
CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

EVALUATION OF QUALITY PARAMETERS OF PARBOILED AND NON-PARBOILED ZINC BIOFORTIFIED BRRI DHAN84 RICE VARIETY IN BANGLADESH

Tanjina Akter[1,2], Md. Shihabul Awal[1], Md. Abdul Wazed[3], Anwara Akhtar Khatun[1], Md. Shakil[2], Md. Murtuza Kamal[4], Md. Hasan Al Banna[5], N. H. M. Rubel Mozumder[1]✉

[1]*Department of Food Science and Nutrition, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.*
[2]*Department of Food Technology, Chulalongkorn University, Bangkok-10330, Thailand.*
[3]*Department of Food Engineering and Technology, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.*
[4]*Department of Food Processing and Preservation, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh.*
[5]*Faculty of Nutrition and Food Science, Patuakhali Science and Technology University, Bangladesh.*
✉ *rubel.infs@hstu.ac.bd*

https://doi.org/10.34302/crpjfst/2023.15.3.6

Article history:
Received: 11 September 2022
Accepted: 10 August 2023

Keywords:
Biofortification,
BRRI dhan84,
Parboiling,
Quality parameters,
Zinc rice.

ABSTRACT

Zinc deficiency is a global public health problem in developing countries, including Bangladesh, where rice is the primary consumed staple food. To combat zinc deficiency in Bangladesh, BRRI dhan84 (paddy) has been released as a zinc-biofortified and high-yielding rice variety. Therefore, the objective of this study was to evaluate the changes in physicochemical properties, nutritional attributes, and contents of zinc in newly released rice variety after parboiling and cooking using standard methods. Significant differences were noted among different properties. The study revealed that the parboiling method increased fat (2.36%), protein (9.42%), and zinc (2.741%), whereas those not using parboiling methods resulted in 1.72% fat, 6.68% protein and 2.732% zinc. In contrast, other components like fiber, carbohydrates, ash, and iron decreased after parboiling. Physicochemical analysis showed that parboiled rice was found to be slightly higher in length (6.507 mm), broader in width (2.032 mm), lower in solid gruel loss (0.090%), and also higher in head rice yield (80.09%) than non-parboiled rice. A prolonged cooking time of approximately 39.41 minutes was observed in parboiled rice as compared to non-parboiled rice. However, the cooking process negatively affected the nutrient contents of both parboiled and non-parboiled rice than uncooked or raw rice. Zinc content was generally similar between parboiled and non-parboiled rice after cooking (2.264-2.344 mg/100g). The sensory test further revealed that the parboiled rice obtained more overall acceptability, although the rice color was darker than that of non-parboiled rice. The study concluded that, depending on desired physicochemical and nutritional properties, the zinc-biofortified BRRI dhan84 rice variety could be the important option for improving rice grain nutritional quality to overcome the micronutrient problem in Bangladesh.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most common and consumed cereals worldwide, and it is considered a staple food by 50% of the world’s population (Liu et al., 2019). A significant proportion (50-85%) of the daily energy requirements of the world's population, especially those living in Asian and African continents, are fulfilled by their daily rice consumption (Zeng et al., 2010). In general, rice contains macronutrients, mainly carbohydrates, protein, and dietary fibers, together with micronutrients, including vitamin A and several B vitamins, and also minerals. It also contains trace minerals, most importantly zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu), and the relative contents of these trace minerals may vary depending on several factors, typically varieties, fertilizer used, soil type, milling technique, environmental condition, and cultivation methods, etc. (Verma & Srivastav, 2017). In particular, the level of Zn (11–16 µg/g) in rice is subjective to the milling process and thus distinctly varied from county to county, causing the low intake of Zn when compared with estimated average requirements (EAR) in a population group (Mayer et al., 2008). According to the World Health Organization (WHO), zinc deficiency is one of the fifth leading etiological causes of illness and diseases in developing countries, ranked eleventh globally (Cakmak, 2008). Globally, about 17% of the population is estimated to be at risk of inadequate dietary zinc intake, and the number is as high as 22% in East and Southeast Asia (Wessells & Brown, 2012). An additional 175 million people globally, including 63 million in South Asia, are expected to become Zn deficient by 2050 (Smith & Myers, 2018). In Bangladesh, numerous people, especially children and pregnant women, suffer from micronutrient deficiencies, particularly zinc insufficiency (Nguyen et al., 2014). Hence, there is a continuous search to improve the deficiency problem of Zn by adopting dietary-based interventions relating to cost-effective management practices such as genetically modified plant breeding and biofortification.

Parboiling is a hydrothermal process that alters the quality and processing behaviors of rice by first soaking the paddy in water to become tender, followed by draining, heating, and or steaming to precook the grain, and finally drying (Bhattacharya, 2011). This plays a vital role in postharvest handling and processing, including storage, milling, cooking, and eating quality (Patindol et al., 2008). During milling, the breakage of parboiled rice is significantly decreased by healing the cracks and chalkiness of rice kernels. Parboiling also improves the nutritional quality of rice, preventing the loss of vitamins and other micronutrients during milling. Cooked parboiled rice is firmer, fluffier, and less sticky than cooked raw rice (Bhattacharya, 2011). Mayer et al. (2008) evaluated the impact of milling on Bangladeshi parboiled rice, reporting 24–39% lower Zn concentration in milled compared to non-milled (brown) parboiled rice. Biswas et al. (2018) reported that Zn concentration in milled parboiled rice was 8–20% lower compared to brown parboiled rice, but it was 13–28% higher than milled non-parboiled rice. In contrast, Denardin et al. (2004) reported 44% lower Zn concentration in milled parboiled rice compared to milled non-parboiled rice without reporting the degree of milling.

HarvestPlus and its partners specifically target these essential micronutrients to improve the nutritional profile of commonly consumed staple crops such as maize, wheat, and rice to address this nutritional gap. (Jena et al., 2018; White & Broadley, 2009). A study conducted in Asia has revealed that biofortified rice varieties with up to 28 micrograms per gram in the milled grain have improved the Zn intake of Zn deficient population groups (Andersson et al., 2017). Thus, this establishes the opportunity for increasing daily Zn intake, particularly when combined with dietary diversity and nutritional education approaches (Singh et al., 2016), which could combat and eradicate deficiency problems of this micronutrient (Bouis et al., 2011). Though several strategies currently exist to combat micronutrient deficiencies or "hidden hunger" through food fortification, distribution of dietary supplements, and promotion of dietary diversification (Bouis et al., 2011), in many situations, these methods are unsuccessful due to elevated costs, complex logistics, low compliance, and limited access to various foods (Singh et al., 2016). Over the past few decades, Bangladesh Rice Research Institute (BRRI), in collaboration with Harvest Plus, has developed five open-pollinated zinc rice cultivars, such as BRRI dhan62, BRRI dhan64, BRRI dhan72, BRRI dhan74, and BRRI dhan84 in the years of 2013, 2014, 2015, 2015, and 2017 respectively. Among all these varieties, BBRI dhan84 is a newly developed improved variety with a high yield over the other zinc biofortified rice varieties for the Boro season. It was genetically modified through crossing between BRRI dhan29/IR68144//BRRIdhan28///BR11 to get a higher zinc content in polished grain. BRRI dhan84 is a fine-slender-grain with a red pericarp (Kader et al., 2020). This new zinc rice variety offers competitive yield characteristics with market-leading varieties for commercial production. BRRI dhan84 contains the highest zinc level (27.6 ppm) among the other zinc rice varieties. The protein and amylose percentages of BRRI dhan84 are 9.7% and 25.9%, respectively. BRRI dhan84 is a straight type that can be processed in any milling machine, with a milling outturn of 70% and a head rice recovery of 53% (Kader et al., 2020).

Recently, a grain quality characterization and a sensory acceptability analysis were carried out with two varieties of zinc-biofortified rice and local control by Woods et al. (2020). Their results showed that the grain quality properties of rice have an influence on acceptability and that consumers accept zinc-biofortified rice varieties. In another study, Hotz et al. (2015) determined the increase in zinc and iron content in Bangladeshi rice varieties when zinc sulfate and iron–EDTA were added to the soaking water before parboiling, using local parboiling conditions. The results displayed that the addition of 1300 mg zinc L^{-1} increased raw polished rice zinc content from 16.6 to 44.9 mg kg^{-1} and from 12.6 to 32.9 mg kg^{-1} in the open and closed parboiling systems, equivalent to 170% and 161% increases, respectively. Retention of zinc after washing and cooking was 70–81% across all concentrations tested (Hotz et al., 2015).

