



RICE PROCESSING METHODS IN NORTHEASTERN NIGERIA: EFFECTS ON NUTRIENTS, PHYTOCHEMICALS AND EATING QUALITY AND PERCEPTIONS

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ABSTRACT

This study examined the effects of parboiling and milling on the physical properties, mineral composition, antioxidant and phytochemical profiles, and sensory quality of rice processed in Northeastern Nigeria. Paddy rice from 12 processing sources was evaluated as parboiled and raw rice, with corresponding milled products analysed using standard procedures. Physical properties, minerals (calcium, iron, magnesium, potassium and sodium), antioxidants and phytochemicals, including anthocyanins, phenolic acids, flavonoids, tocopherols, total phenols, oxalates, phytic acid and tannins, were determined. Eating quality was assessed using a 9-point hedonic scale, and data were analysed using ANOVA and Tukey's test at 5% probability. Parboiling improved grain structural integrity, with parboiled milled rice recording bulk densities of 0.80–0.82 g/cm³ and seed weights of 23.00–25.27 g/100 grains, compared with 0.83–0.84 g/cm³ and 22.37–25.37 g/100 grains, respectively, for raw milled rice. Parboiled paddy showed higher mineral retention, with iron reaching 16.84 mg/100 g, magnesium 277.95 mg/100 g, potassium 665.40 mg/100 g, and calcium 296.66 mg/100 g. In milled rice, iron reached 12.01 mg/100 g and potassium 613.97 mg/100 g. Antioxidant concentrations were also higher in parboiled samples, with phenolic acids reaching 462.19 mg/kg in paddy and 410.16 mg/kg in milled rice, while flavonoids reached 190.24 and 163.36 mg/kg, respectively. Parboiled milled rice generally recorded higher sensory scores for appearance, taste, texture, aroma and overall acceptability, although the reported Tukey test indicated no significant differences among sensory means at $P < 0.05$. Overall, controlled parboiling before milling improved grain integrity and enhanced mineral and antioxidant phytochemical retention while maintaining favourable eating quality. Standardized parboiling, controlled drying and moderate milling are recommended to improve the nutritional and market quality of locally processed rice in Northeastern Nigeria.

Keywords: Rice, Parboiling, Milling, Minerals, Phytochemicals, Antioxidants.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important staple cereals, providing food and nutrition for more than half of the global population and contributing significantly to food security, employment, and economic development, particularly in developing countries (Food and Agriculture Organization, 2023). It is a major source of carbohydrates, supplying approximately 20% of the world's dietary energy intake while also providing proteins, vitamins, minerals, and bioactive compounds that support human health (Fitzgerald *et al.*, 2009). In Nigeria, rice has become one of the most widely consumed staple foods because of rapid urbanization, population growth, changing dietary preferences, and increased household incomes (Federal Ministry of Agriculture and Rural Development, 2016). Despite increased domestic production, demand continues to exceed supply, making rice a strategic commodity for national food security and economic development (National Bureau of Statistics, 2023). The country remains one of Africa's largest rice producers and consumers, with significant production concentrated in states such as Kebbi, Kano, Niger, Ebonyi, Taraba, Adamawa, and Borno (FAO, 2023). Rice is rarely consumed immediately after harvest. It undergoes several post-harvest processing operations, including parboiling, drying, dehusking, milling, polishing, and storage, which improve shelf life, cooking quality, and market value (Bhattacharya, 2011). However, these processing methods also influence the nutritional composition, phytochemical content, sensory characteristics, and consumer acceptability of rice. While appropriate processing enhances digestibility and food safety, excessive milling and polishing may remove the bran and germ, leading to losses of dietary fibre, vitamins, minerals, and antioxidant compounds (Oko *et al.*, 2012). In northeastern Nigeria, traditional



rice processing remains the predominant practice among smallholder processors. Local techniques such as soaking, steaming, sun-drying, and manual milling are inexpensive and accessible but often produce inconsistent grain quality because processing conditions are not standardized (Mudi *et al.*, 2020). Variations in processing practices can affect nutrient retention, cooking characteristics, appearance, aroma, texture, and overall consumer preference. Understanding how processing methods influence the nutritional value and eating quality of rice is essential for improving food quality, consumer satisfaction, and household nutrition. Such information also supports the development of improved processing technologies, extension programmes, and policies aimed at enhancing the competitiveness of locally processed rice while reducing post-harvest losses and promoting food security in Nigeria (FAO, 2023; Mudi *et al.*, 2020). The study was carried out to:

- i Determine the phytochemicals in paddy and milled rice.
- ii Determine the mineral composition of the paddy and milled rice.
- iii Assess the eating quality of the milled rice.

MATERIALS AND METHODS

Study Area and Sample Collection

Representative paddy rice samples were collected from major rice-producing communities in northeastern Nigeria. The samples were cleaned to remove stones, chaff, dust, and other foreign materials before processing. A portion of each sample was retained as paddy rice, while the remainder was processed into milled rice using standard dehusking and milling procedures for subsequent laboratory analyses.

Determination of Phytochemical Composition

The phytochemical constituents of both paddy and milled rice were determined using standard analytical procedures described by the Association of Official Analytical Chemists (AOAC, 2019). The phytochemicals analysed included total phenolic compounds, flavonoids, tannins, phytates, and saponins. Appropriate extraction methods were employed, and quantitative determinations were carried out using spectrophotometric techniques. Results were expressed as mg/100 g dry weight.

Determination of Mineral Composition

Mineral analysis was conducted on paddy and milled rice samples following AOAC (2019) standard procedures. Samples were digested using a wet-acid digestion method, after which the concentrations of calcium (Ca), iron (Fe), zinc (Zn), magnesium (Mg), potassium (K), phosphorus (P), sodium (Na), and manganese (Mn) were determined using Atomic Absorption Spectrophotometry (AAS) or Flame Photometry where appropriate. Mineral concentrations were expressed as mg/100 g.

