



COMPARATIVE EFFECTS OF TRADITIONAL AND MODERN RICE PROCESSING TECHNOLOGIES ON NUTRITIONAL COMPOSITION, PHYTOCHEMICAL RETENTION AND FUNCTIONAL PROPERTIES OF RICE IN NORTHEASTERN NIGERIA

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ABSTRACT

This study assessed the rice processing methods used in Northeastern Nigeria and examined their effects on the physical, functional and proximate qualities of processed rice. A survey was conducted in 12 rice milling centres across Adamawa, Bauchi, Borno, Gombe, Taraba and Yobe States. Rice samples representing traditional, small-scale mechanized and semi-industrial processing methods were collected and analysed using standard procedures. Proximate composition, functional properties, milling recovery and selected physical quality characteristics were determined. The data were subjected to analysis of variance, and significant differences were separated using Tukey's HSD test at $P < 0.05$. The survey indicated that more than half (58.3%) of the processors used improved processing technologies, although traditional methods were still practiced. Small-scale mechanized milling was the most widely used method (58.3%). Modern commercial mills recorded the highest milling recovery (68.9%), followed by locally fabricated mills (61.7%) and traditional stone mills (55.3%). Modern milling also produced more uniform whiteness (83.3%) and a lower occurrence of foreign materials (16.7%) than stone milling, which recorded 25.0% and 66.7%, respectively. The proximate analysis showed clear differences associated with processing methods. Parboiled milled rice generally retained higher levels of protein (10.85–13.96%), fibre (4.57–10.92%), fat (1.21–2.52%) and ash (1.13–2.22%) than raw milled rice, whereas raw milled rice generally had higher carbohydrate contents (78.71–82.65%). Functional properties also varied among rice varieties and processing treatments, particularly with respect to gelatinization and viscosity characteristics. Overall, the findings indicate that appropriate parboiling, together with improved and controlled milling practices, can enhance nutrient retention, reduce grain breakage, improve milling recovery and produce rice with better physical and functional qualities. The study recommends investment in improved processing facilities, regular training for processors, standardization of parboiling and milling procedures, and stronger quality-control measures to improve the nutritional quality, market value and competitiveness of locally processed rice in Northeastern Nigeria.

Keywords: Rice, Processing, Proximate, Composition, Functional, Properties.

INTRODUCTION

Rice (*Oryza sativa* L.) is among the most widely consumed cereal crops in the world and plays an important role in food security, employment and economic development. Its importance is particularly evident in developing countries where it serves as a major source of dietary energy and income for millions of households (FAO, 2024; OECD & FAO, 2024). In Nigeria, rice has become an important staple food and a major agricultural commodity. Nevertheless, problems associated with post-harvest handling and processing continue to influence the quality, nutritional value and market competitiveness of locally produced rice. Processing involves a number of operations, including parboiling, drying, dehulling, milling, polishing, grading and packaging. When properly carried out, these operations can improve milling recovery, grain appearance, storage stability, cooking characteristics and consumer acceptability. However, poor processing conditions or excessive milling and polishing may result in the removal or reduction of important nutritional components, particularly dietary fibre, minerals, vitamins and phytochemicals such as phenolic compounds, flavonoids, tocopherols and γ -oryzanol (FAO, 2024; Food Research International, 2024).

The quality of processed rice is determined by more than its physical appearance alone. Nutritional composition, functional characteristics and eating quality are also important considerations.



Properties such as water absorption capacity, swelling power, bulk density, gelatinization behaviour and pasting characteristics influence the performance of rice during cooking and its suitability for different food and industrial applications. Similarly, phytochemicals present in rice may contribute to its antioxidant capacity and other potential health-promoting effects. Although a number of studies have examined rice processing and quality, information on the combined effects of the processing practices commonly used in Northeastern Nigeria remains limited. In particular, there is a need to better understand how traditional and improved processing methods influence the physical, nutritional and functional characteristics of rice under local processing conditions. Such information is important for identifying practices that can improve product quality while reducing processing losses.

This study therefore examined rice processing methods and their effects on the nutritional composition, phytochemical content, functional properties and eating quality of rice processed in Northeastern Nigeria. The findings are intended to provide useful information for improving processing practices, enhancing nutrient retention and consumer acceptability, reducing post-harvest losses, promoting value addition and improving the competitiveness of locally processed rice (FAO, 2024; OECD & FAO, 2024).

