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Effects of Storage and Processing Parameters on Pasting Properties of Ofada for Production of Boiled and Mashed Rice

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Abstract

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This study was designed to determine the effect of storage duration and processing conditions on pasting characteristics of Ofada rice and to determine the optimum pasting parameters for the production of boiled and mashed rice. The interactions of variables (storage, soaking, parboiling and drying) were studied using response surface methodology and pasting responses (final viscosity, trough, setback viscosity, breakdown, pasting temperature and pasting time) were analysed. The coefficient of R^2 and adequate precision ranged between 0.994–0.7374 and 26.825–5.375, respectively, which indicate good fitness of the model. Parboiling temperature, drying temperature and storage duration significantly influenced the pasting properties of grain as revealed by positive coefficients in the model. The pasting requirements for boiled rice are storage of paddy for nine months, soaking for two days and 19 h, parboiling at 90.42°C and drying at 30°C, while for mashed rice storage of paddy for one month followed by soaking for five days, parboiling at 80°C and drying at 54.22°C are required.

Keywords: dry; modelling; Ofada; optimisation; parboiling; response surface methodology; soaking

Finding appropriate solutions for quality rice processing is one of the main challenges encountered by rice processors in Nigeria (Ajala & Gana 2015). Rice is used for various process applications mainly in the form of boiled rice and as mashed porridge rolled into balls, both eaten with soup. The pasting characteristic of rice is one of the major indicators that determine its utilisation in final products.

In Nigeria, rice in paddy form is processed through a parboiling process. Parboiling is a hydrothermal process consisting of soaking, heating and drying operations that modify the qualitative parameters and processing behaviour of rice (Mir & Bosco 2013). Numerous studies have shown that processing conditions affect the functionality and quality of the final rice product (Hamaker *et al.* 1993; Perdon *et al.* 2001). Zhou *et al.* (2002) revealed that one of the sensitive indices of the ageing process in rice is the change in pasting properties, which is dependent on storage temperature and duration. Pasting is a phenomenon that occurs during rice cooking following gelatinisation of rice starch, which involves swelling, exudation of molecular components from the granules and eventual total disruption of the granules (Danbaba *et al.* 2012). Several investigations have been conducted on the effect of specific unit operations (soaking time, parboiling temperature, drying temperature and storage duration) on the quality of rice (Daniels *et al.* 1998; Otegbayo *et al.* 2002; Zhou *et al.* 2002; Patindol *et al.* 2008;

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Adekoyeni *et al.* 2012). The present study was aimed at investigating the effect of the interactions of these various operation units on the pasting characteristic that determines the end use of rice. The results of this study provide relevant technical data on the optimum conditions for soaking, parboiling, drying and duration of storage for milled rice processing for utilisation as boiled rice and mashed porridge popularly called 'tuwo'. The major insight of this research work is the determination of optimum storage duration and processing conditions to give optimum pasting characteristics for boiled and mashed rice products.

MATERIAL AND METHODS

Experimental design and paddy processing. Ofada paddy (OS 6) was purchased at farm gate in Mokolokin, Nigeria. The farmers' practices with respect to storage duration (1–9 months) and processing unit operations (soaking, parboiling, and drying) in the area were adopted for the treatment. D-Optimal response surface methodology was used for the design of the experiment (Design Expert 6.0.6 software). The independent and levels of variables were decided mainly from the literature (Otegbayo

Table 1. Effects of storage duration and processing conditions on the pasting properties of Ofada rice

