakage during cooking. Although only slight differences were observed in thousand-kernel weight, BBR recorded the highest value, followed closely by BRW and PBR. The minimal variation indicates that kernel size was largely comparable among the three rice varieties **[32]**. Therefore, the differences in cooking behaviour are more likely to be associated with variations in grain microstructure and physicochemical properties than with kernel weight alone. Overall, the higher density of PBR explains its slower hydration rate and greater resistance to structural disruption during cooking. These findings show that processing-induced changes in grain microstructure play a key role in determining the physical and cooking characteristics of rice **[10].**

Nutritional Analysis

Cooking significantly affected the nutritional composition of all rice varieties ($p < 0.05$). Moisture content increased after cooking, particularly in soaked, pressure-cooked samples (T_1), due to increased water absorption during thermal processing. Consequently, the energy value decreased because increased moisture content diluted nutrient concentration on a wet-weight basis, consistent with the findings of **[24].** Carbohydrate and ash contents generally decreased following cooking, particularly under moist-heat treatments. This reduction can be explained by starch gelatinization and the leaching of water-soluble nutrients into the cooking medium. Fat content showed comparatively little variation during processing because lipids are less susceptible to thermal losses. Protein content varied with cooking method, likely reflecting heat-induced denaturation and changes in protein–starch interactions during cooking. Dietary fibre also decreased after thermal treatment because heating partially disrupted structural polysaccharides within the grain. Similarly, starch and total sugar contents declined after cooking, with open-vessel cooking (T_3) showing greater retention, whereas roasting followed by pressure cooking (T_5) produced the greatest reduction. The reason for the alteration of nutrient composition is the increase in absorbed moisture during the process; cooking causes it to evaporate and decompose at temperature to form other compounds. It is also thought to be caused by the gelatinisation of starch; where starch grains will absorb the cooking liquid and swell, also by leaching out of water-soluble compounds into the cooking liquid. These changes are influenced by the method of cooking **[9]**. More nutrients are lost by methods of cooking that utilize excessive water as water soluble nutrients will escape and diffuse into the cooking liquid and in methods of cooking by limited water retention is greater. These observations are consistent with the physicochemical changes associated with starch gelatinization and thermal processing **[7]**.

Pairwise comparison of nutrient composition of rice *Oryza sativa* varieties under different cooking conditions

The comparative analysis demonstrated that both rice variety and cooking method significantly influenced the nutritional composition of cooked rice ($p < 0.05$). Moisture, protein, starch and total sugar exhibited the greatest variation among treatments, whereas ash content remained comparatively stable. These findings indicate that nutrients respond differently to thermal processing depending on their chemical characteristics and distribution within the grain **[27]**. Brown basmati rice (BBR) consistently retained higher amounts of dietary fibre, fat and ash than white basmati rice (BRW) and parboiled rice (PBR), reflecting the retention of the bran layer, where these nutrients are predominantly concentrated. In contrast, BRW contained lower amounts of fibre and minerals because polishing removes much of the bran and germ before cooking **[1]**. Parboiled rice (PBR) exhibited greater nutritional stability across several cooking treatments. This is likely because hydrothermal processing before milling redistributes water-soluble nutrients into the endosperm and reduces their susceptibility to cooking losses. Among the cooking methods, soaking followed by pressure cooking (T_1) resulted in the highest moisture retention, whereas roasting followed by pressure cooking (T_5) caused greater reductions in starch and total sugar. Overall, these findings support the view that the interaction between grain structure and cooking conditions governs the nutritional quality of cooked rice and agree with the observations of **[31].**

Nutrient retention calculation

Nutrient retention was significantly influenced by both rice variety and cooking method (**$p < 0.05$**), indicating that no single cooking method maximised the retention of all nutrients. Instead, nutrient retention depended on each rice variety's structural characteristics and the thermal conditions used during cooking. For white basmati rice (BRW), open-vessel cooking (T_3) resulted in the highest protein retention, whereas pressure cooking produced greater protein retention in brown basmati rice (BBR). In parboiled rice (PBR), roasting followed by pressure cooking (T_5) yielded the highest protein retention. This likely reflects the structural modifications induced during hydrothermal processing, which improve protein stability during subsequent heat treatment. Similar trends on the structural modification of rice have been reported by **[35]**. Pressure cooking (T_2) resulted in greater fat retention in BRW and BBR, whereas soaking followed by pressure cooking (T_1) was more effective in preserving fat in PBR. Fibre retention remained highest in BBR because of the intact bran layer, while PBR exhibited improved fibre retention following roasting combined with pressure cooking (T_5). Retention of nutrients can be strongly influenced by cooking temperature and time and the amount of water involved. Pressure-cooked foods can be expected to retain a significantly higher percentage of the water-soluble vitamins (B-complex group, vitamin C) and minerals than foods which were cooked with excess water. With a limited amount of cooking water, leaching out of soluble components occurs only to a limited extent and the cooking time is also reduced, hence minimal loss of soluble contents due to thermally caused decomposition is possible. Pre-roasting also improves the retention of water-soluble and protein values due to less leaching during cooking process **[3]**. Collectively, these findings demonstrate that nutrient retention is governed by the interaction between grain structure and cooking conditions, indicating that the most suitable cooking method depends on the rice variety.