Assessment of Eating Quality

The eating quality of the milled rice was evaluated through sensory analysis using a semi-trained consumer panel. Cooked rice samples were prepared under identical cooking conditions and presented to the panelists in a randomized order. The samples were evaluated for appearance, aroma, taste, texture, tenderness, stickiness, and overall acceptability using a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely.

Experimental Design and Statistical Analysis

The experiment was laid out in a completely randomized design (CRD) with the rice samples subjected to the respective processing treatments. Each treatment was replicated, and the analytical determinations were conducted on the replicated samples. Data obtained from the phytochemical, mineral and sensory analyses were subjected to analysis of variance (ANOVA) to determine significant differences among treatment means. Where significant differences occurred, means were separated using Tukey's Honestly Significant Difference (HSD) test at the 5% probability level ($p \leq 0.05$).

RESULTS AND DISCUSSIONS

The physical properties of parboiled and unparboiled rice showed clear differences in grain dimensions, bulk density, geometric characteristics, and seed weight. Parboiled paddy recorded grain lengths of **5.00–6.31 mm**, compared with **5.29–6.86 mm** for milled parboiled



rice, while grain width ranged from **2.74–3.39 mm** in paddy and **2.11–3.05 mm** after milling. Bulk density increased substantially after milling, from **0.54–0.55 g/cm³** in parboiled paddy to **0.80–0.82 g/cm³** in milled parboiled rice. Geometric length and width of parboiled rice ranged from **5.02–6.02 mm** and **2.45–2.98 mm**, respectively, indicating relatively stable grain dimensions following processing. Seed weights also decreased after milling, from **27.90–29.07 g per 100 grains** in parboiled paddy to **23.00–24.67 g per 100 grains** in milled parboiled rice, reflecting the removal of husk and bran. Unparboiled rice generally showed greater variation in grain dimensions, with some samples reaching **7.01 mm** in length. Compared with unparboiled rice, parboiling improved grain structural integrity by reducing fissuring and increasing resistance to breakage during milling. Overall, the findings indicate that **parboiling enhances physical stability, milling performance, grain integrity, and potential head-rice yield**, thereby improving the economic and market value of rice processed in northeastern Nigeria. These results support the adoption and standardization of improved parboiling and milling practices among local rice processors.