Run	Storage duration (month)	Soaking time (day)	Parboiling temperature (°C)	Drying temperature (°C)	Peak (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)	Peak time (min)	Pasting temperature (°C)
1	1	5	120	70	28	24	3.75	39	15	6.94	49.35
2	1	1	80	70	96	88	7.92	171	84	5.90	49.30
3	5	1	80	30	770	762	8	1243	481	6.40	87.95
4	1	5	80	30	139	90	48.92	164	74	5.54	49.40
5	9	5	80	30	1332	1240	91.5	2160	920	5.93	81.10
6	5	3	80	50	1571	1414	156.5	2520	1106	5.77	80.30
7	5	5	120	30	634	606	27.5	898	292	5.77	87.18
8	1	1	80	70	103	94	8.58	178	84	6.13	49.3
9	9	5	120	70	1951	929	46.5	1392	463	6.97	85.55
10	5	3	120	50	767	746	21	1178	433	6.93	84.38
11	9	3	120	30	815	792	23	1162	371	7.00	85.51
12	5	5	100	50	1745	1534	210.5	2727	1193	5.83	79.85
13	5	1	120	70	620	592	28	915	324	6.90	90.18
14	9	3	100	50	1374	680	43.5	2348	1018	6.90	84.10
15	9	1	120	50	967	938	29	1411	474	5.97	81.90
16	1	5	120	70	27	24	3.17	38	14	6.94	49.30
17	5	1	100	50	646	624	22.5	916	293	6.97	90.35
18	5	3	100	50	693	671	21.6	945	274	6.83	89.11
19	1	5	80	30	136	87	49.17	158	71	5.57	49.40
20	1	1	120	30	33	32	6.83	46	14	6.97	49.20
21	9	1	100	30	1017	994	23	1558	564	6.37	84.70
22	5	5	80	70	1535	1385	150	2423	1037	6.37	80.70
23	9	1	80	70	1706	1584	122	2899	1315	6.03	81.90
24	9	5	80	30	1299	1224	44.5	2072	848	5.97	81.45
25	1	1	120	30	30	33	3.42	49	16	6.97	49.25

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et al. 2001; Patindol *et al.* 2008) and based on a preliminary investigation of rice processing in the area (Table 1). Paddy (4 kg) was soaked in cold water at ambient temperature (28 ± 2°C) to hydrate the kernels, parboiled at varying temperatures at constant pressure using an autoclave for 15 min, tempered for 30 min and air-dried in an oven. The combinations of treatment parameters for the experiment are shown in Table 1. The rice sample was milled (hulling and debranning) in a grantex cono disc milling machine and ground in a hammer mill, sieved (200 micron size) and analysed.

The pasting properties of rice flour were determined using the method described by Mir and Bosco (2013). The following parameters were determined on the RVA curve: peak viscosity, trough (hold viscosity), final viscosity, breakdown, setback, pasting temperature and pasting time.

Statistical analyses. Data from the pasting experiments were analysed and optimised using the Design Expert 6.0.6 software components. F (P = 0.05) was estimated using Statistical Analysis System version 10.0 as described by Magnus *et al.* (1997).

RESULTS AND DISCUSSION

The pasting properties determined in this study are presented in Table 1. The determined parameters were significant at $P < 0.05$ except for breakdown viscosity (Table 2). The minimum and maximum range of peak, trough, breakdown, final viscosity, setback, peak time and pasting temperature were 27–1951 RVU, 24–1584 RVU, 3–211 RVU, 38–2899 RVU, 14–1315 RVU, 5.54–7 min and 49.20–90.35°C, respectively. The F indicated that the pasting characteristic is more dependent on storage duration and parboiling temperature than on soaking time and drying temperature (Table 3). Effect of storage was significant ($P < 0.05$) on all the pasting parameters except breakdown viscosity and pasting time. Quadratic coefficient models of effect of storage and processing conditions on pasting are shown in Table 4.

The minimum and maximum peak times were 5.54 and 7 min respectively with an average of 6.39 min and the result were also significant at $P < 0.05$. The maximum peak time was obtained from rice stored for nine months, soaked for three days, parboiled at 120°C and dried at 30°C.

The pasting temperatures recorded in the experiment were significant at $P < 0.05$ and ranged from 49.2 to 90.35°C. The pasting temperature is the temperature at which viscosity start to rise. It was observed that Ofada rice stored for one month has a low pasting temperature (less than 50°C) compared to those of rice stored for five and nine months which fall between 78 and 90°C. The range of pasting temperatures recorded in this experiment is similar to the results documented by Eke-Ejiofor *et al.* (2011). Low pasting temperature indicates faster swelling. Higher peak temperature suggests the presence of long amylopectin chains.

