International Journal of Food Science and Nutrition
www.foodsciencejournal.com
ISSN: 2455-4898
Received: 03-01-2026, Accepted: 02-02-2026, Published: 17-02-2026
Volume 11, Issue 1, 2026, Page No. 75-83

A comparative study of red rice variety *Chhohartu* with Basmati rice: Physical, nutritive, phytochemical, pasting and cooking properties

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Abstract
This study highlights the comparison between physical, compositional, phytochemical, pasting and cooking properties of red rice variety *Chhohartu* and basmati rice variety. Red rice showed greater antioxidant capacity with DPPH scavenging activity at 91.18% compared to basmati rice (24.03%). It was rich in flavonoid content (0.42 mg RE/g) and phenolic (3.00 mg GAE/g). Its anthocyanins, which give it its vivid red colour, highlight its medicinal uses and health advantages. The compact grains of red rice showed better toughness and energy absorption, while the elongated grains of basmati rice showed higher hardness making it perfect for milling and processing according to dimensional and mechanical studies. Pasting analysis revealed that basmati rice cooked more quickly and had higher elongation ratio, improving its culinary adaptability, whereas red rice had higher setback and peak viscosity, indicating better starch stability. Red rice's hard texture was emphasized by frictional and gravimetric qualities, which affected its flow behaviour and storage. These results highlight the complementary functions of red rice and basmati rice, positioning red rice as a nutrient-dense option for healthconscious diets, while basmati rice's exceptional sensory and mechanical qualities serve premium culinary applications.

Keywords: Red rice, Basmati, antioxidant, phenolic content, viscosity

Introduction
Rice (*Qryza sativa*) is a vital component of diet worldwide, serving as a primary source of nutrition for millions of people. Among primary rice-producing countries, India accounts for 33.23% production, followed by China (31.94%), Vietnam (10.61%), and South Korea (2.54%). Smaller contributions come from Japan, Phillipines, Sri Lanka and Spain, accounting for 3.05% collectively. Most of the production originates from East Asia (34.62%) and South Asia (38.58%), with the remainder from Southeast Asia (25.03%). The global rice production rose from approximately 755.8 million tons in 2019 to around 799.9 million tons in 2023, whereas in India, rice production saw significant growth, rising from 178.3 million tons to 206.7 million tons during the similar period (FAOSTAT, 2024) [10]. The rise in rice production worldwide, which reflects ongoing advancements in agricultural practices and crop yields, is significant not only for meeting the growing demand but also because rice serves as a crucial source of carbohydrates, fibre, vitamins, and minerals, thereby supporting energy levels, digestive health, and overall well-being.

Red rice, renowned for its nutritional richness and vibrant color is diversely found in countries like India, Thailand, Vietnam, Cambodia, and Bangladesh, where traditional farming practices celebrate its cultural and culinary significance. In India, red rice is cultivated in states like Kerala, West Bengal, Assam, Tamil Nadu, Jammu & Kashmir, Uttarakhand and some parts of Himachal Pradesh contributing significantly to the overall rice production, which has seen an increase to about 196.2 million tons in 2022, with red rice varieties making up a notable portion of this total. In Himachal Pradesh state of India, red rice is locally known as *Laal Dhaan* because of its distinctive reddish tint, which varies in intensity among the hulled grains. The land races of rice, including *Begmi, Bhrigu, Red rice, Desi Dhan, Jattu, Jhinjan, Juin, Karad, Kafayala, Lal Dhan, Lalu Dhan, Matali, and Roda Dhan*, are named after their cultivation regions or unique characteristics, often reflecting the local dialects of the area. These names are mostly derived from local dialects of the area (Thakur and Kumari, 2020) [29]. The variety '*Chhohartu*,' recognized as a farmer's variety, originates from Tehsil Chirgaon in Shimla district, India and is officially registered under the Protection of Plant Varieties and Farmers' Rights Authority in village Shirotkhala, Laloti, Tehsil Chirgaon, District Shimla, Himachal Pradesh. This registration recognizes the landrace for its distinctive red-colored decorticated grains and its name is derived from the Chhohara Valley, its place of origin.

Basmati rice is renowned for its distinctive aroma and is characterized by extra-long, slender grains with a pleasant fragrance, flavour, and texture. When cooked, the grains expand to twice their original length, making them highly sought after in both domestic and international markets. India stands as the leading producer of basmati rice, with the earlymaturing variety of basmati rice cultivated extensively in Punjab, Haryana, Delhi, Uttar Pradesh in India.

While comparing to white rice, red rice with higher levels of ash (1.20 to 1.61%), protein (7.47-11.51%), fat (1.20-1.53%), total phenols, anthocyanins, and antioxidant activity, whereas basmati rice also provides superior nutritional advantages (Thakur and Kumari 2020; Somaratne *et al.*, 2017) [29, 25]. Because of these characteristics, red rice is a great low-glycemic ingredient for functional foods. Moreover, red rice has a high manganese level in its bran, which greatly enhances its antioxidant qualities. It is also a rich source of zinc, iron, and other minerals. The presence of important biochemicals in red rice extracts, including ferulic, isoferulic, p-coumaric, syringic, chlorogenic, and sinapic acids, has been linked to have potent anti-free-radical scavenging properties. The main tocopherols found in red rice lipids are αtocotrienol, α-tocopherol, δ-tocopherol, β-tocopherol, γ-tocotrienol, and δ-tocotrienol. Red rice's characteristic colour comes from its anthocyanins and proanthocyanidins, which are essential nutrients with antioxidant qualities that also have anti-inflammatory, anti-allergic, and anti-carcinogenic effects.

