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EFFECT OF DEGREE OF MILLING ON PROXIMATE AND MINERAL COMPOSITION, PHYSICOCHEMICAL, COLOUR CHARACTERISTICS AND PASTING PROPERTIES OF BROKEN BROWN RICE FRACTION FROM A SELECTED VARIETY (FARO 64)

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ABSTRACT: *The effect of degree of milling (DOMs) between 0 and 12% on proximate and mineral composition, physicochemical, colour, and pasting properties of broken brown rice from the FARO 64 rice variety were evaluated. Each milling level reduced the ash, protein, fat, and fibre content. Ash and fibre were removed most at 9% DOM. Maximum fat loss was observed at 3% DOM. The levels of Ca, Na, Mg, and K were not significantly different (p< 0.05) at 9 and 12 DOM. The starch and the amylose contents increased from 0 to 12% DOM. The least values were at 0 DOM for L* and h, while the highest were at 12 DOM for a*, b*, and c. WAC and WBC increased as the DOM increased from 0 to 12%. Pasting properties differed significantly (P<0.05) for BDV at 0-12% DOM, while PV, TV, FV, and SBV differed significantly (P<0.05) at 0-6% DOM.*

KEYWORDS: Paddy rice, degree of milling, brown rice, pasting properties, amylose content and gel consistency

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INTRODUCTION

Rice is one of the oldest and most important crops in the world, directly feeding more people than any other crop (CGIAR, 2019). It is a staple food for some 4 billion people worldwide, and it provides 27% of the calories in low- and middle-income countries (GRiSP 2013a; Matz, 2014). Rice hull, brown rice, milled rice, and rice bran are milling fractions of paddy rice that can be processed into rice products (Juliano and Hicks, 1996). For optimal milling, rice should have 20% husk, 8-12% bran, and 68-72% milled or white rice, depending on the variety (Esa *et al.,* 2013; Borresen and Ryan, 2014).

Most consumers prefer white rice with little or no bran remaining on the endosperm due to its better palatability and cooking properties than brown rice. However, trend is now shifting towards the rice that is rich both in nutritional and cooking qualities. Brown rice, which is whole grain rice with intact bran layer after the inedible outer hull is removed, contains three times more fibre than milled rice (Parengam *et al.,* 2012). The insoluble dietary fibre fraction enhances stool weight, prevents intestinal mucosa carcinogen, eases faeces emptying, and supports normal colonic microfloral growth (Daou and Zhang, 2014). The dietary fibres may also lower serum cholesterol, LDL, blood pressure, glycemia, and insulin sensitivity (Yanai *et al.,* 2014).

Brown rice contains essential nutrients like iron, zinc, thiamine, niacin, vitamin E, dietary fiber, protein, and carbohydrate (Pascual *et al.*, 2013). In addition, bioactive ingredients such γ-oryzanols, tocotrienols, and polyphenols have been found (Leardkamolkarn *et al.,* 2011). Some brown rice varieties have a low glycemic index (GI), which can reduce type II diabetes(Greenwood *et al.,* 2013), coronary heart disease (Mirrahimi *et al.,* 2014), obesity and cancer (Romieu *et al.,* 2012; Nagle *et al.,* 2013).

The degree of milling (DOM), not only determines the level of whiteness of rice but also affects their physicochemical, nutritional properties, starch gelatinization and sensory quality as various nutrients are concentrated in the outer bran layer (Mohapatra and Bal, 2007; Monks *et al.,* 2013). The concentration of these nutrients is reduced with increase in milling as these are removed gradually as degree of milling increases. To develop rice with suitable chemical composition, physicochemical, colour, and pasting properties, bran removal must be prioritised and controlled.

Many researchers have studied the effect of milling on the physicochemical properties on physicochemical, cooking and textural properties of rice. Mohapatra and Bal, (2007) investigated the effect of degree of milling on the milling energy requirement and cooking properties of aromatic long slender rice variety. Monks *et al.* (2013) also investigated the effects of milling on proximate composition and technological properties of rice. To determine if pasting and Mixolab rheological features are related, Sandhu *et al.* (2018) examined the effects of milling degree on physicochemical, structural, pasting, and cooking aspects of short and long grain Indica rice varieties Wang *et al.* (2021) examined how milling affects physicochemical and pasting properties of Simiao rice

Reddy *et al.* (2017) investigated how polishing affected proximate composition, mineral content, antioxidants, and physico-chemical properties of three pigmented rice varieties. However, Paiva *et al.* (2016) investigated coloured rice's nutritional and technological properties after polishing and parboiling. Somaratne *et al.* (2017) investigated how varietal

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differences and degree of milling affect GI and antioxidant characteristics of pigmented and nonpigmented basmati rice.

