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Effect of Storage Duration and Processing Parameters on Some Cooking Properties of *Ofada* Rice

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A B S T R A C T

Effects of storage duration, soaking time and parboiling temperature on cooking properties (cooking time, water uptake ratio, solid loss, cooked kernel length, and amylose) of *Ofada* rice was determined and optimised using response surface methodology. Storage duration, soaking time and parboiling temperature were 1, 5, and 9 months; 1, 3, and 5 days; and 80, 100, and 120°C. Data were analysed by ANOVA and regression analysis. The cooking time ranged between 14-38 min, water uptake ratio (WUR) 2.51-4.61, solid loss 1.47-4.78%, cooked kernel length 6.32-11.90 and amylose 17.34-26.28%. There exist significant differences in the cooking properties. The coefficient R^2 ranged between 0.97-0.75 which is a positive indicator of the model fitness. Storage duration and parboiling temperature influenced cooking except in solid loss and cooked kernel length respectively. Effect of soaking time was found prominent in WUR and solid loss. Optimum treatment for quality cooking properties are storage of paddy for 5 months, soaking for 18h and parboiling at 80°C to yield 20 min cooking time, 4.22 water uptake ratio, 4.11% solid loss, 10.58 mm cooked kernel length and 25.08% amylose. The validated experiment yielded 21.41 min, 3.99, 2.73%, 8.20 mm and 26.39% for cooking time, water uptake ratio, solid loss, cooked kernel length and amylose respectively.

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Introduction

One of the popular indigenous rice varieties in Nigeria is *Ofada* rice. It is a generic name used to describe some rice varieties cultivated and processed in a group of communities of Ogun State and some rice producing clusters of South-West, Nigeria (Adekoyeni et al., 2018; NCRI and ARC, 2007). The market demand and values of rice depend on its physical qualities, eating and cooking characteristics which are subject to processing conditions of paddy (Ghadge and Prasad, 2012; Ashish et al., 2012).

Storage is an integral part of the post-harvest handling of rice and rice may be stored in the paddy forms for lengthy periods of time before processing (Jirasak, 2008). Traditional processing of *Ofada* rice involves three stages of treatment (soaking, parboiling and drying). These post harvest handling operations affect the qualities of milled rice (Adekoyeni et al., 2012). It is recorded that amylose contents of rice also vary with storage and processing parameters and a major determinant of cooking value of rice. Rice starches with high amylose:amylopectin ratio take up more water during boiling and are acknowledged extra pleasant for eating and cooking purpose (Singh et al., 2006). Amylose content is significantly affected by the various storage intervals and treatments. Rice varieties with amylose content of more than 25% absorb more water and have a fluffy texture after cooking (Oko et al., 2012).

The economic value of rice depends on its cooking and processing quality, which can be measured in terms of water uptake ratio, grain cooked kernel length during cooking, solids in cooking water and cooking time. Linear cooked kernel length of rice on cooking is a cooking characteristic of good rice. Some varieties expand more in size than others upon cooking. Length-wise expansion without increase in girth is considered a highly desirable trait of high quality rice. Consumer preference associated with opportunity cost of cooking time and cooking convenience of rice (Akanji, 1995). Soaked milled rice of high gelatinization temperature elongates less during cooking than low and intermediate gelatinizing rice. Parboiling temperature also affect quality of processed rice (Patindol et al., 2008). Although, genetic plays a large role in the determination of rice grain attributes, non genetic factors contribute substantially to the cooking attributes. Careful examination of research findings have lent strength to the influence of rough rice handling and processing on the quality of Nigerian rice.

Optimisation is an act of making the best combination of elements or variables selected to synthesis a system in order to yield the best result (Akinoso and Adeyanju, 2010). The major insight of this study was to determine effect of paddy storage duration, soaking time and parboiling temperature on cooking qualities of *Ofada* rice and to determine optimum combinations of the treatments to yield best cooking properties using response surface methodology.

Materials and Methods

Ofada paddy (OS 6) was purchased at farm gate in Mokoloki-Ofada, a renounce area for *Ofada* rice production. The storage duration and processing unit operations (soaking and parboiling) used as treatment was adopted from the methods of processing of paddy adopted by the rice farmers in the area. D-Optimal response surface methodology (Design Expert 6.0.6 software) was used for the design of the experiment. The independent and levels of variables were decided mainly from literatures (Patindol et al., 2008; Daniel et al., 1998; Adeniran et al., 2012; Otegbayo et al., 2001) and on the preliminary investigation on the processing of rice in the area (Table 1). The paddy was threshed manually and cleaned to obtain the rough rice within 12 hours, mixed thoroughly and stored in a dry cool place.

