PREDICTION AND VALIDATION OF PHYSICAL QUALITIES OF *OFADA* RICE AS AFFECTED BY STORAGE DURATION AND PROCESSING CONDITIONS USING RESPONSE SURFACE METHODOLOGY

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Abstract
The objective of the study was to produce optimum physical qualities of Ofada rice with varying independent variables of storage duration and processing conditions using response surface D-Optimal. The experimental design independent variables were storage duration (1 - 9 months) and processing conditions (soaking, 1-5 days; parboiling, 80-120□C; drying, 30 -70□C) and responses were size characteristics, head rice yield, brokenness, chalkiness and colour value. The experimental results were evaluated, optimised and modelled using response surface methodology. The result revealed that storage duration and processing parameters affected physical quality of Ofada rice. The predicted R^2 ranged between 0.9148 and 0.7373 which confirmed the fitness of the model. Coefficient of the quadratic model showed the effect of soaking time influence positively size characteristics, brokenness, chalkiness and colour value. Parboiling and drying temperature determined head rice yield, parboiling positively influence colour value of Ofada rice while the effect of paddy storage was more felt on lightness. The best optimum solution for storage and processing conditions as predicted include storage of paddy for 1 month, soaking in water for 1 day, parboiling at 119.92°C and drying at 30.32°C.

Keywords: Ofada rice, response surface methodology, OS6 processing conditions, optimisation

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1. INTRODUCTION

Nigeria milled rice domestic consumption annual growth rate continue to decrease to negative index -3.85% in 2016 (United State Department of Agriculture, Mundi index, 2016). The growing demand for imported rice is still very high despite government ban on the product.). Rice imports in Nigeria have represented a good proportion of total food imports overtime (*Diagne et al. 2011*; Nkang *et al.,* 2011) and the country is the highest importer of rice in Africa, and the second highest in the World (Sowunmi *et al.,* 2014). Nigeria is reputed to have comparative resource advantage in rice (*Oryza sativa L*) production (Nkang *et al*., 2006), however, there is consumer preference for imported rather than for locally processed rice with the former possessing better processing and cooking qualities (Adeyemi *et al.,* 1985). The non competitiveness of Nigerian rice industry is majorly as a result of obsolete and inefficient processing technology (especially parboiling) which lead to smelling and unappealing products, presence of stones, uneven grains (Adekoyeni *et al.,* 2012; Daramola, 2005; WARDA, 2003).

"*Ofada*" is a generic name used to describe all rice produced and processed in South West, Nigeria. OS6 is one the earlier introduced *Ofada* rice and it's a short grain robust rice which could be likened to the popular "basmatic rice" from India and Pakistan (NCRI and ARC, 2007). It is obvious that the market demand and values of rice depend on its physical qualities such as head rice yield, chalkiness, brokenness, colour, size characteristics and so on which are subject to processing conditions and storage of paddy (Patindol *et al*., 2008; Daniel *et al*., 1998).

Traditional processing of *Ofada* paddy involves three stages of treatment; soaking, parboiling, and drying. The methods of process handling vary from one locality to the other which results to large variation of quality of

Ofada rice available in the market. There is a need to develop optimum storage duration and processing parameters for local rice varieties for quality and competitiveness through optimisation and modelling using response surface methodology. 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. Optimum conditions are those that produce the best, most favourable or most beneficial result from a system or process (Olaoye and Oyewole, 2012; Akinoso and Adeyanju, 2010). The main objective of the research work was to optimise storage duration of paddy and processing parameters (soaking time, parboiling temperature, and drying temperature) of OS6 *Ofada* paddy to produce milled rice with high competitive physical qualities. The results of this study would make relevant technical data available on optimum soaking, parboiling, drying, and storage duration for *Ofada* paddy rice processing for present and prospective investors that would have relied on "trial and error" method in processing *Ofada* rice.

2. 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, parboiling, drying) 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, Chukwu and Oseh, 2009) 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 for processing at 1, 5 and 9 months as described in the experimental design.

The major processing operations in the processing of paddy rice were soaking, parboiling/steaming, drying, and milling. 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 minutes. The parboiled paddy was tempered for 30 min to cool and air dried in oven at 30°C, 50°C and 70°C. The rice samples were milled (hulling and debranning) in grantex cono disc milling machine.

Determination of physical properties

Size characteristics: Size characteristics were determined as described by Patindol *et al.,* 2008 and Gayin *et al.,* 2009. Linear dimensions (length and width) of 20 grains were measured with digital vernier callipers with accuracy of 0.05mm. The mean of the 20 measurements were recorded.

