Food Sci. Preserv., 31(5), 745-755 (2024)
pISSN: 3022-5477, eISSN: 3022-5485

Food Science and Preservation
https://doi.org/10.11002/fsp.2024.31.5.745

Research Article

Comparative study on the nutritional and sensory properties, and drying kinetics of two Nigerian rice cultivars

Esther Ayomide Ogunwale[1], Peter Madabuchi Chikieze[1], Kehinde Adekunbi Taiwo[1], Tunde Afolabi Morakinyo[1], Charles Taiwo Akanbi[1], Saka Olasunkanmi Gbadamosi[1], Babatunde Olawoye[2]*, Micheal Olusegun Awoleye[3], Dorcas Lola Alabi[4], Oyebanji Olubunmi Alagbo[4], Olufemi Adebola Koya[5]

[1]*Department of Food Science and Technology, Obafemi Awolowo University, Ile-Ife, Osun State 220282, Nigeria*
[2]*Department of Food Science and Technology, First Technical University, Ibadan, Oyo State 200255, Nigeria*
[3]*African Institute for Science Policy and Innovation (AISPI), Obafemi Awolowo University, Ile-Ife, Osun State 220282, Nigeria*
[4]*Department of Agric Extension, Obafemi Awolowo University, Ile-Ife, Osun State 220282, Nigeria*
[5]*Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife, Osun State 220282, Nigeria*

Abstract The demand for locally process rice grain has led to the development of improved processing conditions for maximum nutritional and quality products. This study, therefore, investigates the effect of parboiling temperature and time on the nutritional, sensory, and drying kinetics of two Nigerian rice cultivars. Agric and Ofada rice cultivars were subjected to three different parboiling temperatures (120, 135, and 150℃) and time (15, 20, and 25 min). The parboiled rice was analyzed for proximate composition, mineral content, sensory properties, and drying kinetics. Parboiling the rice cultivars at the three different temperatures significantly reduces the moisture content, ash, and crude fat of the rice grain. The total carbohydrate of the rice cultivars increased with an increase in parboiling temperature. All the mineral elements analyzed in this study were increased significantly with an increase in the parboiling temperature. Of all the rice samples, only paddy rice parboiled at 150℃ for 25 min was the least accepted by the panelists. The drying kinetics revealed the Page model best predicts the drying of the two Nigerian rice cultivars. This study concluded the parboiling process significantly improved the nutritional, minerals, and sensory properties of the two Nigerian rice cultivars.

Keywords parboiling, rice processing, drying kinetics, sensory evaluation

Citation: Ogunwale EA, Chikieze PM, Taiwo KA, Morakinyo TA, Akanbi CT, Gbadamosi SO, Olawoye B, Awoleye MO, Alabi DL, Alagbo OO, Koya OA. Comparative study on the nutritional and sensory properties, and drying kinetics of two Nigerian rice cultivars. Food Sci. Preserv., 31(5), 745-755 (2024)

Received: August 08, 2024
Revised: August 21, 2024
Accepted: August 22, 2024

***Corresponding author**
Babatunde Olawoye
Tel: +234-7068110907
E-mail: btolawoye@gmail.com

1. Introduction

Rice (*Oryza saliva* L.) is one of the leading food crops of the world and is the staple food of approximately one-half of the world's population (Singh et al., 2003). With improved health services, the world's population has increased greatly. This motivates every nation to search for ways and means to increase the production of food with good quality to support its expanding population. Nigeria is not exceptional in this regard. Rice, the most productive cereal crop, has been thought of as a remedy to supplement wheat, sorghum, and millet as food crops. Rice (*Oryza sativa* L.) is the only cereal crop that is cooked and consumed primarily as whole grain, so grain quality considerations are far more important than for other food crops (Hossain et al., 2009). Locally milled rice in Nigeria is of poor quality; it overcooks, breaks easily, and is sun-dried on the floor with a lot of sand. These attributes resulted in less patronage of locally processed rice as it has been perceived as less inferior than rice imported to the country and hence, the need to improve the quality of locally produced rice.

Parboiling, a three-step hydrothermal processing of rice, improves the quality of rice, and consists of soaking, steaming, or heating and drying of the rice paddy. It is done mainly to harden the rice kernel, which in turn improves milling yield, nutritional properties, and resistance against spoilage microorganisms and insects. Several researchers such as Luh (1991) have reviewed the benefits of parboiling processing in paddy rice. Traditionally, the parboiling of paddy rice is done by first soaking the rice kernel at room temperature in water, followed by boiling or steaming at 100. Finally, the steamed rice kernel is sun-dried in the openings leading to the migration of impurities. The soaking methods used in the traditional method of parboiling had been reported to be slow leading to microbial contamination of the rice kernel. Also, traditional soaking of rice paddy for a long time results in the enzymatic changes in the amino acid and sugar content of the rice which contribute to the onset of a Maillard reaction, hence to the rice quality.

Steaming or boiling during the parboiling process results in the gelatinization of the rice starch. This gelatinization led to changes in the physiochemical properties' characteristics of the paddy rice, which in turn affects other processing operations of milling, storage, eating and cooking properties. According to Islam et al. (2001), the quality properties of parboiled rice, which include hardness of the rice, maximum viscosity volume expansion ratio, adhesion, and hardness of cooked rice, as well as the solid content, were affected. They attributed the change in the quality of parboiled rice to parboiling treatment. For consumer acceptability of parboiled paddy rice, there is a need for the development of processing conditions for better rice quality. One of the processing conditions that has gained wide attention in recent times is the parboiling temperature. Kimura et al. (1983) reported in their research a better rice quality when subjected to parboiling at low temperatures ranging between 80℃ to 100℃. However, a report of broken rice and longer cooking time was reported by the author, which they attributed to the low-temperature processing.

This research, therefore, aimed at parboiling two varieties of Nigerian rice (Agric and Ofada rice grain) at high temperatures (120, 135, and 150℃) and investigating the effects of the hydrothermal processing on the chemical composition, minerals, and sensory properties of the rice grain as well as the drying kinetics of the two Nigerian rice varieties.