Numerous researches have already been performed regarding the nutritional properties, functional properties, and other effects of rice and rice bran. However, to the best of our knowledge, no detailed study has been conducted concerning the proximate, functional properties, and cooking qualities of zinc-biofortified rice in Bangladesh. Therefore, the current study is designed to determine the proximate composition, physicochemical properties, and cooking characteristics of parboiled and non-parboiled zinc-biofortified BRRI dhan84 rice so that after consuming this product the deficiency of Zn could be reduced in Bangladesh.

2. Materials and methods

2.1. Rice samples

A newly released zinc biofortified rice (BRRI dhan84) was collected from the regional branch of the Bangladesh Rice Research Institute (BRRI), Rangpur, Bangladesh. After collection, foreign materials were removed from the paddy and separated into two batches. Each batch was individually packed in a polythene bag and stored at room temperature. One batch was processed further as a parboiled rice sample, and the other was considered as a non-parboiled sample.

2.2. Sample Preparation

2.2.1. Parboiling and milling technique of BRRI dhan84

The collected paddy sample was divided into two portions. One portion was used as non-parboiled, and another portion was utilized for parboiling operation. The general workflow of this study is shown in Figure 1. This study used the traditional parboiling method, where paddy was first soaked in normal water (1:4 w/v) for

12 hours at ambient temperature. The water was drained, and then the hydrated paddy was placed in an aluminum pot with water for boiling. Boiling was stopped whenever the paddy seemed to be boiled by visual inspection. Then, the boiled paddy was spread on the floor under the sun for drying. In the case of non-parboiling rice, collected paddy was directly dried under the sun without soaking and boiling.

The dried parboiled and non-parboiled paddy was dehulled using a laboratory dehusking machine (model number- THU35B-3-T). All the dehulled rice was put in sealed polyethylene bags without milling and stored at room temperature for further analysis.

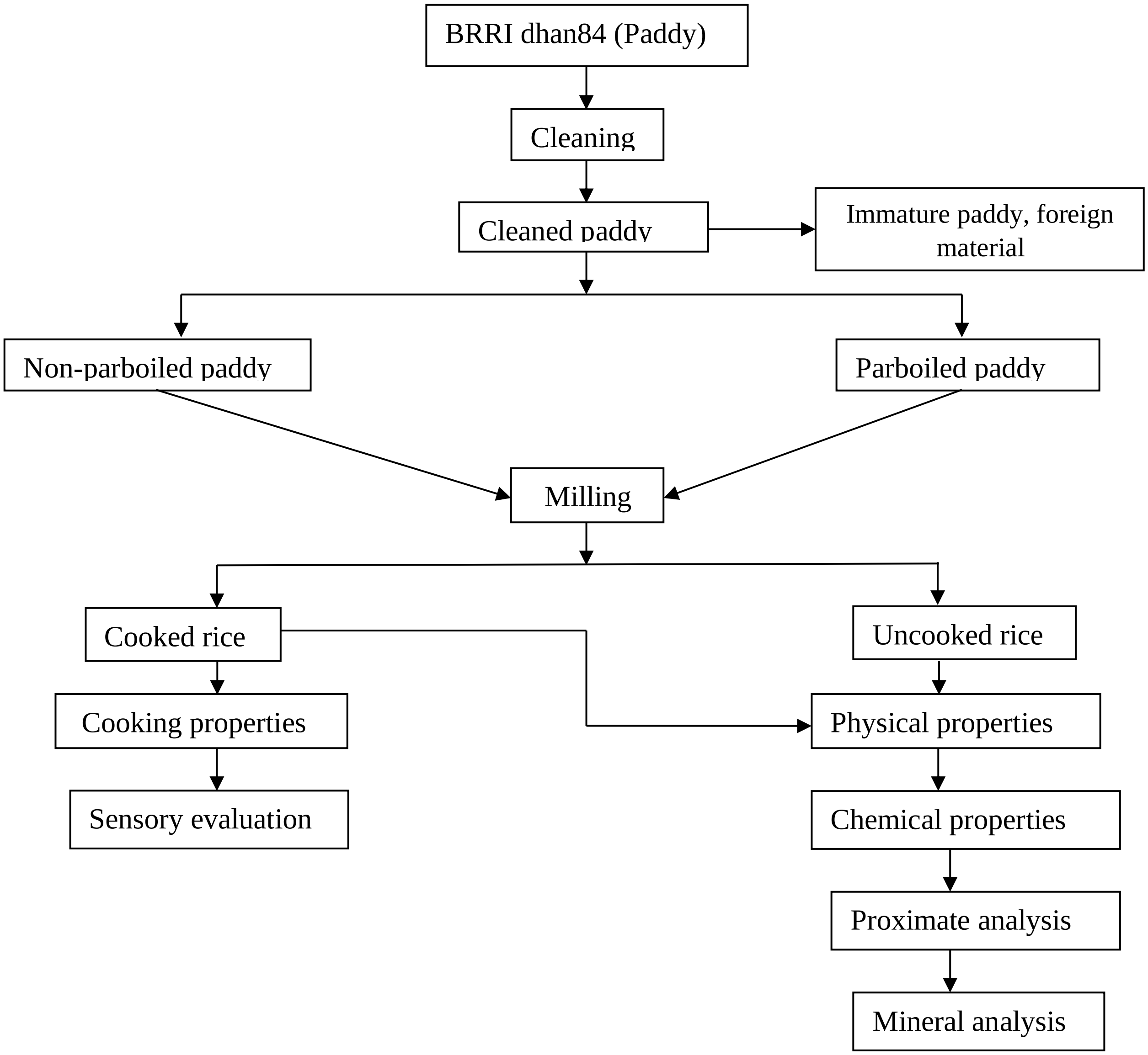

Figure 1. The flowchart of this study design

2.3. Physical properties

2.3.1. Length and width

The length and width were determined manually using a micrometer digital screw gauge. After de-husking, ten whole rice kernels were randomly chosen from each non-parboiled and parboiled sample. The average length (mm) and width (mm) of these grains were recorded (Fofana et al., 2011).

2.3.2. Length-breath ratio

The length and breadth (at the midpoint) of 10 uncooked head rice kernels were measured using a micrometer digital screw gauge. The length-breath ratio was determined by dividing the cumulative length of 10 rice kernels by the breadth of 10 kernels. A mean of three replicates was taken for this measurement (Sanusi et al., 2017).

2.3.3. Bulk density

First, rice was taken up to the 100 ml mark in a beaker, and then measured the mass of rice grains without the beaker. The recorded mass of the rice grain was divided by the rice volume.

2.3.4. Thousand kernel weights

The 1000 rice kernel was selected randomly and then carefully weighed on a digital scale (Kern 572-30) with an accuracy of 0.001g. The procedure was repeated three times, and average values were taken in grams (Varnamkhasti et al., 2008).

2.3.5. Head rice yield

Head rice was defined as dehusked rice grains with a length of more than three-quarters of the whole grain. The head rice was manually separated from 50 g of cleaned dehusked rice sample. Then, the head rice yield (HRY) was calculated using the method stated by Wazed et al. (2021) and Wazed et al. (2022) as follows:

$$\%\ \text{Head rice yield} = \frac{\text{Weight of head rice}}{\text{Weight of milled rice sample}\,(\text{g})} \times 100 \qquad (1)$$

2.4. Cooking properties of BRRI dhan84 rice

2.4.1. Cooking time determination

The cooking was conducted using an electric rice cooker (Miyako electric rice cooker) for both samples. 10 g of non-parboiled rice sample was taken in a bowl and rinsed adequately with water before being cooked. Then, the rice kernels were placed in the cooking pot of an electric rice cooker with the rice to water ratio of 1:3 (w/w), and cooking was continued until the electric cooker automatically turned off. Simmering was done for 5 minutes to obtain completely cooked rice. The exact cooking process was followed for parboiled rice.