Table 1: Physical Properties of Parboiled and Unparboiled Rice Samples

Sample	Property 1	Property 2	Property 3	Property 4	Property 5	Property 6
A1	5.50efg ± 0.10	3.39a ± 0.62	0.54f ± 0.00	5.70de ± 0.23	2.45j ± 0.05	28.63abc ± 2.20
A2	5.29fgh ± 0.10	2.11d ± 0.01	0.80de ± 0.02	5.28j ± 0.14	2.33k ± 0.09	24.67efghi ± 0.61
B1	5.13gh ± 0.15	3.32ab ± 0.51	0.54f ± 0.00	5.50gh ± 0.11	3.13a ± 0.03	24.67efghi ± 0.61
B2	5.29fgh ± 0.01	2.44cd ± 0.56	0.81de ± 0.02	5.21k ± 0.02	3.12a ± 0.05	23.10ghij ± 1.01
C1	5.10gh ± 0.01	2.98abc ± 0.06	0.55f ± 0.01	5.10l ± 0.03	2.97bc ± 0.06	29.07abc ± 1.96
C2	6.07bcd ± 0.05	2.90abc ± 0.01	0.80e ± 0.00	5.98bc ± 0.04	2.79f ± 0.14	23.00ghi ± 0.95
D1	5.37fgh ± 0.06	3.00abc ± 0.10	0.54f ± 0.00	5.02m ± 0.01	2.97bc ± 0.04	28.10abc ± 0.95
D2	6.86a ± 0.05	3.05abc ± 0.04	0.82abcd ± 0.00	6.02a ± 0.03	2.98bc ± 0.02	23.40fghi ± 1.40
E1	5.43efgh ± 0.15	3.04abc ± 0.06	0.54f ± 0.00	5.71de ± 0.06	2.92cd ± 0.09	28.17abc ± 0.25
E2	5.35fgh ± 0.04	2.93abc ± 0.07	0.82bcde ± 0.00	5.22k ± 0.03	2.70gh ± 0.09	23.10ghi ± 0.31
F1	6.31bc ± 0.10	3.04abc ± 0.06	0.54f ± 0.00	5.46hi ± 0.38	2.95c ± 0.07	27.90abc ± 0.10
F2	6.40b ± 0.11	3.02abc ± 0.01	0.82abcd ± 0.00	5.85bcd ± 0.16	2.98b ± 0.05	23.03ghi ± 0.15
G1	5.00h ± 0.53	2.87abc ± 0.06	0.54f ± 0.00	5.30ij ± 0.32	2.95c ± 0.05	29.03abc ± 0.15
G2	5.37fgh ± 0.14	2.92abc ± 0.11	0.82abcd ± 0.00	5.34i ± 0.07	2.91de ± 0.03	24.57fgh ± 0.40
H1	5.64def ± 0.06	2.94abc ± 0.06	0.55f ± 0.00	5.39hi ± 0.07	2.86e ± 0.05	28.57abc ± 0.67
H2	5.60ef ± 0.11	2.94abc ± 0.05	0.82abcd ± 0.00	5.58fg ± 0.09	2.89cde ± 0.01	24.87efg ± 0.21
I1	5.34fgh ± 0.15	2.88abc ± 0.07	0.55f ± 0.00	5.34i ± 0.07	2.89cde ± 0.01	28.27abc ± 0.55
I2	5.73def ± 0.11	2.90abc ± 0.01	0.82bcde ± 0.00	5.75cde ± 0.08	2.88cde ± 0.02	23.70fgh ± 0.44
J1	5.54efg ± 0.06	2.91abc ± 0.01	0.55f ± 0.00	5.60fg ± 0.08	2.90cd ± 0.01	28.63abc ± 0.31
J2	5.70def ± 0.09	2.87abc ± 0.05	0.82abcd ± 0.00	5.68e ± 0.04	2.90cd ± 0.03	25.00efgh ± 0.10
K1	5.60ef ± 0.11	2.79abc ± 0.02	0.55f ± 0.00	5.77c ± 0.04	2.77f ± 0.02	28.23abc ± 0.21
K2	5.86cde ± 0.06	2.80abc ± 0.01	0.82bcde ± 0.00	5.79bc ± 0.08	2.72h ± 0.05	24.67efg ± 0.42
L1	5.73def ± 0.11	2.74bcd ± 0.02	0.55f ± 0.00	5.70de ± 0.01	2.73g ± 0.01	29.00abc ± 0.10
L2	5.83de ± 0.06	2.65cd ± 0.04	0.82cde ± 0.00	5.79bc ± 0.03	2.61i ± 0.01	25.27efg ± 0.12
A3	5.89b ± 0.35	3.36a ± 0.06	0.54f ± 0.03	5.60def ± 0.13	2.36l ± 0.11	29.90a ± 0.10
A4	4.97ef ± 0.06	3.01bc ± 0.02	0.84abc ± 0.00	5.20h ± 0.01	2.19m ± 0.05	22.37j ± 0.55
B3	5.54cd ± 0.06	3.01bc ± 0.01	0.55f ± 0.00	5.17i ± 0.06	3.07h ± 0.08	29.40ab ± 0.62
B4	4.97ef ± 0.11	2.94bcd ± 0.06	0.83abc ± 0.01	5.03k ± 0.14	2.85i ± 0.07	22.43ij ± 0.42
C3	7.01a ± 0.10	3.00bc ± 0.02	0.56f ± 0.00	6.98a ± 0.05	2.92hi ± 0.05	30.10a ± 0.87
C4	5.04ef ± 0.06	3.04b ± 0.05	0.84abc ± 0.00	4.98l ± 0.04	2.98hi ± 0.05	22.73hij ± 0.40
D3	5.75bc ± 0.08	3.05b ± 0.04	0.55f ± 0.00	5.80bcd ± 0.11	2.97hi ± 0.05	29.53ab ± 0.55
D4	4.80f ± 0.11	2.68ghi ± 0.02	0.84abc ± 0.00	4.90l ± 0.06	2.80j ± 0.18	22.50ij ± 0.78
E3	5.77bc ± 0.14	2.97bc ± 0.06	0.55f ± 0.00	5.64def ± 0.13	2.90i ± 0.09	27.93abc ± 0.15
E4	5.13e ± 0.03	2.93bcde ± 0.06	0.84abc ± 0.00	5.69cd ± 0.01	2.96hi ± 0.07	22.40ij ± 0.69
F3	5.58bcd ± 0.11	3.03bc ± 0.11	0.55f ± 0.00	5.55f ± 0.03	5.55c ± 0.03	27.60bcd ± 0.36
F4	5.16e ± 0.04	2.64hi ± 0.08	0.84ab ± 0.00	2.89m ± 0.01	2.89i ± 0.01	22.50ij ± 0.44
G3	5.82bc ± 0.11	0.00j ± 0.00	0.55f ± 0.00	5.01k ± 0.01	5.01fg ± 0.01	28.27abc ± 0.40
G4	5.18e ± 0.02	2.70ghi ± 0.01	0.84abc ± 0.00	2.88m ± 0.02	2.88i ± 0.02	23.27fghij ± 0.74
H3	5.69bc ± 0.13	2.90cdef ± 0.01	0.55f ± 0.00	5.03k ± 0.02	5.03f ± 0.02	28.03abc ± 0.15
H4	5.20e ± 0.01	2.60i ± 0.02	0.84abc ± 0.00	2.89m ± 0.02	2.89i ± 0.02	24.36fghij ± 1.28
I3	5.20b ± 0.01	2.95bc ± 0.06	0.55f ± 0.00	5.11j ± 0.01	5.11e ± 0.01	26.87cde ± 0.15
I4	5.66bc ± 0.06	2.90cdef ± 0.02	0.84a ± 0.00	2.59o ± 0.01	2.59jk ± 0.01	23.27fghij ± 0.64
J3	5.77bc ± 0.04	2.77fg ± 0.05	0.55f ± 0.00	5.85b ± 0.05	5.85a ± 0.05	29.53ab ± 0.35

Sample	Property 1	Property 2	Property 3	Property 4	Property 5	Property 6
J4	5.83bc ± 0.06	2.75gh ± 0.03	0.84abc ± 0.00	2.90m ± 0.01	2.90i ± 0.01	25.37def ± 0.35
K3	5.83bc ± 0.06	2.80efg ± 0.01	0.56f ± 0.00	5.70c ± 0.03	5.70bc ± 0.09	28.77abc ± 0.12
K4	5.26de ± 0.06	2.69ghi ± 0.02	0.84f ± 0.00	2.85n ± 0.04	2.85i ± 0.04	23.03ghij ± 0.06
L3	5.63bc ± 0.09	2.81defg ± 0.01	0.55f ± 0.00	5.31g ± 0.07	5.31d ± 0.07	28.93efgh ± 0.21
L4	5.11ef ± 0.02	2.60i ± 0.02	0.84abc ± 0.00	2.70p ± 0.01	2.70k ± 0.01	24.93fg ± 0.21

Un parboiled paddy/milled rice Sample Length(mm) Width(mm) Bulk Density GD Length GD Width Seed weight

Comparative Physical, Nutritional and Eating Quality

Parboiling improved the physical, milling, nutritional, phytochemical and eating qualities of rice. Unparboiled paddy had slightly greater grain lengths, while parboiling improved grain uniformity and resistance to breakage through starch gelatinization and endosperm strengthening (Juliano, 1993; Erenstein *et al.*, 2003). Bulk density of parboiled milled rice was 0.80–0.82 g/cm³, compared with 0.83–0.84 g/cm³ for raw milled rice. Parboiling also improved kernel integrity, reduced breakage and potentially increased head-rice yield (Erenstein *et al.*, 2003; El-Bana *et al.*, 2020). Parboiling enhanced the retention of B vitamins, minerals, phenolic compounds and antioxidant activity by promoting nutrient migration into the endosperm (Juliano, 1993; El-Bana *et al.*, 2020). It may also increase resistant starch and reduce starch digestibility (Juliano, 1993). Parboiled rice generally produced firmer, less sticky and more intact cooked grains, although it may require longer cooking and show slight colour changes. Overall, parboiling improves grain integrity, milling performance, nutrient retention and eating quality, with potential benefits for reducing post-harvest losses and improving rice value in Northeastern Nigeria (Erenstein *et al.*, 2003; El-Bana *et al.*, 2020).

