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Physical and Pasting Properties of 'Ofada' Rice (*Oryza sativa L.*) Varieties

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ABSTRACT

In this study, grain physical and pasting properties of *ofada* rice cultivated in South-West Nigeria was evaluated using Standard Evaluation System (SES) for rice with the aim of providing basic information for brand development and utilization of *ofada* in the development of novel food products. Results showed that size and shape of *ofada* rice ranged from 5.9 to 9.0 mm and 1.8 to 3.0 mm respectively. The 1000-grain weight was between 24.0 to 31.0 g. Percentage hull was significantly different among the cultivars, ranging from 16 to 21. Peak viscosity ranged between 112.7 and 152.8 BU, minimum, setback and final viscosities varied from 80.3 to 117.2 BU, 104.0 to 143.3BU and 190.8 and 232.3 BU respectively. Gelatinization temperature was not significantly different and varied between 64.1 to 64.7°C. Significant difference ($p < 5\%$) was observed among the samples in terms of minimum setback and final viscosities respectively. Significant negative association was observed between kernel length and gelatinization temperature ($r = -0.65$), set-back and gelatinization temperature ($r = -67$) while positive correlation was observed between breakdown viscosity and peak viscosity ($r = 0.86$). The good pasting behaviour makes *ofada* flour good material for the production of stiff dough products, better palatability and water binding capacity while physical qualities give *ofada* an advantage during milling. This attributes could be exploited for the development of new varieties and utilization in food development of the *ofada* rice value-chain.

Keywords: *Ofada* rice, grain size and shape, peak viscosity, gelatinization temperature.

Introduction

Rice (*Oryza sativa L*) production and consumption in Nigeria represent a significant part of the government strategy to overcome food shortage and improve food self-sufficiency for both local consumption and export.

Ofada is a generic name used to describe some rice varieties cultivated and processed in a group of communities in Ogun State and some rice producing clusters in South-West Nigeria. Cooked *ofada* is a special delicacy eaten by the natives of this region and traditionally served in *stomatococcus danielle leaves*.The mode of preparation, serving and emotional value obtained in eating *Ofada* rice is traced to its indigenousness that connects people to their cultural heritage and food habit (CMDG, 2006).

Rice is the only cereal crop eaten mainly as whole grains and, therefore, grain quality consideration is much more important than for any other crop. The appearance of milled rice grain has been reported as an important quality attribute considered by consumers when shopping for rice (Unnevehr *et al*., 1992). Thus, grain shape and size are the first criteria of rice quality that breeders consider in developing new varieties for release for commercial production. The length/width ratio falling between 2.5 and 3.0 has been considered widely acceptable as

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long as the length is more than 6.0 mm (Mohsenin, 1980; Kunze and Wratten, 1985; Cruz and Khush, 2000; Hossain *et al*., 2009).

Physical properties of rice are of fundamental importance for design, dimensioning, manufacturing and operating different equipment used in post-harvest processing (Afonso, 2001; Silva and Correa, 2000). The marketing values of milled rice also depend on its physical characteristics.

Cooking, eating and end-use quality characteristics of rice are largely determined by the properties of the starch that makes up 90 per cent of milled rice (Danbaba *et al*., 2011). Gelatinization temperature, amylose and amylopectin content and pasting behaviour (rheological characteristics) are the important starch properties which influence end-use quality of rice (SanjivaRao *et al*., 1952; Juliano *et al*., 1965; Cagampang *et al*., 1973; Cruz and Khush, 2000; Vanaja and Babu, 2003).

This study was designed to evaluate the physical characteristics and pasting behaviour of *ofada* rice varieties, a local rice variety from South-West Nigeria. It is intended to provide baseline information on the end-use quality of the rice varieties for proper branding and development of novel rice-based foods in Nigeria.

Materials and Methods

Sources of materials

Twelve (12) *Ofada* rice varieties were collected from farmers' fields in Ogun (5), Osun (3), Ekiti (3) and Lagos (1) States, with two improved varieties (FARO 11 and FARO 46) added as control. The samples were cleaned manually and stored in paper bags before analysis at the Grain Quality Laboratory of the National Cereals Research Institute, Badeggi, Nigeria.