2.4.2. Elongation ratio and length–breadth ratio

The elongation ratio was measured according to the method described by Sanusi et al. (2017). The length of 10 randomly selected cooked rice was measured, and then the average length of 10 cooked rice was divided by the average length of uncooked rice. This procedure was repeated three times, and average values were taken. The elongation ratio was expressed as follows:

$$\text{Elongation ratio} = \frac{\text{Average length of cooked rice (mm)}}{\text{Average length of uncooked rice (mm)}} \qquad (2)$$

2.4.3. Water uptake ratio

10 g of rice were cooked in 30 ml of distilled water for a minimum cooking time on an electric rice cooker. After cooking, the excess water was drained, and the samples were wiped softly by tissue to remove the clinging surface water on the cooked rice. Then, the cooked rice was weighed, and the water uptake ratio was measured by dividing the weight of the rice after cooking by the weight of the rice before cooking (Zohoun et al., 2018).

2.4.4. Gruel solid loss (%)

10 g of whole rice was taken in an aluminum pot with 30 ml water. The rice kernel was cooked in an induction cooker for the predetermined cooking time. After cooking, the gruel was separated from the cooked rice and transferred into a pre-weighed dried petri dish.

The gruel-containing petri dish was placed in an oven at 100°C for 24 hours to remove moisture. The weight of the petri dish was taken after drying (constant weight), and the mean of the three replicates was recorded. Gruel solid loss was calculated as the ratio of the increase in weight of the dish to the weight of the uncooked rice and expressed as follows (Qadir & Wani, 2022).

$$\text{Gruel solid loss (\%)} = \frac{\text{Increase in weight of petri dish (g)}}{\text{Weight of uncooked rice sample (g)}} \times 100 \qquad (3)$$

2.5. Chemical properties of BRRI dhan84 rice

2.5.1. Determination of starch

The starch content of rice was determined by the Lane and Eynon method (AOAC, 2000). Approximately 5 g of rice powder was taken in a beaker with 30 ml of water and heated in a water bath at 60°C for 25 min. A total of 100 ml of 95% ethanol was added and stirred for 15 min. It was filtered using Whatman filter paper no. 2, and the residue was soaked for 1 h in a 50% ethanol solution. The residue was then filtered and washed in a 50% ethanol solution for 4 h. The residue was collected in a round bottom flask and then filled with 100 ml of water and 20 ml of 6M HCl. The condenser was fitted to the flask and heated for 2.5 hours. The mixture was then allowed to cool before being neutralized with a 40% NaOH solution. After that, 10 ml of Fehling solution was titrated against a neutralized sample solution in a conical flask. When a copper sulfate-like color appeared, 3 drops of methylene blue indicator were added, and the titration continued. The brick-red color denoted the endpoint. The following formula was used to calculate the starch content:

$$\text{\% Reducing sugar} = \frac{\text{Factor for Fehling's solution} \times \text{dilution}}{\text{Titre value} \times \text{ weight of powder}} \times 100 \qquad (4)$$

$$\text{\% Starch} = \text{\% reducing sugar} \times 0.9 \qquad (5)$$

2.5.2. Determination of amylose content

Amylose content was determined by following the methods as described by Sompong et al. (2011) and Alam et al. (2023). A volumetric flask was filled with 0.02 g of rice powder. Then, 0.2 ml of 95% ethanol was added. After that, 1.8 ml of 1N NaOH was added, followed by distilled water to make a total volume of 20 ml. It was maintained at room temperature for 20 minutes before boiling for 10 minutes at 45°C, and then Whatman filter paper no. 2 was used to filter it. Then, 1 ml of filtrate was transferred to a 50 mL tube, along with 0.2 ml of 1M acetic acid and 0.4 ml of Lugol's solution, and distilled water was added to make a total volume of 20 ml. The mixture was thoroughly mixed and stored at room temperature for 20 minutes. Then, using a spectrophotometer (T80 U/VIS, United Kingdom), the absorbance was measured at 620 nm. The amylose content was determined using a potato amylose standard curve and expressed as g/100 g extract.

2.5.3. Determination of phenolic content

The phenolic content was determined by using the procedure as explained by Saikia et al. (2012) with certain modifications. Precisely, 1 g of rice powder was extracted for 15 minutes with 20 ml of 25% ethanol and filtered through Whatman no. 2 filter paper. 1 ml of filtrate, 1 ml of Folin reagent, and 5 ml of Na_2CO_3 were then transferred to a volumetric flask and stored at room temperature for 1 hour. Then, by using a spectrophotometer (T80 U/VIS, United Kingdom), the absorbance was measured at 765 nm. The phenolic content was expressed in mg GAE/100 g.

2.6. Proximate analysis of non-parboiled and parboiled rice

2.6.1. Determination of moisture content

The moisture content was determined by oven drying as described in the official AOAC (2005) method. Briefly, an empty crucible was first washed, dried, cooled, and weighed. Then, the exact quantity (5.0 ± 0.001 g) of the rice sample was taken in a crucible and weighed. The crucible was placed inside the oven and dried at 105°C overnight. After drying, the crucible was removed from the oven and cooled in desiccators, and again, weight was taken. After that, the crucible with the sample was again placed in the oven and dried for 30 minutes, then removed from the oven, cooled in desiccators, and weighed. Drying, cooling, and weighing were repeated until two consecutive weights were the same. The same procedure was followed for all samples. Three replications were performed for each sample to reduce bias, and mean moisture content was then calculated as follows:

% Moisture content (wb)=

$$\frac{\text{Initial weight of sample} - \text{Bone dry weight of sample}}{\text{Initial weight of sample}} \times 100 \qquad (6)$$

The moisture-free samples were then used to determine the crude protein, lipid, and ash content.

2.6.2. Determination of ash

The total ash content of the sample was determined by the AOAC (2005) method. The oven-dried rice sample was taken in a crucible and left inside a muffle furnace at 550°C for 6 hours. The muffle furnace was turned off, and waited till the temperature reached at 250°C, carefully opened the door and transferred the crucible to a desiccator to avoid losing ash and gaining moisture. After cooling, the weight of the crucible was recorded. The difference between the weight of oven-dried matter and the final weight represented the ash content, expressed in percentage. It was calculated by using the following formula:

% Ash =

$$\frac{\text{Weight of crucible with ash}(g) - \text{Weight of empty crucible}(g)}{\text{Weight of sample}(g)} \times 100 \qquad (7)$$

2.6.3. Determination of protein

The protein content was determined by the method of AOAC (2005) using the Kjeldhal apparatus. Precisely, 1 g ground rice sample was taken into a volumetric flask with 1g selenium, 0.1 g $CuSO_4$, and 10 g K_2SO_4. Then, 25 ml of concentrated H_2SO_4 was added. After that, the volumetric flask was heated at 100°C for 3 hours and then cooled for 20 minutes at room temperature. After digestion, exactly 300 ml of distilled water and 125 ml of 40% NaOH were added to the volumetric flask. The 250 ml of 4% boric acid solution and 2-3 drops of mixed indicator were taken in a conical flask. The volumetric flask was connected to one end of the condenser, and the conical flask was connected to the other end. The volumetric flask was heated continuously until the conical flask was filled to 150 ml. The conical flask was disconnected and taken for titration against 0.2 N of H_2SO_4 solution. The endpoint was indicated by the orange color. The total nitrogen value was then calculated by using the following formula:

$$\%\text{Nitrogen} = \frac{\text{Titrate value} \times N \times 0.014 \times 100}{\text{Weight of sample}(g)} \qquad (8)$$

Where, % Protein = % Nitrogen × 6.25;

Here, 0.014 = Mili-equivalent weight of N_2.

2.6.4. Determination of fat content

The crude fat content of rice samples was determined using the AOAC (2005) method. Exactly, 1.0 g of sample was taken into the thimble and plugged with cotton. The thimble was attached to the Soxhlet apparatus with a round bottom flask containing 200 ml of petroleum benzene. The petroleum benzene was filled into a weighted conical flask. The fat was extracted for 6 hours. After that, benzene was evaporated until the conical flask was completely dried and then cooled in desiccators. Then the weight is taken. The fat content was then determined by using the following formula:

$$\% \text{ Fat Content} = [(W_1 - W_2)/W] \times 100 \quad (9)$$

Where, W= Weight of the sample; W_1= Weight of the evaporated flask with sample; W_2= Weight of empty flask.