2. Materials and methods

2.1. Sample collection and preparation

Freshly harvested local paddy rice (*Oryza sativa),* called Agric rice and Ofada rice, were obtained from a local market in Ile-Ife, Osun State, Nigeria. The varieties of the rice were affirmed at the herbarium of the Department of Botany, Obafemi Awolowo University, Ile-Ife, Nigeria. About 500 g of cleaned paddy rice were soaked separately in distilled water (1:10 w/v) at 70℃ for 6 h to hydrate the kernels (Morakinyo et al., 2014). After this, the water was drained off, and the hydrated kernels were then placed in 1 L of water (room temperature) then parboiled at three different temperatures (120, 135, and 15℃) and time (15, 20, and 25 min) using an electric pressure cooker (MES6817, Bosch, Stuttgart, Germany). Following parboiling, the samples were sun-dried (30±2℃) until a moisture content range of 14% to 15% was obtained. The dried samples were dehulled using a laboratory dehuller (SKU: Seedbro, Illinois, USA).

2.2. Determination of chemical composition of the cultivars

The proximate composition of the Agric and Ofada rice samples which included moisture, crude protein (Kjeldahl method), crude fat (Soxhlet extraction), crude ash, crude fiber, and carbohydrate [= 100 - (moisture% + protein% + fat% + ash%)], was analyzed by the standard procedure of the AOAC (2005).

2.3. Determination of mineral content of rice cultivars

The mineral content of the rice samples was determined using the methods of AOAC (2005). Calcium, Magnesium, Sodium, Zinc, Iron, Copper, Manganese, Chromium, Phosphorus and Potassium were determined by Atomic Absorption Spectrometry.

2.4. Oven drying precedures

Two hundred g (200 g) of the Agric and Ofada rice grain were spread evenly in a thin layer of a convective hot-air oven with an airflow and heating control unit and an electric fan mad dryer chamber. The drying of the parboiled rice grain was done at 60℃ drying temperatures, and a constant air velocity of 1.2 m^2/s was measured using a vane probe

https://doi.org/10.11002/fsp.2024.31.5.745

anemometer (GD155, Rika Tech, Hunan, China). Samples were weighed at 1 h intervals during the oven-drying process. The initial and final moisture content of the rice grain was measured using a gravimetric method (Olawoye et al., 2017).

The moisture ratio (MR) of the rice grain was obtained using the equation below.

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

Where M, M_0, and M_e are moisture content at any drying time (t), initial and equilibrium moisture content, respectively. The value of M_e had been reported to be relatively small compared to M and M_0, hence its negligibility. Equation (1) now becomes:

$$MR = \frac{M}{M_0} \quad (2)$$

2.5. Mathematical modeling of paddy rice grain drying curve

The drying curve obtained for the convective drying of the paddy rice grain was fitted into three known drying kinetics models, and they are Lewis, Page and Henderson, and Pabis model, as shown in equations (3)-(5), respectively

$$MR = \exp(-kt) \quad (3)$$

$$\mathrm{MR} = \exp(-kt^n) \quad (4)$$

$$\mathrm{MR} = a\ \exp(-kt) \quad (5)$$

2.6. Statistical fitting of dry kinetics models

The goodness of fit of the drying kinetics models was evaluated using the coefficient of determinant and root mean square of errors as shown in equations (6)-(7) below:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_{a,i} - y_{p,i})^2}{\sum_{i=1}^{n}(y_{p,i} - y_{a,ave})^2} \quad (6)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_{p,i} - y_{a,i})^2} \quad (7)$$

2.7. Sensory evaluation

Prior to the conduct of the sensory evaluation, ethical approval by IRB was obtained from Research Ethics Board of Obafemi Awolowo University, Ile-Ife, Nigeria (approval no. EIC 9021-20231012). The 9-point hedonic scale assessment, as described by Devraj et al. (2020), was used. Panelists from the Department of Food Science and Technology were selected based on their proper knowledge and familiarity with polished rice. Following the processing treatment and levels, 10 samples of the two milled, polished rice species were cooked differently without any additives for 20 min using the same volume of water and allowed to cool before serving to the panelists for proper evaluation. Water was given to each panelist for oral rinsing in between tasting of the samples. All the samples were evaluated organoleptically using the 9-point hedonic scale from 1 to 9, representing “dislike very much” to “like very much”, respectively. The panelists scored the coded samples in terms of the degree of liking to texture, flavor, color, appearance, taste, and overall acceptability. The sensory scores obtained for all samples were analyzed using statistical methods of analysis.

2.8. Data analysis

All tests were replicated as necessary for each variable, and the data were expressed as mean±standard deviation (SD). All statistical analyses were performed using SPSS software (version 20.0) for the analysis of variance (ANOVA). Multiple comparisons by Duncan’s multiple range test (DMRT) were used for varietal difference at $p<0.05$ level.

3. Results and discussion

3.1. Effect of processing on proximate composition of two Nigerian rice cultivars

The result of the proximate composition observed among the rice samples was shown in Table 1. The carbohydrate content in the samples ranged between 79.80-89.19% and a mean value of ±1.64%. Aside from the raw Agric and Ofada samples which had the lowest carbohydrate percentage (79.80% and 79.66%, respectively), virtually all the rice samples have appreciably high carbohydrate content (Table 1). In these results it is not surprising that the carbohydrate content among the samples was high. This is because rice is a representative food source of carbohydrates. Although these values are higher