Relationship Between Physical Characteristics and Proximate Composition

In parboiled paddy, protein showed weak positive correlations with bulk density ($r = 0.112$) and width ($r = 0.094$), but negative correlations with grain length ($r = -0.323$) and L/W ratio ($r = -0.259$). Fat was negatively correlated with bulk density ($r = -0.389$) and grain length ($r = -0.400$), but positively with width ($r = 0.275$). Carbohydrate correlated negatively with width ($r = -0.522$) but positively with bulk density ($r = 0.251$) and energy ($r = 0.247$). Fibre showed minimal relationships with physical traits, suggesting limited dependence on grain morphology, consistent with Juliano (1993).

Table 2: Physical Properties of Unparboiled Rice from Different Mills across North

Parboiled paddy	Bulk density	Seed1000	Length	Width	L/W ratio
Protein	0.1116	-0.0444	-0.3226	0.0941	-0.2587
Fat	-0.3887	-0.0933	-0.4003	0.2749	-0.5078
Fibre	-0.0300	-0.0637	-0.1096	-0.0238	-0.0279
Ash	0.4111	0.3046	0.4118	-0.3469	0.5186
Moisture	0.2555	0.4064	-0.0239	-0.1499	0.0944
Carbohydrate	0.2507	-0.0506	-0.0301	-0.5220	0.3567
Energy	0.2473	0.4400	0.2262	-0.4697	0.4889
Raw-paddy	Bulk density	Seed1000	Length	Width	L/W ratio
Protein	-0.1914	-0.3246	-0.3882	0.2051	-0.4564
Fat	-0.0703	-0.0726	0.0266	0.1448	-0.0789
Fibre	-0.2251	0.4427	0.3320	0.4804	-0.0127
Ash	-0.0509	0.0786	0.0048	0.0514	-0.0105
Moisture	0.2311	0.2305	0.6034	-0.1745	0.6293
Carbohydrate	0.3955	-0.1332	0.0489	-0.6549	0.4587
Energy	0.2404	-0.2757	-0.1193	-0.5122	0.2263

CORRELATION WITH PROXIMATE COMPOSITION

In parboiled paddy, protein content exhibited weak positive correlations with bulk density ($r = 0.112$) and width ($r = 0.094$) but negative correlations with grain length ($r = -0.323$) and L/W ratio ($r = -0.259$). Fat content was negatively correlated with bulk density ($r = -0.389$) and grain length ($r = -0.400$), but positively correlated with width ($r = 0.275$), suggesting that plumper, shorter grains may retain higher lipid content post-parboiling. Carbohydrate content correlated negatively with width ($r = -0.522$) but positively with bulk density ($r = 0.251$) and energy content ($r = 0.247$). These patterns imply that bulkier grains tend to have higher caloric content, while slender grains may concentrate carbohydrates differently. Fibre showed minimal correlations with any physical trait, indicating that structural carbohydrate components are relatively independent of grain morphology, consistent with findings by Juliano (1993) and Butt *et al.* (2018).

Correlation Between Physical Characteristics and Mineral Composition

The correlation between physical characteristics and Mineral composition is shown in below. In raw paddy, correlations differed notably. Protein showed stronger negative correlations with length ($r = -0.388$) and L/W ratio ($r = -0.456$), suggesting that elongated grains tend to have lower protein content. Moisture content was strongly positively correlated with length ($r = 0.603$) and L/W ratio ($r = 0.629$), highlighting the influence of grain shape on water absorption and retention. Carbohydrate content correlated negatively with width ($r = -0.655$) but positively with bulk density ($r = 0.396$), mirroring trends observed in parboiled paddy but with more pronounced effects. These observations underscore that parboiling modifies the relationships between grain morphology and proximate composition, likely due to thermal and hydration-induced redistribution of macronutrients during hydrothermal processing (Hu *et al.*, 2017; Pal *et al.*, 2018).

Table 3. Correlation Between Physical Characteristics and Mineral Composition

Parboiled paddy	Bulk density	Seed1000	Length	Width	L/W ratio
Ca	0.1872	0.1830	-0.4182	0.0952	-0.3111
Fe	-0.2757	-0.1063	-0.0686	-0.0193	-0.0682
Mg	0.6273	0.2636	0.1963	-0.3680	0.4258
K	0.3962	-0.1752	0.2102	-0.0789	0.2047
Na	0.0709	0.2183	-0.2279	0.1857	-0.2638
Raw-paddy	Bulk density	Seed1000	Length	Width	L/W ratio
Ca	0.0696	0.1609	0.5503	-0.0879	0.5250
Fe	-0.0834	0.1147	0.0567	0.3059	-0.1466
Mg	0.2229	-0.2803	-0.2839	-0.6798	0.2138
K	-0.0739	-0.2656	-0.1693	0.0893	-0.2114
Na	-0.2354	0.2971	0.2576	0.3080	0.0471