2.6.5. Determination of fiber content

The fiber content was determined by the AOAC (2005) method with some modifications. Fat-free (2 g) sample was taken in a 500 ml beaker and added 200 ml of 0.255 N H_2SO_4, then boiled for 30 min. The mixture was filtered with a muslin filter cloth, and the residue was washed with hot water until free from acid. Then, the residue was transferred into a beaker, and 0.313 N of 200 ml NaOH was added and boiled for 30 minutes. After that, the mixture was filtered with a muslin filter cloth, and the residue was washed with hot water until free from alkali and then washed with alcohol and diethyl ether. It was then transferred to a crucible and dried overnight at 105°C. The crucible was then heated for 6 hours at 550°C in a muffle furnace. After that, it was allowed to cool before being weighed. The crude fiber was obtained by the following formula:

$$\% \text{ Crude Fiber} = [(W_1 - W_2)/W] \times 100 \quad (10)$$

Where, W= Weight of the sample; W_1= Weight of crucible with sample; W_2= Weight of empty crucible.

2.6.6. Determination of carbohydrate content

The total carbohydrate content of any food product has been calculated by the different method for many years rather than analyzed directly. The carbohydrate content of the developed samples was determined by subtracting the measured protein, fat, fiber, ash, and moisture from 100 (Roshid et al., 2016; Roni et al., 2021; Wazed and Islam, 2021; Alam et al., 2020; Moni et al., 2023). Therefore,

$$\text{Percentage of carbohydrates} = 100 - \{\text{moisture} + \text{protein} + \text{ash} + \text{fat} + \text{fiber}\} \quad (11)$$

2.7. Mineral analysis of BRRI dhan84 rice

Zinc (Zn), iron (Fe), and calcium (Ca) were analyzed by AOAC (2005) method using an atomic absorption spectrophotometer. The digested sample was analyzed for mineral contents by an atomic absorption spectrophotometer. Different electrode lamps were used for each mineral. The equipment was run for standard solutions of each mineral before and during determination to check that it worked properly. The dilution factor for all minerals was 100. To determine Ca, 1.0 ml of lithium oxide solution was added to the original solution to unmask Ca from Mg. The concentrations of minerals were recorded in terms of “ppm” and converted to milligrams (mg) of the minerals by multiplying the ppm with the dilution factor and dividing by 1000, as follows:

Mineral content =

$$\frac{\text{absorbancey}(\text{ppm}) \times \text{dry wt} \times \text{D}}{\text{Wt. of sample} \times 1000} \quad (12)$$

2.8. Sensory evaluation

Twenty experienced but untrained panelists participated in the evaluation of cooked rice samples. They were provided with instructions to taste the rice samples and cleanse their palate between each tasting. The panelists were then asked to rate various sensory attributes of both parboiled and non-parboiled cooked rice, including color, aroma, texture, taste, and overall acceptability. These sensory attributes were evaluated using the Likert Scale, as Edmonson (2005) described.

2.9. Statistical analysis

The experiments were conducted in triplicate, and the results were reported as the mean value and the corresponding standard deviation. The data were statistically analyzed by paired-samples t-test (physical properties, cooking qualities, and sensory attributes) and one-way ANOVA (chemical properties, proximate compositions, total phenol content, and mineral contents) using Duncan's multiple range tests at 5% significance level using SPSS version 22.

3. Results and discussions

3.1. Physical Properties of non-parboiled and parboiled BRRI dhan84

The physical properties of non-parboiled and parboiled BRRI dhan84 rice are presented in Table 1. The length of parboiled BRRI dhan84 rice decreased significantly compared to non-parboiled, resulting from 6.507 mm and 6.781 mm, respectively. In contrast, the width of parboiled BRRI dhan84 rice experienced a slight increase compared to non-parboiled rice but was statistically insignificant. According to Kurien et al. (1964), parboiling and subsequent drying reduce the length of rice while increasing the breadth for rough and brown rice. This might be related to the hardening of rice grains due to parboiling followed by drying. The length-breath ratio of non-parboiled BRRI dhan84 rice was significantly higher than the parboiled one. According to the classification of rice given by Bhattacharya et al. (1980), based on grain L/B ratio, both samples fall in slender (L/B ratio > 3.0). In bulk density and 1000 kernel weight of BRRI dhan84 rice, there was no significant change between non-parboiled and parboiled. This could be due to the precision of different preprocessing treatments (Oghbaei & Prakash, 2010). The bulk density and 1000 kernel weight of non-parboiled and parboiled rice were 0.902 g/mL and 0.900 g/mL, 18.40 g and 17.80 g, respectively. This is possibly due to the precision of different preprocessing treatments (Oghbaei & Prakash, 2010). Similar results have been reported by Chavan et al. (2018), who studied the effect of parboiling on the Pusa Basmati 1121 rice varieties.

Table 1. Physical properties of uncooked non-parboiled and parboiled BRRI dhan84 rice

Parameters	**Uncooked rice**			
	Non-parboiled	**Parboiled**	**t-statistics**	**p-value**
Length (mm)	6.781 ± 0.214	6.507 ± 0.223	6.025	0.000*
Width (mm)	1.966 ± 0.195	2.032 ± 0.099	-1.860	0.073
Length/Breath ratio	3.49 ± 0.414	3.21 ± 0.205	3.884	0.001*
Bulk density (g/ml)	0.902 ± 0.130	0.900 ± 0.003	0.294	0.797
1000 kernel weight (gm)	18.40 ± 0.235	17.80 ± 0.036	3.988	0.058
Head Rice Yield (%)	64.39 ± 4.78	80.09 ± 1.96	- 4.369	0.049*

All values are expressed as means ± SD. *Significant ($P \leq 0.05$).

Parboiled BRRI dhan84 rice recorded the highest HRY (80.09%), while non-parboiled rice recorded the lowest (64.39%) (Table 1). This finding indicates that the parboiling method significantly increased ($p < 0.05$) the head rice yield of BRRI dhan84 rice. Head rice yield increased because parboiling enhanced the rice hardness through starch gelatinization, making the grain less prone to breaking during milling (Jagtap et al., 2008). These findings are higher than those of Kader et al. (2020) for non-parboiled rice. The higher HRY or reduction in rice breakage depends on selecting the best soaking temperature and steaming time, using the best parboiling equipment that allows the uniform distribution of heat during soaking and steaming (Ndindeng et al., 2015), and milling with a rubber roll type mill (Bhattacharya, 1969).

3.2. Effect of cooking on non-parboiled and parboiled BRRI dhan84 rice

Cooking properties such as water uptake ratio, grain elongation ratio, gruel solids loss in the cooking water, and optimal cooking time for rice are presented in Table 2. The water uptake ratios of non-parboiled and parboiled rice were not statistically different, demonstrating 2.180 and 2.113, respectively, for non-parboiled and parboiled cooked rice. These findings align with Meresa et al. (2020), who studied the influence of parboiling conditions on the cooking quality of selected rice. Regarding elongation ratio, non-parboiled and parboiled cooked rice yielded 1.1168 and 1.1171, respectively. Parboiling did not affect the rice elongation ratio. Compared to non-parboiled rice, parboiling significantly reduced gruel solid loss during cooking, with values of 1.033 % and 0.090 %, respectively. This may occur due to the seal of internal cracks and reduced starch solubilization in cooking water due to hydrothermal treatment (Pal et al., 2018) of milled rice and parboiled milled rice among different rice varieties. These findings are also supported by Chavan et al. (2018). Parboiled BRRI dhan84 rice recorded the longest cooking time (39.41 min), while non-parboiled rice recorded the shortest cooking time (34.45 min), as indicated in Table 2. It specifies that cooking time for parboiled rice was significantly longer than for non-parboiled rice. Disorganized cellular structure can enhance the probability of high water absorption during cooking and can contribute to longer cooking time (Thomas et al., 2013). Sareepuang et al. (2008) also argue that the longer cooking time of parboiled rice may be due to strong cohesion between the endosperm cells, which are tightly packed, making starch grains hydrate at a slower rate. Economically, the longer cooking time of parboiled rice involves more combustibles (fuel, gas, or firewood) and, therefore, higher cooking costs. Cooking time also depends on the parboiling process, rice variety, and storage time (Issah et al., 2015).