A thorough examination of red rice variety *Chhohartu's* basic proximate, phytochemical, physical, mechanical, pasting, and cooking characteristics has not received much attention by the researchers. Therefore, the main aim of the study was to carry out in-depth study of various traits of *Chhohartu* with a particular emphasis on comparing it with attributes of basmati rice.

Materials and methods

1. Materials

The de-husked red rice variety *Chhohartu* was procured from from local farmers in Rohru, Himachal Pradesh, India and Basmati rice variety PB 1509 was sourced from rice milling facilities in Sangrur, Punjab, respectively. The dehusked rice samples were handcleaned to eliminate impurities like dust, dirt, chaff, and broken kernels.

2. Proximate analysis

The rice kernels were milled into flour and analyzed for moisture, fat, protein, ash and fiber according to AOAC (2000) [1] standards.

3. Phytochemical properties

3.1 Total phenolic content

The total phenolic content (TPC) was determined using a modified version of the FolinCiocalteu method as explained by Chen *et al*. (2022a) [7]. Concisely, gallic acid monohydrate (0.025 g) was mixed in 60% ethanol to create the standard curve. The resulting solution was then diluted to 250 mL using the same solvent. Pipettes were used to transfer aliquots of 50 mL gallic acid monohydrate solution (0.00, 0.25, 0.50, 0.75, 1.00, 1.25, and 1.50 mL) into cuvettes. The volume of each cuvette was adjusted to 10 mL by adding 1 mL of Folin-Ciocalteu reagent and 2 mL of 12% Na_2CO_3 solution. The mixtures were then incubated at 30°C for one hour. A gallic acid monohydrate-free control solution was included. Absorbance was recorded at 765 nm using a UV spectrophotometer to determine the total phenolic content (TPC).

3.2 Total flavonoid content (TFC)

The methodology adopted by Ghasemzadeh *et al*. (2018) [12] was used to measure TFC. Twenty mg of rutin was dissolved in 100 mL of deionised water in order to create a standard curve. After transferring aliquots of the rutin solution (0, 0.2, 0.4, 0.8, 1.2, 1.6 and 2.0 mL) to cuvettes, 300 µL of 5% sodium nitrite was added. After five minutes of incubation at room temperature, 300 µL of 10% aluminium nitrate was introduced, and the mixture was incubated for 6 min. The final volume was then adjusted to 10 mL with 60% ethanol after adding 4 mL of 4% sodium hydroxide. After carefully mixing the mixture, it was incubated for 12 min at room temperature. A UV spectrophotometer was used to measure absorbance at 510 nm in order to quantify the TFC.

3.3 Antioxidant assay

2,2-Diphenyl-1-picrylhydrazyl radical scavenging activity (DPPH) assay DPPH radical solution containing 100 µmol/L was made in methanol. In addition, 1.5 mL of DPPH solution was mixed with 100 µL of suitably diluted crude extracts. The absorbance was measured at 517 nm after the mixture was incubated for 30 min at room temperature in the dark (Pang *et al*., 2018) [19]. The following formula was used to determine DPPH scavenging activity (%):

$$DPPH (\%) = (1-A_{sample}/A_{control}) \times 100 \quad (1)$$

FRAP assay

The ferric reducing antioxidant power (FRAP) of the extract was evaluated according to the methodology adopted by Chen *et al*. (2022b) [8]. The FRAP reagent was made by combining 10 mM TPTZ solution (in 40 mM hydrochloric acid), 0.3 M sodium acetate buffer (pH 3.6), and 20 mM ferric chloride in 1:1:10 ratio. A test tube was filled with 10 µL of extract and 240 µL of FRAP reagent. The absorbance of the combination at 595 nm was measured following a half-hour incubation period at 37°C. This formula was used to determine the FRAP activity (%):

$$\text{FRAP reducing activity } (\%) = (1 - A_1/A_2) \times 100 \quad (2)$$

where, A_1 is the FRAP reagent absorption without sample, and A_2 is the extract sample absorption.

4. Dimensional properties

A digital vernier calliper with an accuracy of ±0.01mm was used to measure the average size of ten randomly chosen kernels in terms of their three primary perpendicular dimensions: length (L), width (W), and thickness (T) (Xu *et al*., 2024) [31]. Eq. (3) and (4) was used to calculate the arithmetic mean diameter (Da) and geometric mean diameter (Dg).

$$Da = \frac{(L+W+T)}{3} \quad (3)$$

$$Dg = \sqrt[3]{(L \times W \times T)} \quad (4)$$

where, W = width (mm), T = thickness (mm), and L = length (mm)

The ratio of the kernel's real surface area to the surface area of a sphere with the same volume as the kernel is known as sphericity. The degree to which an object's shape resembles a sphere is measured. The isoperimetric property of a sphere was used to compute the sphericity using Eq. (5) (Varnamkhasti *et al*., 2008) [30].

$$\emptyset = \frac{\sqrt[3]{(L \times W \times T)}}{L} \quad (5)$$

The volume (mm³) of the kernel was computed using Eq. (6), assuming the kernel's shape is like a scalene ellipsoid, where the dimensions follow the relationship L > W > T.

$$Vu = (L \times W \times T \times \emptyset) \quad (6)$$

where, W = width (mm), T = thickness (mm), and L = length (mm), ϕ= sphericity

The shape parameters-flakiness ratio, aspect ratio, and elongation ratio of the rice grains were calculated using Eq.

