Bulletin of the *Transilvania* University of Brasov
Series II: Forestry • Wood Industry • Agricultural Food Engineering • Vol. 16(65) No. 1 – 2023
https://doi.org/10.31926/but.fwiafe.2023.16.65.1.7

THE PHYSICAL, MECHANICAL, AND NUTRITIONAL PROPERTIES OF FRESHLY HARVESTED PADDY RICE VARIETIES DRIED AT DIFFERENT TEMPERATURES

Babatunde O. ADETIFA[1] Victor O. ADEBOYE[1]
Adebanke O. ADENIYI[1] Sodiq O. ABDUL[2]
Taiwo M. SAMUEL[1]

Abstract: *Rice has become a major food in Nigeria, but the acceptance of the local varieties is low due to the presence of impurities traceable, to poor processing and low quality. This study investigates the effect of drying temperature on selected properties of Ofada white and Boromo paddy rice. Using standard methods, selected physical, mechanical and nutritional properties of the rice varieties were estimated when freshly harvested and after drying at 50, 60 and 80°C to 14% moisture content (wet basis). The drying temperature had a significant effect on the length, width, thickness, arithmetic diameter, geometric diameter, equivalent diameter, sphericity, grain volume, surface area, bulk density, true density, porosity, angle of repose and thousand-grain weight, bending strength, compressive strength, fracture energy, carbohydrate content, crude protein, and amylose content. This study concludes that drying temperature significantly affects rice properties and should be considered in the design and selection of processing machines.*

Key words: *Ofada white, Boromo rice, drying temperature, physical properties, mechanical properties, nutritional properties.*

1. Introduction

Rice (*Oryza sativa L.*) is perhaps the main staple food crop consumed by man, containing around 75% of the calories and 55% of the protein in a typical diet. Considered as a fundamental staple grain, it is cultivated in more than 75% of African countries [10]. Rice is cultivated in tropical areas where rain and sunlight are

[1] Department of Agricultural Engineering, Faculty of Engineering, College of Engineering and Environmental Studies, Olabisi Onabanjo University, 112104,Ibogun, Ogun State, Nigeria;
[2] Department of Industrial Engineering, Faculty of Technology, University of Ibadan, P.M.B 5017, G.P.O, Ibadan, Oyo State.
Correspondence: Babatunde O. Adetifa; email: olusola.adetifa@oouagoiwoye.edu.ng.

abundant [20]. In many countries, technical advancement endeavours are focused on rice to address issues in production, processing, and storage. Some of these issues affect rice quality, quantity and nutrients.

The nutrients of rice have been reported to reduce as a result of field losses (especially during harvest), storage, transport, excessive drying, and milling. The moisture content of paddy at harvest is around 22-26% wet basis (*Wb*), especially if harvested during the rainy season [26]. At this stage, deterioration occurs faster. So, inappropriate drying of rice gives rise to low quality. When rice is harvested and stored without proper drying, it gives rise to insect infestation, mould caused by fungi, changes in rice color, and also, it starts developing unpleasant odors. For rough rice, drying temperature, storage temperature, and storage time, all affect rice quality [18]. The temperature of drying in particular has a critical effect on the hardness of rice.

Drying has been reported to affect the shape, composition, and dimension of biomaterials. The inner structure of these materials changes during drying, leading to stress and shrinkage. Moisture gradient forms as a result of the removal of water, causing shrinkage stresses [16]. Properties of grains are usually affected by the grain moisture content, drying temperature, airflow rate, and residence time [12]. The drying process alters the rice structure due to shrinkage or elongation, which can affect consumer preferences [14]. The drying temperature of food has been reported to affect material shrinkage. There is a significant volume reduction when food is dried at a low temperature (20°C), but reduced shrinkage at a higher drying temperature (50 to 70°C) [16]. Similarly, Pattama et al. [22] observed that longer drying time affected the peak, breakdown, final viscosity and set back of Thai native rice cultivars, while Somchart et al. [25] reported the effect of drying temperature and moisture content on the properties of Thai jasmine paddy rice.

The mechanical properties of rice are critical and there is a need for these properties to be investigated, estimated and applied in the design of rice processing machinery. The physical and mechanical properties of rice have been employed in the planting, harvesting, drying, storage, processing, and handling of rice [15]. As indicated by Chandio et al. [8], the mechanical properties of rice and wheat straw are indispensable for the design of machines for milling, cleaning and handling. These properties are also important in studying the effect of harvesting, sifting and handling. According to Jouki and Khazaei [13], the physical and mechanical properties of rice, which are essential for machine development, depends on grain moisture content. Moisture content affects density, angle of repose and coefficient of friction. Most studies on the mechanical properties of plant materials have only reported their stress, force, and energy to break or their Young's modulus and the modulus of rigidity. According to Sarker et al. [24], assessing the effects of different drying strategies on the mechanical properties can assist in adopting a reasonable drying practice for quality rice production.

Adebowale et al. [2] reported the effect of the moisture content on some properties of five different paddy rice varieties. An increase in moisture content was reported to increase most of these properties aside from the bulk density and true density. Similarly, Adeyanju et al. [4] observed that an increase in the moisture content of *Ofada* rice increases the physical and thermal properties. On the other hand, Anuonye et al. [5] reported that soaking *Ofada* rice for eight days without changing the soaking water significantly reduces the milling returns, cooking characteristics, and the pasting properties.

To forestall decay after harvest, the moisture content of paddy should be reduced to a level suitable for storage by limiting the effect of respiration, hindering mould development and creation of mycotoxins. Wiset et al. [26] recommended a moisture content of around 13-14% *Wb*, which is suitable for safe storage and milling. Therefore, the objective of this study is to assess the effect of drying temperature on some selected physical, mechanical, and nutritional properties of some freshly harvested varieties of paddy rice. This would be achieved by determining the moisture content of the freshly harvested paddy rice varieties; comparatively analyzing the physical, mechanical, and nutritional properties of the selected freshly harvested varieties of rice before and after drying at different temperatures (to a moisture content of 14% *Wb*).