Sample pre-treatment

After cleaning, the rice samples were parboiled using a locally fabricated laboratory parboiler. Water was first heated in the parboiler provided with cover, and 500 g each of the samples in cloth bag were immersed into it and stirred thoroughly such that the final temperature of the water was around 75 $\pm$ 2°C and left overnight to soak. After 18 h, the water was drained and soaked paddy steamed until the hull started to open. It was then spread out on a wooden tray and allowed to air-dry (32 $\pm$ 2°C) in the laboratory before dehulling and subsequently milled with McGill miller (Model: H.T. McGill Inc. Miller 3, USA). Milled rice was then sorted and physical characteristics determined.

Physical characterization

The physical properties studied were the grain size and shape, 1000-grain weight, percentage hull and endosperm colour. All the milled rice samples were subjected to physical characterization based on the methods reported by International Rice Research Institute (IRRI, 1980; 1996). Length and width of twenty randomly selected whole grains were determined using vernier caliper, while the grain shape in terms of length to width ratio was determined using the equation:

Length to width ratio = Average grain length (mm)
Average grain width (mm)

The results of length, width and length to width ratio were then compared to standard kernel classification for rice outlined in IRRI (1980).

Endosperm colour was determined subjectively by visual observation, while hull (%) was evaluated as difference between the milled rice weight and the paddy.

$$\text{Hull \%} = \frac{\text{Average weight of brown rice}}{\text{Weight of original sample}} \times 100$$

Rheological properties

The pasting characteristics of rice flour slurries were measured with a Brabender viskograph-E (Brabender® OHG, Duisberg, Germany) in accordance with the method described by Gayin *et al*. (2009). The slurries were first heated from 50 to 95°C at a rate of 1.5°C/minute, and then held at 95°C for 15 min before cooling back to 50°C at 1.5°C/min and finally held at 50°C for 15 min. The following parameters were then determined from the

Brabender viscograph pasting curves: gelatinization temperature, maximum or peak viscosity, minimum viscosity, final viscosity, breakdown viscosity, and setback viscosity.

Statistical data analysis

One-way analysis of variance (ANOVA) was used to analyze significant difference among the samples using CropStat (Version 7.2, International Rice Research Institute, 2007). Fishers' Least Significant Difference (LSD) test was used to test differences between means according to the method described by Gomez and Gomez (1984). Correlation coefficient between variables was obtained using MSTATC 1.3 and significance determined according to Gomez and Gomez (1984).

Results and Discussion

Grain size and shape

The physical appearance of milled rice is an important quality criteria for consumers and preference for grain size and shape vary from one group of consumers to another (Cruz and Khush, 2000). The physical characteristics of *ofada* rice within moisture content range between 11.9 and 13.8% are shown in Table 1. The result indicates that the highest grain length was recorded for *ofada* 10 (9.0 mm) and least for ofada 3 (5.9 mm) and the mean length value was 7.1 mm. Fifty per cent of the ofada rice varieties show comparable grain length with the control. There was a significant difference ($p \leq 0.05$) observed among the ofada varieties. Jennings *et al.* (1979) classified milled rice length as extra-long (>7.50 mm), long (6.61 – 7.50 mm), medium (5.51 – 6.60 mm) and short (<5.50 mm). Based on this classification, therefore, *ofada* rice can be said to be medium to long kernel rice varieties. Shape, defined by the length-width ratio ranged between 1.8 to 2.6 with an average of 2.3 (Table 1). The shapes of milled rice in terms of length-width ratio are slender (>3.0), medium (2.1–3.0), bold (1.1 – 2.0) and round (<1.1) (Jennings *et al.* (1979). *Ofada* rice is medium grained in term of size except *ofada* 3 which is a bold grain variety. Slender grains breaks easily during milling, whereas round grains are difficult to break. Unnevehr *et al.* (1992) reported that there are more than 10 variations of grain size and more than 5 variations for grain shape, confirming the significant variation ($p < 0.05$) observed among the *ofada* rice varieties in terms of size and shape. The result of this study is

Table 1. Physical characteristics of *Ofada* rice varieties from four states of South-West Nigeria