The study specifically sought to:

- i. Conduct a survey of rice milling processes and practices in Northeastern Nigeria.
- ii. Determine the physical and functional properties of paddy and milled rice.
- iii. Determine the proximate composition of paddy and milled rice.

MATERIALS AND METHODS

Area of the Study

The study was conducted in Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe States of Northeastern Nigeria, covering Sudan and Sahel savannah agroecological zones. The region experiences annual rainfall of about 500–1,200 mm and temperatures of 25–40°C, with rice production and processing widely practiced using traditional, semi-mechanized, and modern technologies.

Sample Collection and Processing Methods

Rice samples were collected from major processing centres across the six states between June and September 2025. Traditional (hand pounding), semi-mechanized (small-scale milling), and modern (integrated mechanical milling) processing methods were evaluated. Representative samples were randomly collected, labelled, transported to the laboratory, and stored appropriately. Three independent samples were obtained for each processing category and used as experimental replicates.

Experimental Design

A completely randomized design (CRD) was used, with processing method as the treatment factor. Each analytical determination was conducted in triplicate to assess variability and reproducibility.

Proximate Composition

Moisture, crude protein, crude fat, crude fibre, ash, and carbohydrate contents were determined using standard AOAC procedures (AOAC, 2023). Moisture was determined by oven drying at 105°C, protein by the Kjeldahl method using a 6.25 conversion factor, fat by Soxhlet extraction, ash by incineration at 550°C, and fibre by acid–alkali digestion. Carbohydrate was calculated by difference.

Determination of Phytochemical Composition

Total phenolic content was determined using the Folin–Ciocalteu method and expressed as mg GAE/g, while total flavonoid content was determined using the aluminium chloride method and expressed as mg QE/g. Antioxidant activity was assessed using the DPPH free-radical-scavenging assay. All analyses were conducted in triplicate using appropriate blanks and standards.

Determination of Functional Properties

Water and oil absorption capacities were determined according to Beuchat (1977), while swelling power and water solubility index were determined following Leach et al. (1959). Bulk density was determined from the mass-to-volume relationship, and gelatinization characteristics were assessed using the alkali spreading value technique. All measurements were performed in triplicate.



Statistical Analysis

Laboratory and sensory data were expressed as mean $\pm$ standard deviation (SD). ANOVA was conducted using IBM SPSS Statistics version 29.0 to assess the effects of processing methods. Significant differences among means were separated using Tukey's HSD test at $p < 0.05$. Pearson's product-moment correlation analysis was also used to examine relationships among nutritional, phytochemical, functional, and sensory characteristics, with statistical significance set at $p < 0.05$.

RESULTS AND DISCUSSION

Survey on the Milling Process and Practices across North Eastern Nigeria

A total of 12 rice milling centers were surveyed across Borno, Yobe, Gombe, Bauchi, and Adamawa and Taraba States of North Eastern Nigeria. These centers represented diverse socio-demographic characteristics, parboiling and milling methods, drying and polishing practices, as well as perceptions on nutrients, phytochemicals, and eating quality of rice.

Table 1: Socio-demographic Characteristics of the Respondents (N=12)

Variable	Frequency	(%)
Sex (Male)	8	66.7
Sex (Female)	4	33.3
Age (30–40 years)	5	40.7
Age (41–50 years)	4	33.3
Age (51+ years)	3	24.0
Educational level – No formal 2		16.7
Primary	2	16.7
Secondary	3	25.0
Tertiary	5	41.6
Years of experience (>10)	7	58.3

Table 1 shows that, majority (66.7%) of the respondents are male indicating that rice milling practices and handling is predominantly taken care of by male and about 33.3% handled by female. The result also indicated that, rice milling is gradually handled by the younger generation (the youth) about 40.7 percent of the respondents were aged between 30 – 40 years and 33.3% were aged 41 – 50 years. The older generation (51 years and above) covers 24.0 percent. The level of education at tertiary level was impressively 41.6 percent indicating greater awareness in the need to couple jobs, trade and education. The higher percentage may be due to the fact that majority of the respondents (40.7) are youth (30 – 40 years) which covers the educationally aware population. Juliano, 2019.