Table 1. Proximate composition of two Nigerian rice cultivars

Samples[1)]	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Carbohydrate (%)
O_{Raw}	11.00±0.85[b2)]	7.75±0.02[a]	0.37±0.01[abc]	0.41±0.07[ab]	0.83±0.01[c]	79.66±0.86[a]
$O_{120/15}$	9.80±0.85[ab]	7.67±0.02[a]	0.40±0.02[bc]	0.21±0.06[a]	0.85±0.02[c]	81.10±0.87[ab]
$O_{120/20}$	8.40±0.57[ab]	7.70±0.02[a]	0.41±0.03[c]	0.21±0.06[a]	0.86±0.01[c]	82.44±0.62[ab]
$O_{120/25}$	9.00±0.85[ab]	7.70±0.01[a]	0.40±0.02[bc]	0.41±0.06[ab]	0.85±0.02[c]	81.66±0.88[ab]
$O_{135/15}$	7.90±0.10[a]	7.59±0.04[a]	0.39±0.01[abc]	0.41±0.06[ab]	0.87±0.01[c]	82.86±0.95[ab]
$O_{135/20}$	7.40±0.57[a]	7.48±0.05[a]	0.36±0.02[abc]	0.21±0.06[a]	0.83±0.02[c]	83.73±0.50[b]
$O_{135/25}$	9.10±0.42[ab]	7.43±0.03[a]	0.34±0.01[abc]	0.21±0.06[a]	0.63±0.02[b]	82.31±0.42[ab]
$O_{150/15}$	8.20±0.28[ab]	7.54±0.04[a]	0.35±0.01[abc]	0.21±0.06[a]	0.52±0.01[a]	83.20±0.25[b]
$O_{150/20}$	8.40±1.41[ab]	7.53±0.02[a]	0.33±0.01[ab]	0.61±0.22[b]	0.50±0.03[a]	82.65±1.73[ab]
$O_{150/25}$	8.50±0.14[ab]	7.50±0.01[a]	0.32±0.01[a]	1.01±0.06[c]	0.50±0.02[a]	89.19±0.12[c]
A_{Raw}	12.20±0.28[a2)]	7.13±0.02[a]	0.33±0.02[a]	0.10±0.00[d]	0.56±0.04[bc]	79.80±0.36[b]
$A_{120/15}$	8.70±0.14[ab]	7.34±0.01[a]	0.30±0.02[ab]	1.20±0.00[a]	0.66±0.03[a]	81.81±0.09[ab]
$A_{120/20}$	7.80±0.00[b]	7.24±0.02[a]	0.24±0.01[bcd]	0.80±0.00[bc]	0.64±0.02[ab]	83.30±0.05[ab]
$A_{120/25}$	6.80±0.28[b]	7.20±0.03[a]	0.23±0.02[cd]	0.80±0.00[bc]	0.60±0.02[abc]	84.38±0.31[a]
$A_{135/15}$	8.40±1.70[ab]	7.59±0.04[a]	0.29±0.01[abc]	0.60±0.00[c]	0.52±0.01[c]	82.61±1.64[ab]
$A_{135/20}$	7.50±0.71[b]	7.23±0.02[a]	0.25±0.01[bcd]	1.20±0.00[a]	0.61±0.01[abc]	83.22±0.71[ab]
$A_{135/25}$	7.90±0.99[b]	7.23±0.02[a]	0.23±0.02[cd]	0.80±0.00[bc]	0.57±0.02[bc]	83.29±0.97[ab]
$A_{150/15}$	8.70±1.27[ab]	7.26±0.01[a]	0.24±0.01[bcd]	0.90±0.14[b]	0.56±0.02[bc]	82.35±1.44[ab]
$A_{150/20}$	8.90±0.99[ab]	7.23±0.01[a]	0.25±0.01[bcd]	0.90±0.14[b]	0.57±0.01[abc]	82.15±1.09[ab]
$A_{150/25}$	6.50±1.84[b]	7.22±0.01[a]	0.33±0.02[d]	1.00±0.00[ab]	0.56±0.04[bc]	84.51±1.90[a]

[1)]Parboiled conditions (℃/min) of the two rice cultivars.
[2)]All values are mean±SD (n=3) and different superscripts ([a-d]) within the same column indicate significant differences ($p<0.05$).

than the values obtained by Eggum et al. (1982), they are in line with the values reported by Edeogu et al. (2007), those who analyzed the proximate composition of staple foods crops in Ebonyi state. Among the rice samples, it was observed that the Agric rice sample had a lower carbohydrate content when compared to the Ofada rice samples. On the effect of temperature and time on the carbohydrate content of the rice samples, the temperature of processing had no significant difference in the carbohydrate content of the rice samples, however, increasing the processing temperature and time of 150 and 25 mins, respectively, there was a profound increase in the carbohydrate content of the rice samples. The raw rice samples had the lowest carbohydrate content. This low carbohydrate content may be attributed to its high moisture content which also affects the milling quality and other environmental factors. The high percentage of carbohydrates in the rice samples shows that rice is a good source of energy.

Raw Agric and Ofada rice samples had the highest percentage of moisture content (control samples) when compared to other processed rice samples. The high percentage of moisture content may be attributed to low drying temperature (Zheng and Lan, 2007) and prolonged parboiling. Such a high percentage of moisture content affects the milling characteristics and the taste or palatability of cooked rice as well (Zheng and Lan, 2007). Ebuehi and Oyewole (2007) reported that the moisture content of rice also affects storage. This may be as a result of hydrological status or agronomic potential. It follows that the $A_{150/25}$ sample may have a longer shelf life compared to the other rice samples due to its lower moisture content. From the result, it could be seen that the processing had a profound effect on the moisture content of the rice samples. Increasing the processing time from 15 to

https://doi.org/10.11002/fsp.2024.31.5.745

25 min led to an approximately 20% reduction in the moisture content of the rice samples.

The Ofada rice samples were observed to contain a higher concentration of crude fibre when compared with the Agric rice samples. These results were in agreement with the findings of Sitorus et al. (2021), those who analyzed the chemical compositions of different fractions of rice varieties obtained during milling. He observed that milling of the rice generally decreases the fibre contents of rice. A sample with a high crude fiber resulted in high textural properties of the rice samples. It helps the rice grains retain their shape and prevent them from becoming overly soft or mushy during cooking. Additionally, fiber contributes to a more balanced and satisfying mouthfeel when consumed. From the result, the crude fiber content of the rice samples is affected by the processing time, as the increase in the processing time led to a significant decrease in the crude fiber content of the rice samples.