Ofada	Length (mm)	Width (mm)	L/W Ratio (g)	1000-KW	Hull (%)	Hull colour	EC	MC (%)
1	6.4 ± 0.02	2.8 ± 0.10	2.3 ± 0.01	25 ± 0.07	18.00	Mixture	Mixture	12.6 ± 1.0
2	6.3 ± 0.05	3.0 ± 1.30	2.1 ± 0.02	25 ± 0.04	18.00	Mixture	Red	13.4 ± 0.2
3	5.9 ± 0.03	3.2 ± 0.04	1.8 ± 0.11	24 ± 0.12	19.00	Gold	Mixture	13.8 ± 0.3
4	6.9 ± 0.02	3.0 ± 0.04	2.3 ± 0.10	24 ± 0.08	20.00	Gold	Mixture	13.6 ± 0.3
5	6.8 ± 0.10	3.1 ± 0.50	2.2 ± 0.01	26 ± 0.11	16.00	Mixture	White	12.9 ± 0.1
6	7.2 ± 0.04	3.2 ± 0.02	2.3 ± 0.12	27 ± 0.12	18.00	Gold	White	11.9 ± 1.0
7	7.6 ± 0.07	3.0 ± 0.11	2.5 ± 0.01	27 ± 0.81	17.00	Gold	White	13.6 ± 0.4
8	8.0 ± 0.12	3.1 ± 0.15	2.6 ± 0.12	29 ± 0.51	21.00	Gold	White	13.1 ± 1.0
9	7.6 ± 0.40	3.0 ± 0.02	2.5 ± 0.21	29 ± 0.07	21.00	Gold	White	13.2 ± 0.2
10	9.0 ± 0.18	3.0 ± 0.07	3.0 ± 0.13	31 ± 0.12	21.00	Straw	White	13.3 ± 0.2
11	6.9 ± 0.02	3.1 ± 0.05	2.2 ± 0.12	26 ± 0.11	20.00	Straw	Mixture	12.6 ± 0.2
12	7.0 ± 0.50	3.0 ± 0.08	2.3 ± 0.11	25 ± 0.12	20.00	Mixture	NA	12.8 ± 0.3
Mean	7.1 ± 0.80	3.04 ± 0.1	2.3 ± 0.01	26.5 ± 22	19.00	NA	White	13.0 ± 0.4
FARO 11	7.0 ± 0.6	3.1 ± 0.09	2.3 ± 0.02	27 ± 0.04	18.00	Straw	White	11.4 ± 0.3
FARO 46	8.0 ± 0.6	2.6 ± 0.06	3.1 ± 0.08	29 ± 0.06	19.00	Gold	White	11.6 ± 0.3
LSD (5%)	0.533	0.208	0.169	2.085	3.264	NA	NA	0.816

KW = kernel weight, *L/W = length/width; all data are mean ± standard deviation of three readings based on measurements of fully developed mature grains of typical variety within each *Ofada*. FARO = Federal Agricultural Research Oryza, NA = Not applicable, EC = Endosperm colour, MC = Moisture content.

in agreement with the work of Webb (1985) who reported that the grain size and shape of modern varieties are short to medium bold grain with translucent appearance like that of *ofada* varieties.

1000-grain weight

The 1000-grain weight is a useful index in measuring the relative amount of dockage or foreign material in a given lot of rice and the amount of shrivelled or immature kernels (Luh, 1980). In this study, the 1000-grain weight ranged from 24.0 g (*ofada* 3 and 4) to 31.0g in *ofada* 10. This value could be used to estimate the weight contained in holding bins of known volume during storage and handling. Grain weight has also been reported to vary with moisture content (Ogut, 1998; Jha, 1999; Simonyan *et al.*, 2007).

Hull weight and pigmentation

In most rice varieties, hull percentage expressed as weight based on weight of rough rice range from 17 – 24%. In our study, hull weight of *ofada* ranged between 16.0% (*ofada* 5) to 21% in *ofada* 8, 9 and 10 with a mean value of 19.0%. There was a significant difference ($p \leq 0.05$) observed among the rice varieties in terms of hull weight. Milled rice recovery is directly related to brown rice yield. Therefore, a lower hull weight may result in higher milled rice. High percentage of hull may cause considerable damage to processing equipment through excessive wear of machine parts and inter-connecting transfer facilities. *Ofada* rice hull colour were mainly golden (*ofada* 3, 4, 6, 7, 8 and 9) and straw (*ofada* 10 and 11) with a mixture of the two colours observed in *ofada* 1, 2, 5 and 12 (Table 1). Hull colour has a direct effect on the quality of parboiled milled rice. During rice parboiling, rough rice is usually soaked in hot water for a period of 4 – 24 h depending on the techniques used. During this period, hull pigment is absorbed into rice kernel and impact colour to the finished product.