2. Materials and Methods

2.1. Sample Preparation

Two (2) freshly harvested local rice variety samples namely, *Ofada* white and Boromo rice (Boromo) of about 5 kg each were obtained from a farm located at Owowo (also called Awowo) (7.04942° N, 3.2329° E) in Ewekoro local government area in Ogun State Nigeria. It was then cleaned in a separator, after which it was stored in a refrigerator at about 4°C temperature to conserve the moisture content before the experiment. The bulk material was weighed on an electronic weighing scale and divided into 10 lots of equal weights for the experiment using a seed riffle type divider, which is appropriate for dividing materials. The oven-drying method was used in the drying of the varieties of rice at different temperatures. The temperatures used in drying the materials are 50, 60, and 80°C. The rice was dried to 14% moisture content (wet basis).

2.2. Moisture Content Determination

The moisture content of the two local rice varieties was determined by making use of the oven-drying method. The moisture content was determined by weighing the grain in a dish (W_w) and then placing the material in the oven at 105°C for 72 hours. The weight of the material in the dish (W_d) was measured after 72 hours.The moisture content (M_{wb}) was determined by using Equation (1).

$$M_{wb}\left[\%\right] = \frac{W_w - W_d}{W_w} \cdot 100 \qquad (1)$$

where M_{wb} is the moisture content (wet basis) [%], and W_w, W_d are the weight of the sample/material before and after drying, respectively.

2.3. Physical Properties

The methodology reported by Arije et al. [7] for different rice varieties was adopted. A sum of 100 rice grains was randomly selected from the two rice varieties. The length (*L*), width (*W*), and thickness (*T*) of the rice were measured with a Vernier Calliper. The mass of each selected rice grain was measured using a digital weighing scale. The arithmetic mean diameter (D_a), geometric mean diameter (D_g) and equivalent diameter (D_p) were estimated from Equations (2), (3), and (4), respectively.

$$D_a = \frac{L + W + T}{3} \tag{2}$$

$$D_g = (L \cdot W \cdot T)^{\frac{1}{3}} \tag{3}$$

$$D_p = \left(L \cdot \frac{(W + T)^2}{4} \right)^{\frac{1}{2}} \tag{4}$$

The sphericity (*Ø* – a measure describing the shape) of the rice samples was determined using Equation (5).

$$\phi = \frac{(L \cdot W \cdot T)^{\frac{1}{3}}}{L} \tag{5}$$

Grain volume (*V*), surface area (*S*) and aspect ratio (R_a) were estimated from Equations (6), (7) and (8), respectively.

$$V = 0.25\left[\left(\frac{\pi}{6}\right) \cdot L (W + T)^2\right] \tag{6}$$

$$S = \frac{\pi \cdot B \cdot L^2}{\left(2L - \sqrt{W \cdot T}\right)} \tag{7}$$

$$R_a = \frac{L}{W} \tag{8}$$

The bulk and true densities of the rice grains were also determined. The bulk density was determined by measuring the weight of a particular volume of the rice grains. The experiment was carried out in five replicates. Using the toluene displacement method, the true density of the rice grains was estimated. 10 g of the rice grains were poured into a measuring cylinder containing 50 ml toluene. The volume of toluene displaced as a result of the addition of 10 g of rice, which was recorded. The bulk density and the true density of the rice was then estimated with Equations (9) and (10), respectively. The percentage of pore spaces in the bulk of rice grains – porosity (*ε*) was then estimated using Equation (11).

$$n_b = \frac{M}{V} \tag{9}$$

$$n_t = \frac{\text{Weight of grains}}{\text{Volume of toluene displaced}} \tag{10}$$

$$\varepsilon[\%] = \left(1 - \frac{n_b}{n_t}\right) \cdot 100 \tag{11}$$

where:

η_b and η_t are the bulk and true densities, respectively [kgm^{-3}];
ε – the porosity [%];
M – mass of rice [kg];
V – volume [m].

The thousand-grain weight (*TGW*) was determined by counting and weighing 1000 rice grains. This was replicated five times. In addition, the angle of repose (*Ø*), which is the angle formed by the pile of the grains to the horizontal, was measured by slowly pouring the rice grains in the middle of a flat dish of diameter *D* (allowing it to form a heap) until the rice grains begin to fall freely from the heap of height *H*. This procedure was also replicated five times. The angle of repose was then estimated using Equation (12).

$$\phi = \frac{\tan^{-1}(2H)}{D} \quad (12)$$

2.4. Mechanical Properties

The mechanical properties covered in this study are the bending strength, compressive strength, fracture energy and modulus of elasticity. They were all carried out in line with Sadeghi et al. [23].

The bending strength (*σ*), in MPa, was determined using Equations (13) and (14).

$$\sigma = \frac{F \cdot L \cdot T}{8I} \quad (13)$$

$$I = 0.049W \cdot T^2 \quad (14)$$

where:

F represents the peak bending force [N];

L – the linear distance between the supports [m];

I – the moment of inertia [m^4].

The response of the rice samples to the crushing load was investigated with a static compression test. The static compressive strength (R_c) was then determined using Equation (15).

$$R_c = \frac{F_c}{A_0} \quad (15)$$

where F_c is the highest compressive load that crushed the rice grain, and A_0 is the initial cross-section of the rice grains.

The fracture energy (*G*), in J/m^2, of the rice grains, was estimated with Equation (16).

$$G = \frac{\int (F \cdot d \cdot \delta)}{A} \quad (16)$$

where $\int (F \cdot d \cdot \delta)$ is the area of the force–deformation curve, while A is the surface area of the fracture [m^2].