Table 2: Type of Processing Methods Practiced by the Rice Mills

Processing Methods	Frequency	Percentage (%)
Traditional hand pounding	2	16.7
Small-scale mechanized milling	7	58.3
Semi-industrial milling	3	25.0
Total	12	100

Table 2 shows the types of rice processing methods, practiced by the mills in Northeastern Nigeria. The method predominantly practiced is small scale mechanized milling which covers 58.3% of the respondents, and the semi-industrial milling practiced was about 25.0%.

The findings in Table 3 indicated that majority (66.7%) of rice processors had higher awareness of the nutritional importance of processing methods, while 25.0% had moderate awareness and 8.3% had low awareness. This suggests that most processors understand that processing, particularly milling and polishing, and can significantly influence nutrient retention. Excessive polishing can remove the bran and germ and reduce important nutrients such as vitamins, minerals, and dietary fibre (Juliano, 2019). Previous studies also reported a substantial nutrient loss from traditional processing and showed that processors with greater nutritional awareness were more likely to adopt improved practices that



enhance nutrient retention (Adeyemi *et al.*, 2020; Ituen *et al.*, 2021). Therefore, strengthening nutritional education, extension training, and access to improved processing technologies is essential for promoting nutrient-sensitive rice processing, reducing micronutrient losses, and improving food and nutrition security in Nigeria (World Bank, 2021). Table 4: Distribution of Respondents According to Preference for Modern or Traditional Rice Processing Technologies Table indicated that majority (58.3%) of the respondents preferred modern rice-processing technologies, while 41.7% continued to rely on traditional methods, indicating a gradual transition toward modernization. Modern technologies are preferred because they generally offer higher milling efficiency, reduced grain breakage, improved appearance, and better processing control (Fofana *et al.*, 2019). However, continued reliance on traditional methods reflects constraints such as high equipment costs, inadequate infrastructure, limited technical knowledge, and cultural or consumer preferences for traditional rice characteristics (Oyeyink & Oyeyinka, 2021; Adamu & Abubakar, 2020; Juliano & Villareal, 2019). The findings therefore highlight the need for affordable modern processing technologies, technical training, improved infrastructure, and public-private investment to enhance rice quality, reduce post-harvest losses, and promote nutrition-sensitive processing while accommodating desirable local rice attributes.

Table 3: Distribution of Respondents According to Awareness of Nutritional Importance of Rice Processing Methods

Technology Preference	Frequency	Percentage (%)
Modern Technology	7	58.3
Traditional Technology	5	41.7
Total	12	100
Awareness Level	Frequency	Percentage (%)
High Awareness	8	66.7
Moderate Awareness	3	25.0
Low Awareness	1	8.3
Total	12	100

Table 4 shows that 33.3% of rice processors had no formal education, 25.0% had primary education, 25.0% had secondary education, and only 16.7% had tertiary education. Thus, most processors had relatively low formal education, which may constrain their ability to understand and adopt modern processing technologies, food-safety practices, and nutrient-preservation techniques (Okoye *et al.*, 2017; Oboh & Akindahunsi, 2018). Previous studies similarly found that processors with higher education were more likely to adopt improved processing, hygiene, drying, and packaging practices (Yusuf *et al.*, 2019; Danso-Abbeam *et al.*, 2020). The findings therefore emphasized the need for practical, visual, and hands-on capacity-building programmes, particularly for processors with limited formal education, to improve processing efficiency, hygiene, nutrient retention, and market competitiveness.

Table 4: Distribution of Level of Education

Level of Education	Frequency	Percentage
No Formal Education	4	33.3
Primary Education	3	25.0
Secondary Education	3	25.0
Tertiary Education	2	16.7
Total	12	100.0



Table 5: Distribution of Rice Processors by Processing Experience

Years Experience	Frequency	Percentage
1–5 years	3	25.0
6–10 years	5	41.7
11–15 years	2	16.7
Above 15 years	2	16.7
Total	12	100.0

Table 6 shows that 41.7% of processors had 6–10 years of experience, 25.0% had 1–5 years, while 16.7% each had 11–15 years and more than 15 years of experience. This indicates that most processors possess considerable practical knowledge that can support efficient processing and quality management (Ojo & Ogundele, 2016; Akinoso *et al.*, 2019). However, experience alone may also sustain traditional practices that compromise hygiene, nutrient retention, and shelf-life, such as uncontrolled sun drying (FAO, 2021). The findings therefore emphasize the importance of combining processors' indigenous knowledge and experience with modern food-science innovations, particularly through training on improved parboiling, drying, milling, packaging, and food-safety practices (Sharma *et al.*, 2020).