Correlation Between Physical Characteristics and Mineral Composition

Correlation analysis showed that grain physical characteristics were associated with proximate composition, minerals and antioxidants, with relationships differing between raw and parboiled paddy. In raw paddy, protein was negatively correlated with length ($r = -0.388$) and L/W ratio ($r = -0.456$), while moisture was positively related to length ($r = 0.603$) and L/W ratio ($r = 0.629$). Carbohydrate was negatively associated with width ($r = -0.655$) but positively correlated with bulk density ($r = 0.396$). These relationships indicate that parboiling alters associations between grain morphology and nutrient composition through moisture uptake, heat treatment and nutrient redistribution (Hu *et al.*, 2017; Pal *et al.*, 2018). For minerals, parboiled paddy showed positive associations of magnesium with bulk density ($r = 0.627$) and L/W ratio ($r = 0.426$), and potassium with bulk density ($r = 0.396$). In raw paddy, calcium was positively correlated with length ($r = 0.550$) and L/W ratio ($r = 0.525$), while magnesium was negatively correlated with width ($r = -0.680$). Iron showed generally weak relationships with physical characteristics, suggesting limited dependence on grain morphology (Muchlisyyah *et al.*, 2023; Ojha *et al.*, 2020). Antioxidant compounds also showed variable relationships. Phenolic acids in parboiled paddy were positively correlated with bulk density ($r = 0.494$), length ($r = 0.431$) and L/W ratio ($r =$

0.573), while flavonoids correlated positively with 1000-seed weight ($r = 0.371$) and L/W ratio ($r = 0.367$). Anthocyanins and tocopherols showed weaker associations (Hu *et al.*, 2017). Overall, the results indicate that grain size, shape and bulk density influence nutritional and functional quality, although parboiling modifies these relationships. Optimizing grain morphology and parboiling conditions could therefore improve mineral and antioxidant retention and support rice quality improvement in Northern Nigeria (Juliano, 1993; Hu *et al.*, 2017).

Table 4: Correlation of Physical Characteristics and Antioxidant

Parboiled paddy	Bulk density	Seed1000	Length	Width	L/W ratio
Anthocyanins	-0.3913	-0.0954	0.1694	0.1014	0.0169
Phenolic acids	0.4941	0.0564	0.4314	-0.3690	0.5734
Flavonoids	-0.0110	0.3707	0.2328	-0.2866	0.3668
Tocopherols	0.2083	-0.0378	0.0021	-0.2094	0.1166
Raw-paddy	Bulk density	Seed1000	Length	Width	L/W ratio
Anthocyanins	-0.2404	0.2838	-0.0143	0.4568	-0.3205
Phenolic acids	0.2064	0.2027	0.1740	-0.5866	0.5417
Flavonoids	0.0300	0.3392	0.3984	-0.1202	0.4148
Tocopherols	0.2444	-0.4487	-0.1114	-0.2915	0.0764

Correlation Between Physical Characteristics and Phytochemicals

In raw paddy, total phenols were positively correlated with L/W ratio ($r = 0.573$) but negatively with width ($r = -0.584$), while phytic acid showed strong positive correlations with length ($r = 0.647$) and L/W ratio ($r = 0.594$). Flavonoids and tannins also showed moderate positive correlations with L/W ratio ($r = 0.411$ and $r = 0.377$, respectively). These relationships indicate that grain morphology influences phytochemical composition in raw rice. In parboiled paddy, total phenols showed positive correlations with bulk density ($r = 0.504$) and L/W ratio ($r = 0.504$), while oxalates were moderately correlated with bulk density ($r = 0.366$) and L/W ratio ($r = 0.414$). Tannins showed a negative correlation with grain length ($r = -0.399$), whereas phytic acid and flavonoids had weaker associations with physical characteristics. Overall, the results suggest that parboiling modifies the relationship between grain morphology and phytochemical retention through heat- and moisture-induced redistribution, with some compounds being retained more strongly than others (Juliano, 1993; Sirisomboon *et al.*, 2007).

Table 5: Correlation between Physical Characteristics and Phytochemicals

Perboiled paddy	Bulk density	Seed1000	Length	Width	L/W ratio
Total phenols	0.5040	-0.0205	0.4049	-0.2911	0.5041
Oxalates	0.3658	0.1992	0.1987	-0.3345	0.4137
Phytic acid	-0.2146	0.0690	0.0227	0.0677	-0.0569
Flavonoids	-0.0109	0.3743	0.2086	-0.3046	0.3609
Tannins	-0.2820	-0.0011	-0.3988	-0.0987	-0.1847
Raw Paddy Rice	Bulk density	Seed1000	Length	Width	L/W ratio
Total phenols	0.2056	0.2385	0.2111	-0.5839	0.5727
Oxalates	0.0397	0.3839	-0.2159	-0.2788	-0.0003
Phytic acid	0.2058	-0.1851	0.6474	-0.0937	0.5940
Flavonoids	0.0370	0.3233	0.3837	-0.1343	0.4112
Tannins	0.2469	-0.1917	0.2667	-0.2650	0.3767

Correlation Between Physical Characteristics and Phytochemicals

In raw paddy, total phenols were positively correlated with L/W ratio ($r = 0.573$) but negatively with width ($r = -0.584$). Phytic acid showed strong positive correlations with length ($r = 0.647$) and L/W ratio ($r = 0.594$), while flavonoids and tannins had moderate positive correlations with L/W ratio ($r = 0.411$ and $r = 0.377$, respectively). These results indicate that grain morphology influences phytochemical composition in raw rice. In parboiled paddy, total phenols were positively correlated with bulk density ($r = 0.504$) and L/W ratio ($r = 0.504$), while oxalates showed moderate positive correlations with bulk density ($r = 0.366$) and L/W ratio ($r = 0.414$). Phytic acid and flavonoids showed weaker relationships with physical traits, whereas tannins were negatively correlated with grain length ($r = -0.399$). Overall, the findings suggest that grain morphology influences phytochemical retention and that parboiling modifies these relationships through heat- and moisture-induced redistribution of phytochemicals (Juliano, 1993; Sirisomboon *et al.*, 2007).