This present study investigated the effect of milling degree on proximate and mineral composition, physicochemical, colour, and pasting qualities of brown rice fraction from a selected variety (FARO 64) and established correlations between evaluated properties. The food-processing business should benefit from this study.

MATERIALS AND METHODS

Materials Source and Preparation

Freshly harvested Federal Agricultural Research Oryza – FARO 64 paddy rice variety was obtained from Rice Breeding Laboratory, Rice Research Programme, National Cereals Research Institute (NCRI), Badeggi, Niger State, Nigeria.

Milling of Paddy Rice

The paddy grains were spread on trays and allowed to equilibrate in the laboratory at 32 ℃ for 18 h. Moisture content of the paddy rice was measured using convention method (AOAC, 2010). The paddy grains were subsequently tempered to 12±1% (db) moisture content. Equation 1 calculates water addition using Ascheri *et al.* (2016) method.

$$Amount\ of\ water\ added\ (g) = \frac{(Mf - Mi)\ \times Sw}{100 - Mf} \qquad 1$$

Where,

M*f* = Final moisture content (g), M*i* = Initial moisture content g and S*w* = Sample weight (g).

Paddy grains (250 g) were processed into fractions according to Lanning (2012). Grain dehulling was done with a laboratory rubber roll-type rice husker (Model THU35B Testing Rice Husker - No. 1012526 – 2010, Satake Corporation, Japan). According to Umesha (2015), a laboratory friction and abrasion vertical type whitener (Satake Grain Testing Mill - No. 553504, Satake Engineering Co. Japan) was used to polish the brown rice fraction to 0, 3, 6, 9, and 12% DOM at room temperature.

Broken brown rice (<75% milled grain length) was used to make brown rice flour. The broken brown rice was cleaned and air-dried at 32˚C ± 2˚C for 30-60 min. The dried grains were ground into flour with a laboratory Hammer mill (Apex – 11482, Apex Construction Ltd.) fitted with 0.015 and 0.010 inch (0.381 and 0.254 mm) sieves to obtain fine rice grits. Once packed in polyethylene bags, the flour was stored at room temperature until use.

Proximate Composition of the Milled Rice

Proximate content was determined according to AOAC (2010) while the carbohydrate was calculated by the method of difference by subtracting the sum of percentage moisture, ash, crude protein, crude fibre and ether extract from 100% on dry basis.

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Mineral Contents

Ashes of grain samples were dissolved into 10% ($^v/_v$) HCl, filtered and made up to mark 100ml in a volumetric flask. Calcium, sodium, magnesium and potassium were determined by flame photometry (AOAC, 2010). After wet digestion with a mixture of perchloric and nitric acid, Atomic Absorption Spectrophotometry (AAS, Model Spq, pyeunicam, UK) was used to determine the concentration. Phosphorus was estimated calorimetrically by ammonium the molybdate method.

Gross and Metabolized Energy

The gross energy was determined using bomb calorimeter. The feed was burnt in a closed container (Bomb calorimeter) and heat produced from it was measured.

$$Gross\ heat\ of\ combustion\ Cal/g = \frac{T\ X\ W - (C1 + C2 + C3)}{M} \qquad 2$$

Where, T = Rise in temperature, W = Water equivalent and M = Weight of substance

Water-binding and Absorption Capacity

The water-binding and absorption capacity were determined as outlined by Navarro-Cortez *et al.* (2016) and modified. At room temperature (29 ±1 °C), 2 g of ground product was dissolved in 40 ml of water. After 30 min of gentle stirring, the suspension was centrifuged at 2200 rpm for 15 min (Universal Compact Centrifuge HERMLE 211 Labortechnik GmbH Mod Z 200A, Germany). The free water was then decanted from the paste and drained for 10 min. The WSI is the supernatant's dry solids weight as a percentage of the dry sample's weight (Equation 3).

$$Bound\ water\ \% = \left(\frac{\mathrm{Wp} - \mathrm{Ws}}{Ws}\right) X\ 100 \qquad 3$$

Where, Wp = Weight of paste after centrifugation and Ws = Weight of initial sample. The water absorbed was calculated as the difference between the initial water used and the volume of the supernatant obtained after centrifuging. The result of WAI was expressed as per unit weight of the original dry solids.

Swelling Power

The swelling power of all the flours was determined according to a modification of the method of Leach *et al.* (1959). One gram of sample was transferred into a weighed graduated 50 ml centrifuge tube, and distilled water added to give a total volume of 40 ml. After stirring the sample by hand, it was heated at 85 ºC in a Grant Instruments Ltd water bath (Cambridgeshire, UK) for 30 minutes with steady shaking. After cooling to ambient temperature, materials were centrifuged at 2200 rpm for 15 min. The supernatant was transferred into a can, dried in a hot air oven (BS Gallenkamp, UK) and the dry residue weighed. The sediment paste was weighed. The sediment volume in the tube was immediately read to determine swelling volume. The swelling power was calculated using Equation 4.