Table 6: Distribution of Rice Processors by Household Size

Household Size	Frequency	Percentage
1–5 members	4	33.3
6–10 members	6	50.0
Above 10 members	2	16.7
Total	12	100.0

Table 6 showed that, half (50.0%) of processors had household sizes of 6–10 members, while 33.3% had 1–5 members and 16.7% had more than 10 members. Larger households can provide family labour for drying, winnowing, packaging, and transportation, thereby reducing labour costs (Oni & Ajayi, 2018). However, they may also increase household consumption and reduce funds available for reinvestment in processing activities (Adewumi *et al.*, 2019). Household size can also influence knowledge transfer, hygiene practices, and adoption of improved processing technologies (Bello *et al.*, 2021). Therefore, training and policy interventions should consider household structure, with cooperative processing arrangements and standardized quality-control practices encouraged among larger households to improve efficiency, hygiene, nutrient preservation, and product quality.

Table 7 showed that, rice processors in Northeastern Nigeria predominantly use traditional stone mills (41.7%) and locally fabricated milling machines (33.3%), while only 25.0% use modern commercial rice mills. This indicates continued dependence on traditional and semi-mechanized technologies, largely due to financial, infrastructural, and security constraints. Traditional milling is affordable and accessible but may result in greater grain breakage, inconsistent polishing, and food-safety concerns (Oko *et al.*, 2012), whereas modern mills generally provide better milling recovery, grain uniformity, and product quality (Juliano, 2010; Akinbode, 2013). Milling technology also affects nutritional quality, with less intensive milling potentially retaining more fibre and micronutrients, while highly polished rice may have improved appearance and storage stability but greater nutrient losses (Fitzgerald *et al.*, 2009). The findings therefore support targeted subsidies, improved access to credit, extension training, public–private partnerships, and development of affordable improved milling technologies suited to small-scale processors in the region.

Table 7: Type of Rice Milling Machines Used by Processors in North Eastern Nigeria

Milling Machine Type	Frequency	Percentage
Traditional stone mill	5	41.7
Locally fabricated mill	4	33.3
Modern commercial rice mill	3	25.0
Total	12	100



Table 8 revealed a substantial difference in milling recovery, with traditional stone mills recording 55.3%, locally fabricated mills 61.7%, and modern commercial mills 68.9%. The higher recovery from modern mills indicated a greater efficiency in reducing grain breakage and maximizing usable rice output (Odenigbo *et al.*, 2014). The lower recovery of traditional mills may increase economic losses and post-harvest waste, while locally fabricated mills demonstrate potential for improved performance through technical upgrades. Milling recovery also influences the quantity of bran and germ available for value addition, including use in animal feed, functional foods, and nutraceutical products (Champagne, 2017). Therefore, investment in improved milling infrastructure, technical upgrading of local mills, processor training, and utilization of rice-processing by-products could improve processing efficiency, reduce losses, create additional income opportunities, and strengthen food-system resilience in Northeastern Nigeria.

Table 8: Average Milling Recovery Rate (%) by Milling Method

Milling Method Recovery Rate	
Traditional stone mill	55.3
Locally fabricated mill	61.7
Modern commercial rice mill	68.9

Table 9 showed a clear difference in milled-rice quality among processing methods. Stone mills recorded the highest levels of broken grains (75%) and foreign materials (66.7%), indicating poorer milling quality and greater contamination risks, while modern mills produced more uniformly white rice (83.3%), lower contamination (16.7%), and better aroma (66.7%). High levels of broken grains reduce market value and consumer preference, although they can be redirected to products such as rice flour and processed foods (Custodio *et al.*, 2019). Modern milling improves appearance and marketability but excessive polishing can remove nutrient-rich bran and germ layers, resulting in losses of B vitamins, minerals, and phytochemicals (Fitzgerald *et al.*, 2009). The findings therefore emphasized the need to balance physical quality and consumer appeal with nutritional preservation through improved milling technologies, partial polishing, appropriate fortification, quality-control systems, and processor training.