The average peak viscosity (801 RVU) recorded was higher than that reported by Danbaba *et al.* (2012). The maximum peak value was obtained in the rice sample stored for nine months and subjected to a five-day soaking period, parboiling at 120°C and drying at 70°C, while the minimum peak was for one month of storage but with similar processing conditions. The variation in the peak viscosity could be attributed to storage duration since the same processing conditions were utilised. Storage of rice results in changes to its properties such as swelling; three months of storage is regarded as the minimum period required to elicit major changes in the hardness of cooked rice (Katekhong & Charoenrein 2012). Perez and Juliano (1981) as well as Daniels *et al.* (1998) reported that rapid changes occurred in stored rice in the first six weeks and first month, respectively. The data recorded in this experiment

Table 2. ANOVA for regression of pasting properties as a function of processing conditions

Parameters	P	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Peak (RVA)	0.0003	0.9381	0.8515	–0.3633	10.337
Trough (RVA)	0.0013	0.9152	0.7966	–1.2596	8.625
Breakdown (RVA)	0.1738	0.7173	0.3216	–5.4171	5.375
Final viscosity (RVA)	0.0013	0.9159	0.7981	–0.6288	8.766
Setback (RVA)	0.006	0.8806	0.7134	–1.2816	7.645
Peak time (min)	0.008	0.8724	0.6938	–1.1176	6.798
Pasting temperature (°C)	< 0.0001	0.994	0.9855	0.9018	26.825

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Table 3. Significance of *F* (*P* < 0.05) for effect of storage and processing conditions on pasting properties

	Peak (RVA)	Trough	Breakdown	Final viscosity	Setback	Pasting time (min)	Pasting temperature (°C)
		(RVU)					
T	67.74	49.66	–	42.61	28.22	–	388.54
S	–	–	–	–	–	10.24	–
P	–	6.45	–	7.71	9.06	76.91	–
D	5.6	–	–	–	–	6.06	–
T*S	–	–	–	–	–	5.87	–
T*P	–	–	–	–	–	7.8	–
S*P	–	–	–	–	–	–	–
T*D	7.53	–	–	–	–	–	–
S*D	–	–	–	–	–	18.72	–
P*D	–	–	–	–	–	–	–
T*S*P	–	–	–	–	–	13.94	–
T*S*D	–	–	–	–	–	5.15	–
T*P*D	–	–	–	–	–	15.29	98.4
S*P*D	–	5.54	–	–	–	8.26	48.36
T*S*P*D	–	–	–	–	–	–	26.94

T – storage duration; S – soaking time; P – parboiling temperature; D – drying temperature

revealed an increased peak with increased storage duration in contrast to the conclusions reported by Katekhong and Charoenrein (2012). The peak is affected by both amylose and amylopectin as well as by the molecular conformation of starch molecules (Lin *et al.* 2010). High peak viscosity values are important in the preparation of stiff dough products such as 'tuwo shinkafa', which is popular among the Hausas in Nigeria. Increases in drying temperature and storage duration were proportional to the increase in peak viscosity as shown by the positive coefficients in Table 4.

Table 4. Coefficient of model on effect of storage and processing conditions on pasting properties of Ofada rice