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$$\text{Swelling power} = \frac{\text{Weight of wet mass of sediment}}{\text{Weight of dry matter in the gel}} \qquad 4$$

Gelatinization Temperature

This was indexed by alkali spreading test. A 7-point numerical spreading scale (IRRI, 2013) was used to assess the degree of spreading of milled rice kernel in a weak alkali solution (1.7% KOH) at temperature of 39 ±2 ℃. The ASV score categorized GT into four groups, according to Eram *et al*, (2014): 2-3 = high (75-79 ˚C), 4-5 = intermediate (70-74 ˚C), and 6-7 = low (55-69 ˚C).

Total Starch

Rice flour starch was isolated by alkali protein extraction (Sodhi and Singh, 2003) with minor modifications. 20 g rice flours was soaked in 200 ml 0.2% NaOH solution for 3 h and steeped at 20 ℃ overnight. The steep liquor was drained off and the slurry was then diluted to the original volume with 0.2% NaOH solution. The process was repeated four times until the supernatant became clear and and the Biuret protein test was negative. The slurry was centrifuged at 3500 rpm and the starch was dried in cabinet drier at 50˚C overnight. The starch was passed through 100 mesh sieve and stored in plastic bag at -4 ℃ in a freezer until analysed.

Amylose Content

A simplified Avaro *et al.* (2011) method was used: 100 mg of rice powder was mixed with 1ml of 95% ethanol and 9 ml of 1N NaOH in a 100-ml volumetric flask. The content was heated in a boiling water bath to gelatinize the starch. After 1 h cooling, distilled water was added and content mixed. For each set of the run, low, intermediate and high amylose standard were included as checks. 5 ml of the gelatinized starch solution was measured into volumetric flask and 1 ml of 1N acetic acid, 2 ml Iodine solution were added and volume made up with distilled water. The content was stirred and left for 20 min before absorbance measurement at 620 mμ with a spectrophotometer - Model AA-6650, Shimadzu Co. Japan. Milled rice was classified by amylose content according to IRRI ((2013) as 1-2% amylose = waxy, >2% amylose = non-waxy, 2-9% amylose = very low, 20-25% amylose = intermediate and 25-33% amylose = high.

Gel Consistency

Gel consistency in rice genotypes was determined as described by Tang *et al.* (1991) and Sattari *et al.* (2015) with slight modifications reported by Chemutai *et al.* (2016). Rice flour (500 mg) was weighed in triplicates and placed in a 15 mm × 150 mm test tube. Drops of 95% ethanol containing 0.025% thymol blue totalling 0.026 ml in volume was added to each tube. The tubes were shaken and the content mixed thoroughly in order to prevent clumping of the rice flour. The mixture was vortexed gently, and then 2 ml of 0.2 N KOH was added and vortexed again.

The test tubes were covered with glass marbles and placed over a boiling water bath at 92 ℃ for 6 min. Once removed, they were maintained at room temperature for 5 min before being placed in an ice bath for 15 min. After this, the tubes were set horizontally on a graph paper on a flat laboratory bench for 30 min, and the blue gel length was measured in mm from the

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bottom of the tube to the end of the gel. Category of consistency (mm) is indicated as - Soft = 61-100, Medium = 41-60 or Hard = 26-40.

Colour Determinations

The colour of the milled rice samples was measured using a Colour Meter PCE-CSM 2 (Deutschland GmbH) connected to CQCS3 software to record L*, a* and b* values. A white plate was used to calibrate the spectrophotometer before the reading was taken.

Where,

L* represented lightness (with 0 = darkness/ blackness to 100 = perfect/brightness);

a* corresponds to the extent of red-green colour (in the range from negative = green to positive = redness and 0 = neutral); and

b* represents yellow-blueness (in the range from negative = blueness to positive = yellowness and 0 = neutral).

The Chroma (C) and hue angle (h) were calculated using the Equations 5 and 6 as given by Mohan *et al.* (2014).

$$C = \sqrt{a} *^2 + b *^2 \qquad 5$$

$$h = tan^{-1} \left({b *}/{a *} \right) \qquad 6$$

Determination of Pasting Properties

A Rapid Visco-Analyzer (RVA) (Newport Scientific, Warriewood, Australia) was used to analyse the pasting properties of rice flour upon heating and cooling according to the method described by Adeniji *et al.* (2010). Approximately 3 g of rice flour was mixed with 25 ml of distilled water; thereafter mixed at 50 °C for one min at 160 rpm and then heated from 50 °C to 95 °C at 12 °C/min. The hot paste was held at 95 °C for 2.5 min and then cooled down to 50 °C at a cooling rate of 12 °C/min and typical RVA parameters are measured. RVA General Pasting Method (STD1) was applied. Parameters such as PV-Peak Viscosity; T-Trough; BD-Breakdown; FV- Final Viscosity; SB- Setback; Pasting Time and Pasting Temperature were recorded.