The value for percentage fat content obtained in this study ranged between 0.23-0.33% for Agric rice samples and 0.32-0.41% for Ofada rice samples. Generally, it was observed that an increase in parboiling temperature and time significantly reduced the crude fat content of the rice samples. This could be due to the liberation of the fat content during the use of steam to parboil the rice samples. Among the two Nigerian rice cultivars, the crude fat content of the Ofada rice sample was a little higher than that of the Agric rice samples. The range of values obtained for the percentage of fats signifies that the percentage of fat is considerably low among each sample as they are in line with the values obtained by Ibukun (2008). The effect of excess intake of dietary fat has some well-established health implications, especially for the overweight. The consumption of excess amounts of saturated fats has been recognized as the most important dietary factor aiding increased levels of cholesterol. Besides the cholesterol implications due to high fat intake, obesity is a factor in the causation of disease (Byrd-Bredbenner et al., 2019). In this regard, all samples could be said to be preferred. The results of this study are in agreement with the results reported by Willis et al. (1982) and Eggum et al. (1982), who gave a fat range of 0.2 to 1.95% in different milling fractions. The low-fat content may be attributed to the degree of milling. Milling of rice removes the outer layer of the grains where most of the fats are concentrated (Frei et al., 2003).

The protein content of the rice samples ranged between 7.43-7.75% for Ofada rice and 7.13-7.59% with no significant difference ($p>0.05$) among the rice samples. The parboiling process slightly decreased the protein content in the Ofada rice samples compared to the Agric rice sample, where a slight increase in the protein content was observed. All the samples should be highly prized because of their relatively high percentage of crude protein when compared to the reported values of Eggum et al. (1982). This might be as a result of genotype and environmental factors. It is worth noting that the amino acid balance of rice protein is exceptionally good. This is in agreement with the findings of Ebuehi and Oyewole (2007) those who analyzed the effect of soaking and parboiling on the physical characteristics, nutrient composition, and sensory evaluation of the rice varieties. For each sample, the parboiling temperature and time range had little or no effect on their protein contents, according to the result in Table 1.

The ash content of a food sample gives an idea of the mineral elements present in the food sample. Among the rice samples, samples $A_{120/15}$ and $A_{135/20}$ had the highest ash content (1.20±0.00) each, while samples A_{Raw} and $A_{135/15}$ had the least ash content (0.10±0.00 and 0.60±0.00), respectively for the Agric rice samples. $O_{150/25}$ recorded the highest ash content (1.01%), while Ofada rice samples parboiled at 135℃ had the least ash content (0.21%). The percentage ash content obtained is slightly lower than the values obtained by Ibukun (2008). The values of each sample with respect to the raw sample vary as well. This slight difference might be a result of the parboiling temperature, which affects the ash content of the samples.

3.2. Effects of processing on mineral content of two Nigerian rice cultivars

Trace amounts of mineral elements were found; these minerals are potassium, manganese, zinc, and magnesium. A significant difference in mineral content was observed between all samples prepared from the control (Table 2). In potassium, sample $A_{135/25}$ had the highest value, while sample $A_{120/20}$ had the lowest value. For the Ofada rice samples, $O_{150/25}$ had the highest (119 mg/kg) potassium compared to other Ofada rice samples. From the result, it could be seen that an increase in the parboiling temperature and time significantly increased the potassium concentration in the rice

Table 2. Mineral composition of the two Nigerian rice cultivars (mg/kg)

Samples[1)]	Potassium	Magnesium	Zinc	Manganess
O_{Raw}	81.0±0.06[a2)]	31.0±0.06[a]	49.0±0.06[a]	26.0±0.06[a]
$O_{120/15}$	79.0±0.06[a]	61.0±0.06[b]	51.0±0.06[a]	29.0±0.06[ab]
$O_{120/20}$	80.0±0.06[a]	63.0±0.06[b]	53.0±0.06[a]	29.0±0.06[ab]
$O_{120/25}$	89.0±0.06[ab]	72.0±0.06[b]	62.0±0.06[a]	34.0±0.06[ab]
$O_{135/15}$	95.0±0.06[abc]	48.0±0.06[ab]	47.0±0.06[a]	31.0±0.06[ab]
$O_{135/20}$	97.0±0.06[abc]	52.0±0.06[ab]	52.0±0.06[a]	37.0±0.06[ab]
$O_{135/25}$	107.0±0.06[bc]	60.0±0.06[b]	54.0±0.06[a]	45.0±0.06[ab]
$O_{150/15}$	101.0±0.06[abc]	66.0±0.06[b]	55.0±0.06[a]	35.0±0.06[ab]
$O_{150/20}$	103.0±0.06[abc]	64.0±0.06[b]	58.0±0.06[a]	39.0±0.06[ab]
$O_{150/25}$	119.0±0.06[c]	71.0±0.06[b]	70.0±0.06[a]	52.0±0.06[b]
A_{Raw}	64±0.01[a2)]	31±0.00[a]	40±0.01[a]	21±0.00[a]
$A_{120/15}$	62±0.01[a]	42±0.01[a]	38±0.00[a]	20±0.00[a]
$A_{120/20}$	61±0.01[a]	50±0.01[a]	39±0.01[a]	22±0.00[a]
$A_{120/25}$	70±0.01[a]	51±0.01[a]	47±0.01[a]	26±0.00[a]
$A_{135/15}$	71±0.01[a]	40±0.01[a]	45±0.01[a]	30±0.00[a]
$A_{135/20}$	82±0.01[a]	40±0.01[a]	50±0.01[a]	31±0.00[a]
$A_{135/25}$	87±0.01[a]	47±0.01[a]	60±0.01[a]	39±0.01[a]
$A_{150/15}$	80±0.01[a]	50±0.01[a]	62±0.01[a]	37±0.00[a]
$A_{150/20}$	85±0.01[a]	47±0.01[a]	66±0.01[a]	44±0.00[a]
$A_{150/25}$	85±0.01[a]	53±0.01[a]	78±0.02[a]	45±0.00[a]