Table 2. Cooking properties of non-parboiled and parboiled cooked BRRI dhan84 rice

Parameters	**Cooked rice**			
	Non-parboiled	**Parboiled**	**t-statistics**	**p-value**
Water uptake ratio	2.180 ± 0.199	2.113 ± 0.035	0.675	0.569
Elongation ratio	1.116 ± 0.078	1.117 ± 0.091	0.044	0.691
Gruel solid loss (%)	1.033 ± 0.056	0.090± 0.010	34.574	0.001*
Cooking time (min)	34.45 ± 0.060	39.41 ± 0.029	41.250	0.001*

All values are expressed as means ± SD. *Significant ($P \leq 0.05$).

3.3. Amylose, starch, and total phenol content of uncooked and cooked BRRI dhan84 rice

In terms of cooking and gelling characteristics, the amylose content of rice is one of the most vital parameters for rice quality, which affects the cooking, eating, and pasting characteristics of rice (Asghar et al., 2012). In this study, the amylose content of uncooked non-parboiled and parboiled BRRI dhan84 was 22.37 % and 21.58 %, respectively (Table 3). This amylose percentage was lower than that of Kader et al. (2020), who found a 25.9% amylose content in the same non-parboiled rice. This could be due to the differences in the environmental conditions in which the crop is grown, particularly temperature (Hettiarachchy et al., 1997). The amylose percentage of parboiled BRRI dhan84 rice was significantly lower compared to non-parboiled BRRI dhan84 rice. This reduction may be due to the leaching of amylose molecules into the dissolving water during soaking and consequent steaming during parboiling (Otegbayo et al., 2001). Starch is a major component of rice endosperm. The starch content of uncooked non-parboiled and parboiled BRRI dhan84 rice was 62.10 % and 57.03 %, respectively (Table 3). This reduction in starch after parboiling might be due to amylose leaching during soaking and steaming and the development of an amylose-lipid complex during steaming (Singh et al., 2006). The total phenolic content (TPC) in uncooked non-parboiled and parboiled BRRI dhan84 rice was found to be 4.44 mg GAE/g and 1.31 mg GAE/g, respectively (Table 3). The parboiling decreased the TPC significantly. Cooking reduced the percentage of starch, amylose, and TPC in both non-parboiled and parboiled BRRI dhan84 rice (Table 3). The non-parboiled and parboiled cooked BRRI dhan84 rice contained significantly lower starch content than that of uncooked rice, with 53.70% and 46.74%, respectively. TPC of both non-parboiled and parboiled reduced from 4.44 to 0.81 mg GAE/g and 1.31 to 0.73 mg GAE/g, respectively. Most of the phenolic content is unstable and easily destroyed in the presence of heat, light, and oxygen, which could be the possible reason for the reduction of TPC after parboiling and followed by cooking (Junior et al., 2010). In another study, Widyasaputra et al. (2020) reported a similar reduction trend for TPC in black rice after parboiling. A reduction of TPC in cooked rice has also been observed by Pal et al. (2018) in previous research. According to Zhang & Hamauzu (2004), the breakdown or conversion of phenolic to other compounds and vapor during cooking is the cause of phenolic losses during cooking.

3.4. Proximate composition of BRRI dhan84 rice

The proximate compositions of uncooked and cooked non-parboiled and parboiled rice of BRRI dhan84 are presented in Table 4. The percentage of ash, fat, protein, and carbohydrates in parboiled rice was found to be higher than that of non-parboiled rice. The highest amount of ash (1.99%) was estimated in parboiled uncooked rice. The finding was higher than the value (1.3%) as presented in the Food Composition Table for Bangladesh (Shaheen *et al.*, 2013), which was attributed to the parboiling process. The parboiling process caused the degradation and diffusion of components from rice bran and husk into rice endosperm, which brought about a significant increase in ash percent (Thammapat et al., 2016). The fat content of parboiled rice samples was also significantly greater than that of non-parboiled rice. This might be explained by the increased temperature and steaming pressure that happens during the parboiling process, which causes the leaching and rupturing of the oil globules (Chukwu et al., 2009). The fat content of the parboiled uncooked sample exceeds the limit of 1.7% set by FAO (1994) for sound conservation and prevention of rice turning rancid during storage. The protein content increased significantly after parboiling. The Food Composition Table for Bangladesh quantified 7.8% protein in parboiled uncooked rice, which

Table 3. Chemical properties of uncooked and cooked BRRI dhan84 rice

Parameters	Uncooked rice		Cooked rice	
	Non-parboiled	Parboiled	Non-parboiled	Parboiled
Amylose (%)	22.37 ± 0.34^a	21.58 ± 0.18^b	17.22 ± 0.13^c	16.78 ± 0.14^d
Starch (%)	62.10 ± 1.67^a	57.03 ± 0.85^b	53.70 ± 1.77^c	46.74 ± 0.95^d
Total Phenolic content (mg GAE/g)	4.44 ± 0.14^a	1.31 ± 0.01^b	0.81 ± 0.27^c	0.73 ± 0.01^c

All values are expressed as means ± SD. Mean with different superscript letters in the same row indicates a significant difference ($p \leq 0.05$) from each other.

was lower than the current study. The increase in protein content in parboiled rice could be due to the synthesis of some enzymes, which may result in the production of some amino acid during protein synthesis, or it might be due to the endosperm of parboiled rice, which had a good number of proteins as well as parboiled milled rice (Uwaegbute et al., 2000). For protein contents, the current result of non-parboiled and parboiled rice is lower than that of a study, as explained by Kader et al. (2020), reporting 9.7% protein in non-parboiled BRRI dhan84.

The parboiling significantly decreased the carbohydrate of rice also compared to non-parboiling from 77.91% to 75.53%. This could be attributed to the leaching of soluble carbohydrate components during soaking, drying, and molecule rupturing caused by steaming.

Table 4. Proximate composition of non-parboiled-parboiled and uncooked-cooked BRRI dhan84 rice

Parameters	Uncooked rice		Cooked rice	
	Non-parboiled	Parboiled	Non-parboiled	Parboiled
Moisture	10.86±0.115^{c}	9.89±0.370^{d}	52.83±0.577^{a}	50.67±0.289^{b}
Ash	1.98±0.243^{a}	1.99±0.493^{a}	0.61±0.005^{b}	0.52±0.006^{b}
Fat	1.72±0.327^{b}	2.36±0.035^{a}	0.15±0.004^{c}	0.23±0.021^{c}
Protein	6.68±0.050^{b}	9.42±0.91^{a}	4.17±0.085^{d}	4.78±0.131^{c}
Fiber	0.97±0.072^{a}	0.81±0.226^{ab}	0.85±0.031^{ab}	0.69±0.059^{b}
Carbohydrate	77.92±0.083^{a}	75.53±0.625^{b}	41.38±0.624^{d}	43.12±0.377^{c}

All values are expressed as means ± SD. Mean with different superscript letters in the same row indicates a significant difference ($p \leq 0.05$) from each other.

After cooking, both non-parboiled and parboiled samples were found to show a significant decrease in all proximate compositions except moisture content. Similar trends were found by Boora (2015) for Improved Pusa Basmati-I (an Indian rice variety). According to Ebuehi & Oyewole (2007), cooking and soaking in water changed the protein content of Ada and Aroso rice types. Cooking rice denatures the protein, and soaking increases the solubility of specific proteins, resulting in a protein decrease (Ebuehi & Oyewole, 2007). The reduction in fat content caused by cooking might be attributed to chemical and physical changes in fat that occur during heating (Roth & Rock, 1972). The increased moisture level, which also impacts milling quality, may be responsible for reducing carbohydrate content in cooked rice (USA Rice Federation, 2002). In this study, after cooking, the highest amount of carbohydrate (43.12%) was estimated in parboiled rice, which was higher than the value (23.2%) as reported by the Food Composition Table for Bangladesh (Shaheen et al., 2013). Also, parboiled BRRI dhan84 rice retained more fat and protein after cooking than non-parboiled rice. The retention of some nutrients in parboiled rice is because of water-soaking before parboiling, which penetrates the void space and seals the internal cracks of the rice grain. As a result, compared to non-parboiled rice, the leaching of solids into cooking water and solubilization of the kernels decreases significantly during cooking (Luh & Shinlu, 1991).