	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time (min)	Peak temperature (°C)
			(RVU)				
Intercept	719.93	1881.88	–326.75	–2537.39	–115.64	–1.52	–8.96
T	163.73	471.52	26.20	730.30	83.71	–0.18	–1.55
S	–397.38	–230.58	0.67	–7.46	19.79	0.72	1.69
P	–27.19	–84.53	–0.56	–38.34	–21.25	–0.22	1.61
D	61.34	91.42	14.77	173.3	83.71	–0.18	–1.55
T^2	–11.94	–20.81	–1.50	–21.08	–6.79	-1.21×10^{-3}	–1.26
S^2	35.19	52.66	6.80	29.99	11.43	–0.16	–0.5
P^2	0.13	0.50	0.62	0.35	0.18	-1.04×10^{-3}	-9.16×10^{-3}
D^2	–0.56	–0.60	–0.09	–1.16	–0.55	1.34×10^{-3}	0.01
ST	12.38	–5.13	–0.84	–7.13	–3.94	0.02	0.04
SP	0.61	–6.94	–0.3	–1.47	–0.60	-1.66×10^{-3}	0.02
SD	3.32	1.83	0.16	2.48	0.89	4.70×10^{-3}	–0.03
DT	2.40	0.26	0.16	1.45	0.80	4.36×10^{-4}	6.42×10^{-3}
PD	–0.19	–0.35	–0.06	–0.63	–0.31	3.78×10^{-4}	4.18×10^{-3}
PT	0.33	–1.27	–0.11	–3.42	–1.96	-1.31×10^{-3}	9.05×10^{-3}

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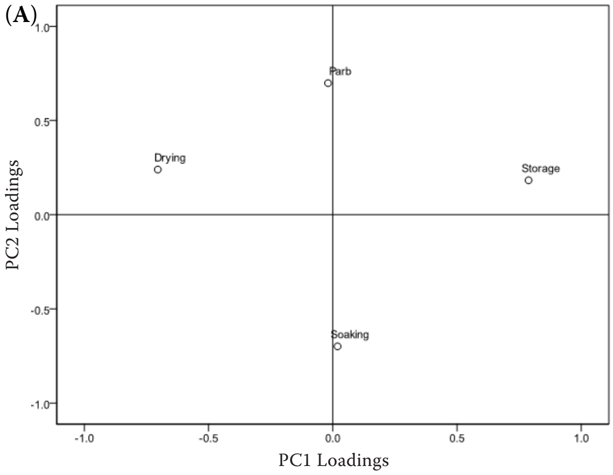
(A)



(B)

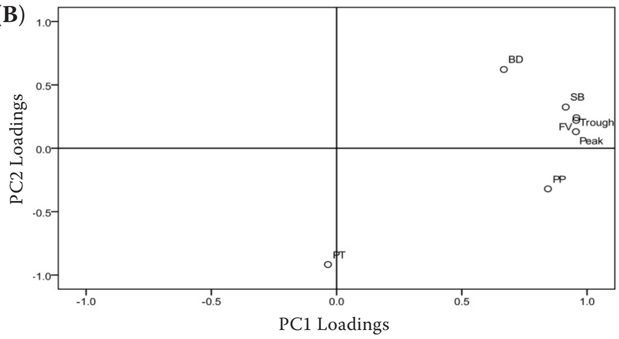


Figure 1. Principal component (PC) loading for (**A**) storage and processing parameters and (**B**) pasting properties

BD – breakdown; SB – setback; FV – final viscosity; Trough – trough viscosity; Peak – peak viscosity; PP – pasting temp; PT – pasting time

The highest trough value of 1584 RVU was obtained from the rice sample stored for nine months and processed according to the following conditions: one day soaking time, 80°C parboiling temperature and 70°C drying; the minimum trough (24 RVU), meanwhile, was obtained from the rice sample stored for one month, soaked for one day, parboiled at 120°C and dried at 50°C. High trough indicates a tendency of the rice starch to break down during cooking; thus, trough values usually decrease with cooking (Danbaba *et al* 2012). Removal of bran in the milling process reduces the amylase content of rice and thereby results in less active amylase and higher trough viscosity (Perdon *et al.* 2001).

Breakdown viscosity describes the ability of swollen starch granules to rupture when held at high temperatures with continuous shearing (Patindol *et al.* 2008). The maximum breakdown was recorded at processing conditions of five days of soaking, 100°C parboiling temperature, 50°C drying temperature and five months of storage. At high breakdown there is tendency for the rice to stick (Gayin *et al.* 2009). Breakdown viscosity decreases with increasing amylose content (Lin *et al.* 2010). Minimal levels of breakdown viscosity results in rice that can be used to prepare dishes involving boiled rice that does not stick together. Such dishes are enjoyed by many in Nigeria.