1)Parboiled conditions (℃/min) of the two rice cultivars.
2)All values are mean±SD (n=3) and different superscripts (a-c) within the same column indicate significant differences ($p<0.05$).

samples. For the manganese concentration in the rice samples. There was a significant increase in the manganese concentration of the rice sample, with the highest manganese concentration being recorded for rice samples parboiled at 150℃ for 25 min. Among the rice varieties, the Ofada rice sample had a higher manganese concentration compared to the Agric rice samples. The zinc concentration recorded for the rice samples ranged between 47-70 mg/kg for the Ofada rice sample and 38-78 mg/kg for Agric rice samples. The rice sample parboiled at 150℃ for 25 min had the highest zinc concentration of the two rice cultivars. Finally, in magnesium, sample $A_{150/25}$ had the highest concentration of magnesium for the Agric rice samples, while $A_{135/15}$ and $A_{135/20}$ had the lowest magnesium concentration. Also, $O_{150/25}$ had the highest magnesium concentration (71 mg/kg) compared to other Ofada rice samples. This result is expected since the mineral content is from the percentage ash content of the rice. Edeogu et al. (2007) reported that the ash content of a food sample gives an idea of the mineral elements present in the food sample. More so, since greater amounts of rice bran are removed from the grains during milling and polishing, more minerals are lost.

In general, the levels of minerals in rice samples parboiled at 150℃ exceeded the levels observed in the remaining samples; this disparity may stem from the utilization of higher parboiling temperatures during the paddy processing. This elevated temperature likely served to prevent substantial mineral loss during the subsequent milling phase. Nonetheless, comparing the mineral content percentages of the remaining samples reveals a marginal reduction, in contrast to the findings reported by Ibukun (2008).

It is noteworthy that the mineral element levels of rice can

https://doi.org/10.11002/fsp.2024.31.5.745

be influenced by the fertility of the paddy field, as demonstrated by Balasubramanian et al. (2007). Thus, the reduction in mineral element values may be attributed to the parboiling temperature's impact on milling efficiency or the paddy field's fertility. Importantly, even in light of these fluctuations, the mineral content values for the three samples subjected to a parboiling temperature of 150℃ remained marginally within the acceptable standards for rice mineral contents.

3.3. Sensory evaluation of two Nigerian rice cultivars

The two Nigerian rice varieties were differently subjected to sensory evaluation with respect to appearance, aroma, color, texture, taste, and overall acceptability by a semi-trained taste panel comprising 20 judges using the 9-point hedonic rating scale.

The data in Table 3 represents the result of the sensory evaluation of the two Nigerian rice varieties. In terms of appearance, there was a significant difference only in $O_{120/15}$, $O_{135/15}$, and $O_{150/25}$ for the Ofada rice grains. For Agric rice grains, parboiling at 150℃ had a significant effect on the appearance of the cooked rice grain and hence lowered the panelist's preference for the samples. This could be due to the coloration of the cooked rice grain as a result of the higher thermal parboiling processing leading to the brown coloration (Millard reaction) of the cooked Agric rice grains. From the result, it could be noted that the two Nigerian rice cultivars parboiled at 135℃ had a wider consumer acceptance in terms of the appearance of the rice grain.

In terms of aroma, there was no significant difference in all Ofada rice samples except for Ofada rice parboiled at 120℃ for 15 min. This sample ($O_{120/15}$) was rated low when compared to other Ofada rice samples. Parboiling of Agric rice grain at 150℃ significantly affects the consumer perception of the samples with respect to the aroma of the Agric rice samples. This could be a result of the aroma stimulated by the intermediate product of the Maillard reaction.

Table 3. Sensory scores of the two Nigerian rice cultivars

Samples[1)]	Appearance	Aroma	Colour	Texture	Taste	Overall acceptability
$O_{120/15}$	5.10±1.52[c2)]	5.90±1.11[b]	5.20±1.31[c]	5.10±1.97[c]	5.20±1.32[c]	5.30±1.25[c]
$O_{120/20}$	7.10±1.45[ab]	6.80±1.40[a]	6.70±1.49[a]	6.70±1.77[b]	6.90±1.10[a]	7.30 0.95[a]
$O_{120/25}$	6.90±0.74[b]	6.60±1.08[a]	6.10±0.89[b]	6.70±1.59[b]	6.60±1.26[a]	7.00±0.67[a]
$O_{135/15}$	6.30±1.64[b]	6.30±1.49[a]	6.80±1.69[a]	6.70±2.06[b]	6.30±1.64[b]	6.40±1.43[b]
$O_{135/20}$	7.50±1.43[a]	6.60±0.97[a]	7.00±1.05[a]	6.20±1.40[c]	6.00±1.05[b]	7.30±1.25[a]
$O_{135/25}$	7.10±1.29[ab]	6.10±0.99[a]	6.30±0.82[ab]	6.90±1.45[b]	6.20±1.23[b]	7.00±0.47[a]
$O_{150/15}$	7.40±1.58[ab]	6.50±1.18[a]	7.00±1.76[a]	8.00±1.05[a]	6.70±0.95[a]	7.40±1.07[a]
$O_{150/20}$	8.00±1.25[a]	6.40±1.58[a]	7.40±1.71[a]	7.20±1.75[ab]	7.10±1.27[a]	7.30±1.34[a]
$O_{150/25}$	5.80±1.81[c]	6.20±0.79[a]	5.30±1.49[c]	5.60±1.90[c]	6.00±1.56[b]	5.90±1.97[bc]
$A_{120/15}$	7.90±0.88[a2)]	7.80±0.79[a]	8.10±0.88[a]	7.40±1.17[a]	7.50±0.71[a]	7.80±0.63[a]
$A_{120/20}$	7.30±1.25[a]	7.40±1.08[a]	7.70±1.06[a]	7.50±1.35[a]	7.30±1.34[a]	7.40±1.07[a]
$A_{120/25}$	7.90±0.88[a]	7.70±0.82[a]	8.00±0.67[a]	7.70±0.68[a]	8.20±0.79[a]	8.10±0.88[a]
$A_{135/15}$	7.60±0.97[a]	7.80±1.14[a]	7.50±0.85[a]	7.20±1.32[a]	7.70±0.82[a]	7.60±1.08[a]
$A_{135/20}$	8.10±0.88[a]	7.70±0.82[a]	7.90±1.10[a]	7.40±1.35[a]	7.80±0.92[a]	7.50±1.18
$A_{135/25}$	7.50±1.35[a]	8.00±0.94[a]	7.70±0.68[a]	7.10±0.74[a]	7.80±0.92[a]	7.80±0.79[a]
$A_{150/15}$	6.40±1.17[b]	6.90±1.29[b]	6.20±1.32[b]	6.50±1.27[b]	6.50±1.20[b]	6.60±0.94[b]
$A_{150/20}$	6.50±1.58[c]	6.60±1.58[b]	6.00±1.41[b]	6.20±1.40[b]	7.10±0.99[a]	6.20±1.87[b]
$A_{150/25}$	4.20±1.81[d]	6.10±1.52[b]	3.70±1.70[c]	4.00±1.83[c]	4.50±1.78[c]	3.80±1.75[c]