The apparent modulus of elasticity (*E*) in Pascal for a giving deformation (*δ*), in meter, was estimated using Equation (17).

$$E = \frac{F \cdot L^3}{48I \cdot \delta} \quad (17)$$

2.5. Nutritional Properties

Using standard experimental procedures, the crude protein, carbohydrate, amylose and lipid contents of the rice samples were calculated, while the rice taste value was estimated using a model reported by Zheng and Lan [27].

A. Determination of Crude Protein Content

Two grams (2 g) of the rice sample, 2 g of anhydrous sodium sulphate, 1 g of hydrated cupric sulphate, a pinch of selenium powder, and 10 ml of concentrated sulphate acid were placed in a 100 ml digestion flask. The mixture was mildly heated until the solution became transparent, and then continued for another hour. The mixture was allowed to cool before being used. The mixture was diluted and well shaken. The diluted mixture (5 ml) was poured into a distillation apparatus. The evaporator was covered, and 5ml of 40% NaOH was carefully added to prevent ammonia from escaping. After this, steam was let in till the volume was doubled. The trapped ammonia was titrated to the endpoint (green to pink) against a standard 0.1 normality of the HCl, and the volume of the titre was recorded. The crude protein content was then estimated using Equation (18).

$$\text{Crude Protein}[\%]=\frac{V_t \cdot F \cdot c \cdot f \cdot M_N \cdot C_f}{1000 W_s} \quad (18)$$

where:

V_t is the volume of titre [ml];

F – the normality of the HCl;

f – the dilution factor of the titrant;

M_N – the molecular weight of Nitrogen (14.007 g/mol);

C_f – the Protein conversion factor (6.25);

W_s – the weight of the sample [g];

1000 – the unit conversion factor.

B. Determination of Carbohydrate Content

The difference was calculated by subtracting the amount of % ash, % protein, % fat, % moisture, and % crude fibre from 100 % (Equation 19).

$$\text{Carbohydrate}[\%] = 100 - \%\text{ash} + \%\text{protein} + \%\text{fat} + \%\text{moisture} + \%\text{crude fibe} \quad (19)$$

C. Determination of Amylose Content

The amylose content of the *Ofada* white and Boromo rice samples was estimated. 100 mg of the samples were milled and then the flour was dispersed in 1 ml of 95% ethanol and 9 ml of 1N NaOH. This was heated for 10 minutes in a boiling water bath to get a gelatinized starch. The starch was diluted using distilled water and 5 ml of the starch solution was pipetted into a 100 ml volumetric flask, 1 and 2 ml of acetic acid and iodine solution, respectively, were added and made up to volume. While the absorbance was read at 620nm, the amount of amylose in the sample was calculated using an amylose standard curve.

D. Determination of Lipid Content

The AOAC [6] Soxhlet extraction methods were used to determine the lipid content of the rice samples. Two grams of each sample was weighed and placed into a thimble in a folded filter paper. A rack was used to fill the thimble containing the sample into the extraction instrument. With the aid of a rack, 4 ml acetone (solvent) was poured into a weighted empty flask, and the flask and its contents were poured into the instrument chamber. At 100°C, the machine was permitted to stand for 30 minutes. After 50 minutes, the instrument was connected to a tap that refluxed inside the system, and the solvent was recovered by an automated siphoning device in the machine, leaving fat in the flask. The fat was removed from the flask, dried in the oven for 15 minutes, cooled in a desiccator, and reweighed; the weight of fat equalled the weight of the bowl, plus fat minus the weight of the dish.

E.Determination of Rice Taste Value

The taste value of the rice samples dried at different temperatures was estimated using the mathematical model developed by Zheng and Lan [27]. The values obtained from the experimental determination of the amylose, moisture, protein and lipid contents were inputted into Equation (20) to get the estimated taste value of the rice samples.

$$S = \frac{23149}{A^{1.33} \cdot P^{0.81} \cdot \left[1.5 + \left(15 - M\right)\right]^{0.06} \cdot F^{0.28}} - 2 \quad (20)$$

where:

S is the rice taste value [%];
A – the rice amylose composition [%];
P – the rice protein composition [%];
M – the rice moisture content [%];
F – the rice lipid content [%].

The data obtained from the laboratory were analyzed using Microsoft Excel and SPSS to determine if there is a significant difference between the means of the physical and mechanical properties of the sample before drying and the sample after drying at different temperatures.

3. Results and Discussions

The average moisture content (wet basis) for freshly harvested *Ofada* white and Boromo rice were estimated to be 38.33 and 58.89%, respectively. The physical, mechanical and nutritional properties of these rice varieties are hereunder presented.

3.1. Physical Properties

A summary of the physical properties of *Ofada* and Boromo rice are presented in Tables 1, 2 and 3, respectively.

From Table 1, the mean length of fresh *Ofada* rice and Boromo rice was found to be 8.60 and 7.95 mm, respectively. When dried at 50, 60, and 80°C, the mean lengths were correspondingly reduced to 8.45, 8.36, 8.39 mm for *Ofada* rice and 7.79, 7.94, 7.76 mm for Boromo rice. The mean width of fresh *Ofada* white and Boromo rice was found to be 3.39 and 3.44 mm respectively. When dried at 50, 60, an 80ºC, the mean widths of both species of rice were found to be correspondingly reduced to 3.38, 3.36, 3.33 mm for *Ofada* rice and 3.26, 3.32, 3.26 mm for Boromo rice. The mean value for the thickness of fresh *Ofada* white and Boromo rice was found to be 2.30 and 1.91 mm, respectively. When dried at 50, 60, and 80°C, the mean values of thickness were found as being 2.20, 2.22, and 2.23, respectively for *Ofada* rice and 1.79, 1.74, and 1.70 mm for Boromo rice. Naik et al. [19] reported the average length, width and thickness of rice to be 6.28, 2.11 and 1.80 mm, respectively. In Adekoyeni [3], the length, width and thickness of *Ofada* rice varied from 5.5-6.3 mm, 2.5-3.0 mm, and 1.9-2.4 mm respectively.