The major processing operations in the processing of paddy rice were storage (1-9 months), soaking (1-5 days), and parboiling (80-120°C). After storage for specific months as designed (1, 5, and 9 months), the paddy was cleaned by winnowing to remove the chaffs and immature paddy. Paddy (2 kg) was soaked in cold water at ambient (28°C±2°C) typically for 1, 3 and 5 day(s) to hydrate the kernels. The soaked paddy were parboiled at varied temperatures (80°C, 100°C, and 120°C) at constant pressure using digital autoclave for 15 min, tempered for 30 min to cool and air dried in oven at 30°C. The rice samples were milled (hulling and debranning) in grantex cono disc milling machine. The combination of treatments is presented in Table 1.

Determination of Cooking Properties on Rice

The cooking parameters that were estimated include the amylose, cooking time, cooked kernel length ratio, water uptake ratio and solid loss.

Cooking time: Rice was cooked in excess water. Twenty rice grains were cooked with a colander in boiler placed on an electric heater (100°C) and timer for cooking time. The cooking time of the rice was recorded after complete absence of white chalk when the rice grain was pressed with spoon against the pot or rubbed in between the fingers (Danbaba et al., 2011).

Water uptake ratio: Rice was cooked in excess water. 2 g rice was cooked with 20 mL water in a 100 mL beaker placed on the electric cooker (Sareepuang et al., 2008). Samples were removed at cooking time, weighed and calculated using equation below:

$$\text{Water uptake ratio} = \frac{\text{weight of cooked rice}}{\text{weight of raw rice}}$$

Cooked kernel length: A sample of 2 g rice grain was cooked in 20 mL water for cooking time. The cooked rice grains were placed on bloating paper. The grains, which were intact at both the end, were selected. The lengths of the randomly picked 10 cooked kernels were measured using a digital calliper.

Solid loss: *Ofada* rice grain 2 g was cooked with 20 mL water in a 100 mL beaker placed on an electric heater. The cooked grains in gruel was determined by drying an aliquot of cooking water in a petri dish at 100°C in a hot air oven until completely dry. The amount of solids leached was calculated as percentage of rice dry weight.

Determination of amylose content: Amylose content of the rice was estimated as described by (Perez and Juliano, 1981).

To 100 mg of rice flour, 1 mL of 95% ethanol and 9 mL of 1.0 N NaOH was added. This was mixed well and heated in a boiling water-bath for 10 min. Samples were diluted to 100 mL with distilled water. From this suspension, 5 mL of sample was taken and 1 mL of acetic acid (57.75 mL in 1ltr water) was added to acidify the sample along with 1.5 mL of iodine solution (0.2% iodine + 2% potassium iodide) and the volume was made to 100 mL with distilled water. The samples were incubated at room temperature for 20 min. The absorbance was measured at 620 nm using spectrophotometer. As a control, NaOH solution was used. The amylose content was calculated in comparison with standard graph.

Statistical Analysis

Data from the cooking properties were analysed by ANOVA and regression analysis. Optimisation and modelling using the (Design Expert 6.0.6 software) components. The adequacy of model was checked by coefficient of determination R^2, adjusted-R^2, and adequate precision. F-value (P=0.05) using Statistical Analysis System version 10.0 as described by Magnus et al. (1997).

Results and Discussions

The results of cooking properties of *Ofada* rice as affected by processing conditions and storage is presented in Table1. The result ranges between 14-38 min, 2.51-4.86, 1.47-5.10%, 6.20-11.90 mm and 17.26-26.28% for cooking time, water uptake ratio, percentage solid loss, cooked kernel length, and amylose respectively. There exist significant differences (P<0.05) in the cooking properties (Table 2). The coefficient R^2, adjusted R^2, predicted R^2 and adequate precision of the model ranged between 0.97-0.75, 0.95-0.59, 0.91-0.37, and 21.51-6.16 respectively (Table 2). Aside from 0.37 predictive R^2 recorded, other are closed to 1. The closeness of these R squares to 1, the better the significances of the fitness of the model. Adequate precision greater than 4 is also an indicator of good fitness of the model for prediction.