3.5. Mineral content of BRRI dhan84 rice

Table 5 represents the mineral composition of BRRI dhan84 rice. The calcium content of uncooked parboiled rice was significantly higher than that of non-parboiled BRRI dhan84 rice. These findings align with a previous study on the Nigerian long-grained rice variety IR-8 (Chukwu et al., 2009). Compared to non-parboiling, parboiling significantly reduced the iron content of BRRI dhan84 to 4.871 mg/100g from 5.105 mg/100g and increased the zinc content of rice slightly from 2.732 mg/100g to 2.741 mg/100g. In general, no significant difference in zinc was found between parboiled and non-parboiled uncooked rice. The highest amount of zinc (2.741 mg/100 g) was estimated in parboiled uncooked rice, which was higher than the value (1.90 mg/100 g) as reported by Food Composition Table for Bangladesh (Shaheen et al., 2013), which was expected because these biofortified varieties were bred to have higher zinc concentration compared to other commercial varieties (Taleon et al., 2021). Besides, this slight rise in zinc content in parboiled BRRI dhan84 rice contradicts the findings of Chukwu et al. (2009) for parboiled and non-parboiled rice, which might be attributed to differences in rice varieties, physical and chemical properties of the rice grain and the parboiling method (Taleon et al., 2020). The zinc content was found in this study to be compatible with findings concerning non-parboiled rice (Kader et al., 2020).

After cooking, both parboiled and non-parboiled rice showed a considerable decrease in calcium, iron, and zinc content. This decrease in minerals might be attributed to increased moisture levels and minerals leaching into the cooking water during the cooking process (Adepoju et al., 2012). The finding is consistent with a previous study of non-parboiled and parboiled cooked rice of different rice varieties (Thomas et al., 2016). The Food Composition Table for Bangladesh (Shaheen et al., 2013) quantified 0.58 mg/100 g zinc in parboiled cooked rice, which was lower than the current study. The higher zinc (2.344 mg/100g) found in the biofortified variety BRRI dhan84 for parboiled cooked rice suggests that the additional zinc in this biofortified variety is more concentrated in the endosperm, similar to the findings of Taleon et al. (2020).

Table 5. The mineral content of uncooked and cooked BRRI dhan84 rice

Parameters (mg/100g)	**Uncooked**		**Cooked**	
	Non-parboiled	**Parboiled**	**Non-parboiled**	**Parboiled**
Calcium	4.603 ± 0.083^{b}	5.100 ± 0.030^{a}	3.733 ± 0.025^{d}	4.320 ± 0.170^{c}
Iron	5.105 ± 0.034^{a}	4.871 ± 0.535^{b}	4.659 ± 0.717^{c}	4.571 ± 0.061^{c}
Zinc	2.732 ± 0.029^{a}	2.741 ± 0.031^{a}	2.264 ± 0.033^{c}	2.344 ± 0.064^{b}

All values are expressed as means ± SD. Mean with different superscript letters in the same row indicates a significant difference ($p \leq 0.05$) from each other.

3.6. Sensory analysis

The results of the sensory assessment showed that the color, texture, and overall acceptability of cooked parboiled BRRI dhan84 rice were significantly different from the non-parboiled rice (Table 6). The parboiled rice was darker in color than the non-parboiled rice, with values of 2.04 and 3.08, respectively. The panel appreciated the lighter color of non-parboiled rice, although both rice scored a low color preference rating. The degree of color change has been reported to be influenced by soaking temperature, heating duration, and heating and drying temperatures (Bhattacharya, 1985). In another study, it was found that the grain color is associated with the iron content. As the rice is milled, iron content decreases, and there is a slight change in the color of the rice. In the case of aroma and taste, both parboiled and non-parboiled exhibited an almost similar score (Gregorio et al., 2000). However, these scores were in the neutral range of the Likert scale for the taste of rice. Non-parboiled rice secured a significantly higher score in textural properties compared to parboiled rice. They found that parboiled rice was slightly stiffer. This might be due to the stiffening of parboiled rice after parboiling. Besides, as rice aged, texture was improved because of the modification of interactions among the components of grains (Butt et al., 2008). Although parboiled rice received a higher overall acceptability rating by the panel, cooked parboiled and non-parboiled rice scored almost near the agree and neutral ranges, respectively.

Table 6. Sensory evaluation of cooked non-parboiled and parboiled BRRI dhan84

Parameters	**Cooked**			
	Non-parboiled	**Parboiled**	**t-statistics**	**p-value**
Color	3.08 ± 0.812	2.04 ± 0.735	-5.099	0.000*
Aroma	3.92 ± 0.702	3.96 ± 0.735	0.214	0.832
Texture	3.92 ± 0.640	2.92 ± 0.862	-4.804	0.000*
Taste	3.04 ± 0.735	3.08 ± 0.640	0.253	0.802
Overall acceptability	3.04 ± 0.790	3.60 ± 0.866	3.219	0.004*

All values are expressed as means ± SD. *Significant ($P < 0.05$).

4. Conclusions

The parboiling process practiced by almost every rice industry in Bangladesh affected the properties of rice in both positive and negative ways. Cooking for rice consumption was the most common method adopted by the people of Bangladesh that, resulted in the lowering of almost all nutritional constituents. The present study was the first to evaluate the physicochemical properties, proximate composition, and cooking characteristics of BRRI dhan84 rice and its changes during parboiling. It can be concluded that parboiling resulted in an increase in mineral, fat, and protein content. In contrast, other constituents were significantly lower compared to raw rice. Parboiling had a positive effect on the physical properties but some negative aspects, especially in terms of cooking time. The cooking process negatively affected all properties except the antioxidant activity, total phenol content (TPC), and moisture content. The results of the current study reflected that the consumption of BRRI dhan84 rice could be extended to society by making people aware of its nutritional constituents and its possible application on different food items.

5. References

Adepoju, O.T., Sunday, B.E., Folaranmi, O.A. (2012). Nutrient composition and contribution of plantain (Musa paradisiacea) products to dietary diversity of Nigerian consumers. *African Journal of Biotechnology*, 11(71), 13601-13605.

Alam, S., Bari, T., Sohany, M., Nayem, M. F., & Shakil, M. Formulation and quality evaluation of instant soft drink powder prepared from hog plum (Spondius mangifera) and mint (Mentha spicata). Volume 5; Issue 1; January 2020; Page No. 33-37.

Andersson, M.S., Saltzman, A., Virk, P.S., Pfeiffer, W.H. (2017). Progress update: Crop development of biofortified staple food crops under harvestplus. *African Journal of Food, Agriculture, Nutrition and Development*, 17(2), 11905-11935.

AOAC. (2000). " Invert sugar in sugars and syrups, Lane and Eynon general volumetric method (Method 923.09) Official Methods of Analysis of Association of Official

Analytical Chemists.15th edition, Better World Books, Reno, NV, USA

AOAC. (2005). “Official Method of Analysis”. 18th ed. Association of Official Analytical Chemists, Maryland, USA.

Asghar, S., Anjum, F. M., Amir, M. R. and Khan, M. A. 2012. Cooking and eating characteristics of rice (Oryza sativa L.)-A review. Pak J *Food Science*, 22: 128-32.

Bhattacharya, K.R. (1969). Breakage of rice during milling, and effect of parboiling. *Cereal Chemistry*, 46, 478-485.

Bhattacharya, K.R., Sowbhagya, C.M., Indhudhara, Y.M., Swarny. (1980). Quality of Indian rice. *Journal of Food Science and Technology*, 17,189-193.