The Arithmetic Mean Diameter (*AMD*) of fresh *Ofada* rice and those dried at 50, 60, and 80°C, were estimated at 4.76, 4.67, 4.65, and 4.65 mm, respectively, while for Boromo rice, the *AMD* of freshly harvested, and when dried at 50, 60, and 80°C was found to be 4.44, 4.28, 4.33, and 4.24 mm, respectively. The Geometric Mean Diameter (*GMD*) of freshly harvested *Ofada* rice was 4.06 mm and when dried at 50, 60, and 80°C the *GMD* was 3.96 mm. For Boromo rice, the *GMD* when freshly harvested was 3.73 mm, while when dried at 50, 60, and 80°C the *GMD* was 3.56, 3.57, and 3.50 mm, respectively. The mean value of the equivalent diameter of fresh *Ofada* white and Boromo rice was found to be 4.11 and 3.85 mm, respectively. The mean value of both species of rice dried at 50, 60, and 80°C was found to be: 4.03, 4.02, and 4.02

mm, respectively for *Ofada* rice, and 3.67, 3.70, and 3.63 mm, respectively for Boromo rice. *Ofada* and Boromo rice were observed to have the same mean sphericity (0.47) when freshly harvested. Regardless of the drying temperature, the sphericity of *Ofada* rice remained at 0.47 while that of Boromo rice varied between 0.45 and 0.46.

The mean value of the grain volume of fresh *Ofada* white and Boromo rice was found to be 36.62 and 30.16 mm^3 respectively. After drying at 50, 60, and 80°C the grain volume was found to be 34.46, 34.28, and 34.11 mm^3, respectively, for *Ofada* rice and 26.40, 26.70, and 25.28 mm^3, respectively, for Boromo rice. For the surface area, freshly harvested *Ofada* and Boromo rice have a mean value of 45.01 and 38.21 mm^2, respectively, while after drying at 50, 60, and 80°C the mean value was estimated to be 42.99, 42.85, and 42.83 mm^2, respectively, for *Ofada* rice, and 35.04, 35.23, 33.89 mm^2, respectively, for Boromo rice.

Table 1

Physical properties of Ofada white paddy rice

Property	Sample size	Freshly harvested	Dried at 50°C	Dried at 60°C	Dried at 80°C
Length [mm]	100	8.60±0.62	8.45±0.58	8.36±0.56	8.39±0.58
Width [mm]	100	3.39±0.30	3.38±0.28	3.36±0.26	3.33±0.27
Thickness [mm]	100	2.30±0.19	2.20±0.23	2.22±0.23	2.23±0.24
Arithmetic mean diameter [mm]	100	4.76±0.25	4.67±0.23	4.65±0.23	4.65±0.22
Geometric mean diameter [mm]	100	4.06±0.21	3.96±0.20	3.96±0.21	3.96±0.20
Equivalent diameter [mm]	100	4.11±0.21	4.03±0.20	4.02±0.20	4.02±0.20
Sphericity	100	0.47±0.03	0.47±0.03	0.47±0.03	0.47±0.03
Grain volume [mm^3]	100	36.62±5.79	34.46±5.01	34.28±5.11	34.11±4.96
Surface area [mm^2]	100	45.01±4.53	42.99±4.19	42.85±4.34	42.83±4.16
Aspect ratio	100	2.56±0.28	2.52±0.28	2.50±0.24	2.54±0.30
Bulk density [kgm^{-3}]	5	592.93±35.63	535.33±3.53	529.87±4.04	517.20±3.60
True density [kgm^{-3}]	5	1144.44±106.50	948.48±75.45	945.45±49.79	963.64±49.79
Porosity [%}	5	47.72±6.95	43.23±5.10	43.84±2.76	46.22±2.60
TGW	5	33.86±0.92	29.74±0.34	29.62±0.08	29.60±1.01
Angle of repose	5	45.84±2.14	33.29±3.92	34.63±2.51	35.41±1.58

From Table 1, *Ofada* rice was observed to have a higher aspect ratio compared to Boromo rice. The aspect ratio of freshly harvested *Ofada* rice, *Ofada* rice dried at 50, 60, and 80°C was estimated at 2.56, 2.52, 2.50, and 2.54, respectively. Similarly, the aspect ratio of freshly harvested Boromo rice, Boromo rice dried at 50, 60, and 80°C was estimated at 2.32, 2.41, 2.41, and 2.39, respectively. The mean bulk density of fresh *Ofada* white, and Boromo rice was found to be 592.93 and 527.73 kgm^{-3} respectively, while the respective mean bulk density of *Ofada* white and Boromo rice dried at 50, 60, and 80°C was found to be 535.33, 529.87, and 517.20 kgm^{-3}, and 455.47, 453.07, 446.67 kgm^{-3}, respectively. For the true density, freshly harvested *Ofada* and Boromo rice have a mean value of 1144.44 and 1094.44 kgm^{-3}, respectively, while after drying at 50, 60, and 80°C the mean value was estimated to be 948.48, 945.45, 963.64 kgm^{-3}, respectively, for *Ofada* rice and 747.25, 835.66, 848.48 kgm^{-3}, respectively, for Boromo rice.