Head rice yield: The head rice yield (HRY %) was calculated as percentage of whole milled grains respect to parboiled paddy, the average value of the duplicates was calculated Patindol *et al*., 2008.

$$\text{Head rice (\%)} = \frac{\text{Weight of whole grains}}{\text{Weight of paddy samples}} \times 100$$

Percentage chalky rice: The percentage rice chalkiness was calculated from five replicates of 100g samples, according to the method outlined by WARDA, 1995.

$$\text{Chalkiness(\%)} = \frac{\text{Weight of chalky grain}}{100\text{g}} \times 100$$

Determination of colour of rice flour: The colour was determined by the method described by Alvarez *et al*., 2008 using a portable PCMTM colour Tee colorimeter (SM3002421). The instrument was first standardized with a white A4 paper. The instrument software was configured to read the desired scale or index. Three grams of the sample was weighed into a transparent bag and the reflected rays sent the signal to the tri-stimulus filter which was connected to the phototubes. The colour measurement circuit records L, a, and b coordinates which were then converted to colour coordinates L*, a* and b* values.

Colour value, B = $\sqrt{(a*)^2 + (b*)^2}$

The L, a, b type of scales simulate this as:
L (lightness) axis – 0 is black, 100 is white
a (red-green) axis – positive values are red; negative values are green and 0 is neutral
b (yellow-blue) axis – positive values are yellow; negative values are blue and 0 is neutral

Statistical analysis:
The significant terms in the model were found by Analysis of Variance (ANOVA) for each response. The adequacy of model was checked by coefficient of determination R^2, adjusted-R^2, and adequate precision. The desired goals for each variables and response were chosen based on consumer preference. All the independent variables were kept within range while the responses were maximized.

Table 1: Physical properties of *Ofada* rice

Run	Soaking day	Parboiling □C	Drying □C	Storage Month	Length mm	Width mm	HRY %	Chalkiness %	Lightness %
1	1	120	70	1	6.28	2.86	72.98	0	66
2	1	80	70	1	5.54	2.92	50.74	47.18	69.59
3	5	80	30	5	5.55	2.84	71.25	1.91	71.26
4	5	80	30	1	5.7	2.82	58.63	42.37	74.09
5	3	80	30	9	5.87	2.83	64	0	72.55
6	5	80	50	5	5.72	2.9	58	36.42	74.82
7	1	120	30	5	6.01	2.5	65.25	0	75.08
8	5	80	70	1	5.53	2.94	52.61	49.64	69.56
9	3	120	70	9	6.13	2.7	65.25	0	66.97
10	3	120	50	5	5.94	2.82	70	1.04	78.8
11	5	120	30	9	6.04	2.67	70.75	0	71.04
12	1	100	50	5	5.72	2.92	75.5	1.79	74.74
13	3	120	70	5	5.81	3.02	65.5	0.18	77.33
14	1	100	50	9	5.87	2.7	74.25	0	69.02
15	5	120	50	9	6.17	2.67	74.75	0	70.75
16	1	120	70	1	6.29	2.88	67.48	0	70
17	3	100	50	5	5.88	2.88	72.5	1.18	77.96
18	5	100	50	5	5.94	2.96	70.96	1.62	71.06
19	1	80	30	1	5.73	2.83	53.8	43.31	74.03
20	1	120	30	1	5.97	3.03	69.88	0	77.37
21	5	100	30	9	5.73	2.8	76.5	3.78	67.91
22	1	80	70	5	5.96	2.84	54.75	33.21	77.25
23	5	80	70	9	5.77	2.93	60.25	0.42	71.16
24	1	80	30	9	5.9	2.67	70.25	44.35	73.72
25	1	120	30	1	6.02	3.02	76.45	0	77.49

Values are means of three replicates

Table 2: ANOVA of regression of physical properties as a function of storage and processing conditions

Parameters	p-value	R^2	Adjusted R^2	Adequate precision
Length (mm)	0.0051	0.8852	0.7244	8.348
Width (mm)	0.0303	0.8243	0.5782	6.699
HRY (%)	0.0013	0.9148	0.7956	9.976
Chalkiness (%)	0.0174	0.8467	0.632	5.933
Lightness	0.0082	0.8716	0.6919	6.907

Table 3: Coefficient of the model for effect of storage and processing parameters on physical quality of *Ofada* rice