Cooking time: The maximum cooking time (38 min) was obtained from *Ofada* rice stored for 9 months, soaked for 3 days and parboiled 120°C while the minimum cooking time (14 min) was at 1-month storage of paddy, 1 day of soaking, 80°C parboiling temperature. The result revealed that short period of storage and low parboiling temperature favours reduction in cooking time. The coefficient of F-value in Table 3 revealed that storage duration and parboiling temperature have significant effect on cooking time. Minimal storage duration, soaking time and parboiling temperature reduced cooking time which is more desirable by the consumers. The quadratic model equation describing effect of storage and processing conditions on cooking time (CT) of *Ofada* rice is presented (Eq.1). The cooking time range of parboiled rice obtained in this experiment is higher compared with 10-25 min reported by Adeyemi et al., (1986). However, Otegbayo et al. (2001), revealed cooking time between 52-56 min which is higher than the result obtained in this study. Research works from different backgrounds have shown that parboiling increased cooking time of rice (Saeed et al., 2011; Otegbayo et al., 2001). The degree of gelatinisation of the starch to form hard gels may be one of the factors responsible for the data obtained. The removal of bran layers that are richer in proteins and lipids probably facilitates water migration into rice kernels during cooking thereby, reducing the cooking time (Saleh and Meullent, 2008).

Table1 Cooking properties as affected by storage and processing parameters

Run	Storage Months	Soaking Days	Parboiling °C	CT min	WUR	SL %	CKL mm	Amylose %
1	1	1	120	25	2.66	1.69	6.2	17.34
2	1	1	80	14	3.26	4.05	7.59	21.67
3	5	5	80	19	4.61	4.78	9.2	22.93
4	1	5	80	16	3.69	4.7	6.32	21.29
5	9	3	80	23	4.23	2.63	11.64	24.71
6	5	5	80	19	4.39	5.1	10.89	23.76
7	5	1	120	34	3.46	2.99	9.23	22.93
8	1	5	80	15	3.2	4.09	6.77	20.05
9	9	3	120	38	3.43	3.21	9.64	22.55
10	5	3	120	33	3.49	3.6	9.8	21.47
11	9	5	120	36	3.38	3.28	9.85	20.98
12	5	1	100	32	3.98	4.16	10.44	23.09
13	5	3	120	36	3.3	2.94	9.9	22.05
14	9	1	100	30	4.01	4.55	9.55	25.51
15	9	5	120	35	3.86	2.82	9.3	22.38
16	1	1	120	26	2.84	3.58	7.52	17.96
17	5	3	100	29	3.99	3.37	10.83	18.12
18	5	5	100	28	3.76	3.99	7.71	24.06
19	1	1	80	15	3.27	5.01	8.45	20.54
20	1	1	120	23	2.51	1.53	8	17.26
21	9	5	100	35	4.08	4.27	11.61	24.95
22	5	1	80	21	4.29	3.9	11.52	24.44
23	9	5	80	20	4.86	3.51	11.9	25.15
24	9	1	80	21	4.2	2.65	10.7	26.28
25	1	1	120	24	2.56	1.47	8.09	17.46

CT: Cooking time; WUR: Water uptake ration; SL: Solid loss; CKL: Cooked kernel length

Table 2 ANOVA of regression of cooking properties as a function of storage and processing parameters

Parameters	Mean	p-value	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Cooking time (min)	25.88	<0.0001	0.97	0.95	0.91	21.51
Water uptake ratio	3.65	<0.0001	0.95	0.92	0.85	18.09
Solid loss	3.51	0.0036	0.75	0.59	0.37	6.16
Cooked kernel length (mm)	9.31	<0.0001	0.86	0.78	0.64	11.64
Amylose, %	21.96	0.0001	0.85	0.76	0.55	10.47

Table 3 Significance F-values (P<0.05) for effect storage, soaking and parboiling conditions on cooking properties

	Cooking time min	Water Uptake ratio	Solid loss %	CKL mm	Amylose %
S	66.07	52.22	-	38.33	50.01
T	-	7.03	6.99	-	-
P	129.62	41.87	14.56		22.22
S×T	-	-	-	-	-
S×P	-	8.24	-	-	-
T×P	-	-	-	-	-
S×T×P	4.69	-	-	-	-

S: Storage duration, T: Soaking time, P: Parboiling temperature

Table 4 Predicted solutions for optimisation of cooking qualities of *Ofada* rice