Statistical Analysis

Data obtained were subjected to one-way analysis of variance (ANOVA): Post Hoc Multiple Comparison using SPSS software (IBM SPSS Statistics version 23). The significance of the difference among means was separated using Duncan's multiple range tests at p<0.05. Values were expressed as means ± S.E. The Association between different properties was determined using Pearson's correlation coefficients.

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RESULTS AND DISCUSSION

Proximate Composition of Brown Rice Milled to Different Degree of Milling

The proximate composition of brown rice of FARO 64 variety milled to between 0 and 12% degrees of milling (DOM) is shown in Table 1. The moisture content varied between 11.68% in sample at 0 DOM and 12.43% in sample milled to 12%. There were significant differences ($P < 0.05$) in the moisture content of the milled grain except at 6 and 9% DOM. Differences in the moisture content of milled rice with various DOM have been reported not to be significantly different (Liu *et al.*, 2017 and Wang *et al.*, 2021). The differences observed in this study might be as a result of tempering which was employed for the pre-treatment of paddy to aid hulling. This might have caused adhesion of thin layer of molecules of water to the surface of the bran layer.

The results showed that each milling stage led to a decrease in ash, protein, fat and fibre content and an increase in carbohydrate values (Table 1). Ash content decreased from 1.70% at 0 DOM to 0.94% at 12 DOM, showing a significant decrease of 44.71%. In the same vein, fibre content was reduced significantly from 2.01% to 0.97% when DOM increased from 0 to 12%. On a general note, the results above depicted that the highest proportions of ash and fibre contents were removed at 9% DOM. This, according to Sandhu *et al.* (2018) indicated that testa (middle layer) and aleurone (innermost layer) of bran concentrated in inorganic mineral matter were removed at 9% DOM.

Fat content decreased from 3.75% at 0 DOM to 0.64% at 12 DOM, with a significant decrease of 82.93% when the DOM increased from 0 to 12%. The reduction in fat content reflected that maximum loss was observed at 3% DOM indicating the highest concentration of fat was present in the pericarp than in the testa and aleurone layer.

This observation is consistent with the findings of Sandhu *et al.* (2018) and Wang *et al.* (2021). The protein content decreased gradually with increase in DOM from 0 – 6%, and the maximum decrease of 20.89% was observed when DOM increased to 12. This might be as a result of what Wang *et al.* (2021) attributed to the uneven distribution of protein in Simiao rice. In addition, this is an indication that protein may be concentrated in the testa (middle layer) and aleurone (innermost layer) of bran. This is contrary to the report of Sandhu *et al.* (2018) that the highest concentration of proteins might be present in the pericarp, which is the outermost layer of bran.

The higher variations in fat and fibre content in samples with lower DOM could be attributed to the presence of more bran layers. Milling of brown rice causes minimum loss of protein and carbohydrate, but significant losses (in the range of 60 – 90%) of other components like fibre, lipids and minerals (USDA, 2014). Brown rice, generally, contains fibre three times more than white rice (Parengam *et al*., 2012) and fat four times more than milled rice (Upadhyay and Karn, 2018).

The amount of the total carbohydrates as affected by polishing treatment was analysed by the variance in the respective moisture, ash, fat, fibre and protein contents of the samples, and ranged from 72.26 to 79.55% at 0-12 DOM. Values of 74.38-85.57% was reported by Reddy *et al.* (2017) from three different pigmented rice varieties from India. The energy content decreased from 4154.33 to 3986.67 kCal as the DOM increased from 0% to 12% with

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significant differences (p≤ 0.05) among the samples. Highest decrease of 138 (3.32%) was recorded at 3% DOM while further polishing resulted in less significant decrease.

Mineral Composition of Brown Rice Milled to Different Degree of Milling

Effect of degree of milling on mineral composition of brown rice is presented in Table 2. Brown rice at 0 DOM and sample milled to 3 DOM contained significantly higher contents of calcium (Ca) 0.055-0.088mg/g, sodium (Na) 0.317-0.368 mg/g, magnesium (Mg) 0.930-1.406 mg/g and potassium (K) 1.493-1.620 mg/g as compared to brown rice milled to 6-12 DOM. Among all the minerals at the different DOM, phosphorus content (1.957 - 3.493 mg/g) was the highest, followed by potassium (0.933 - 1.620 mg/g), magnesium (0.303 - 1.406 mg/g), sodium (0.076 - 0.368 mg/g), while calcium content (0.034 - 0.088 mg/g) was the lowest. This is similar to the finding of Reddy *et al.* (2017).