Bhattacharya, K.R. (1985). Parboiling of Rice. In “Rice Chemistry and Technology,” ed. By B.O. Juliano. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, pp. 289-348.

Bhattacharya, K.R. (2011). Effect of parboiling on rice quality. Rice Quality: A Guide to Rice Properties and Analysis, 247-297.

Biswas, J.C., Haque, M.M., Khan, F.H., Islam, M.R., Dipti, S.S., Akter, M., Ahmed, H.U. (2018). Zinc fortification: Effect of polishing on parboiled and unparboiled rice. *Current Plant Biology*, 16, 22-26.

Boora, P. (2015). Effect of cooking methods on nutritional quality of rice (Oryza sativa) varieties. *Journal of Dairying, Foods & Home Sciences*, 34(2), 136-140.

Bouis, H.E., Hotz, C., McClafferty, B., Meenakshi, J.V, Pfeiffer, W. H. (2011). Biofortification: a new tool to reduce micronutrient malnutrition. *Food and Nutrition Bulletin*, 32, S31-S40.

Butt, M.S., Anjum, F.M., Salim-ur-Rehman, Tahir-Nadeem, M., Sharif, M.K., Anwer, M. (2008). Selected quality attributes of fine basmati rice: Effect of storage history and varieties. *International Journal of Food Properties*, 11(3), 698-711.

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant and Soil*, 302(1), 1-17.

Chavan, P., Sharma, S. R., Mittal, T. C., Mahajan, G., & Gupta, S. K. (2018). Effect of parboiling technique on physico-chemical and nutritional characteristics of basmati rice. *Agricultural Research Journal*, 55(3), 490-499. https://doi.org/10.1155/2020/8810553.

Chukwu, O., Oseh, F.J., Chukwu, O., Oseh, F.J., Contents, N. (2009). Response of Nutritional Contents of Rice (*Oryza sativa*) to Parboiling Temperatures. *American-Eurasian Journal of Sustainable Agriculture*, 3(3), 381-387.

Denardin, C.C., Da Silva, L.P., Storck, C.R., Nornberg, J.L. (2004). Composiçao mineral de cultivares de arroz integral, parboilizado e branco. *Alimentos e Nutriçao*, 15(2), 125-130.

Ebuehi, O.A. T., Oyewole, A.C. (2007). Effect of cooking and soaking on physical characteristics, nutrient composition and sensory evaluation of indigenous and foreign rice varieties in Nigeria. *African Journal of Biotechnology*, 6(8), 1016-1020.

Edmonson, D.R. (2005). Likert Scale: A History. Retrieved from CHARM database. https://ojs.library.carleton.ca/index.php/pcharm/article/view/1613.

FAO. (1994). Le riz dans la nutrition humaine. Food and Agriculture Organization of the United Nations. Rapport d’un comité special mixte FAO/OMS d’expertswww.fao.org/docrep/004/w0073f/w0073f44. htm, Paper n° 56. Rome.Rome/Italy.

Fofana, M., Wanvoeke, J., Manful, J., Futakuchi, K., Van, Mele, P., Zossou, E., Bléoussi, T.M.R. (2011). Effect of improved parboiling methods on the physical and cooked grain characteristics of rice varieties in Benin. *International Food Research Journal*, 18, 715-721.

Gregorio, G.B., Senadhira, D., Htut, H., Graham, R.D. (2000). Breeding for trace mineral density in rice. *Food and Nutrition Bulletin*, 21(4), 382-6.

Hettiarachchy, N., Griffin, V., Gnanasambandam, R., Moldenhauer, K., SIebenmorgen, T. (1997). Physicochemical properties of three rice varieties. *Journal of Food Quality*, 20, 279-290.

Hotz, C., Kabir, K. A., Dipti, S. S., Arsenaultd, J.E., Bipule M. (2015). Rice fortification with zinc during parboiling may improve the adequacy of zinc intakes in Bangladesh. *Journal of the Science of Food and Agriculture*, 95, 379-385.

Issah, M H., Appiah, F., Ninfaa, A.D. (2015). Effect of Parboiling on the Quality of Processed Degan Rice (*Oryza* Spp). *International Journal of Sciences: Basic and Applied Research*, 24(3), 153-163.

Jagtap, P.S., Subramanian, R., Singh, V. (2008). Influence of soaking on crushing strength of raw and parboiled rice. *International Journal of Food Properties*, 11(1), 127–136.

Jena, J., Sethy, P., Jena, T., Misra, S. R., Sahoo, S. K., Dash, G. K., & Palai, J. B. (2018). Rice biofortification: A brief review. *Journal of pharmacognosy and phytochemistry*, 7(1), 2644-2647. https://www.phytojournal.com/archives/2018.v7.i1.3024.

Junior, M. R. M., Leite, A. V., & Dragano, N. R. V. (2010). Supercritical fluid extraction and stabilization of phenolic compounds from natural sources–review (supercritical extraction and stabilization of phenolic compounds). *The Open Chemical Engineering Journal*, 4(1). https://doi.org/10.2174/1874123101004020051.

Kader, M.A., Biswas, P.S., Aditya, T.L., Anisuzzaman, M., Hore, T.K., Haq, M.E. (2020). Zinc Enriched High Yielding Rice Variety BRRI dhan84 for Dry Season Rice Growing Areas of Bangladesh. *Asian Plant Research Journal*, 6(1), 6–13.

Kurien, P.P., Radhakrishnamurthy, R., Desikachar, H.S.R., Subrahmanyan, V. (1964). Effect of parboiling on the swelling quality of rice. *Cereal Chemistry*, 41, 16-22.

Liu, K., Zheng, J., Chen, F. (2019). Effect of domestic cooking on rice protein digestibility. *Food Science and Nutrition*, 7 (2),608-616.

Luh, B.S., Shinlu. (1991). Degree of Parboiling and properties of the rice caryopsis. In: Rice production. 2nd edition. Luh, B.S. ed. AVI publishing co., New York. 1, 341.

Mayer, A.B., Latham, M.L., Duxbury, J.M., Hassan, N., Frongillo, E.A. (2008). A food based approach to improving zinc nutrition through increasing the zinc concentration of rice in Bangladesh. *Journal of Hunger & Environmental Nutrition*, 2(1), 19-39.

Meresa, A., Demissew, A., Yilma, S., Tegegne, G., & Temesgen, K. (2020). Effect of parboiling conditions on physical and cooking quality of selected rice varieties. *International Journal of Food Science*, 2020.https://doi.org/10.1155/2020/881055.

Moni, A., Wazed, M.A., Khatun, M.N., Yasmin, S., Mondal, S.C. and Ahmed, M. (2023). Effects of various emulsifiers on physicochemical and sensory attributes of cake during storage. *Food Research*, 7(2), 365–372. https://doi.org/10.26656/fr.2017.7(2).899

Ndindeng, S.A., Manful, J.T., Futakuchi, K., Mapiemfu, D.L., Akoa-Etoa, J M., Bigoga, J., Moreira, J. (2015). A novel artisanal parboiling technology for rice processors in sub-Saharan Africa. *Food Sciences and Nutrition*,3(6),557–568.

Nguyen, P.H., Nguyen, H., Gonzalez-Casanova, I., Copeland, E., Strizich, G., Lowe, A., et al. (2014). Micronutrient intakes among women of reproductive age in Vietnam. PLoS ONE, 9,e89504.

Oghbaei, M., Prakash, J. (2010). Effect of cooking on nutritional quality of raw and parboiled rice. *International Journal of Nutrition and Dietetics*, 47, 188-199.

Otegbayo, B.O., Osamuel, F., Fashakin, J.B. (2001). Effect of parboiling on physico-chemical qualities of two local rice varieties in Nigeria. *Journal of Food Technology in Africa*, 6(4), 130-132.

Pal, P., Singh, N., Kaur, P., Kaur, A. (2018). Effect of Parboiling on Phenolic, Protein, and Pasting Properties of Rice from Different Paddy Varieties. *Journal of Food Science*,83(11),2761–2771.

Patindol, J., Newton, J., Wang, Y. (2008). Functional properties as affected by laboratory‐scale parboiling of rough rice and brown rice. *Journal of Food Science*, 73(8), E370-E377.