No	Storage	Soaking	Parboiling	CT	WUR	SS	E	Amylose	Desirability
1	5.00	18	80.00	20	4.22175	4.11	10.58	25.08	0.738
2	5.00	17.52	80.00	21.7	4.22247	4.12	10.61	24.91	0.731
3	5.00	22.08	80.00	21.99	4.21716	4.09	10.7	24.84	0.73

CT: Cooking time; WUR: Water uptake ration; SS: Solid loss; E: Elongation

Water uptake ratio: The highest water uptake ratio (4.86) was obtained from paddy stored for 9 months followed by soaking for 5 day, and parboiling at 80°C while the least water uptake ratio (2.51) was obtained from paddy stored for 1month, soaked for 1day, and parboiled at 120°C (Table 1). The highest water uptake ratio was obtained at the least parboiling temperature (80°C) is in line with the explanation of Biswa (1987), that parboiled milled rice of low gelatinization temperature varieties absorbed higher water content than intermediate i.e. gelatinization temperature varieties at room temperature. This was not in line with the discovery of Mehdizadeh and Zomorodian, (2009), which stated that high gelatinization temperature meaning higher water absorption. All the processing parameters have effects on the WUR as shown by F-value in Table 3. Amylose content was reported by Frei and Becker (2003) to affect the water uptake of rice. Increase in amylose content improves water uptake. The interactions of the processing conditions have favoured increase in water uptake which translates to more gain for rice vendors in term of volume (Fofana et al., 2011). The quadratic model equation describing effect of storage and processing conditions on water uptake ratio (WUR) of Ofada rice is presented (Eq.2).

Solid loss: Soaking time and parboiling temperature are the two major factors that contribute to solid loss in *Ofada* rice as shown in Table 3. The quadratic model equation describing effect of storage and processing conditions on solid loss of *Ofada* rice is presented (Eq.3). The lowest solid loss (1.47 %) was from paddy stored for 1 month, soaked for 1 day, and parboiled at 120°C while the highest solid loss (5.10 %) was from paddy stored for 5 months, soaked for 5 days, and parboiled at 80°C. The trend of the result revealed that solid loss decreased with increase in parboiling temperature. This is supported by the Sareepuang et al. (2008), that parboiling caused stronger structure of rice starch as a result of gelatinization. Solids in cooking water (loss in solids) affect the stability of the cooked rice (Juliano et al., 1982). The variation in values may be as a result of the variation in the rice consistency, due to bursting of the grains during and after cooking, as they were subjected to different processing conditions (Oko et al., 2012).

Cooked kernel length: The longitudinal increase in rice after cooking was from 6.20 to 11.90 mm. Maximum increase in rice length was recorded in rice stored for 9 months, soaked for 5 days and parboiled at 80°C. The result revealed that low parboiling temperature and increase in soaking time favoured grain cooked kernel length (Table 1). Effect of storage duration significantly leads to increase in cooked kernel length (Table 3). According to Ashish et al. (2012), high volume expansion correlates with high amylose content. Similar condition for high cooked kernel length is also recorded for high amylose content in rice. The quadratic model equation describing effect of storage and processing conditions on cooked kernel length (CKL) of Ofada rice is presented (Eq.4).

Amylose: Amylose content is considered the single most important characteristic for predicting rice cooking and processing behaviour (Juliano, 1985; Lii et al., 1996). The highest amount of amylose (26.28 %) was obtained at 9 months storage with processing conditions of 1-day soaking period, and 80°C parboiling temperature while the lowest (17.26 %) was at 1-month storage duration, 1 days soaking period, and 120°C parboiling temperature. The coefficient of quadratic model equation (Eq.5), showed that only storage positively contributes to the concentration of amylose in *Ofada* rice. This might be in agreement with the statement that amount of amylose soluble in boiling – water decreases during rice storage (Zhou et al., 2002). Therefore, a decrease in the loss of soluble amylose during the course of storage increased the total amylose content of the milled rice. In some Nigeria local varieties as reported by Otegbayo et al. (2001), parboiling at 120°C produced 22.39% amylose content while the result for non-parboiled was 28.58%. The result indicated that parboiling as a processing operation reduced amylose (A) content of rice.