(7), (8), and (9), respectively. The elongation ratio (*Er*), and flakiness ratio (*Fr*) describe the kernel's shape tendencies, while the aspect ratio (*Ar*) helps determine whether the grains will roll or slide on their flat surfaces.

$$Fr = \frac{T}{W} \quad (7)$$

$$Er = \frac{L}{W} \quad (8)$$

$$Ar = \frac{W}{L} \times 100 \quad (9)$$

Eq. (10) was used to determine the shape of the rice kernels to a sphere with the same geometric mean diameter in order to get their surface area (mm²). The whole area that the object's exterior surface occupies is represented by its surface area (Sa).

$$Sa = (Dg)^2 \quad (10)$$

where, Dg= geometric mean diameter (mm)
The specific surface area (cm²) and projected area (mm²) are the key factors in determining the aerodynamic properties of rice kernels. The surface area perpendicular to an applied force is known as the projected area (Pa), and it is particularly significant for developing devices like kernel cleaners.

$$Pa = \frac{(\pi \times L \times W)}{4} \quad (11)$$

$$Ss = \frac{(Sa.\rho b)}{M} \quad (12)$$

where, W=width (mm), L=length (mm), ρb=bulk density (kg/cm^2), Sa=surface area (cm^2), M = mass of kernels (g)

5. Gravimetric properties

The thousand kernel mass (g) and unit mass (g) of rice kernels were measured using an electronic balance (Ishida MB.150), with an accuracy of 0.001 g. The mass (*M*) to volume (*Vu*) ratio of a sample is known as its bulk density (kg/cm²). It shows how much material can fit in a given amount of space. A measuring cylinder of known capacity is filled with kernels that have been dropped from a height, and the weight of the filled cylinder is determined using an electronic balance in order to calculate bulk density (Qadir & Wani, 2023) [20]. The bulk density is then calculated based on the mass and volume of the sample.

$$\rho b = \frac{M}{Vu} \quad (13)$$

where, Vu= Volume of the kernel (mm^3), M=mass of kernels (g),
The real volume of a known weight of randomly chosen kernel samples was measured in order to ascertain the genuine density. Using the toluene displacement approach, the kernels' real volume was determined. In this method, a measured quantity of rice kernels is immersed in a known volume of toluene in a measuring cylinder, and the displaced toluene volume (Vt) is used to calculate the kernel’s actual volume.

$$\rho t = \frac{M}{Vt} \quad (14)$$

where, Vt= Displaced toluene volume (mm^3), M=mass of kernels (g),
The quantity of pores in bulk material is referred to as porosity (%). It is defined as the ratio of the volume of the pores to the overall volume and represents the volumetric percentage of air contained inside the bulk. The link between true density and bulk density was used to calculate the porosity of rice kernels, as outlined below.

$$\varepsilon = \left(1 - \frac{\rho b}{\rho t}\right) \times 100 \quad (15)$$

where, ρt = True density (kg/m^3), ρb= Bulk density (kg/m^3)

6. Frictional properties

The angle of repose was measured using an open-ended cylinder with a height of 8 cm and a diameter of 6 cm. The cylinder was positioned on a circular plate, filled with kernels, and gradually lifted until a cone shape was created. The diameter and height of the resulting cone were measured using a vernier calliper, and the angle of repose was then calculated as follows (Ghadge & Prasad, 2012) [11].

$$\theta = \tan^{-1}\frac{2h}{d} \quad (16)$$

where, *d*= diameter of the pile (mm), *h* = height of the pile (mm)

The angle of static friction was measured on four different surfaces: perpendicular plywood, parallel plywood, galvanized iron, and glass, as these materials are commonly used in storage, transportation, and handling operations. A bottomless cylindrical pipe with a diameter of 60 mm and a height of 80 mm was positioned on each surface, filled with kernels, and gradually elevated using a screw mechanism till the cylinder began to slide. After measuring the tilt angle (τ) on a graduated scale, the angle of static friction was computed as follows:
$\mu = \tan \tau$ (17)
where, τ = angle of tilt.