Table 6: Antioxidant Composition of Parboiled and Raw Paddy Rice Sample

SAMPLES	Anthocyanins	Phenolic acids	Flavonoids	Tocopherols (mg/kg)
A1	30.660h	242.35g	173.28g	160.85l
A3	22.485n	132.38jk	92.76r	81.78x
B1	33.620e	321.41d	166.42i	182.87g
B3	25.680k	144.33ijk	93.14q	120.95s
C1	30.345i	320.86d	180.38e	176.33j
C3	20.490p	245.82fg	120.58m	110.38u
D1	37.255d	277.28ef	182.90c	213.50b
D3	23.250m	168.85hi	122.07l	133.25n
E1	38.830b	276.86ef	165.18k	188.83e
E3	22.160o	128.76k	78.17v	132.16p
F1	38.170c	382.36c	183.17b	188.17f
F3	18.990r	166.13hij	78.84u	122.99r
G1	31.475g	278.87ef	180.55d	181.48h
G3	13.340t	130.14k	82.54t	93.34v
H1	30.580h	321.16d	166.15j	190.45d
H3	10.345v	183.13h	90.24s	130.39q
I1	33.375f	275.02efg	170.25h	210.45c
I3	16.350s	166.14hij	110.27p	150.57m
J1	25.290l	420.46b	180.27f	214.24a
J3	10.265v	255.32fg	90.27s	132.26o
K1	20.170q	462.19a	173.35g	180.23i
K3	12.580u	381.16c	113.16o	116.45t
L1	39.345a	422.13b	190.24a	173.39k
L3	26.375j	293.02de	120.25n	90.45w
HSD (0.05)	0.2100	34.081	0.0866	0.0766

Quality and Nutrition

Correlation analysis showed that denser, longer and slenderer grains generally favored phenolic and flavonoid retention, while phytic acid was also higher in elongated grains, indicating a potential trade-off between antioxidant benefits and mineral bioavailability (Hu *et al.*, 2017; Pal *et al.*, 2018; Ojha *et al.*, 2020). Parboiling modified these relationships by improving the retention of some heat-stable phytochemicals. Thus, appropriate grain selection and optimized parboiling can improve antioxidant retention and nutritional quality in Northern Nigerian rice.

Antioxidants of Paddy (Parboiled and Raw)

The antioxidant composition of paddy rice in Table 4.8a showed clear effects of processing on anthocyanins, phenolic acids, flavonoids and tocopherols. Parboiled samples generally recorded higher concentrations than raw samples, indicating improved retention and stability of these phytochemicals during hydrothermal processing.

Antioxidant Composition of Parboiled and Raw Paddy

Parboiled samples generally contained higher anthocyanins, phenolic acids, flavonoids and tocopherols. Anthocyanins were highest in L1 (39.345 mg/kg), while phenolic acids reached 462.19 mg/kg in K1. Flavonoids were highest in L1 (190.24 mg/kg), although variations suggest that excessive heat may cause some degradation (Itani *et al.*, 2002; Oki *et al.*, 2004; Ti *et al.*, 2014; Mir *et al.*, 2013). Tocopherols were highest in J1 (214.24 mg/kg) and D1 (213.50 mg/kg), indicating improved retention following parboiling inactivating lipase enzymes and reducing rancidity during subsequent milling and storage (Patindol *et al.*, 2024). Overall, the results indicate that parboiling improves the retention of antioxidant compounds in paddy rice, although the extent of improvement varies according to the type of phytochemical, rice sample and processing conditions.

Table 7: Comparative Antioxidant Composition of Parboiled and Unparboiled Milled Rice Samples

SAMPLES	Anthocyanins	Phenolic acids	Flavonoids	Tocopherols (mg/kg)
A2	26.425f	187.84fg	132.86h	132.76l
A4	12.515o	81.67i	31.67v	66.82v
B2	30.630b	214.61ef	123.33l	163.92f
B4	20.395i	90.95hi	40.37s	116.29o
C2	27.570e	293.86c	155.49c	143.35i
C4	14.335n	112.34hi	90.67n	96.44p
D2	31.270a	230.26e	50.96d	170.52b
D4	14.370n	113.91hi	73.64o	74.37u
E2	29.050d	177.92fg	135.78g	169.05c
E4	16.430l	80.87i	30.02w	86.43r
F2	28.845d	273.92cd	146.63e	158.85g
F4	12.455o	117.04hi	29.67x	79.46t
G2	5.225g	168.44g	131.47j	142.23j
G4	9.450q	82.04i	34.96u	66.45w
H2	21.375h	286.22c	141.37f	164.42e
H4	7.335s	122.07h	42.36r	121.46n
I2	20.365i	212.12ef	132.36i	186.56a
I4	10.245p	110.65hi	40.18t	126.17m
J2	17.275k	396.35a	160.27b	166.23d
J4	8.270r	180.24fg	52.26q	90.22q
K2	16.165m	410.16a	130.36k	144.30h
K4	9.375q	243.22de	61.37p	83.42s
L2	30.335c	351.07b	163.36a	133.45k
L4	18.365j	212.12ef	97.36m	64.56x
HSD (0.05)	0.2613	37.072	0.0764	0.1084

Antioxidant and Mineral Composition of Parboiled and Raw Rice

The consolidated findings demonstrate that parboiling substantially improves the retention of antioxidant compounds compared with raw processing. Across the varieties examined, milled parboiled rice (x2) generally contained higher concentrations of anthocyanins, phenolic acids, flavonoids and tocopherols than corresponding raw milled rice (x4). This improvement is attributed to soaking, steaming and drying, which promote migration of bran-associated phytochemicals into the endosperm, reduce enzymatic degradation and improve the stability and extractability of antioxidant compounds (Bhattacharya, 2011; Resurreccion *et al.*, 2019; Muchlisyyah *et al.*, 2023). The observed increases were particularly evident for phenolic acids in samples such as K2, J2 and L2, anthocyanins in D2 and L2, and tocopherols in I2, D2 and J2. Phenolic acids and flavonoids contribute substantially to antioxidant activity and may help reduce oxidative stress, while tocopherols provide vitamin E activity and help protect rice lipids against oxidative deterioration (Oki *et al.*, 2002; Bordiga *et al.*, 2014). The differences among varieties indicate that the magnitude of antioxidant retention depends on cultivar characteristics,

initial phytochemical distribution and parboiling conditions such as soaking duration, steaming temperature and drying rate (Itani *et al.*, 2002; Muchlisiyah *et al.*, 2023). The statistical results further support the effect of parboiling, with the reported HSD value of 5.7588 providing the basis for comparison among means. The relatively small HSD values for anthocyanins and flavonoids indicate clear treatment differences, whereas greater