Qadir, N., & Wani, I. A. (2022). Cooking, Sensory Properties, Curcumin Retention, and In vitro Digestibility of Rice as Affected by Polishing and Turmeric Concentration. Starch‐Stärke, 74(9-10), 2200054.

Roni, R.A., Sani, M.N.H., Munira, S., Wazed, M.A., Siddiquee, S. (2021). Nutritional Composition and Sensory Evaluation of Cake Fortified with Moringa oleifera Leaf Powder and Ripe Banana Flour. *Applied Science*,11, 8474.

Roshid M.M., Wazed, M.A., Islam, M.R., Mahomud, M.S., Khatun, H. (2016). Preparation of gluten free bread using the mixture of different cereals grain flour. *International Journal of Advanced Multidisciplinary Research*, 3(5), 9-16.

Roth, H., Rock, S.P. (1972). Chemistry and technology of frying fat. II. Technology. Bakers Digest, 38-44.

Saikia, S., Dutta, H., Saikia, D., Mahanta, C. L. (2012). Quality characterisation and estimation of phytochemicals content and antioxidant capacity of aromatic pigmented and non-pigmented rice varieties. *Food Research International*,46, 334-340.

Sanusi, M. S., Akinoso, R., & Danbaba, N. (2017). Evaluation of physical, milling and cooking properties of four new rice (Oryza sativa L.) varieties in Nigeria. *International Journal of Food Studies*, 6(2).

Sareepuang, K., Siriamornpun, S., Wiset, L., Meeso, N. (2008). Effect of Soaking Temperature on Physical, Chemical and Cooking Properties of Parboiled Fragrant Rice. *World Journal of Agricultural Sciences*, 4 (4), 409-415.

Shaheen, N., Rahim, A.T.M.A., Mohiduzzaman, M., Banu, C.P., Bari, M. L., Tukun, A.B., Mannan, M.A., Bhattacharjee, L., Stadlmayr, B. (2013). Food Composition Table for Bangladesh, Institute of Nutrition and Food Science, Centre for Advanced Research in Sciences, University of Dhaka, Bangladesh, Final Research. Result, 6-7.

Singh, N., Inouchi, N., Nishinari, K. (2006). Structural, thermal and viscoelastic characteristics of starches separated from normal, sugary and waxy maize. *Food Hydrocolloids*, 20(6), 923-935.

Singh, S. S., Hazra, K.K., Praharaj, C.S., Singh, U. (2016). Biofortification : Pathway Ahead and Future Challenges. *Biofortification of Food Crops*, 479-492.

Smith, M. R., & Myers, S. S. (2018). Impact of anthropogenic CO2 emissions on global human nutrition. Nature Climate Change, 8(9), 834-839.

Sompong, R., Siebenhandl-Ehn, S., Linsberger-Martin, G., Berghofer, E. (2011). Physicochemical and antioxidative properties of red and black rice varieties from Thailand, China and Sri Lanka. *Food Chemistry*, 124, 132-140.

Taleon, V., Gallego, S., Orozco, J.C., Grenier, C. (2020). Retention of Zn, Fe and phytic acid in parboiled biofortified and non-biofortified rice. *Food Chemistry*, 8,100105.

Taleon, V., Hasan, M.Z., Jongstra, R., Wegmüller, R., Bashar, M.K. (2021). Effect of parboiling conditions on zinc and iron retention in biofortified and non-biofortified milled rice. Journal of The Science of Food and Agriculture published by John Wiley & Sons Ltd on behalf of Society of Chemical Industry. 1-9.

Thammapat, P., Meeso, N., Siriamornpun, S. (2016). Effects of the traditional method and an alternative parboiling process on the fatty acids, vitamin E, γ-oryzanol and phenolic acids of glutinous rice. *Food Chemistry*, 194, 230-236.

Thomas, R., Wan-Nadiah, W.A., Bhat, R. (2013). Physiochemical properties, proximate composition, and cooking qualities of locally grown and imported rice varieties marketed in Penang, *Malaysia. International Food Research Journal*, 20(3),1345-1351.

Thomas, A.O., Olayinka, A., Kayode, A. (2016). Comparative Study of Nutrient Composition and Retention of Raw and Cooked Imported and Local Rice (*Oryza sativa*) Varieties. *British Journal of Applied Science and Technology*, 16(2), 1-9.

USA Rice Federation (2002). The natural history of rice. Online Food Cult. Encyclopedia, pp. 1-4.

Uwaegbute, A.C., Iroegbu, C.U., Eke, O. (2000). Chemical and sensory evaluation of germinated cowpeas (Vigna unguiculata) and their products. *Food Chemistry*, 68(2), 141–146.

Varnamkhasti, M.G., Mobli, H., Jafari, A., Keyhani, A., Soltanabadi, M., Rafiee, S., Kheiralipour, K. (2008). Some physical properties of rough rice (*Oryza Sativa* L.) grain. *Journal of Cereal Science*, 47(3), 496-501.

Verma, D.K., Srivastav, P.P. (2017). Proximate Composition, Mineral Content and Fatty Acids Analyses of Aromatic and Non-Aromatic Indian Rice. *Rice Science*, 24(1), 21-31.

Wazed, M.A., Mozumder, N.H.M.R. and Sarker M.S.H. (2021). Effect of Two Stage Drying Employing Fluidized Bed Drying, Tempering Followed by Fixed Bed Drying on Head Rice Yield of BRRI Dhan28 Rice Variety in Bangladesh. *Sustainability in Food and Agriculture*, 2(2), 74-78.

Wazed, M.A., Islam, M.R. (2021). Influence of barley, corn and rice flour on physical, chemical and sensory characteristics of gluten-free bread. *Malaysian Journal of Halal Research*, 4(2), 36-41. https://doi.org/10.2478/mjhr-2021-0008

Wazed, M.A., Mozumder, N.H.M.R. and Sarker M.S.H. (2022). Head rice yield of paddy dried in two stage and conventional drying methods. *AgricEngInt: CIGR Journal*, 24(3), 190-200.

Alam, M.S., Sarker, M.S.H., Hasan, S.M.K., Ahmed, M., Wazed, M.A. (2023). Comparison on drying characteristic, efficiency, unit drying cost and quality of maize dried by a novel multi-crop mobile dryer, existing industrial dryer and sun drying method. *Journal of Agriculture and Food Research*,14,100804.

Wessells, K.R., Brown, K.H. (2012). Estimating the global prevalence of zinc deficiency:results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS ONE*, 7, e50568.

Widyasaputra, R., Syamsir, E., & Budijanto, S. (2020). The changes of moisture content, total phenolic content and pasting profile caused by parboiling process of black rice. In IOP Conference Series: Earth and Environmental Science (Vol. 443, No. 1, p. 012004). IOP Publishing.

White, P. J., & Broadley, M. R. (2009). Biofortification of crops with seven mineral elements often lacking in human diets–iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phytologist*, 182(1), 49-84.

Woods, B.J., Gallego-Castillo, S., Talsma, E.F., A´lvarez, D. (2020) The acceptance of zinc biofortified rice in Latin America: A consumer sensory study and grain quality characterization. PLoS ONE, 15(11), e0242202.

Zeng, Y., Zhang, H., Wang, L., Pu, X., Du, J., Yang, S., Liu, J. (2010). Genotypic variation in element concentrations in brown rice from Yunnan landraces in China. *Environmental Geochemistry and Health*, 32(3), 165-177.

Zhang, D., Hamauzu, Y. (2004). Phenolic compounds and their antioxidant properties in different tissues of carrot (*Daucus carota* L.). Food Agriculture and Environment, 2 (1), 95-100.

Zohoun, E.V.,Tang, E.N., Soumanou, M.M., Manful, J., Akissoe, N.H., Bigoga, J., Futakuchi, K., Ndindeng, S.A. (2018). Physicochemical and nutritional properties of rice as affected by parboiling steaming time at atmospheric pressure and variety. *Food Science and Nutrition*, 6, 638-652.

Acknowledgment

The authors would like to acknowledge the laboratory support given by the Food Engineering and Technology Lab, Faculty of Engineering, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh, and the National Science and Technology (NST) for providing financial support to conduct research.