The values obtained for Ca, Na, Mg and K were not significantly different (p≤ 0.05) at 9 and 12 DOM. This observation is in agreement with Sandhu *et al.* (2018) who reported a constant level in the reduction of minerals as a result of increase in degree of milling after the initial significant reduction. The loss recorded from 0 to 12 DOM showed 61.36% for calcium; 79.35 for sodium; 78.45% for magnesium; 42.41% for potassium and 43.97% for phosphorus respectively. Highest reduction of 67.41% (in sodium), 46.14% (in magnesium), 23.36 (in potassium) and 15.29% (in phosphorus) were recorded at 9 DOM while highest reduction of 37.50% (in calcium) was recorded at 3 DOM.

Variations in the amount of mineral removal after each DOM may be as a result of distribution of different minerals in different layers of bran (Sandhu *et al.*, 2018). This result of losses of various minerals at different DOM is an indication that Ca may be highly concentrated in the outermost layer (pericarp) while Na, Mg, K and P may be highly concentrated in the innermost layer (aleurone).

Physicochemical Properties of Brown Rice Milled to Different Degree of Milling

Table 3 shows the results of effect of degree of milling on the physicochemical properties of brown rice milled to different degree of milling. The results showed that, as the DOM increased from 0 to 12%, the starch and the amylose contents increased from 74.36 – 82.79% and 21.31 – 23.92% respectively. Similar observation has been made that each milling stage led to an increase in total starch and amylose content (Wang *et al.*, 2021) which shows a higher amylose concentration in the endosperm core than in its outer counterpart.

Amylose content did not change significantly (p< 0.05) with respect to the polishing level at 0 - 3 DOM and 9-12 DOM while amylose content was significantly (p < 0.05) different at 6% DOM. The increase recorded in the amylose content as DOM increased from 0 to 12 showed maximum of 8.19% at 6% DOM. The largest drop observed here may be an indication that branny layer may be concentrated in the testa (middle layer) than in the pericarp as reported by Wang *et al.* (2021) or in the aleurone (innermost layer) of bran.

The maximum increase of 4.04% in total starch content was observed when the DOM increased from 0 to 3%. This is in agreement with Wang *et al.* (2021) who reported maximum increase of 5.0% as DOM increased from 0 to 2%. Thereafter, the increase in the total starch content was less obvious and with further increases in the DOM at 6 and 12%

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respectively. The difference in the removal of bran during the milling process may be responsible for the difference (Wang *et al.*, 2021).

Results of the water absorption capacity (WAC) and water binding capacity (WBC) of brown rice milled to different degree of milling are presented in Table 3. The results showed that, as the DOM increased from 0 to 12%, WAC increased from 6.20 to 6.82. WBC followed the same trend by increasing from 93.00 to 102.33%. WAC and WBC did not change significantly ($p< 0.05$) with respect to the polishing level at 3-9% DOM while the two parameters were significantly ($p< 0.05$) different at 0% and 12% DOM. The highest reduction in WAC and WBC were 3.51% and 3.57% respectively at 12% DOM. This may be as a result of complete removal of branny material at aleurone level (innermost layer). Higher bran level may have limited rate of water absorption and consequent lower binding power.

Colour Characteristics of Brown Rice Milled to Different Degree of Milling

The results of lightness (*L**), redness (*a**), yellowness (*b**), Chroma (c) and hue angle (h) values of brown rice milled to 0-12 DOM. L* value ranged from 82.87 - 93.78; a* value ranged from 0.30-1.98; b* value ranged from 5.25 - 9.54 as shown in Table 4. The Chroma and the hue angle values ranged from 5.26 - 9.77 and 78.29 - 86.70 respectively. The least values were recorded at 0 DOM for L* and h while the highest values were recorded at 12 DOM for a*, b* and c. There were significant differences ($p \leq 0.05$) observed in the colour characteristics of brown rice milled to 0-12 DOM. The differences in L*, a* and b* might be attributed to lower content of proteins and mineral matter. The implication and contribution of constituents such as proteins and minerals to yellowness and redness in cereal flours has been reported (Singh *et al.,* 2014).

It was observed that removal of branny layers increased *L** and decreased *a** and *b** wherein the extent of the change of lightness (4.40%) and redness (50.54%) was the highest at 9% DOM; and yellowness was highest at DOM 12. Zhong *et al.* (2014) and Sandhu *et al.* (2018) also reported similar trends of *L**, *a** and *b** values of Indian and Chinese rice varieties with varying DOM. The results obtained were in accordance with reports of Ma *et al.* (2019) that the colour parameters of brown rice and outer endosperm removed decreased with increasing DOM.

Pearson's correlation coefficients (r) as presented in Table 5 indicated that DOM is significantly and negatively correlated with the colour parameters viz a* (r = -.979*) and b* (r = -.980*) at $p< 0.05$ level but was significantly and positively correlated with L* (r = .980**) at 0.01 level. For the proximate parameters, DOM is significantly and negatively correlated with ash (r = -.939**), protein (r = -.792**), fat (r = -.983**) and fibre (r = -.955**) at 0.01 level. Generally, protein, fat, ash and fibre were significantly and negatively correlated with L* but positively correlated with a* and b*.