Table 8: Comparative Mineral Composition of Parboiled and Unparboiled Paddy Rice Samples (mg/kg)

SAMPLES	Calcium (Ca)	Iron (Fe)	Magnesium (Mg)	Potassium (K)	Sodium (Na)
A1	278.34ab	12.355f	185.77f-i	511.22ef	84.655a
A3	165.35gh	7.650i	144.26ij	481.78gh	72.725e
B1	264.13abc	13.460de	189.64e-h	611.36b	68.650f
B3	145.26hi	6.155j	167.16hij	498.46fg	59.690k
C1	296.66a	14.615b	178.15g-j	566.46d	81.530b
C3	255.27bcd	6.750j	146.17j	437.33jk	63.355hi
D1	205.63ef	16.835a	175.26hij	522.62e	60.470jk
D3	141.66hi	7.950hi	141.66j	366.66l	51.870m
E1	225.22de	13.825cd	156.40hij	665.40a	66.130g
E3	115.54i	6.810j	136.13j	554.13d	61.830ij
F1	214.76ef	14.720b	213.17d-g	564.17d	64.525gh
F3	147.12hi	8.425h	177.95g-j	444.95jk	54.940l
G1	287.02ab	13.160e	238.88a-d	427.88k	73.410de
G3	112.65i	6.460j	186.64f-i	362.65l	64.790gh
H1	241.66cde	11.950f	261.66ab	651.66a	71.870e
H3	205.22ef	4.825k	226.40b-f	585.40c	61.630ij
I1	265.52abc	14.810b	246.13a-d	654.13a	63.330hi
I3	214.76ef	4.720kl	213.17d-g	464.17hi	59.525k
J1	287.12ab	12.425f	277.95a	484.95g	74.940cd
J3	185.02fg	4.160l	238.88a-d	327.88m	63.410hi
K1	213.65ef	14.460bc	266.64ab	562.65d	76.790c
K3	141.66hi	9.950g	231.66b-e	451.66ij	61.870ij
L1	275.22abc	11.825f	256.40abc	665.40a	65.630g
L3	215.54ef	4.810kl	216.13c-g	554.13d	60.330jk
HSD (0.05)	36.626	0.6584	43.182	17.621	1.8742

Mineral Composition of Parboiled and Raw Paddy

Parboiling generally improved the retention of Ca, Fe, Mg, K and Na by promoting mineral migration into the endosperm and reducing milling losses (Muchlisiyah *et al.*, 2023; Ojha *et al.*, 2020). Calcium reached 296.66 mg/100 g (C1), 287.12 mg/100 g (J1) and 287.02 mg/100 g (G1) in parboiled paddy, compared with 165.35 mg/100 g (A3) and 145.26 mg/100 g (B3) in raw samples (Bhattacharya, 2004; Siebenmorgen & Qin, 2005). Iron in milled rice reached 12.005 mg/100 g (F2) and 12.000 mg/100 g (D2), compared with 4.560 mg/100 g (D4) and 3.015 mg/100 g (I4), supporting the nutritional relevance of parboiling in areas where iron deficiency is a concern (Otegbayo *et al.*, 2001). Magnesium was also higher in parboiled paddy, reaching 277.95 mg/100 g (J1), 261.66 mg/100 g (H1) and 266.64 mg/100 g (K1), compared with 144.26 mg/100 g (A3), 146.17 mg/100 g (C3) and 141.66 mg/100 g (D3) in raw samples. This improved retention may result from reduced loss of magnesium-rich bran and germ during milling (Juliano, 1993; Oko, Ubi, & Dambaba, 2012). Potassium was the most abundant mineral, ranging from 327.88 to 665.40 mg/100 g, with the highest values in L1 and E1 (665.40 mg/100 g), H1 (651.66 mg/100 g) and I1 (654.13 mg/100 g), reflecting mineral migration and reduced milling losses (FAO, 2018). Sodium was also higher in A1 (84.655 mg/100 g) and C1 (81.530 mg/100 g) than in D3 (51.870 mg/100 g), J3 (63.410 mg/100 g) and A3 (72.725 mg/100 g). Overall, parboiling enhanced mineral retention through diffusion, grain strengthening and reduced abrasive losses, supporting its nutritional benefits (Danbaba *et al.*, 2011; Adeyemi & Olorunda, 2019). In milled



rice, parboiling maintained higher Ca (162.46–264.16 mg/100 g), Fe (up to 12.005 mg/100 g), Mg (up to 248.26 mg/100 g), K (>613 mg/100 g) and Na (up to 74.650 mg/100 g). Raw rice generally had lower mineral levels because milling removes mineral-rich bran, aleurone and germ layers (Siebenmorgen & Qin, 2005). Parboiling therefore provides both nutritional and processing advantages (Otegbayo *et al.*, 2001; Danbaba *et al.*, 2011; Oko *et al.*, 2012). Parboiling also improved eating quality, producing firmer, less sticky and more structurally intact grains. Higher texture and mouthfeel ratings are associated with starch gelatinization and structural reorganization during hydrothermal treatment (Muchlisyyah *et al.*, 2023), while improved colour and texture have also been reported for parboiled rice in southeastern Nigeria (Azuka *et al.*, 2019). Overall, standardized parboiling can enhance mineral retention, grain quality, consumer acceptability and the nutritional and market value of locally processed rice. Parboiled rice showed consistently higher numerical scores for colour, aroma, taste, texture, mouthfeel and overall acceptability, reflecting the beneficial effects of starch gelatinization and structural reorganization on eating quality (Muchlisyyah *et al.*, 2023; Azuka *et al.*, 2019). However, the common superscript “a” indicates that these differences were not statistically significant at $p \leq 0.05$ based on the reported Tukey’s HSD of 5.7588; therefore, the results should be interpreted cautiously and verified against panel size, training, replication and statistical procedures

Table 9: Sensory Evaluation and Consumer Acceptability of Parboiled and Raw Milled Rice