Table 9: Observed Quality Attributes of Rice after Milling

Quality Attribute	Stone Mill (%)	Local Fabricated Mill (%)	Modern Mill (%)
High proportion of broken rice	75.0	58.3	33.3
Uniform whiteness	25.0	41.7	83.3
Presence of foreign materials	66.7	50.0	16.7
Pleasant aroma	33.3	41.7	66.7

Functional Properties of Paddy Rice

The functional properties of rice as presented in Table 10, including gelatinization, viscosity, and gelatinization temperature parameters (onset, final, and peak), are key determinants of both cooking behaviour and eating quality. Table 11 presents these properties for parboiled and raw paddy samples across multiple varieties. Several patterns emerge, reflecting the impact of rice processing methods on functional quality.

Table 10: Functional Properties of Paddy Rice

Sample code	Gelatinization	Viscosity	GTONset	GTFinal	GTPeak
A1	216.43bc	300.11a	88.700a	92.80ab	93.05ef
A3	234.50ab	298.56abc	88.900a	93.20ab	94.40cde
B1	244.82ab	289.64e	88.900a	90.25ab	91.30fg
B3	272.95a	290.53de	89.750a	94.30ab	94.20cde
C1	182.13c	223.95g	88.450a	89.60ab	89.65gh
C3	184.33c	268.55f	88.550a	89.35ab	89.95gh
D1	255.14ab	297.37a-d	74.950b	88.40ab	88.55h
D3	231.46ab	300.00a	89.550a	93.00ab	93.55cde
E1	269.96a	300.00a	81.900ab	93.90ab	94.05cde
E3	267.20a	299.38ab	74.900b	97.95a	98.15b
F1	252.69ab	291.62cde	86.650ab	101.85a	101.90a
F3	274.93a	299.01ab	90.150a	91.45ab	93.80cde
G1	255.39ab	224.35cde	82.700ab	91.85ab	92.80ef
G3	233.41ab	268.76ab	90.200a	91.96ab	93.80cde
H1	252.70ab	295.86a-e	89.400a	94.06ab	95.21cd
H3	273.40a	293.64a-e	90.250a	91.36ab	93.85cde
I1	254.14ab	292.32b-e	77.600ab	50.00b	90.15gh
I3	234.42ab	298.55abc	88.900a	92.25ab	94.25cde
J1	262.69ab	299.92a	88.150a	89.95ab	94.40cde
J3	231.40ab	300.01a	89.900a	93.75ab	95.35c
K1	217.31bc	299.36ab	88.750a	92.80ab	93.85cde
K3	233.48ab	291.40de	88.900a	93.30ab	94.25cde
L1	182.14c	268.52f	88.550a	89.10ab	89.85gh
L3	243.87ab	296.50a-e	80.605ab	92.26ab	93.35de
HSD (0.05)	46.318	7.1292	12.696	45.328	1.9300

showed that, parboiling generally increased gelatinization temperatures and altered paste viscosity compared with raw paddy, although the magnitude of change varied among rice genotypes. For example, sample D showed a marked increase in gelatinization onset temperature from 74.95°C to 89.55°C, while sample C showed an increase in viscosity from 223.95 to 268.55 cP after parboiling. These changes are attributed to starch gelatinization, retrogradation, and structural reorganization during hydrothermal treatment (Juliano, 2019; Hu *et al.*, 2017; Butt *et al.*, 2018). The significant HSD values for viscosity (7.13) and peak gelatinization temperature (1.93°C) confirm that processing significantly influenced starch functionality. Overall, parboiling modifies starch behaviour, producing functional characteristics associated with firmer, less sticky cooked rice, while potentially increasing resistant starch and slowing starch digestion (Shobana *et al.*, 2016; Ibrahim *et al.*, 2021). However, the observed varietal differences highlight the importance of rice genotype selection and optimized parboiling conditions for achieving desirable cooking, nutritional, and sensory qualities.