Pasting Properties of Brown Rice Milled to Different Degree of Milling

The effects of the DOMs on the pasting properties of brown rice milled to 0-12% DOM are presented in Table 6. The values of paste viscosity parameters increased from 1216.33 to 1859.33 Cp; 1039.33 to 1733.00 Cp; 133.67 to 165.33 Cp; 3623.67 to 4342.67 Cp and 2413.00 to 2593.33 Cp respectively for Peak Viscosity (PV), Trough Viscosity (TV), Breakdown Viscosity (BDV), Final Viscosity (FV) and Setback Viscosity (SBV) as DOM

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increased from 0 to 12%. Similar trend in increases in paste viscosity values was reported by Sandhu *et al.* (2018) and Wang *et al.* (2021) for DOM of 0 to 12% at 2% interval.

The pasting properties among the analysed samples at 0 to 12% DOM showed significant (P<0.05) difference in respect to BDV while PV, TV, FV and SBV showed significant (P<0.05) difference at DOM between 0 and 6%. On the other hand, there was no significant difference in the values of PV, TV, FV and SBV at DOM between 9 and 12%. Differences in amylose, protein, fat and minerals contents which may interact with rice starch up to varying degrees and influence could be attributed to the variations in pasting properties (Bhat and Riar, 2019). When the DOM increased from 0 to 3%, the values of paste viscosity parameters increased significantly by 24.19% (PV), 28.84% (TV), 9.58% (FV) and 3.17% (SBV).

The values for these parameters thereafter increased gradually with further increases in DOM. Increase in starch concentration with increasing DOM as a result of removal of proteins and lipids might partly be attributed to higher paste viscosities due to higher amylose content which provides stability to the swollen granules at elevated temperature. The paste viscosities of rice flour were reported to decrease with the incorporation of proteins from two different types of cowpeas (Shevkani *et al.,* 2015). Buckwheat bran also decreased PV, SB, and FV of wheat flour with the increase of the bran portion (Rachman *et al*., 2020).

The peak viscosity that indicates rapid increase in viscosity after a sufficient number of granules had become swollen (Bhat and Riar, 2020), could be attributed to its high amylose content. This according to Sangeeta and Grewal (2018) allows easier swelling of starch granules due to the weaker binding forces and thus increasing peak viscosity upon heating at lower temperature.

The amylose-lipid complex formation, along with the rate of granular swelling and exudation of amylose significantly determines the trough viscosity (holding viscosity) (Wani *et al.,* 2012) that depicted the minimum hot-paste viscosity. Breakdown viscosity, that gives the measure of disintegration of starch granules upon swelling exhibited validate the paste stability. Thus, increased breakdown viscosity values could be attributed to an increased rate of rupturing of the starch granules upon heating (Baxter *et al.,* 2004).

The FV that indicates the cooking quality of rice shows the degree of interaction between amylose and amylopectin when rice flour forms a gel structure as a result of starch retrogradation (Sandhu *et al.,* 2018; Wang *et al.,* 2021). Thus the higher FV may be an indication of a stronger interaction between amylose and amylopectin. The starch granules that are less swollen upon heating had more chances of leaching out amylose and the leached amylose contributes to increase in the FV due to its re-association that enhances binding of water (Bhat and Riar, 2019). Therefore, milled rice at 12% DOM had a higher starch (82.79%) and amylose content (23.92%) and lower protein (6.21%) and fat (0.64%) content, which resulted in a higher FV (4342.67 cP). The setback viscosity that measures the retro gradation of rice cultivars upon cooling of cooked rice flour was found to be affected by amylose and amylopectin ratio and is the result of hydrogen bonding between the molecular starch containing both hydroxyl and hydrogen acceptor sites (Bhat and Riar, 2018).

According to Pearson's correlation coefficients between DOM and selected pasting properties (Table 7), DOM showed a significant and positive correlation with PV (r = .896**), TV (r = .907**) and FV (r = .938**) but was significantly and negatively correlated with PT (r = -

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.815*) at 0.05 level. DOM was also significantly and positively correlated with amylose (r = .915**) and starch (r = .980**) but Pearson's correlation coefficients was not significant for WAC or WBC. Pearson's correlation coefficients (r) as presented in Table 7 indicated that PV, TV and FV were significantly and negatively correlated with ash, protein, fat and fibre while they are significantly and positively correlated with the starch and amylose.