Table 2

Physical properties of Boromo paddy rice

Property	Sample size	Freshly harvested	Dried at 50°C	Dried at 60°C	Dried at 80°C
Length [mm]	100	7.95±0.59	7.79±0.63	7.94±0.55	7.76±0.52
Width [mm]	100	3.44±0.23	3.26±0.34	3.32±0.25	3.26±0.28
Thickness [mm]	100	1.91±0.33	1.79±0.22	1.74±0.20	1.70±0.20
Arithmetic mean diameter [mm]	100	4.44±0.28	4.28±0.32	4.33±0.25	4.24±0.26
Geometric mean diameter [mm]	100	3.73±0.27	3.56±0.28	3.57±0.22	3.50±0.24
Equivalent diameter [mm]	100	3.85±0.26	3.67±0.29	3.70±0.22	3.63±0.24
Sphericity	100	0.47±0.03	0.46±0.03	0.45±0.03	0.45±0.03
Grain volume [mm^3]	100	30.16±6.09	26.40±6.15	26.70±4.65	25.28±4.90
Surface area [mm^2]	100	38.21±5.45	35.04±5.43	35.23±4.19	33.89±4.36
Aspect ratio	100	2.32±0.18	2.41±0.24	2.41±0.23	2.39±0.20
Bulk density [kgm^{-3}]	5	527.73±18.25	455.47±13.61	453.07±4.750	446.67±14.12
True density [kgm^{-3}]	5	1094.44±103.19	747.25±30.09	835.66±49.55	848.48±33.88
Porosity [%]	5	51.43±4.87	39.01±1.96	45.64±2.98	47.32±1.94
TGW	5	26.56±0.57	21.90±0.16	21.86±0.19	18.86±1.66
Angle of repose	5	42.87±1.81	40.56±2.94	38.47±0.94	34.34±3.43

The mean porosity of fresh *Ofada* rice and Boromo rice was found to be 47.72 and 51.43, respectively. This mean value was reduced after the rice was dried at 50, 60, and 80°C to 43.23, 43.84, 46.22, respectively for *Ofada* rice, and to 39.01, 45.64, 47.32, respectively for Boromo rice. For the thousand grain weight, freshly harvested *Ofada* and Boromo rice have a mean value of 33.86 and 26.56, respectively, while after drying at 50, 60, and 80°C the mean value was estimated to be 29.74, 29.62, 29.60, respectively, for *Ofada* rice, and 21.90, 21.86, 18.86, respectively, for Boromo rice. The mean angle of repose of freshly harvested *Ofada* rice and Boromo rice was found to be 45.84 and 42.87, respectively. After drying at 50, 60, and 80°C the angle of repose was found to be 33.29, 34.63, 35.41, respectively, for *Ofada* rice, and 40.56, 38.47, 34.34, respectively, for Boromo rice.

Table 3 shows the significant factors affecting the physical properties of *Ofada* white and Boromo rice at a 5% level of significance. The length, width, thickness, arithmetic diameter, geometric diameter, equivalent diameter, sphericity, grain volume, surface area, bulk density, true density, and thousand-grain weight of the samples were influenced by the variety of rice, the condition of the rice samples (whether dried or fresh) and the drying temperature. There was no significant difference between the porosity and angle of repose of *Ofada* and Boromo rice. These two properties were influenced by the condition and drying temperature. On the other hand, the difference in the value of the aspect ratio was not influenced by the condition of the rice and the drying temperature, but by the variety. Farahmandfar et al. [11] reported similarly, that rough rice grain length and aspect ratio show a significant difference between the varieties of rice.

Table 3

Significant level of factors affecting the physical characteristics of both species of rice

Property	Variety	Condition	Drying temperature
Length [mm]	0.000	0.003	0.016
Width [mm]	0.024	0.000	0.000
Thickness [mm]	0.000	0.000	0.000
Arithmetic mean diameter [mm]	0.000	0.000	0.000
Geometric mean diameter [mm]	0.000	0.000	0.000
Equivalent diameter [mm]	0.000	0.000	0.000
Sphericity	0.000	0.000	0.006
Grain volume [mm^3]	0.000	0.000	0.000
Surface area [mm^2]	0.000	0.000	0.000
Aspect ratio	0.000	0.258	0.669
Bulk density [kgm^{-3}]	0.000	0.000	0.001
True density [kgm^{-3}]	0.005	0.000	0.000
Porosity [%]	0.714	0.002	0.000
TGW	0.000	0.004	0.034
Angle of repose	0.261	0.000	0.000

3.2. Mechanical Properties

A summary of the mechanical properties of *Ofada* and Boromo rice are presented in Tables 4, 5 and 6, respectively. The average value of the bending strength of *Ofada* and Boromo rice are 16.28 and 17.33 MPa, respectively. The mean value of the *Ofada* white and Boromo rice when dried at 50, 60 and 80°C temperatures were 17.20, 17.87, 18.28 MPa, and 21.48, 22.72, 23.73 MPa, respectively. The mean compressive strength of *Ofada* and Boromo rice are 19.46 Nmm^{-2} and 19.59 Nmm^{-2}. When dried at 50, 60 and 80°C the mean compressive strength of *Ofada* was 20.35, 21.75, 23.59 Nmm^{-2}, respectively, while that of the Boromo rice was 23.05, 23.62, 24.16 Nmm^{-2}, respectively. The mean fracture energy of freshly harvested *Ofada* and Boromo rice was estimated at 40.58 × 10^{-3} and 36.67× 10^{-3} J/m^2, respectively. When dried at 50, 60 and 80°C, there was an increase in the fracture energy to 43.60 × 10^{-3}, 44.11 × 10^{-3}, and 44.95 × 10^{-3} J/m^2, respectively, for *Ofada* rice, while for Boromo rice, the mean fracture energy increased to 42.40 × 10^{-3}, 43.55 × 10^{-3}, and 45.42 × $10^{-3}$$J/m^2$, respectively. The mean modulus of elasticity of the *Ofada* and Boromo rice when dried at 50, 60 and 80°C temperature was 975.80, 979.14, 987.90 MPa and 760.08, 766.46, 785.93 MPa, respectively, while freshly harvested *Ofada* and Boromo rice have a mean modulus of elasticity of 970.74 and 757.95 MPa.