1)Parboiled conditions (℃/min) of the two rice cultivars.
2)All values are mean±SD (n=3) and different superscripts (a-c) within the same column indicate significant differences ($p<0.05$).

The effect of the rice cultivar and parboiling temperature on the color attribute of the cooked rice grain revealed that significant differences only occurred in Ofada rice parboiled at 120℃ for 15 min and 150℃ for 25 min. Ofada rice parboiled at 150℃ for 20 min was the most preferred Ofada rice sample when compared to other Ofada rice grains. For the Agric-cooked rice samples, parboiling the rice at 150℃ for 25 min significantly affected the color as it was the least preferred Agric-cooked rice sample. Parboiling of the Agric rice sample at 120℃ significantly improved the color of the Agric rice grain, as could be seen from the consumer preference for the Agric rice parboiled at that temperature. For Ofada cooked rice samples, rice grain parboiled at 120℃ for 15 min was the least preferred (5.10) Ofada cooked rice samples, while Ofada rice parboiled at 150℃ for 15 mins was the most preferred (8.00) cooked Ofada rice. For Agric rice samples, parboiling at 150℃ significantly affects the textural attributes of the rice. This could be because the higher parboiling temperature had caused great damage to the starch granule.

Parboiling at 120℃ significantly affects the taste of the Ofada rice sample. However, Ofada rice parboiled at 135℃ is not significantly ($p<0.05$) different from each other. Ofada rice sample parboiled at 150℃ for 20 mins was the most preferred Ofada rice in terms of taste. For the Agric sample, parboiling at 150℃ for 25 min significantly or negatively affects the taste of the rice sample. Aric rice samples parboiled at 120℃ for 25 mins were the most preferred rice samples. Finally, the result showing the overall acceptability of the cooked rice samples by the panellist is presented in Table 3. From the result, it could be seen that all the Ofada rice samples fell within the "like" threshold of the Hedonic scale. However, Ofada rice parboiled at 150℃ for 15 min was the most accepted Ofada rice grain. Parboiling of the Agric rice sample at 150℃ for 25 min negatively affected the overall acceptability of the rice sample as it fell within the "dislike" threshold of the Hedonic scale. Agric rice samples parboiled at 120℃ were highly rated by the panelist in terms of the overall acceptability of the rice grain.

3.4. Drying kinetics of paddy rice

The curves depicting the changes in the moisture ratio of the Ofada and Agric paddy rice with drying time using a hot air oven are shown in Fig. 1. From the curves, it could be seen that there was an exponential decrease in the moisture ratio of the paddy rice as the drying time increased. This could be a result of even exposure of the surface of the rice grains to hot air. To properly understand the drying behavior of the rice grain, three (3) drying models were used to mathematically predict the decrease in the moisture content of the rice grains. The result of the mathematical modeling of the drying characteristics of the rice grain is presented in Table 4. In the study, the statistics parameters used for the selection of best-drying kinetics models were the coefficient of determinant and root mean square of error (R^2 and RMSE). The drying kinetics result of the rice grain revealed that the mean coefficient of the determinant of greater than

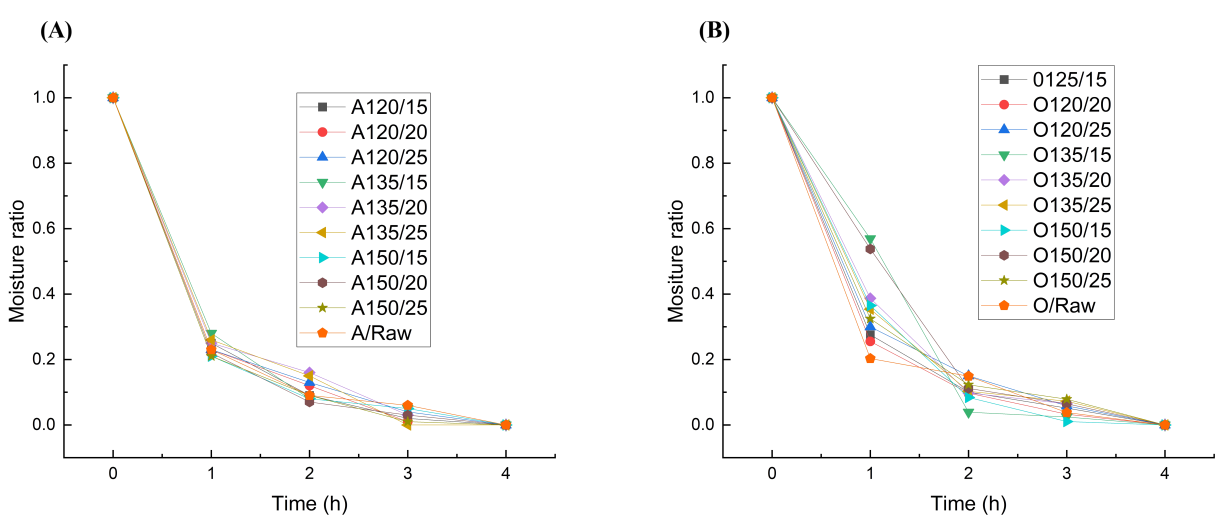

Fig. 1. Moisture ratios of two rice samples, Agric (A) and Ofada (B). Rice samples were parboiled at different conditions (℃/min).