	Length mm	Width mm	HRY (%)	Chalkiness (%)	Lightness
Intercept	6.47	1.01	-70.72	229.71	69.6
S	0.03	0.18	-8.38	16.16	95
P	-0.04	0.05	2.5	-4.33	-0.41
D	0.03	-0.02	0.51	1.37	0.41
T	0.05	0.03	3.8	-13.39	3.04
S^2	$7.73x10^{-3}$	-0.02	0.69	-0.38	0.18
P^2	$2.91x10^{-4}$	$-2.13x10^{-4}$	-0.01	0.02	$3.87x10^{-3}$
D^2	$-2.53x10^{-4}$	$1.63x10^{-4}$	-0.01	$-3.69x10^{-3}$	$1.83x10^{-3}$
T^2	$5.46x10^{-3}$	$-7.26x10^{-4}$	0.06	0.3	-0.27
SP	$-7.59x10^{-4}$	$-1.24x10^{-3}$	0.01	-0.12	-0.05
SD	$1.29x10^{-3}$	$1.99x10^{-4}$	0.05	-0.03	-0.02
ST	$-4.57x10^{-3}$	$2.53x10^{-3}$	-0.02	0.27	0.05
PD	$-6.05x10^{-5}$	$7.15x10^{-5}$	$3.99x10^{-3}$	$-5.38x10^{-3}$	$-2.89x10^{-3}$
PT	$-7.11x10^{-4}$	$-6.9x10^{-4}$	-0.03	0.1	-0.01
DT	$-2.20x10^{-4}$	$3.46x10^{-4}$	-0.01	-0.05	$9.76x10^{-3}$

S-soaking time, P-parboiling temperature, D-drying temperature, T- storage duration

3. RESULTS AND DISCUSSION

Size characteristics: There existed significant differences at $p<0.05$ in sizes of the *Ofada* rice after treatments (Table 1). The maximum and minimum values of length of the rice grain obtained were 6.29 and 5.53 mm respectively with an average value of 5.88 mm. The maximum rice length was obtained from the rice stored for 1 month and processed by soaking for 5 days, parboiled at 120°C, and dried at 50°C. The maximum width value of 3.03 mm was recorded from 1 day of soaking, 120^0C parboiling temperature, 30^0C drying temperature and 1 month storage duration of paddy. The R^2, adjusted R^2, and adjusted precision values for the length and width characteristics of *Ofada* rice are shown (Table 2). The coefficient of the model is presented (Table 3). The low standard deviation and predicted sum of squares (PRESS) values of 0.084 and 1.73 respectively demonstrated that the model is reliable. The non significance of the lack of fit was an indication that the model was fit.

The positive coefficient of soaking time and parboiling temperature showed that increase in soaking time and parboiling temperature favoured elongation of processed *Ofada* rice as shown in Table 3. According to Roy *et al.*, 2011, parboiling contributes to the expansion ratio of rice which may be due to the influence of amylose content and water absorption capacities of the rice varieties. Related length and width to this report were documented by Otegbayo *et al.*, (2001) and Danbaba *et al.*, (2012). According to Danbaba *et al.,* (2012) the ratio of length to width is used for the determination of rice shape. The length to breadth ratio ranging from 2.5 to 3.0 is widely acceptable and the grain length > 6 mm is preferred. The size and shape of rice grain may vary from one group to another group of different regions. The variation might be attached to the varietal factors, processing conditions, climatic and geographical area of the rice origin.

Head rice yield (HRY): The result of percentage HRY ranged from 50.74 to 76.50 %. The minimum value 50.74 % was recorded when rice was soaked for 1 day, parboiled at 80^0C, dried at 70^0C and at storage duration of 1 month while the maximum value 76.45 % was obtained at 1 day of soaking, 120^0C parboiling temperature, 30^0C drying temperature and 1 month storage duration. There were significant differences (P < 0.05) in the result obtained for HRY. The model for the result lack of fit was not significant which was good for the model. The range of HRY is related to the result obtained by Patindol *et al*., (2008) for certain cultivars of rice (Bilivar, Cheniere, Dixebelle and Wells). The effect of the parboiling temperature and cultivar were suspected as the reason behind the variation. It was found out that well parboiled rice is harder and gives a higher yield of head rice upon milling (Marshall *et al*., 1993). Research has shown that rough rice storage history can affect head rice yield and cooking quality of rice (Hamaker *et al.,* 1993; Tamaki *et al*., 1993; Chrastil, 1090. Changes during storage include increase in grain hardness and these changes occur most rapidly in the first months of storage (Daniels *et al., 1998*). However, from the results given in Table 3, soaking time and storage duration were more effective in maximising the head rice yield.

Chalkiness: The degree of percentage chalkiness ranged from 0-49.64 % (Table 4.1). There were significant differences ($p < 0.05$) in the results obtained for the percentage chalkiness in relation to the processing conditions and storage. The R^2, Adjusted R^2, predicted R^2 and adequate precision were presented (Table 2) with 11.73 standard deviation. The coefficient showed the impact of soaking toward elimination of the chalkiness in rice kernel (Table 3). The deductions from the Table 1 revealed that reduction in soaking time, high parboiling temperature, low drying temperature and increased storage duration favoured low percentage of chalkiness. The rice variety with minimum amount of chalkiness is considered as good quality grains in comparison with chalky once which decreases the rice grain quality (Bhonsle and Sellappan, 2010). Chalkiness higher than 1% is considered not acceptable in parboiled rice (Gayin *et al.,* 2009). A lot of research is still on to find out why it has been so difficult to eliminate chalk from rice improvement programs (IRRI, 2007).