Table 6 shows the significant factors affecting the mechanical properties of *Ofada* and Boromo rice. The bending strength of the samples was affected by the rice variety, condition and the drying temperature in line with Sarker et al. [24]. The variety was observed not to influence the values of the compressive strength and fracture energy, but the drying condition and temperature influenced these properties. For the modulus of elasticity, the variety was the only factor affecting it, the effect of other factors was not significant. This corroborates the report of Sarker et al. [24] who reported that drying temperature does not affect the modulus of elasticity.

Table 4

Mechanical properties of Ofada white paddy rice

Property	Freshly harvested	Dried at 50°C	Dried at 60°C	Dried at 80°C
Bending strength [MPa]	16.28±0.03	17.20±0.06	17.87±0.06	18.28±0.04
Compressive Strength [Nmm^{-2}]	19.46±0.10	20.35±0.04	21.75±0.03	23.59±0.03
Fracture Energy [10^{-3} J/m^2]	40.58±0.03	43.60±0.02	44.11±0.02	44.95±0.02
Modulus of elasticity [MPa]	970.74±1.53	975.80±0.17	979.14±1.56	987.90±1.57

Table 5

Mechanical properties of Boromo paddy rice

Property	Freshly harvested	Dried at 50°C	Dried at 60°C	Dried at 80°C
Bending strength [MPa]	17.33±0.08	21.48±0.04	22.72±0.06	23.73±0.03
Compressive Strength [Nmm^{-2}]	19.59±0.03	23.05±0.04	23.62±0.03	24.16±0.02
Fracture Energy [10^{-3} J/m^2]	36.67±0.03	42.40±0.15	43.55±0.07	45.24±0.08
Modulus of elasticity [MPa]	757.95±1.20	760.08±2.49	766.46±0.15	785.93±0.63

Table 6

Significant level of factors affecting the mechanical characteristics of rice

Property	Variety	Condition	Drying temperature
Bending strength	0.000	0.005	0.029
Compressive Strength	0.080	0.000	0.000
Fracture Energy	0.230	0.000	0.000
Modulus of elasticity	0.000	0.826	0.987

3.3. Crude Protein

The mean crude protein content of freshly harvested *Ofada*rice has the highest value (7.17%), as shown in Table 7. This value was observed to decrease as the drying temperature was increased. When dried at 50°C, *Ofada* rice was found to have a protein content of 6.91%. When dried at 60 and 80°C, there was a further reduction of the protein content to 6.80 and 6.73%, respectively. The mean crude protein content of freshly harvested Boromo rice was found to be 7.32% (Table 8), then when dried at 50°C, it resulted in a mean crude protein content of 6.91%. When the Boromo rice was dried and exposed to a temperature of 60°C, a lower mean crude protein content of 6.69% was observed, and when the temperature was increased to 80°C, the mean crude protein content was reduced further to 6.53%.

Table 7

Nutritional properties of Ofada white paddy rice

	Sample Size	Freshly Harvested	Dried at 50 °C	Dried at 60 °C	Dried at 80 °C
Crude Protein [%]	3	7.17±0.04	6.91±0.02	6.80±0.02	6.73±0.04
Carbohydrate [%]	3	74.62±0.05	76.62±0.03	75.92±0.04	75.47±0.05
Amylose [%]	3	22.93±0.02	22.40±0.02	21.83±0.08	21.26±0.05
Lipid [%]	3	0.48±0.04	0.58±1.12	0.73±0.02	0.81±0.02
Rice taste value	3	7.19±2.25	7.06±0.738	7.17±0.720	7.28±0.69

Table 8

Nutritional properties of Boromo paddy rice

	Sample Size	Freshly Harvested	Dried at 50 °C	Dried at 60 °C	Dried at 80 °C
Crude Protein [%]	3	7.32±0.03	6.91±0.04	6.69±0.03	6.53±0.04
Carbohydrate [%]	3	76.49±0.03	75.82±0.16	75.65±0.03	76.24±0.04
Amylose [%]	3	21.75±0.04	21.33±0.04	21.03±0.03	19.68±0.04
Lipid [%]	3	1.66±0.01	1.71±0.05	1.82±0.03	1.94±0.02
Rice taste value	3	5.12±0.03	5.48±0.66	5.63±0.11	6.18±0.31

According to Adekoyeni [3] the protein contents of *Ofada* rice ranges from 8.42 to 10.44%, when dried at 30 and 70°C. Zheng and Lan [27] reported a protein content that ranged from 7.2 to 7.4% for a drying temperature between 40 and 60°C. Otegbayo et al. [21] reported 6.85-8.75% for local varieties of Ekiti rice, while Megat-Rusydi et al. [17] reported values around 4.78 to 6.4%; and Ebuechi and Oyewole [9] found that of *Ofada* and Aroso rice to be 7.30 and 6.95%, respectively for a drying temperature of 60°C. These reported values are within the range of values reported by this study. According to Abbas et al. [1], the values of the protein content were affected by the effectiveness of the method used to harvest, handle and process, the soil type, and the variety. For this study, although the variety was found not to affect the crude protein of the rice, the rice condition and the drying temperature were identified to have significant influence (Table 9).