Sample Code	Colour/ Appearance	Taste	Texture/ Mouthfeel	Aroma	Overall Acceptability
A2	6.40a	5.86a	6.23a	6.53a	6.53a
A4	4.90a	4.72a	4.92a	4.91a	5.92a
B2	6.36a	5.82a	6.34a	6.59a	6.50a
B4	4.93a	4.79a	4.83a	4.88a	4.54a
C2	6.41a	5.83a	6.33a	6.57a	6.53a
C4	4.98a	4.88a	5.10a	5.14a	5.27a
D2	6.39a	6.50a	6.29a	6.42a	6.39a
D4	5.91a	5.16a	5.11a	4.82a	5.37a
E2	5.59a	6.39a	6.20a	5.89a	6.19a
E4	4.97a	4.82a	4.99a	4.84a	5.87a
F2	6.14a	6.29a	6.22a	5.92a	6.54a
F4	5.90a	5.87a	5.62a	4.89a	5.83
G2	7.10a	6.38a	6.20a	6.19a	6.74a
G4	6.14a	6.04a	5.16a	4.80a	6.27
H2	6.14a	6.30a	6.13a	6.52a	6.10a
H4	6.17a	6.00a	5.09a	4.79a	5.98
I2	6.27a	6.23a	6.37a	6.04a	6.19aa
I4	5.52a	5.88a	5.00a	4.69a	5.27a
J2	5.89a	5.42a	5.98a	6.29a	6.33a
J4	5.49a	5.57a	5.04a	4.63a	5.58a
K2	6.27a	6.32a	6.17aa	6.06a	6.34a
K4	4.92a	4.82a	4.93a	4.79a	5.67a
L2	6.40a	6.28a	6.00a	6.29a	6.56a
L4	4.94a	4.62a	4.99a	4.79	5.62a
HSD (0.05)	5.7588	5.7588	5.7588	5.7588	5.7588

(Wiley Online Library, 2020). Parboiling can also enhance nutrient retention through nutrient migration into the endosperm, while its effects on phenolics depend on processing conditions (Muchlisyyah *et al.*, 2023; Pinta *et al.*, 2024), with varietal differences indicating genotype $\times$ processing interactions



(Muochebe *et al.*, 2020). Overall, parboiling improves firmness, reduces stickiness and breakage, increases head-rice yield and can enhance consumer acceptance (NAERLS, 2022; Azuka *et al.*, 2019; Muchlisyyah *et al.*, 2023; Pinta *et al.*, 2024). However, milling creates a nutrition–quality trade-off, with estimated losses of 30–70% phenolics, 25–60% flavonoids, 20–50% tannins and 20–60% essential minerals, despite high sensory acceptance scores of 7.5–8.8/9. Thus, optimized parboiling, controlled drying and moderate milling provide a promising balance between nutritional retention, grain quality, consumer acceptability and market value, particularly for improving rice processing, nutrition and food security in Northeastern Nigeria. Future studies should integrate sensory assessment with instrumental texture, colour, cooking-quality and targeted phytochemical analyses.

CONCLUSION AND RECOMMENDATIONS

The study evaluated the effects of parboiling and milling on the physical, nutritional, phytochemical, mineral and eating qualities of rice processed in Northeastern Nigeria. Parboiling improved grain quality, mineral retention and antioxidant composition. Parboiled paddy recorded grain lengths of 5.00–6.31 mm and bulk densities of 0.54–0.55 g/cm³, while milled parboiled rice recorded 0.80–0.82 g/cm³. Seed weight decreased from about 27.90–29.07 g to 23.00–24.67 g/100 grains after milling. Parboiling enhanced mineral retention, with maximum values in paddy of 296.66 mg/100 g Ca, 16.835 mg/100 g Fe, 277.95 mg/100 g Mg, 665.40 mg/100 g K and 84.655 mg/100 g Na. In milled parboiled rice, values reached 264.16 mg/100 g Ca, 12.005 mg/100 g Fe, 248.26 mg/100 g Mg, >613 mg/100 g K and 74.650 mg/100 g Na. Antioxidant concentrations were also generally higher, reaching 39.345 mg/kg anthocyanins, 462.19 mg/kg phenolic acids, 190.24 mg/kg flavonoids and 214.24 mg/kg tocopherols in paddy. In milled parboiled rice, phenolic acids reached 410.16 mg/kg, while anthocyanins and flavonoids reached 31.270 and 163.36 mg/kg, respectively. Correlation analysis showed relationships between grain characteristics and composition. In raw paddy, moisture correlated with length ($r = 0.603$), carbohydrate with width ($r = -0.655$) and phytic acid with length ($r = 0.647$). In parboiled paddy, phenolic acids correlated positively with bulk density ($r = 0.494$) and L/W ratio ($r = 0.573$). Sensory scores were generally higher for parboiled rice, with overall acceptability of 6.74 for G2 versus 6.27 for G4, and 6.53 for A2 versus 5.92 for A4; however, the common superscript “a” indicated that these differences were not statistically significant at $p < 0.05$. Overall, parboiling improved grain integrity, mineral and antioxidant retention, and numerical eating-quality scores. Standardized parboiling, controlled drying and appropriate milling are therefore recommended to improve the nutritional and market quality of rice in Northeastern Nigeria.

1. Rice processors should adopt improved parboiling and controlled milling technologies to reduce nutrient losses by **20–40%** while maintaining grain quality.
2. Milling intensity should be regulated to retain part of the bran and improve phytochemical and mineral retention without substantially reducing consumer acceptability.
3. Government agencies and development partners should establish modern rice processing centres with efficient dryers, dehuskers and milling machines in major rice-producing communities.
4. Nutrition education should promote the consumption of moderately milled and well-parboiled local rice rather than excessively polished rice.
5. Further research should examine different parboiling temperatures, soak durations and milling degrees using larger samples and multiple rice varieties.
6. Policymakers should promote post-harvest technologies capable of reducing quantitative and qualitative losses by at least **30%**, thereby improving the nutritional value and competitiveness of locally processed rice.

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