7. Mechanical properties

A texture analyser (TAXT2i, Stable Micro Systems) was used to assess the rice kernels' compression behaviour. Three orthogonal directions i.e. horizontal, vertical, and transverse, which were used to examine fifteen kernels. A 75 mm compression platen probe, pre-test speed of 1.5 m/s, test speed of 2.0 m/s, post-test speed of 10 m/s, target value of 5 mm, target type as distance, and trigger force of 10 g were among the test parameters used to determine rupture force (F), deformation at the rupture point (D), energy absorbed at rupture (Ea), toughness (T), and hardness (H), (Sheikh *et al.*, 2021) [22]. A flat probe was used to compress the kernels after they were set on a stationary platform.
The force-deformation curve was used to calculate the rupture force (N), which is the bare minimum of force required to cause a crack or failure in the kernel's microstructure. The change in the rice kernel's initial size at the site of rupture during compression is referred to as deformation at the rupture point (mm). A continuous force decreased on the force-deformation curve or the occurrence of visible or imperceptible failure in the sample, such as the development of cracks, are two indicators of the rupture

point. Hardness (N/mm) is a key parameter related to the strength of the kernel. It is the force required to achieve a given deformation. The area under the force-deformation curve was calculated to determine the energy (N.mm) absorbed by the sample at the rupture site. The energy that the kernel absorbs up to the rupture point, expressed per unit volume (mm³), is known as toughness (mJ/mm³).

$$T = \frac{Ea}{Vu} \quad (18)$$

where, *Vu*= unit volume of kernel (mm³), *Ea*= Energy

8. Pasting characteristics

Rice samples were tested for pasting qualities using a Rapid Visco-Analyzer (RVA,
Model 3D, Newport Scientific Pvt. Ltd., Warriewood, Australia). Three grams of rice flour (14% w.b.) was suspended in 25 ml of distilled water and was heated and cooled under continuous shear (Aoki *et al*., 2012) [2]. The pasting temperature (PT), which indicates the beginning of starch gelatinisation, and the peak viscosity (PV), which represents the rise in viscosity as the temperature rises following PT, were among the characteristics measured. While setback, which represents the last phase of the pasting curve, happened during cooling as the viscosity increased once more as a result of granule retrogradation following the last holding period, breakdown took place during the continual high temperature holding phase.

9. Color measurement

A colorimeter (Colour i5, Gretag Macbeth) was used to measure the rice kernels' colour. The colorimetric parameters L^*, a^*, and b^* were recorded by placing the kernels in a glass container with an optically clear bottom (Susmitha *et al*., 2022) [27]. In this case, L^* denotes lightness, a^* the sample's red-to-green spectrum, and b^* its blue-to-yellow spectrum. The colour variance between various rice samples was calculated using the total colour difference (ΔE^*).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (19)$$

$$\Delta a^* = (a^* - a_0), \Delta b^* = (b^* - b_0), HL^* = (L^* - L_0)$$

where, L_o, a_o, and b_o represent the colorimetric parameters of the control sample.

10. Cooking properties

Cooking time

Two grams of entire rice kernels were boiled in 20 mL of distilled water to estimate the cooking duration. The kernels were then squeezed between two glass slides until no white core was left in them. By adding 2 min to the time it took for the kernels to reach this stage, the ideal cooking time was determined.

Water uptake ratio

In a 200 ml beaker set in a water bath, 2 g of rice were cooked in 20 mL of distilled water to calculate the water uptake ratio. The rice was cooked, and any leftover water was poured off (Chavan *et al*, 2018) [5]. Because of varietal variances, the draining procedure was independent of cooking time.

$$\text{Water Uptake Ratio (g/g)} = \frac{\text{Weight of cooked rice sample}}{\text{Weight of uncooked rice sample}} \quad (20)$$

This ratio reflects how much water the rice absorbs during cooking, providing insight into the rice's cooking properties and texture.

Solids in gruel loss

After drying the gruel made from rice (2 g boiled in 20 ml distilled water) until the minimum cooking time was reached, the total solids left behind were used to calculate the solids in gruel loss. After being moved to a petri dish, the gruel was dried completely in a hot air oven set at 110°C (Chen, 2014) [6]. The weight of the petri plates with dried gruel (W_2) and empty (W_1) were noted. The following formula was used to determine the solids in gruel loss:

Solids in Gruel Loss=$W_2 - W_1$ (21) where, W_2 = weight of empty dish + dry gruel, W_1 = weight of empty petri plate

This method helps evaluate the amount of starch or other solids that leach out during cooking, which can affect the rice's texture and quality.

Elongation ratio

In order to determine the elongation ratio, the length of cooked rice kernels was measured on graph paper and divided by the length of raw, uncooked kernels. The findings were expressed as the elongation ratio, which shows how much length increased while cooking. This ratio provides information on how rice kernels expand and is frequently used to evaluate the textural qualities and cooking quality of various rice types.

11. Statistical analysis

A minimum of three replicates were used for the statistical analysis, and the mean ± standard deviation was used. A one-way analysis of variance (ANOVA) was performed to evaluate the variation between several samples (STATISTICA7.ink). Significant variations between treated samples were found ($p<0.05$) using Duncan's multiple range test.

Results and discussion

1. Proximate analysis

The moisture content of both red rice var. *Chhohartu* and basmati rice samples was 14.63% and 10.32%, respectively (Table 1). The difference in moisture content could be influenced by variations in growing locations, harvesting seasons, and storage conditions. The crude carbohydrate and protein contents of the two samples showed significant differences, while the crude fiber, ash and fat contents varied only slightly. The carbohydrate content was 76.78% to 78.80%, while the crude protein content was 5.12% and 7.08% in red rice var. *Chhohartu* and basmati rice samples. Jan *et al*. (2017) [13] and Thakare *et al*. (2023) [28] reported similar outcomes for basmati rice.