Final viscosity is a parameter which gives an idea of the ability of starch to gel after cooking (Niba *et al.* 2001) The highest final viscosity was recorded for paddy stored for nine months and subjected to one day of soaking, parboiling at 80°C and drying at 70°C, while the lowest value was obtained for one month of storage, parboiling at 120°C and drying at 70°C. Rice with high viscosity gives rise to a firm paste, a property which is governed by the tendency of the starch to undergo retrogradation.

Significant differences ($P < 0.05$) were observed in the values obtained for the setback viscosity as presented in Table 2. The maximum setback was obtained for the rice sample stored for nine months, soaked for one day, parboiled at 80°C and dried at 70°C. The same processing conditions that promoted maximum setback were also those that were optimal for the final viscosity. The minimum setback was obtained in response to one month of storage, one day of soaking, parboiling at 120°C and drying at 30°C. The retrogradation tendency of rice is determined by setback (Danbaba *et al.* 2012). Aging of amylose has major effects on setback viscosity because the molecular movement of starch molecules during pasting slows down at low temperature and the amylose molecules tend to arrange themselves in a parallel fashion and to draw close to each other to combine through hydrogen bonds. Thus, starch with high amylose content is easy to retrograde (Lin *et al.* 2010). Low setback is related to soft rice texture.

Principal component analysis. The loading plots of processing parameters and pasting characteristics are presented in Figure 1 for PC1 and PC2, respectively. Ninety percent of the variations in the processing parameters were explained by the principal components (PCs), 67.7% by PC1 and 22.3% by PC2 (Figure 1A). The results indicated that a storage facility located on the extreme right of the plot was predominantly responsible for the variation in pasting properties such as peak, trough, setback and final viscosity. This is in line with the findings of Daniel *et al.* (1998) who reported that ageing is the main contributor to

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Table 5. Parameters predicted to give optimal pasting properties of boiled non-sticky Ofada rice and stiff/mashed rice

No	Storage (month)	Soaking time (day)	Parboiling temperature (°C)	Drying temperature (°C)	Trouph	Breakdown	Setback	Desirebility	
					(RVU)				
Boiled non-sticky Ofada rice									
1	9	2.83	90.42	30	762	5.358	637.115	0.649	Selected
2	9	2.79	90.98	30	752.54	4.461	627.122	0.629	
3	8.96	2.91	89.35	30	782.29	7.516	655.152	0.628	
Stiff/mashed rice									
1	1	5	80	54.22		128.22	529.96	0.603	Selected
2	1	5	80	50.3		123.12	502.276	0.601	
3	1	5	80.22	50.38		122.73	500.371	0.601	

the molecular changes of starch. Soaking as part of rice processing operations had the lowest effect on the pasting characteristics of Ofada rice.

Low breakdown viscosity, minimum trough value and high setback viscosity were optimal for non-sticky boiled rice, while low setback, high breakdown viscosity and high trough values were suitable for mashed porridge rice. The best processing conditions for boiled Ofada rice are the following: storage of paddy for nine months and processing by soaking for two days and 19 h, parboiling at 90.42°C, and drying at 30°C (Table 5). For stiff paste/mashy/porridge rice, optimal conditions involve storage of paddy for one month followed by soaking for five days, parboiling at 80°C, and drying at 54.22°C (Table 5).

CONCLUSIONS

Storage duration and processing conditions of paddy influenced the pasting properties of Ofada rice. Response surface methodology (design expert) was successfully used to optimise and model the optimum pasting characteristics of Ofada rice for production of boiled and mashed rice. The storage duration of paddy has a major effect on the pasting properties of rice products. This study revealed the optimal parameters for the processing of Ofada rice for the purpose of producing end products with specific characteristics.

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