https://doi.org/10.11002/fsp.2024.31.5.745

Table 4. Constants, coefficients and statistical evaluation for the drying models of two Nigerian rice cultivars

Sample[1)]	Lewis			Page				Henderson and Pabis			
	k	R^2	RMSE	k	n	R^2	RMSE	k	c	R^2	RMSE
$A_{120/15}$	0.0832	0.9143	0.0639	0.0235	1.1370	0.9750	0.0674	0.0541	1.0643	0.9391	0.0418
$A_{120/20}$	0.1483	0.9228	0.0580	0.0731	1.1650	0.9811	0.0182	0.2231	0.9837	0.9928	0.0362
$A_{120/25}$	0.1235	0.9717	0.0233	0.1375	1.0030	0.9923	0.0731	0.1172	1.0084	0.9725	0.0513
$A_{135/15}$	0.0998	0.9920	0.0435	0.3582	0.9978	0.9870	0.0213	0.0108	1.0395	0.9413	0.0017
$A_{135/20}$	0.2647	0.9650	0.0663	0.3455	0.9348	0.9838	0.0091	0.1486	1.1007	0.9879	0.0715
$A_{135/25}$	0.0438	0.9780	0.0421	0.0944	1.0130	0.9742	0.0107	0.2006	1.0313	0.9621	0.0042
$A_{150/15}$	0.1905	0.9304	0.0238	0.3521	1.0941	0.9799	0.0128	0.2194	0.8992	0.9107	0.0109
$A_{150/20}$	0.3217	0.9199	0.0477	0.0547	1.1032	0.9885	0.0982	0.2218	1.0847	0.9448	0.0948
$A_{150/25}$	0.2995	0.9732	0.0616	0.0459	1.3500	0.9747	0.0554	0.0725	0.9926	0.9887	0.0364
A_{Raw}	0.0646	0.9876	0.0498	0.2355	1.2910	0.9772	0.0320	0.6665	1.0631	0.9686	0.0218
Ave	0.1640	0.9555	0.0480	0.1720	1.1089	0.9814	0.0308	0.1935	1.0268	0.9609	0.0371
$O_{120/15}$	0.0734	0.9437	0.0741	0.0551	0.9705	0.9728	0.0328	0.0531	1.0107	0.9438	0.0683
$O_{120/20}$	0.1805	0.9084	0.0138	0.0748	1.0185	0.9895	0.0297	0.3713	1.2019	0.9641	0.0490
$O_{120/25}$	0.2037	0.9715	0.1089	0.1033	1.1873	0.9672	0.0401	0.1311	1.0233	0.9107	0.0133
$O_{135/15}$	0.0987	0.9892	0.0937	0.0103	1.0772	0.9896	0.0237	0.0113	1.0178	0.9532	0.0096
$O_{135/20}$	0.0661	0.9907	0.7810	0.1553	0.9207	0.9798	0.0392	0.1418	0.9855	0.9098	0.0581
$O_{135/25}$	0.3592	0.9348	0.1782	0.2246	0.9312	0.9822	0.0184	0.1765	1.1126	0.9342	0.0609
$O_{150/15}$	0.3137	0.9626	0.0129	0.4270	1.5114	0.9914	0.0253	0.0118	1.0084	0.9607	0.0027
$O_{150/20}$	0.2840	0.9783	0.0483	0.3702	0.7018	0.9807	0.0303	0.0734	0.8919	0.9196	0.0105
$O_{150/25}$	0.0558	0.9520	0.0331	0.0487	0.5737	0.9763	0.0438	0.0964	0.8375	0.9055	0.0727
O_{Raw}	0.1907	0.9930	0.5790	0.2457	0.3648	0.9830	0.0192	1.0873	0.7661	0.9138	0.0091
Ave	0.1826	0.9624	0.1923	0.1715	0.9257	0.9813	0.0303	0.2154	0.9856	0.9315	0.0354

[1)]Parboiled conditions (℃/min) of the two rice cultivars.

0.90 was obtained for the three models used in this study (Lewis, Page Henderson, and Pabis), This result obtained in this study is commensurate with the report of Sitorus et al. (2021) who report a higher coefficient of determinant when modeling the drying characteristics of paddy rice using the Page, Midilli and linear-plus-exponential drying kinetics model. Among the drying kinetics models used in this study, the Page model drying model had the highest coefficient of determinant (R^2) of 0.9818 and 0.9813 for Agric and Ofada paddy rice, respectively. The root means square error (RMSE) obtained for the Agric and Ofada paddy rice (0.0308 and 0.0303, respectively) using the Page drying model had the lowest RMSE value among all the models used in this study. Owing to this, the study proposed a Page drying kinetics model as the best model for the prediction of the moisture content of Agric and Ofada paddy rice grain using a hot air oven. The result obtained in this study is in line with the result of several researchers such as Sripinyowanich and Noomhorm (2011) for dry cooked rice.

4. Conclusions

The study evaluated the effect of parboiling temperature and time on the nutritional composition, mineral content, sensory properties, and drying kinetics of two Nigerian rice cultivars. The parboiling temperature significantly reduced the moisture content, ash, and crude fat of the rice grain, while the total carbohydrate and protein content of the rice grain increased with increasing parboiling temperature and time. Agric rice sample parboiled at 150℃ for 25 min was least preferred in terms of appearance, color, aroma, taste, texture, and overall acceptability. The mathematical modeling of the drying kinetics of the two Nigerian rice cultivars (Agric and Ofada) revealed that the Page model best predicts the drying curves owing to its highest coefficient of determinant and lower root mean of errors.