Qualitative test

The study indicated that thiamine, riboflavin, niacin, tannins and phytates were not detected in any of the rice samples under the conditions of the qualitative assay. These findings should not be interpreted as the complete absence of these compounds, but rather as concentrations below the detection limit of the analytical

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method employed. The low detectable levels are consistent with the effects of milling, soaking and thermal processing, which reduce the concentrations of water-soluble vitamins and certain antinutritional compounds through removal of the bran layer, leaching and thermal degradation reported that polishing removes a substantial proportion of the bran layer [36], where B-group vitamins and several phytochemicals are predominantly concentrated, thereby markedly reducing their concentrations in milled rice. Similarly, demonstrated that vitamins present at low concentrations often require highly sensitive analytical techniques, such as high-performance liquid chromatography (HPLC), for reliable quantification [17]. Therefore, the absence of detectable reactions in the present study more likely reflects the limited sensitivity of the qualitative assay than the complete elimination of these compounds.

Gelatinisation and Retrogradation

Light microscopic examination confirmed progressive starch gelatinization in all rice samples with increasing as temperature. Intact starch granules observed at lower temperatures gradually swelled, lost their structural integrity and eventually formed a continuous gelatinized matrix as heating progressed. These structural changes are consistent with the disruption of crystalline starch regions and increased water absorption during thermal processing [23]. Pressure cooking and soaking followed by pressure cooking produced the greatest degree of gelatinization, reflecting the combined effects of elevated temperature, pressure and moisture availability. The rapid diffusion of water into the endosperm accelerated starch swelling and gelatinization, which is consistent with the higher water uptake, cooked weight and cooking yield observed in these treatments. In contrast, steaming resulted in more gradual gelatinization because heat transfer occurred at a slower rate than under pressure. Roasting followed by pressure cooking exhibited comparatively lower starch swelling, likely reflecting structural modifications induced during dry-heat treatment that reduced subsequent water absorption and starch gelatinization during pressure cooking. Similar observations have been reported by [26]. Retrogradation was evident in all cooked samples following cooling, indicating the reassociation of gelatinized starch molecules into more ordered structures. The highest degree of retrogradation was observed in soaked pressure-cooked rice, suggesting that extensive starch gelatinization promoted greater molecular reassociation during cooling. In contrast, roasting followed by pressure cooking exhibited the lowest degree of retrogradation, indicating that prior dry-heat treatment modified the starch structure and reduced its tendency to reassociate. [25] similarly reported that amylose reassociation during cooling contributes to the formation of firmer starch gel networks.

Conclusion

The composition, physical characteristics, nutrient retention and starch properties of cooked rice. Brown basmati retained higher dietary fibre and mineral content because of the bran layer, while parboiled rice showed better protein retention and structural stability. Pressure cooking improved hydration characteristics and cooking yield, whereas steaming and roasting differentially affected nutrient retention and starch behaviour. Microscopic observations confirmed variations in starch gelatinization and retrogradation among cooking methods, and statistical analysis revealed significant differences ($p < 0.05$) for most parameters. Overall, the findings highlight that selecting an appropriate cooking method according to the rice variety can enhance the nutritional and functional quality of cooked rice. The study was limited to three rice varieties and selected domestic cooking methods under controlled laboratory conditions. In addition, qualitative analysis was used for selected vitamins and antinutritional factors, limiting detection of trace concentrations; the study also used a single batch of each rice variety. Therefore, independent biological replication was limited, which may restrict the generalizability of variety-specific findings. Future studies should include multiple independent batches or lots of each rice variety to strengthen statistical inference. Future studies should include a wider range of rice cultivars and cooking techniques and employ quantitative analytical methods, such as HPLC, to determine vitamin retention. Further investigation of starch digestibility, glycaemic index, sensory quality and advanced structural characterisation techniques (SEM, DSC and XRD) would provide a more comprehensive understanding of the nutritional and functional changes occurring during cooking.

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Conflict of Interest

The authors declare no conflicts of interest.

Authors contribution

The corresponding author contributed to the study's conception and design, supervised the research, reviewed the manuscript, and provided critical revisions and final corrections; co-authors contributed to the study's implementation, data collection, data analysis, literature review, and preparation of the manuscript draft. All authors reviewed, approved and agreed to be accountable for the final version of the manuscript.

Ethical clearance

The study does not require ethical clearance.

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The authors confirm that ChatGPT and Grammarly were used solely as editorial support tools for language editing, grammar checking, sentence rephrasing, clarity enhancement and manuscript formatting. Figure Guilt was used to assist with figure preparation and formatting. The authors critically reviewed, verified, and revised all AI-generated suggestions. The authors take full responsibility for the accuracy, integrity and originality of the manuscript, including all interpretations, analyses and conclusions.

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