3.4. Carbohydrate Content

From Table 7, the average carbohydrate content of freshly harvested *Ofada* rice is found to be 74.62%. When dried at 50, 60, and 80°C, there was a decrease in the carbohydrate content. The mean carbohydrate content after drying at 50°C was 76.62, 75.92% at 60°C, and 75.47% at 80°C. The average carbohydrate content of freshly harvested Boromo rice was found to be 76.49%. This value was reduced after drying at a temperature of 50°C to 75.82%. Using a drying temperature of 60°C, the dried Boromo rice was found to be 75.65%, while at the temperature of 80°C, the dried Boromo rice was found to be 76.24%. Adekoyeni [3] reported the carbohydrate content of rice to range from 78.6 to 84.4% for a drying temperature of 30-70°C. According to Ebuehi and Oyewole [9] at 60°C the mean value of carbohydrate content for *Ofada* rice is 7.38% and the mean value of carbohydrate content for Aroso is 8.11%. From Table 9, further analysis revealed that there was no significant difference in the carbohydrate content of the two rice varieties, but for each variety, the drying temperature and condition affected the carbohydrate content.

3.4. Amylose Content

From Table 7, for *Ofada* rice, it was observed that the mean amylose content was highest when freshly harvested (22.93%). This value was observed to reduce with an increase in the drying temperature when dried at 50°C, *Ofada* white rice was found to have an amylose content of 22.40%. Further reduction was observed when the rice was dried at 60 and 80°C. At 60°C, the amylose content was 21.83% and at 80°C, the amylose was 21.26%. According to table 8, the initial mean amylose content of Boromo rice was 21.75%, when dried at 50, 60 and 80°C, the mean amylose content reduced to 21.33, 21.03 and 19.68%, respectively. Zheng and Lan [27] reported the amylose content of paddy varieties (Dongnong 9316, 420, and 419) freshly harvested and dried between 40 and 60°C, to range from 17.5 to 23.7%. Adekoyeni [3] reported that the total amylose content of *Ofada* rice ranged from 18.12 to 26.54%. The amylose content was found to be affected by varietal differences of the rice, drying condition, and drying temperature (Table 9).

Table 9

Significant level of factors affecting nutritional characteristics of rice

Property	Variety	Condition	Drying temperature
Crude Protein	0.696	0.000	0.000
Lipid	0.000	0.467	0.467
Amylose	0.001	0.010	0.010
Carbohydrate	0.074	0.321	0.321
Rice taste value	0.000	0.450	0.450

3.5. Lipid Content

Table 7 shows that the mean lipid content of freshly harvested rice is the lowest, with a value of 0.48. When dried at 50°C, this value increased as the drying temperature increased. *Ofada* white rice was found to have a lipid content of 0.58. Further increase was observed when the rice was dried at 60 and 80°C. At 60°C, the lipid content is 0.73 and at 80°C, the amylose is 0.81. According to Ebuehi and Oyewole [9], the mean value of lipid content for *Ofada* rice is 2.6% and the mean value of lipid content for Aroso rice is 1.9% at 60°C. Boromo rice in a freshly harvested condition had an average lipid content of 1.66%. This value increased as the drying temperature increased. When dried at 50°C the average lipid content increased to 1.71% and further increased to 1.82% and 1.94% when dried at 60 and 80°C, respectively. Despite the observed variations, further analysis revealed that the lipid content was not affected by the drying temperature and condition, but by rice variety (Table 9).

3.6. Rice Taste Value

From Table 7, it is observed that the rice taste value when it is freshly harvested has a mean value of 7.19, but after it was dried at 50, 60 and 80°C, the rice taste value of *Ofada* rice was found to be 7.06, 7.17, and 7.28%, respectively. From Table 8, it is observed that the mean rice taste value of freshly harvested Boromo rice is 5.12, while after drying at 50°C it increased to 5.48. When the drying temperature was increased to 60 and 80°C, the mean rice taste value increased to 5.63 and 6.18, respectively. The drying temperature and condition were considered not to have any effect on the rice taste value.

4. Conclusion

This study has shown the effect of drying temperature on the physical, mechanical, and nutritional properties of freshly harvested *Ofada* rice (38.33% moisture content (wet basis)) and Boromo rice (58.89% moisture content (wet basis)) before drying and after drying at 50, 60 and 80°C to 14% moisture content (wet basis) using standard experimental procedures. The average length, width, thickness, bending strength, compressive strength, crude protein, and carbohydrate content was 8.36-8.60 mm, 3.33-3.39 mm, 2.20-2.30 mm, 16.28-18.28 MPa, 19.46-23.59 Nmm^{-2}, 6.37-7.17% and 74.62-76.62%, respectively, for *Ofada* white rice and 7.26-7.95 mm, 3.26-3.44 mm, 1.70-1.91 mm, 17.33-23.73 MPa, 19.59-24.16 Nmm^{-2}, 6.53-7.32%, and 75.65-76.49%, respectively for Boromo rice. The statistical analysis revealed the drying condition and drying temperature affected some of these properties.

References

1. Abbas A., Murtaza S., Aslam F. et al., 2011. Effect of processing on nutritional value of rice (*Oryza sativa*). In: World Journal of Medical Sciences, vol. 6(2), pp. 68-73.
2. Adebowale A.R., Sanni L.O., Owo H.O. et al., 2011. Effect of variety and moisture content on some engineering properties of paddy rice. In: Journal of Food Science and Technology - Mysore, vol. 48(5), pp.

551–559. DOI: 10.1007/s13197-010-0173-3.