2. Phytochemical analysis

Red rice var. *Chhohartu* had a flavonoid and phenolic content of 0.42 mg RE/g and 3.00 mg GAE/g respectively, which was much higher than basmati rice variety i.e. 1.60 mg GAE/g and 0.15 mg RE/g (Table 1). The phenolic substances reduce oxidative stress and prevent cellular damage by acting as scavengers of free radicals, whereas flavonoids enhance the antioxidant potential by donating electrons or hydrogen atoms (Sompong *et al*., 2011) [26]. The antioxidant activity was measured by FRAP assay and DPPH radical scavenging. DPPH radical scavenging activity was found to be 91.18% for red rice and 24.03% for basmati rice, which was again significantly higher than basmati rice. This indicates that red rice has a much stronger ability to neutralize free radicals, which can contribute to better health benefits, such as reduced risks of chronic diseases and improved cellular function (Nath *et al*., 2022) [18]. Similarly, significant difference was also observed for the FRAP assay which indicate the ability of antioxidants to reduce ferric ions to ferrous ions, where the FRAP values were much higher in red rice. This may be due to the reason that red rice contains anthocyanin in outer bran layer, which raises its antioxidant activity (Shen *et al*., 2009, Bhat & Riar, 2017) [24, 3].

3. Dimensional properties

The length of red rice was 5.81 mm, but basmati rice displayed a larger length of 8.74 mm, indicating that basmati rice can be classified as long grain and red rice as medium grain variety (Table 2). On the other hand, the width and thickness of red rice was more than the basmati variety. Similar results for basmati rice were reported by Naseer *et al*. (2020) [17]. The geometric mean diameter and arithmetic mean diameter of kernels are fundamental geometric metrics associated with the shape that are essential for developing size and grading equipment. The arithmetic mean diameter was more in basmati variety, whereas the geometric mean diameter was more for red rice. Sphericity is the index of the roundness of the rice kernels. The sphericity value in red rice was slightly higher but the aspect ratio of red rice was much higher than basmati rice. The lower sphericity value of basmati rice depicts its resemblance to a cylindrical shape. Larger aspect ratio and sphericity values often mean that it will be easier to induce the kernels to roll like peas or spheroid grains (Qadir & Wani, 2023) [20]. On the other hand, the ones with lower values can slide on their flat surfaces. This propensity to roll or slide should be required when designing hoppers for the milling process. Red rice was found to have larger volume and surface area than basmati rice. The heat transfer surface has a major impact on the rate of heat transmission to the substance. A material's ability to transport heat quickly improves with a reduced volume per unit surface. Using the surface to volume ratio, one may also characterise how surface area and size affect the drying rates of particulate matter. Compared to smaller particles of the same shape, larger particles dry more slowly when the drying rate is limited by water diffusion within the particle (Ghadge & Prasad, 2012) [11]. The specific surface areas for red rice and basmati rice are 0.27 cm^2 and 0.54 cm^2, respectively, while the projected areas were found to be 13.28 mm^2 and 13.15 mm^2 (Table 2). Increased projected and specific surface area can affect the rate of heat transfer and water absorption in rice kernels during cooking, as well as the effectiveness of grain separation during grading. Moreover, the behaviour and shape of the kernel on oscillating surfaces during processing may be ascertained with the specific surface area. The shape parameter values show the kernel's tendency to be flat and oblong.

4. Gravimetric properties

The thousand kernel weight was found to be more in red rice. Weight is important when designing a grain cleaning system that uses aerodynamic forces. The higher moisture content of red rice may be the cause of its increased weight, which may also have an impact on its storage. The bulk density value was more for the basmati variety, whereas the true density and porosity values were more in red rice (Table 3). When designing storage bins and silos, the bulk density of grains is helpful (Nalladulai *et al*., 2002) [16]. The basmati rice variety would need a larger silo than the red rice with the same weight since the latter has a higher bulk density. True density aids in separating cereal crops on pneumatic sorting tables. The difference in porosity values reflected both bulk and actual density, which are dependent on various factors such as grain diameters and other variables (Devraj *et al*., 2020) [9].

5. Frictional properties

The angle formed between the conical pile's surface and the horizontal surface, or the maximum slope of a stockpile or conical pile created when bulk granular materials are poured onto a horizontal surface is known as the angle of repose (Mirzabe *et al*., 2017) [15]. It shows the cohesiveness of the separate material units and is a reliable predictor of the product's flow (Samyor *et al*., 2016) [21]. The angle of repose for red rice and basmati rice were found to be 39.85º and 36.78º, respectively (Table 3). This phenomenon is crucial for food grain processing, especially when building hoppers for milling machinery. The higher angle of repose in red rice may be attributed to a layer of moisture on the surface of the kernels, which binds the rice grains together through surface tension. This increased cohesion causes the kernels to stick together, leading to greater stability and reduced flowability. Static friction can be defined as the force needed to begin sliding a resting object over the surface divided by the normal force (the object's weight) or as the tangent of an inclined plane's angle (τ) (Varnamkhasti *et al*., 2008) [30]. The angle of static friction varied among three contacting surfaces that are frequently used for handling, storing, and moving rice kernels: plywood, glass, and galvanised iron. For both rice samples, plywood had the greatest angle of static friction, followed by galvanised iron and glass (Table 3).