Pasting temperature (PT) and PV which are key parameters for evaluating rice pasting properties shows that with the increase in the DOM, the PT decreased gradually in the range of 91.63 to 89.53 °C. These values did not change significantly ($p \leq 0.05$) with respect to the polishing at all levels of DOM and are higher than the range of 88.9-80.1 °C reported by Wang *et al.* (2021) which may be due to differences in the rice varieties. The higher PV and lower the PT shows easiness for rice to absorb water for gelatinization during cooking and swelling. It has been reported that proteins and lipids present in cereals (including rice) could prevent the starch granules from swelling and forming gels (Wani *et al.,* 2013; Singh *et al.,* 2014; Anugrahati *et al.,* 2017).

The Peak time which is the measure of the cooking time ranged between 6.97 and 7.00 min among the brown rice flour and polished respectively and were not significantly ($P \leq 0.05$) different. These values are similar to the values (6.98-7.00 min and 88.88-92.00 °C) reported by Rachman *et al.* (2020) in their study on the effects of different levels of buckwheat bran inclusion onto the physicochemical and pasting properties of buckwheat flour gels.

CONCLUSION

This study showed that the nutritional composition of FARO 64 rice variety was affected by the degree of milling. Each milling stage led to a decrease in ash, protein, fat and fibre content and an increase in carbohydrate values, being significant at 6% DOM. There is an indication that protein may be concentrated in the testa (middle layer) and aleurone (innermost layer) of bran. Amylose content was significantly ($p < 0.05$) different at 6% DOM while the increase in the total starch content was less obvious with further increases in DOM at 6%. Lightness increased while yellowness, redness and Chroma decreased gradually with increase in DOM, though the effect was prominent at DOM greater than 6%. The study also revealed that all the brown rice at various degree of milling showed diverse pasting profile. DOM had increased the range of pasting parameter with wide range of peak viscosity, trough viscosity, breakdown viscosity and final viscosity at similar pasting time and temperature. This study could provide more information in production of rice flours of improved nutritional and functional properties with minimal processing by precise control of suitable degree of milling.

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APPENDIX

Table 1: Effect of degree of milling on the proximate composition of brown rice

DOM %	Moisture %	Ash %	Protein %	Fat %	Fibre %	Carbohydrate %	Energy kCal/kg
0	12.43±0.02a	1.70±0.04a	7.85±0.29a	3.75±0.04a	2.01±0.11a	72.26±0.22e	4154.33±3.48a
3	12.29±0.05b	1.58±0.04b	7.54±0.33a	2.72±0.05b	1.68±0.04b	74.18±0.32d	4092.00±3.46b
6	11.97±0.04c	1.50±0.02b	7.10±0.26ab	1.85±0.09c	1.46±0.06b	76.12±0.30c	4071.67±3.48c
9	11.87±0.04c	1.31±0.04c	7.05±0.26ab	0.94±0.09d	1.08±0.07c	77.75±0.28b	4012.33±2.03d
12	11.68±0.04d	0.94±0.04d	6.21±0.19b	0.64±0.03e	0.97±0.07c	79.55±0.14a	3986.67±8.29e

Mean values within the same column with different alphabet (s) are significantly different ($p \leq 0.05$)

Table 2: Effect of degree of milling on mineral composition of brown rice

Parameters mg/g					
DOM	Ca	Na	Mg	K	P
0	0.088±0.013a	0.368±0.031a	1.406±0.232a	1.620±0.078a	3.493±0.147a
3	0.055±0.004a	0.317±0.016ab	0.930±0.326ab	1.493±0.033ab	3.080±0.078b
6	0.038±0.011b	0.270±0.024b	0.700±0.040bc	1.400±0.046b	2.727±0.070c
9	0.036±0.033b	0.088±0.003c	0.377±0.032bc	1.073±0.018c	2.310±0.047d
12	0.034±0.024b	0.076±0.008c	0.303±0.038c	0.933±0.041c	1.957±0.061e

Mean values within the same column with different alphabet (s) are significantly different ($p \leq 0.05$)

Table 3: Effect of degree of milling on the physicochemical properties of brown rice

DOM %	Water absorption capacity	Water binding capacity %	Amylose %	Starch %
0	6.20±.077c	93.00±1.155c	21.31±.180c	74.36±.157e
3	6.42±.060bc	96.33±.882bc	21.41±.026c	77.49±.349d

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6	6.49±.024b	97.33±.333b	23.32±.194b	78.61±.143c
9	6.58±.045b	98.67±.667b	23.90±.075a	81.55±.258b
12	6.82±.118a	102.33±1.764a	23.92±.171a	82.79±.349a

Mean values within the same column with different alphabet (s) are significantly different ($p \leq 0.05$)

Table 4: Effect of degree of milling on colour property of brown rice

DOM	L*	a*	b*	C	h
0	82.87±.046e	1.98±.050a	9.54±.064e	9.77±.052a	78.29±.363e
3	84.85±.032d	1.66±.032b	8.85±.150d	9.00±.153b	79.38±.039d
6	86.22±.104c	0.93±.025c	8.13±.051c	8.18±.050c	83.47±.195c
9	90.24±.105b	0.46±.007d	6.77±.076b	6.79±.076d	86.08±.056b
12	93.78±.159a	0.30±.012e	5.25±.038a	5.26±.038e	86.70±.109a