3. Adekoyeni O.O., 2014. Effect of processing conditions on physical, chemical, cooking, and sensory properties of ofada rice (*Oryza sativa* L.) grain and flakes. PhD Thesis, Department of Food Technology, University of Ibadan, Nigeria.
4. Adeyanju J.A., Abioye A.O., Adekunle A.A. et al. 2021. Investigation on the effect of moisture content on physical and thermal properties of ofada rice (*Oryza sativa* L.) relevant to post-harvest handling. In: LAUTECH – Journal of Engineering and Technology, vol. 15(1), pp. 108-116.
5. Anuonye J.C., Daramola O.F., Chinma C.E. et al., 2016. Effects of processing methods on physicochemical, functional and sensory properties of Ofada rice. In: International Journal of Biotechnology and Food Science, vol. 4(1), pp. 7-14.
6. AOAC, 2000. Official method of analysis, 17th edition, Horowitz Edition Intern, Maryland, USA, vol. 1, pp. 452-456.
7. Arije O.O., Adewumi B.A., Olayanju T.M.A. et al., 2019. A comparative study of physical properties of selected rice varieties in Nigeria. In: Foods and Raw Materials, vol. 7(1), pp. 4-9. DOI: 10.21603/2308-4057-2019-1-4-9.
8. Chandio F.A., Ji C., Ahmed A.T. et al., 2013. Comparison of mechanical properties of wheat and rice straw influenced by loading rates. In: African journal of Biotechnology, vol. 12(10), pp. 1068-1077.
9. Ebuehi O.A.T., Oyewole A.C., 2007. Effect of cooking and soaking on physical characteristics, nutrient composition and sensory evaluation of indigenous and foreign rice varieties in Nigeria. In: African Journal of Biotechnology, vol. 6(8), pp. 1016-1020.
10. Fairhurst T., Dobermann A., 2002. Rice in the Global Food Supply. In: Better Crops International, vol. 16, pp. 3-6.
11. Farahmandfar R., Farahmandfar E., Ramezani A., 2009. Physical properties of rough rice. In: International Journal of Food Engineering, vol. 5(5), ID article 4. DOI: 10.2202/1556-3758.1573.
12. Inprasit C., Noomhorm A., 2006. Effect of drying air temperature and grain temperature of different types of dryer and operation on rice quality. In: Drying Technology, vol. 19(2), pp. 389-404. DOI: 10.1081/DRT-100102912.
13. Jouki M., Khazaei N., 2012. Some physical properties of rice seed (*Oryza sativa*). In: Research Journal of Applied Sciences, Engineering and Technology, vol. 4(13), pp. 1846-1849.
14. Luangmalawat P., Prachayawarakorn S., Nathakaranakule A. et al., 2008. Effect of temperature on drying characteristics and quality of cooked rice. In: Lwt - Food Science and Technology, vol. 41(4), pp. 716-723. DOI: 10.1016/j.lwt.2007.04.010.
15. Lubna T.M.E., 2005. Physiochemical properties and cooking quality of long and short rice (*Oryza sativa*) grains. Master of Science dissertation, Department of Food Science and Technology, Faculty of Agriculture, University of Khartoum, Sudan.
16. Mahiuddin M., Khan M.I.H., Kumar C. et al., 2018. Shrinkage of food materials during drying: current

status and challenges. In: Comprehensive Reviews in Food Science and Food Safety, vol. 17(5), pp. 1113-1126. DOI: 10.1111/1541-4337.12375.

17. Megat-Rusydi M.R., Noralis C.W., Azrina A. et al., 2011. Nutritional changes in germinated legumes and rice varieties. In: International Food Research Journal, vol. 18, pp. 705-713.
18. Meullenet J.F., Marks B.P., Hankins J.A. et al., 2000. Sensory quality of cooked long-grain rice as affected by rough rice moisture content, storage temperature, and storage duration. In: Cereal Chemistry, vol. 77(2), pp. 259-263. DOI: 10.1094/CCHEM.2000.77.2.259.
19. Naik V.S., Veerapaga N., Rao S., 2016. Physical properties and milling characteristics of rice (*Oryza sativa* L.). In: International Journal of Agriculture Sciences, vol. 8(59), pp. 3301-3305.
20. Ogbonnaya C., Friday J.O., 2009. Response of nutritional contents of rice (*Oryza sativa*) to parboiling temperatures. In: American-Eurasian Journal of Sustainable Agriculture, vol. 3(3), pp. 381-387.
21. Otegbayo B.O., Osamuel F., Fashakin J.B., 2001. Effect of parboiling on chemical qualities of two local rice varieties in Nigeria. In: Journal of Food Technilogy in Africa, vol. (6)4, pp. 130-132.
22. Pattama R., Chaleeda B., Varapha K., 2014. Effect of drying involving fluidisation in superheated steam on physicochemical and antioxidant properties of Thai native rice cultivars. In: Journal of Food Engineering, vol. 123, pp. 143-147. DOI: 10.1016/j.jfoodeng.2013.08.025.
23. Sadeghi M., Araghi H.A., Hemmat A. et al., 2010. Physico-mechanical properties of rough rice (*Oryza sativa* L.) grain as affected by variety and moisture content. In: Agric Eng Int: CIGR Journal, vol. 12(3), pp. 129-136.
24. Sarker M.S.H., Kamrul S.M., Hassan M. et al., 2017. Mechanical property and quality aspects of rice dried in industrial dryers. In: Journal of Food Science and Technology - Mysore, vol. 54(12), pp. 4129–4134. DOI: 10.1007/s13197-017-2856-5.
25. Somchart S., Mattaneeya C., Somkiat P. et al., 2008. Comparative study of physicochemical properties of accelerated and naturally aged rice. In: Journal of Food Engineering, vol. 85(2), pp. 268-276. DOI: 10.1016/j.jfoodeng.2007.07.023.
26. Wiset L., Srzednicki G., Driscoll R.H. et al., 2001. Effects of high temperature drying on rice quality. In: Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, vol. 3, pp. 17-23.
27. Zheng X., Lan Y., 2007. Effects of drying temperature and moisture content on rice taste quality. In: Proceedings of the 5th Asia-Pacific Drying Conference, vol. 2, pp. 1112-1117.