Table 11a: Functional Properties of Parboiled Rice

Sample code	Gelatinization	Viscosity	GTOnset	GTFinal	GTPeak
A2	35.53k	98.69j	88.450a	94.250d	94.500bc
A4	235.98fg	298.99a	79.000bc	88.850j	89.300d
B2	70.72j	125.63i	88.350a	93.900def	97.850a
B4	149.62h	210.91g	77.000cd	83.450l	85.600e
C2	244.77d	273.11d	90.050a	95.500ab	96.300ab
C4	246.33d	268.95e	80.100bc	80.650m	83.550e
D2	133.47i	172.68h	88.950a	90.500i	90.850d
D4	237.31ef	291.83c	87.850a	93.450efg	94.350bc
E2	269.18b	296.49b	71.950d	91.950h	92.150cd
E4	274.97ab	299.89a	84.850ab	95.300b	96.350ab
F2	275.95a	299.90a	89.350a	94.000def	95.150abc
F4	268.78b	291.92c	87.100a	96.050a	97.550ab
G2	236.14fg	172.68h	89.350a	93.755def	95.350abc
G4	269.24b	291.91c	87.150a	95.150bc	97.100ab
H2	133.55i	173.13h	87.310a	90.550i	90.850d
H4	269.24b	291.42c	87.000a	96.150a	96.200ab
I2	255.14c	172.94h	89.920a	93.000g	94.650abc
I4	235.94fg	298.55a	88.650a	86.700k	94.550bc
J2	269.88ab	296.19b	88.000a	93.300fg	94.550bc
J4	236.44efg	291.84c	87.850a	94.450cd	96.550ab
K2	35.55k	91.66k	88.500a	94.150de	94.850abc
K4	230.25g	291.65c	76.550cd	88.450j	89.600d
L2	242.71de	266.43f	84.050ab	80.500m	85.950e
L4	268.98b	292.74c	88.805a	96.150a	97.550ab
HSD (0.05)	6.4948	1.6771	6.0854	0.7472	3.2369

Table 11 demonstrated that parboiling significantly altered the functional properties of milled rice, particularly gelatinization, viscosity, and gelatinization temperatures. Parboiled samples generally recorded lower gelatinization and viscosity values than raw-milled samples, which is attributed to partial starch gelatinization and subsequent retrogradation during hydrothermal processing (Juliano, 2019; Sirisomboon *et al.*, 2007). However, the magnitude and direction of these changes varied considerably among rice varieties because of differences in starch composition and amylose–amylopectin ratios (Hu *et al.*, 2017; Shobana *et al.*, 2016). The significant HSD values for gelatinization (6.49), viscosity (1.68), and GT peak (3.24) confirm that parboiling substantially influenced starch functionality. These changes can produce firmer, less sticky, and more stable cooked rice, characteristics preferred in traditional dishes such as *tuwo shinkafa*, while starch restructuring may also increase resistant starch and potentially slow digestion (Ibrahim *et al.*, 2021; Hu *et al.*, 2017). Overall, the findings emphasize that rice variety and parboiling conditions should be carefully optimized to achieve desirable functional, nutritional, and sensory qualities. The proximate composition results for paddy rice (Table 10) further indicate biochemical changes associated with parboiling, reflecting the redistribution and modification of nutrients during hydrothermal processing. Although differences in

several proximate components were not statistically significant at $p \leq 0.05$, the observed variations suggest that parboiling can influence the nutritional composition of rice through changes in nutrient distribution and grain structure.

Table 11b: Functional Properties of Parboiled Rice

Sample Code	Protein	Fat	Fibre	Ash	Moisture	Carbohydrates	Energy value
A1	14.235a	2.020ab	12.755e	1.765bc	6.670 a-d	62.555n	325.64e
A3	12.650a	1.515ab	6.435k	1.335efg	6.670a-d	71.615g	350.60bcd
B1	13.025a	2.160ab	14.265c	1.330efg	5.760f	69.465k	298.74f
B3	11.165a	1.015b	4.150o	1.365ef	6.010ef	75.130d	354.41a-d
C1	11.450a	2.615ab	16.615b	1.515de	7.015ab	68.790lm	303.23f
C3	10.655a	1.450ab	5.465m	1.320efg	6.955ab	76.155c	360.25abc
D1	12.865a	2.210abb	12.455g	1.715cd	6.015ef	69.740jk	351.19bcd
D3	11.720a	1.735ab	3.450qr	0.940hi	6.170def	75.230d	363.37abc
E1	12.145a	2.515ab	13.385d	1.325efg	6.560bcd	69.630jk	349.67b
E3	11.025a	2.160ab	4.565n	0.930hi	6.760abc	73.635f	358.02abc
F1	9.825a	2.015ab	12.560f	2.250a	6.315cde	69.335kl	334.73de
F3	12.130a	1.550ab	4.615n	1.650cd	6.210def	76.945b	369.71ab
G1	12.840a	2.115ab	12.565f	1.950b	6.260c-f	70.755hi	353.50a-d
G3	11.345a	1.165b	3.460q	1.650cd	6.165def	76.465bc	361.68abc
H1	13.720a	2.150ab	11.450h	1.940b	6.170def	68.230m	347.15cd
H3	12.145a	3.015a	3.385r	0.825i	6.560bcd	76.630bc	368.71ab
I1	14.025a	2.160ab	9.565j	2.330a	6.765abc	69.635jk	354.04a-d
I3	12.825a	1.015b	2.560t	1.250fg	6.315cde	74.335e	362.19abc
J1	13.165a	1.595ab	10.915i	2.400a	6.255c-f	70.165ij	347.59cd
J3	11.220a	1.115b	3.155s	1.625cd	6.920ab	76.365bc	360.31abc
K1	12.955a	1.710ab	17.015a	2.360a	7.130a	71.320gh	351.90a-d
K3	11.180a	1.040b	5.825l	1.215fg	6.650a-d	77.780	365.20abc
L1	9.665a	1.415ab	14.235c	1.820bc	6.165def	70.705i	355.17a-d
L3	13.129a	1.180ab	3.915p	1.115gh	6.245c-f	74.425e	371.89a
HSD (0.05)	5.8635	1.8769	0.0700	0.2247	0.5450	0.5973	20.530