6. Mechanical properties

The rupture force was more for the basmati rice sample (Table 3). This indicates that basmati rice exhibits higher resistance to mechanical stress before breaking as compared to red rice. Additionally, it was found that the distortion at the rupture point was minimal for low-moisture rice, measuring 0.34 mm for red rice and 0.46 mm for basmati rice. The variation in moisture content, physical characteristics, and surface area of the kernels may cause the variation in rupture force (Fig. 1), which shows that red rice requires less compression to rupture. The hardness values of red rice and basmati rice were 60.21 and 138.31 N respectively, whereas the toughness values for red rice and basmati rice were 2.98 and 4.85 mJ/mm^3, respectively. These values suggest that basmati rice requires more energy to break, indicating a denser internal structure as compared to red rice. The findings further reinforce the correlation between structural integrity and mechanical properties, where basmati rice, due to its compact structure, can withstand higher rupture forces before breaking. The findings showed that increased moisture content decreased the hardness and force required to rupture the kernel of red rice. Due to the elongated grain structure, compact internal composition, and higher amylose content of basmati rice, it enhances its resistance to deformation and cracking.

7. Pasting properties

Both the rice varieties were examined for the pasting properties, and it was observed that red rice was having a more viscous nature than basmati rice. For red rice, the peak viscosity was 1715 cp, while for basmati rice, it was 717 cp. This relates to the capacity of rice flour starch to absorb water and expand when heated. Flour with a greater peak viscosity typically has stronger molecular integrity and superior swelling power (Shen *et al*., 2022) [23]. The breakdown measurement of the structural disintegration of starch after cooking was greater in red rice (465 cP), whereas in basmati rice, it was lower (142 cP). The breakdown viscosity shows how stable the starch granules are under agitation and heating. A higher breakdown viscosity indicates weaker starch granules that are more likely to disintegrate, whereas a lower value indicates more resistance to shear and heat. The ability of a starch-based flour to form a viscous paste after cooking and cooling is a common way to characterise its quality. The final viscosity values of red rice and basmati rice were 3594 and 1059 cp, respectively. Moreover, in terms of syneresis and retrogradation tendency of starch, the setback was found to be higher in red rice (2344 cP) and lower in basmati rice (484 cP). The pasting temperature was found to be higher in the basmati cultivar. The basmati rice and red rice had pasting time of 7 min, respectively. This indicates the lowest temperature and time needed to cook a specific rice sample, and the temperature at which the increase in viscosity begins (Kaur *et al*., 2023) [14].

8. Colour

Red rice and basmati rice's colour parameters (L^*, a^*, and b^*) were recorded (Table 4). L^* value indicates how light or dark the rice kernels are, which was found to be 34.70 and 40.13 for red and basmati rice variety. Redness, indicated by the a^* value, was lower for basmati rice (2.63) and higher for the red rice (10.40). The lower L^* value and higher a^* value in red rice is due to the presence of anthocyanins in its outer bran layer, which gives the rice its characteristic red hue. On the other hand, basmati rice, which lacks such pigmentation, exhibits a much higher L^* value and lower a^* value, making it appear less red. The b^* value indicating yellowness was less in red rice. Lower b^* value in red rice indicates that it has a reduced yellow component as compared to basmati rice, which has a slightly higher b^* value. Colour parameters a^* and b^* were used to determine hue, an alternative measure of colour property, and chroma, an indication of colour intensity. Red rice showed a reduced hue angle, indicating a greater reddish tone, because of its higher a^* value and lower b^* value. However, basmati rice had a larger hue angle, which made it appear lighter and less vivid in colour due to its relatively balanced a^* and b^* values. There was no discernible change in chroma, a measure of colour saturation or intensity, between the two types. However, it was discovered that red rice had a substantially larger total colour difference (ΔE) value than basmati rice.

9. Cooking properties

It was observed that red rice took more time to cook than basmati rice. It might be because of the presence of a bran layer on red rice (Table 4). This outer layer, which contains fibre, anthocyanin, and vital nutrients, forms a barrier that delays heat penetration and water absorption, increasing the cooking time. The water uptake ratio was higher in the case of basmati rice as compared to red rice, which is a measure of the amount of water absorbed by rice during cooking. This difference suggests that basmati rice has a greater capacity to absorb water, which is probably due to its relatively loose starch structure. This contributes to the characteristic soft and fluffy texture of basmati rice upon cooking. In contrast, red rice with its intact bran layer and dense structure, absorbs less water and retains a firmer texture even after cooking. It was also influenced by bulk density of the grains. The rice with higher bulk density had a higher value of water uptake ratio. Similar trend was observed by Bhat & Riar (2017) [3] on various red rice cultivars of Kashmir. The higher water uptake ratio of basmati rice also suggests that more starch is released into the cooking water, resulting in a greater solid loss (Chavan *et al*., 2017) [4]. Thus, the solid loss in gruel and the elongation ratio, which is the extent to which rice grains increase in length after cooking also showed the same trend. This aligns with the characteristics of basmati rice, which is characterized by long, thin grains that lengthen more dramatically when cooked. Red rice, on the other hand, does not stretch as much and tends to maintain its shape, probably because of its stronger structure and the bran layer, which can prevent the grains from expanding.