Funding

This research was supported by Tertiary Education Fund (National Research Fund), 2022.

Acknowledgements

The authors acknowledge TETFund sponsorship of the National Research Fund (NRF) project titled “Development of a Synchronised Rice Processing Mill for Industrial Use in Nigeria”.

Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

Conceptualization: Taiwo KA, Morakinyo TA, Akanbi CT. Methodology: Ogunwale EA, Chikieze PM, Awoyele MO. Formal analysis: Gbadamosi SO, Olawoye B. Validation: Alabi DL, Alagbo OO, Koya OA. Writing - original draft: Ogunwale EA, Chikieze PM, Olawoye B. Writing - review & editing: Taiwo KA, Gbadamosi SO, Olawoye B.

Ethics approval

This research was approved by IRB from Obafemi Awolowo University Ile-Ife (approval no. EIC 9021-20231012).

ORCID

Esther Ayomide Ogunwale (First author)
https://orcid.org/0000-0001-7881-7043
Peter Madabuchi Chikieze
https://orcid.org/0009-0007-6279-1505
Kehinde Adekunbi Taiwo
https://orcid.org/0000-0003-4353-8591
Tunde Afolabi Morakinyo
https://orcid.org/0000-0003-2536-7952
Charles Taiwo Akanbi
https://orcid.org/0000-0002-5841-8691
Saka Olasunkanmi Gbadamosi
https://orcid.org/0000-0002-9458-7556
Babatunde Olawoye (Corresponding author)
https://orcid.org/0000-0002-3089-1196
Micheal Olusegun Awoleye
https://orcid.org/0000-0002-8223-1368
Dorcas Lola Alabi
https://orcid.org/0000-0002-9758-1475
Oyebanji Olubunmi Alagbo
https://orcid.org/0000-0002-6232-7282
Olufemi Adebola Koya
https://orcid.org/0000-0002-7712-3880

References

AOAC. Official Methods of Analysis. Association of Analytical Chemists International, Washington DC (2005)

Balasubramanian V, Sie M, Hijmans RJ, Otsuka K. Increasing rice production in sub-saharan africa: Challenges and opportunities. Adv Agron, 94, 55-133 (2007)

Byrd-Bredbenner C, Berning JR, Kelley DS, Abbot J, Moe G, Beshgetoor D. Wardlaw’s perspectives in nutrition. McGraw-Hill Education, New York, USA (2019)

Devraj L, Panoth A, Kashampur K, Kumar A, Natarajan V. Study on physicochemical, phytochemical, and antioxidant properties of selected traditional and white rice varieties. J Food Process Eng, 43, e13330 (2020)

Ebuehi OAT, Oyewole AC. Effect of cooking and soaking on physical characteristics, nutrient composition and sensory evaluation of indigenous and foreign rice varieties in nigeria. African J Biotechnol, 6, 1016-1020 (2007)

Edeogu CO, Ezeonu FC, Okaka ANC, Ekuma CE, Eisom SO. Proximate compositions of staple food crops in ebonyi state, South Eastern Nigeria. Int J Biotechnol Biochem, 3, 57-68 (2007)

Eggum BO, Juliano BO, Maningat CC. Protein and energy utilization of rice milling fractions by rats. Plant Foods Human Nutr, 31, 371-374 (1982)

Frei M, Siddhuraju P, Becker K. Studies on the *in vitro* starch digestibility and the glycemic index of six different indigenous rice cultivars from the philippines. Food Chem, 83, 395-402 (2003)

Hossain MS, Singh AK, Fasih-Uz-Zaman. Cooking and eating characteristics of some newly identified inter sub-specific (indica/japonica) rice hybrids. ScienceAsia, 35, 320-325 (2009)

https://doi.org/10.11002/fsp.2024.31.5.745

Ibukun EO. Effect of prolonged parboiling duration on proximate composition of rice. Sci Res Essay, 3, 323-325 (2008)

Islam MR, Shimizu N, Kimura T. Quality evaluation of parboiled rice with physical properties. Food Sci Technol Res, 7, 57-63 (2001)

Kimura T, Hasegawa K, Imamura H, Yoshida A. Mechanisms of adverse effect of amaranth feeding in the rat. J Nutr Sci Vitaminol, 29, 153-159 (1983)

Luh BS. Rice, Volume 2: Utilization. Springer Science & Business Media, Berlin, Germany (1991)

Morakinyo TA, Ogunsina BS, Adebayo AA. Adaptation of impact hammer mill for crushing cocoa pods husk as a livestock feed constituent. J Agric Engin Technol, 22, 1-11 (2014)

Olawoye BT, Kadiri O, Babalola TR. Modelling of thin-layer drying characteristic of unripe cardaba banana (musa abb) slices. Cogent Food Agric, 3, 1290013 (2017)

Singh N, Sodhi NS, Kaur M, Saxena SK. Physico-chemical, morphological, thermal, cooking and textural properties of chalky and translucent rice kernels. Food Chemi, 82, 433-439 (2003)

Sitorus A, Novrinaldi, Putra SA, Cebro IS, Bulan R. Modelling drying kinetics of paddy in swirling fluidized bed dryer. Case Stud Thermal Engin, 28, 101572 (2021)

Sripinyowanich J, Noomhorm A. A new model and quality of unfrozen and frozen cooked rice dried in a microwave vibro-fluidized bed dryer. Drying Technol, 29, 735-748 (2011)

Willis R, Palipane L, Greenfield H. Composition of australian foods. Rice Food Technol Aust, 34, 66-68 (1982)

Zheng X, Lan Y. Effects of drying temperature and moisture content on rice taste quality. Proceedings of the 5th Asia-Pacific Drying Conf, 2, 1112-1117 (2007)