Table 11b shows that parboiling produced generally favourable changes in the proximate composition of paddy rice, although most differences were not statistically significant at the 5% level. Parboiled samples generally recorded slightly higher protein, fat, fibre, ash, and moisture contents, indicating improved retention of nutrients and mineral-rich components during processing (Oko *et al.*, 2012; Adeyemi & Adekoyeni, 2020; Pinta *et al.*, 2024). The most notable improvement was in crude fibre, with parboiled samples showing substantially higher values than raw samples, suggesting better preservation of fibre-rich grain layers (Chukwu & Omodamiro, 2021; Muchlisyyah *et al.*, 2023). In contrast, raw rice generally had higher carbohydrate and energy values, reflecting its greater proportion of starch and digestible carbohydrates (Juliano, 2020). Overall, the findings indicate that parboiling enhances the nutritional stability of rice by promoting protein, fibre, and mineral retention while reducing carbohydrate concentration and energy density. These changes are particularly relevant in Northern Nigeria, where rice is an important staple and improved nutrient retention can contribute to better dietary quality (NAERLS, 2022). The results therefore support the adoption of improved parboiling technologies as a means of enhancing the nutritional and functional quality of locally processed rice, while maintaining desirable sensory characteristics (Pinta *et al.*, 2024; Chukwu & Omodamiro, 2021).

Proximate Composition of Milled Rice

The proximate composition of milled rice samples (parboiled and raw) as presented in Table 12 revealed a significant difference in nutrient contents attributable to processing methods, particularly parboiling and degree of milling. Protein content varied widely among samples, ranging from 10.22% to 13.96%, indicating clear effects of thermal treatment and grain type. Parboiled samples generally exhibited higher protein levels compared to their raw counterparts. For instance, samples A2 (13.160%), F2 (13.665%), H2 (13.225%), and I2 (13.775%) all showed superior protein retention relative to their matched raw samples. This aligns with findings by Adeyemi and Olorunda (2019), who noted that parboiling strengthens Alphabets attached to number 4 (Raw Milled Rice)