Table 1: Proximate composition and phytochemical properties of red rice var. *Chhohartu* and Pusa Basmati 1509

Proximate composition	**Red rice**	**PB 1509**
Moisture	14.63 ± 0.15^b	10.32 ± 0.12^a
Crude fat	1.67 ± 0.09^a	1.74 ± 0.04^a
Crude protein	5.12 ± 0.07^a	7.08 ± 0.10^b
Ash	0.78 ± 0.08^a	0.98 ± 0.01^b
Crude fibre	1.01 ± 0.04^a	1.08 ± 0.04^a
Carbohydrates *Phytochemical properties*	76.78 ± 0.22^a	78.80 ± 0.14^b
Total phenolic content (mg GAE/g)	3.00 ± 0.10^b	1.60 ± 0.11^a
Total flavonoid content (mg RE/g)	0.42 ± 0.03^b	0.15 ± 0.01^a
DPPH radical scavenging activity (%)	91.18 ± 0.91^b	24.03 ± 1.62^a
FRAP (%)	72 ± 1.00^b	33.33 ± 1.53^a

$^{a-b}$ row values followed by the same superscript letter are not significantly different (*p<0.05*); Mean± standard deviation values of triplicates.

Table 2: Dimensional properties of red rice var. *Chhohartu* and Pusa Basmati 1509

Parameters	*Red rice*	*PB 1509*
Length (mm)	5.81±0.14 ^{a}	8.74±0.12^{b}
Width (mm)	2.91±0.11^{b}	1.92±0.07^{a}
Thickness (mm)	2.03±0.06^{b}	1.72±0.03^{a}
Arithmetic mean diameter (mm)	3.58±0.09^{a}	4.12±0.01^{b}
Geometric mean diameter (mm)	3.25±0.08 ^{b}	3.06±0.03^{a}
Sphericity (ϕ)	0.56±0.01^{b}	0.35±0.01^{a}
Volume (mm^3)	19.19±1.70^{b}	10.11±0.54^{a}
Surface area (mm^2)	33.14±1.68^{b}	29.50±0.59^{a}
Projected area (mm^2)	13.28±0.75^{a}	13.15±0.29^{a}
Aspect ratio (%)	50.06±1.36^{b}	21.94±1.04^{a}
Specific surface area (cm^2)	0.27±0.01^{a}	0.54±0.01^{b}
Flakiness ratio	0.70±0.01^{a}	0.90±0.29^{a}
Elongation ratio	1.99±0.05^{a}	4.56±0.22^{b}

Mean± standard deviation values of triplicates; $^{a-b}$ row values followed by the same superscript letter are not significantly different (*p<0.05*).

Table 3: Gravimetric, frictional, mechanical and pasting properties of red rice var. *Chhohartu* and Pusa Basmati 1509

Gravimetric Properties	*Thousand Kernel Weight (g)*	*Bulk Density (g/ml)*	*True Density (g/ml)*	*Porosity (%)*			
Red Rice	21.30±1.44^{a}	0.68±0.16^{a}	1.56±0.11^{b}	55.55±13.76^{b}			
PB 1509	20.48±0.14^{a}	0.91±0.08^{a}	1.24±0.11^{a}	26.09±11.17^{a}			
Frictional Properties	*Angle of Repose*	*Coefficient of st atic Friction*					
		Glass	*Galvanized Iron*	*Plywood parallel*	*Plywood perpendicular*		
Red Rice	39.85±2.26^{a}	0.23±0.02^{a}	0.30±0.01^{a}	0.34±0.02^{a}	1.58±0.09^{b}		
PB 1509	36.78±0.91^{a}	0.29±0.04^{b}	0.32±0.01^{a}	0.33±0.02^{a}	0.35±0.02^{a}		
Mechanical Properties	*Rupture force (N)*	*Deformation at rupture point (mm)*	*Hardness (N)*	*Energy (N.mm)*	*Toughness (mJ/mm^3)*		
Red Rice	43.66±1.08^{a}	0.34±0.03^{a}	60.21±1.04^{a}	57.11±0.94^{b}	2.98±0.01^{a}		
PB 1509	83.66±1.60^{b}	0.46±0.01^{b}	138.31±1.67^{b}	49.06±0.96^{a}	4.85±0.06^{b}		
Pasting Properties	*Peak Viscosity (cp)*	*Hold Viscosity (cp)*	*Breakdown Viscosity(cp)*	*Final Viscosity (cp)*	*Setback Viscosity (cp)*	*Pasting Temperature (℃)*	*Pasting Time(min)*
Red Rice	1715.00±3.05^{b}	1250.00±4.25^{b}	465.00±1.22^{b}	3594±3.23^{b}	2344±4.23^{b}	90.50±0.22^{a}	7.00±0.02^{a}
PB 1509	717.00±4.52^{a}	575.00±5.03^{a}	142.00±1.35^{a}	1059.00±3.52^{a}	484.00±4.52^{a}	95.25±0.32^{b}	7.00±0.03^{a}