$$CT = -85.40 + 0.39S + 2.64T + 1.86P - 0.14S2 - 0.35S2 - 8.17 \times 10^{-3}P2 + 0.01^{ST} + 0.02SP - 8.00 \times 10^{-3}SP \quad (Eq.1)$$

$$WUR = +3.57 + 0.37S + 0.15T - 1.92 \times 10^{-3}P - 0.03S2 + 0.02T2 - 5.82 \times 10^{-5}P2 + 0.01ST + 2.23 \times 10^{-4}SP - 3.42 \times 10^{-3}TP \quad (Eq.2)$$

$$SL = -4.18 - 0.75S + 0.40T + 0.22P - 0.03S2 + 0.07T2 - 1.4 \times 10^{-3}P2 + 0.02ST + 0.01SP - 9.43 \times 10^{-3}TP \quad (Eq.3)$$

$$CKL = +9.23 + 1.10S + 0.91T - 0.03P - 0.08S2 - 0.20T2 + 8.02 \times 10^{-5}P2 + 0.12ST - 2.13 \times 10^{-3}SP - 4.57 \times 10^{-3}SP \quad (Eq.4)$$

$$A = +34.53 + 1.35S - 1.97T - 0.24P - 0.07S2 + 0.36T2 + 8.6 \times 10^{-4}P2 - 0.06ST + 2.46 \times 10^{-3}SP - 1.08 \times 10^{-3}SP \quad (Eq.5)$$

Optimisation of cooking qualities of Ofada rice: The best solution prescribed for good cooking qualities of *Ofada* rice was based on minimum cooking time, high water uptake ratio, minimum solid loss, maximum cooked kernel length and maximum amylose which are the criteria that determines qualities of cooked/boiled rice. The best three desirable predicted solutions are presented in Table 4. The predicted storage and processing conditions include storage of paddy for 5 months, soaking for 18h, and parboiling at 80 °C with desirability of 0.738 to yield 20 min cooking time, 4.22 water uptake ratio, 4.11 % solid loss, 10.58 mm cooked kernel length and 25.08 % amylose. Other relevant solutions are presented in Table 4. The validated experimental results as predicted by the selected solution are 21.41 min, 3.99, 3.73 %, 8.20 mm and 26.39% for cooking time, water uptake ratio, solid loss, cooked kernel length and amylose respectively (Fig. 1).

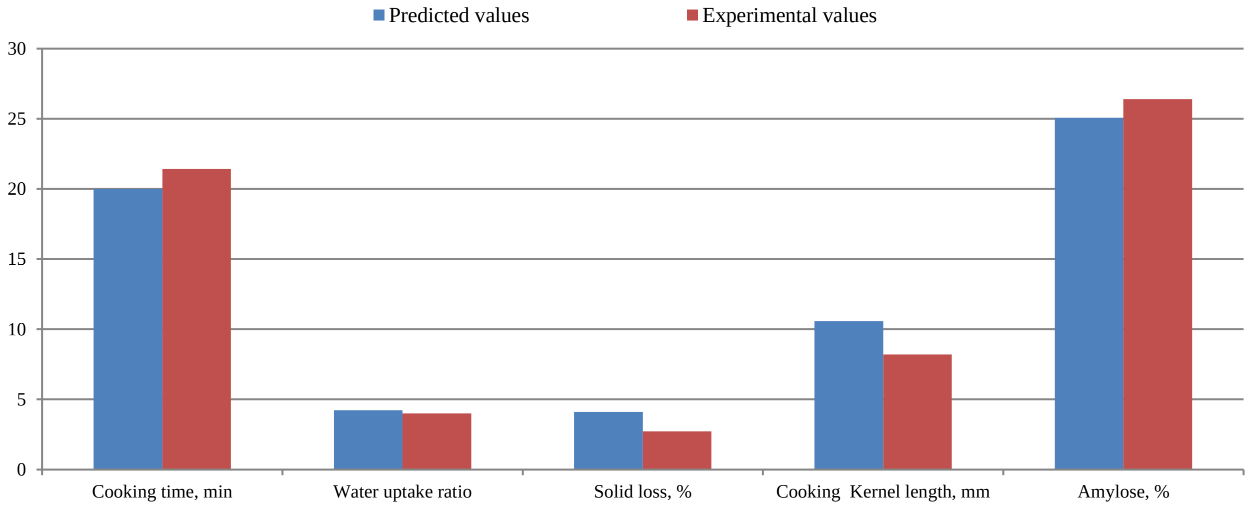

Fig. 1 Predicted and experimental values of cooking properties

Conclusion

Storage duration, soaking time and parboiling temperature influenced cooking properties of *Ofada* rice. Response surface methodology (design expert) was used successfully in the optimisation, modelling and validation of optimum cooking characteristics of Ofada rice for production of boiled rice. Careful selection of storage and processing parameters determine desirable cooking qualities of rice.

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