Table 12: Proximate Composition of Milled Rice

Sample Code	Protein	Fat	Fibre	Ash	Moisture	Carbohydrates	Energy value
A2	13.160c	1.515e	10.495b	1.840b	7.060a	65.435de	360.54b
A4	11.235h	0.720l	1.355m	0.765jk	6.420a-e	79.815abc	370.62b
B2	12.775d	1.220g	7.165h	1.430e	5.465f	63.950e	368.98b
B4	10.725klm	0.865ij	0.625r	0.660l	7.020ab	81.105ab	464.50a
C2	10.850jk	2.515a	8.550c	1.460e	6.660a-e	70.815cde	349.10b
C4	10.435n	0.965h	1.450l	1.265g	6.960abc	80.425ab	371.40b
D2	12.760d	2.165b	7.210gh	1.665d	6.020ef	72.180b-e	358.48b
D4	10.225o	1.015h	1.545k	0.750k	6.665a-e	82.650a	380.16b
E2	11.640g	2.515a	7.235g	1.130h	6.320cde	72.700b-e	359.55b
E4	10.775kl	1.210g	1.565k	0.630l	6.465a-e	78.710abc	368.80b
F2	13.665b	1.535e	8.235d	1.760c	6.425a-e	74.890a-d	447.33b
F4	11.045i	0.715l	1.315m	0.800jk	6.215e	82.285a	379.73b
G2	12.340e	1.755d	5.565i	1.800b	6.365b-e	72.380b-e	354.63b
G4	10.935ij	1.015h	0.755q	0.915c	6.015ef	79.365abc	370.30b
H2	13.225c	2.015c	5.545i	1.250g	6.665a-e	73.650a-d	365.21b
H4	10.640m	1.215g	1.235n	0.630l	6.320cde	80.700ab	376.25b
I2	13.775b	1.211g	4.565j	1.430e	6.465a-e	72.710b-e	356.81b
I4	10.665lm	0.735kl	0.635r	0.760jk	6.425a-e	79.890abc	368.28b
J2	12.180f	1.340f	7.825f	2.215a	6.665a-e	73.780a-d	355.90b
J4	10.665lm	0.815jk	1.235n	0.820j	6.160e	80.705ab	373.71b
K2	12.165f	1.595e	10.915a	1.400ef	6.260e	74.165a-d	359.59b
K4	10.220o	0.715l	1.155o	0.625l	6.920de	79.365abc	364.75b
L2	13.955a	1.210g	8.015e	1.360f	6.525a-e	79.320abc	383.55b
L4	11.180h	0.940hi	0.825p	0.625l	6.635a-e	79.797abc	372.34b
HSD (0.05)	0.1297	0.0856	0.0688	0.0641	0.6828	9.4796	54.156

Proximate Composition of Milled Rice (Parboiled and Raw)

The findings showed that parboiling improved the nutritional quality of milled rice by enhancing protein, fat, fibre, and mineral retention compared with raw-milled rice (Ituen, 2016; Oko *et al.*, 2012). Raw-milled rice generally recorded higher carbohydrate and energy values, while parboiled rice showed slightly greater moisture retention (FAO, 2018; Juliano, 2019). Overall, processing method strongly influenced the nutritional, functional, physical, and sensory quality of rice. Modern milling improved efficiency, appearance, and consumer acceptability, while appropriate parboiling enhanced grain integrity, nutrient retention, cooking quality, and resistance to breakage. However, excessive milling reduced fibre, minerals, and beneficial phytochemicals. Optimized parboiling and milling can therefore improve nutritional retention and economic value (Applied Food Research, 2025). Improved nutrition-sensitive processing technologies should be promoted in Northeastern Nigeria to balance nutrient preservation, functional performance, sensory quality, marketability, and food-security objectives.



CONCLUSION AND RECOMMENDATION

Rice processing methods exert a significant influence on the nutritional composition, phytochemical retention, functional properties, and eating quality of rice produced in Northeastern Nigeria. While modern processing technologies improve grain appearance, milling recovery, storage quality, and consumer preference, excessive polishing may reduce the nutritional and health-promoting components of the grain. Appropriate processing practices, particularly optimized parboiling and controlled milling, can preserve essential nutrients and bioactive compounds while maintaining desirable cooking and sensory characteristics. Therefore, the adoption of improved processing technologies and standardized processing protocols is essential for enhancing the quality, safety, nutritional value, and market competitiveness of locally processed rice. Such improvements will contribute to sustainable food systems, increased value addition, improved livelihoods of rice processors, and enhanced food and nutrition security in Nigeria.

Based on the findings of this study, the following recommendations are proposed:

1. Rice processors should adopt improved and standardized processing technologies, particularly optimized parboiling and controlled milling, to maximize nutrient retention and improve the overall quality of locally processed rice.
2. Government agencies, agricultural extension services, and development partners should strengthen capacity-building programmes through regular training on improved rice processing technologies, quality assurance, and food safety practices.
3. Investment in modern rice processing facilities should be encouraged through accessible credit schemes, subsidies, and public-private partnerships to improve processing efficiency and reduce post-harvest losses.
4. Quality control agencies should develop and enforce standards for rice processing operations to ensure consistency in nutritional quality, food safety, and market competitiveness of locally processed rice.

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