Mean± standard deviation values of triplicates; Values with letters in superscript are not significantly different (*p<0.05*)

Table 4: Color parameters and cooking properties of red rice var. *Chhohartu* and Pusa Basmati 1509

Color	*L**	*a**	*b**	*Hue° Chroma*	*ΔE*
Red Rice	34.70±0.90^{a}	10.40±1.27^{b}	14.20±1.05^{a}	53.70±4.76^{a} 17.66±0.75^{a}	61.65±1.00^{b}
PB 1509	40.13±1.52^{b}	2.63±0.30^{a}	17.20±1.71^{b}	81.28±0.85^{b} 17.40±1.72^{a}	56.34±1.99^{a}
Cooking properties	*Cooking time (min)*	*Water uptake (g/g)*	*Solid loss in gruel (%)*	*Elongation ratio*	
Red Rice	25.00±2.50^{b}	2.50±0.10^{a}	3.43±1.62^{a}	1.43±0.21^{a}	
PB 1509	18.00±2.00^{a}	3.33±0.30^{b}	4.80±1.48^{a}	1.90±0.14^{b}	

Mean± standard deviation values of triplicates; $^{a-b}$ column values followed by the same superscript letter are not significantly different (*p<0.05*)

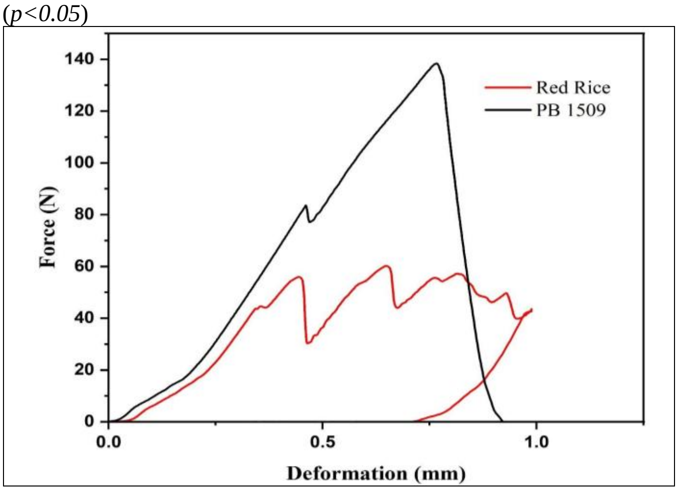

Fig 1: Force-Deformation curves for red rice var. *Chhohartu* and Pusa Basmati 1509

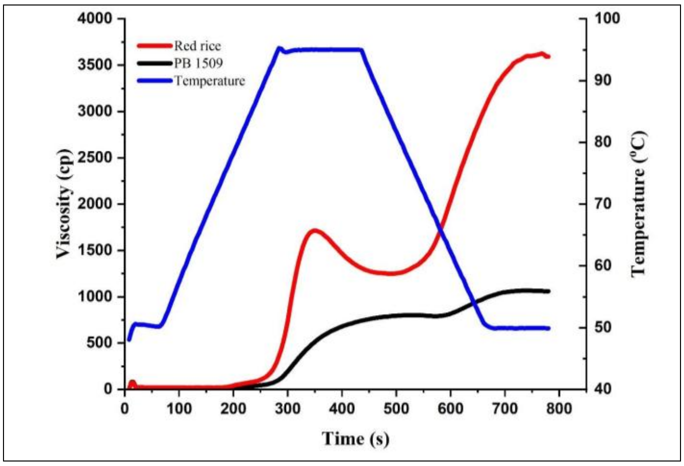

Fig. 2. RVA profile of red rice var. *Chhohartu* and Pusa Basmati 1509

Conclusion

This study draws a clear contrast between red rice and basmati rice across a range of characteristics, from nutritional and phytochemical profiles to physical and cooking properties. Red rice, with its rich phenolic and flavonoid content, stands out as a nutrient-dense grain offering robust antioxidant benefits. Its red pigmentation, attributed to anthocyanins, adds both visual appeal and health value. On the other hand, basmati rice is known for its exceptional cooking quality, particularly its elongation and delicate aroma, making it a staple for premium culinary applications. According to dimensional studies, red rice grains are often wider and shorter than basmati rice grains, which are elongated and slender. In terms of mechanical properties, basmati rice exhibits higher hardness and resilience, which increases its resistance to breaking during handling and milling. Because of its rougher surface, red rice has higher frictional qualities, such as the angle of repose, which also influences its flow behaviour. In contrast to basmati rice, which cooks quickly and causes the grains to elongate, red rice takes longer to cook and has a harder texture after cooking. The physical and mechanical analyses revealed that red rice, being sturdier, is better suited for functional food formulations, while basmati rice, with its superior flow properties, aligns well with processing and storage needs. The distinctiveness of red rice is further shown by color analyses, which contrast the delicate white color of basmati rice with the intense redness caused by anthocyanins. This comparative analysis not only highlights the unique strengths of each variety but also emphasizes their complementary roles—red rice as a health-focused grain and basmati rice as a culinary favourite. Together, they cater to diverse consumer preferences and food industry demands.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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