Mean values within the same column with different alphabet (s) are significantly different ($p \leq 0.05$)
L* represented lightness; a* corresponds to the extent of red-green colour; b* represents yellow-blueness; C represents Chroma and h, hue angle

Table 5: ‡Pearson correlation coefficients among DOM, colour and proximate parameters of brown rice

	DOM	L*	a*	b*	Ash	Protein	Fat	Fibre
DOM	1							
L	**.980****	1						
a	-.979*	**-.936****	1					
b	-.980*	**-.995****	**.937****	1				
Ash	**-.939****	**-.969****	**.867****	**.970****	1			

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Protein	**-.792****	**-.794****	**.754****	**.806****	**.767****	1		
Fat	**-.983****	**-.940****	**.985****	**.936****	**.872****	**.747****	1	
Fibre	**-.955****	**-.929****	**.955****	**.927****	**.852****	**.697****	**.956****	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
‡The pairs of variables with positive correlation coefficients and *P* values below 0.010 tend to increase together while the pairs with negative correlation coefficients and *P* values below 0.010, one variable tends to decrease while the other increases.
Bold letters indicate stronger Pearson correlation coefficients between the respective parameters
DOM Degree of milling, L* Lightness, a* Extent of red-green colour, b* Extent of yellow-blueness colour

Table 6: Effect of degree of milling on pasting properties

DOM	PV (Cp)	TV (Cp)	BDV (Cp)	FV (Cp)	SBV (Cp)	Time (min)	Temp (°C)
0	1216.33±28.88d	1039.33±15.30d	133.67±0.88e	3623.67±33.20d	2413.00±2.52d	7.00±0.00a	91.63±0.62a
3	1604.00±40.43c	1460.33±30.21c	137.67±1.45d	4007.67±48.64c	2492.00±12.77c	7.00±0.00a	90.63±0.29a
6	1748.00±19.50b	1597.67±27.97b	150.33±1.45c	4107.67±14.52b	2547.33±24.67b	6.97±0.00a	90.47±0.02a
9	1782.33±11.47ab	1668.67±9.53a	154.33±0.67b	4261.00±22.28a	2565.33±7.54ab	7.00±0.00a	89.93±0.26a
12	1859.33±9.39a	1733.00±12.10a	165.33±0.67a	4342.67±23.67a	2593.33±17.75a	7.00±0.00a	89.53±0.07a

Mean values within the same column with different alphabet (s) are significantly different ($p \leq 0.05$)
DOM: degree of milling, PV: peak viscosity, TV: trough viscosity. BDV: break down viscosity, FV: final viscosity, SBV: set back viscosity

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Table 7: ‡Pearson correlation coefficients between various physicochemical and selected pasting properties of brown rice at DOM

	DOM	PV	TV	FV	PT	Ash	Protein	Fat	Fibre	Amylose	Starch	WAC	WBC
DOM	1												
PV	**.896****	1											
TV	**.907****	**.988****	1										
FV	**.938****	**.975****	**.977****	1									
PT	-.815*	**-.758****	**-.780****	**-.830****	1								
Ash	**-.939****	**-.767****	**-.766****	**-.844****	**.797****	1							
Protein	**-.792****	-.636*	**-.673****	**-.676****	**.746****	**.767****	1						
Fat	**-.983****	**-.926****	**-.938****	**-.957****	**.795****	**.872****	**.747****	1					
Fibre	**-.955****	**-.870****	**-.892****	**-.900****	**.768****	**.852****	**.697****	**.956****	1				
Amylose	**.915****	**.828****	**.835****	**.840****	**-.685****	**-.779****	**-.649****	**-.933****	**-.924****	1			
Starch	**.980****	**.916****	**.926****	**.968****	**-.817****	**-.912****	**-.717****	**-.983****	**-.941****	**.882****	1		
WAC	.514	.239	.279	.383	-.338	**-.680****	-.315	-.412	-.449	.291	.518*	1	
WBC	.513	.237	.277	.382	-.338	**-.680****	-.316	-.411	-.446	.289	.517*	**1.000****	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

‡The pairs of variables with positive correlation coefficients and *P* values below 0.010 tend to increase together while the pairs with negative correlation coefficients and *P* values below 0.010, one variable tends to decrease while the other increases. Bold letters indicate stronger Pearson correlation coefficients between the respective parameters

DOM Degree of milling, PV Peak viscosity, TV Trough viscosity, FV Final viscosity, PT Pasting Temperature, WAC Water absorption capacity, WBC Water binding capacity

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