Lightness: Colour is an important attribute in acceptability of food products. The result of the colour scales L*, a*, and b* were presented (Table 1). The value of L* represents the lightness of the samples and the results ranged from 65.99 to 78.80. There exist significant differences at $p < 0.05$ on the values of whiteness obtained from the experiment. The closeness of the value to the standard is used to determine the percentage whiteness. The highest lightness was from *Ofada* rice stored for 5 months, soaked for 3 days, parboiled at 100°C and dried at 50°C respectively while lowest was from rice stored for 1 month, soaked for 5 days, parboiled at 120°C and dried at 70°C temperatures respectively. The coefficient of the mathematical quadratic model is presented (Table 3). High coefficients of drying (D) and storage (T) showed that the outcome of rice colour after processing is dependent on parboiling and drying temperatures and storage duration.

Table 4: Predicted solutions for optimisation of physical qualities of *Ofada* rice

No	Soaking time,days	Parboiling temp. °C	Drying temp.° C	Storage , month	Length mm	Width mm	HRY %	Chalkiness %	Lightness	Desirability
1	1.00	119.92	30.32	1.00	6.005	3.016	73.22	0.005	77.612	0.88
2	1.00	119.96	31.76	1.31	6.008	2.998	73.532	0.001	78.043	0.872
3	1.62	120.00	30.00	1.00	6.003	3.009	70.865	-0.18	76.72	0.8723
4	1.18	120.00	37.94	1.00	6.061	2.999	74.313	2.942	77.238	0.872
5	1.00	117.27	30.80	1.00	5.947	3.029	73.894	0.247	76.643	0.872
6	1.00	116.84	30.00	1.19	5.924	3.027	73.674	-0.479	76.746	0.872
7	1.00	116.07	32.27	1.00	5.933	3.03	74.477	0.974	76.238	0.872
8	1.28	120.00	36.72	2.40	6.011	2.944	73.267	-6.276	78.65	0.872
9	4.51	120.00	33.17	1.00	6.114	2.781	68.846	-6.276	73.974	0.872

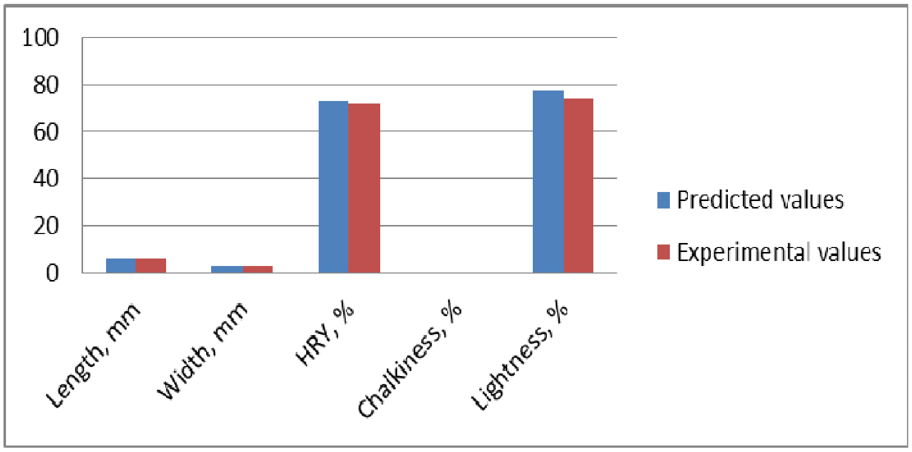

Fig. 1: Predicted and experimental results

Optimisation and experimental validation of physical characteristics of *Ofada* rice

The optimisation was based on maximum length (elongation), maximum width, maximum head rice yield, minimum chalkiness, and maximum lightness. The best optimum solution for storage and processing conditions as predicted include storage of paddy for 1 month, soaking in water for 1 day, parboiling at 119.92°C and drying at 30.32°C. Other solutions and their yields were presented (Table 4). The best predicted conditions were subjected to practical experiment for the validation of the predicted conditions and results (Fig.1). There were no significant differences between the predicted and experimental values which revealed the reliability of the response surface methodology for the optimisation of physical qualities of *Ofada* rice.

4. CONCLUSIONS

The result showed that storage duration and processing conditions affect quality of *Ofada* rice and revealed the best practices for storage duration and processing of paddy for quality. It also revealed the competency of response surface methodology in modelling effect of storage and processing parameters on physical quality of *Ofada* rice. The result is useful for investors and other rice processors who are dependent on trial and error practices in processing of *Ofada* rice.

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