Endosperm colour

This is the anthocyanin pigmentation in the apiculus layer of the rice endosperm. In this study, a mixture of red and white coloured kernels was observed (Table 1). Two kinds of *ofada* rice are identified by farmers and millers based on the colour of the endosperm, *ofada funfun* (white) and *ofada pupa* (red).

Table 2: Pasting properties of *ofada* rice varieties cultivated in four states of South-West Nigeria.

Pasting properties *(BU) Ofada	PV	MV	BDV	FV	SBV	PT (Minute)	GT (°C)
1	124.4	113.1	11.3	226.0	111.2	6.20	64.70
2	118.6	109.1	12.2	217.2	106.8	5.30	64.30
3	115.8	110.2	4.2	190.8	113.2	6.10	64.70
4	125.1	113.1	12.1	208.3	104.3	6.10	64.70
5	137.1	116.2	22.0	226.0	114.5	5.30	64.60
6	123.9	109.3	13.3	223.2	113.2	5.30	64.30
7	125.6	101.2	6.4	232.3	131.1	8.00	64.10
8	112.7	80.3	16.3	215.3	135.2	8.00	64.20
9	152.8	117.2	44.3	261.1	143.5	5.00	64.30
10	123.4	105.3	13.2	229.1	123.1	8.40	64.20
11	117.6	92.2	10.4	228.0	135.2	8.40	64.30
12	117.4	81.3	11.3	221.1	139.2	8.30	64.20
Mean	124.5	104.0	14.8	223.2	122.54	6.70	64.38
FARO11	121.2	114.1	7.2	273.1	158.4	6.30	64.50
FARO46	89.30	74.60	18.10	229.20	149.30	7.30	64.20
LSD(5%)	8.53	9.15	1.78	28.80	5.10	1.10	NS

FARO = Federal Agricultural Research Oryza, an acronym given to rice varieties released in Nigeria for commercial production. PV = Peak viscosity, MV = Minimum viscosity, BDV = Breakdown viscosity, FV = Final viscosity, SBV = Setback viscosity, PT = Peak time, GT = Gelatinization temperature. *Brabender unit, NS = Not significant.

The presence of red coloured kernel is a factor of economic important to the rice miller. During the milling of coloured rice, increased milling pressure is required to remove or minimize dark areas and this often results in low milling yield.

Rheological characteristics of ofada rice

Table 2 shows the rheological characteristics of *ofada* rice. This is the phenomenon during rice cooking following gelatinization of rice starch, involving swelling, exudation of molecular components from the granules and eventual total disruption of the granules (Atwell *et al.*, 1988). Peak viscosity (PV) range between 112.7 and 152.8 BU (Table 2) with a mean value of 124.53BU. These values are slightly higher than the results reported by Gayin *et al.* (2009) for rice varieties under evaluation in Ghana. The high peak viscosity value as noted in this study is of processing advantage. High peak viscosity has been reported to be significant in the preparation of stiff dough products like 'tuwo shinkafa' (Atwell *et al.*, 1988). This gives *ofada* an advantage for its utilization in *towunlaushi*, a stiff dough product made from cereal flour and eaten with stew or vegetable soup. Peak viscosity is indicative of water-binding capacity and ease with which starch granules are disintegrated, and it is often correlated with final product quality (Thomas and Atwell, 1999; Tran *et al.*, 2001).

Minimum viscosity (MV) ranged between 80.3 and 117.2 BU with a mean value of 104.04 BU. MV is the point at which the viscosity reaches its minimum during either the heating or cooling process. PV is usually followed by a breakdown to minimum (trough viscosity) as a result of starch granules rupture and leaching during exposure to high temperature and shear (Normita and Cruz, 2002). The significantly ($p \leq 0.05$) high trough viscosity observed in this study indicates the tendency of *ofada* rice starch to break down during cooking (Table 2). For rice, a higher breakdown is considered to be an indicator of better palatability. In a study comparing the physicochemical properties of rice cultivars, the one with the highest breakdown value was rated the most palatable (Tran *et al.*, 2001).

The increase in viscosity from the minimum to the final value is referred to as the setback and has been correlated with the texture of various end products. High setback is also an indication of the amount of swelling power of the rice sample and is usually related to the amylose content of the sample (Jennifer and Les, 2004; Martin and Smith, 1995). The results on Table 2 revealed that *ofada* 8 and 11 recorded the highest setback viscosity values of 135.2 BU. These values are significantly ($p \leq 0.05$) lower than the control which recorded 158.4 BU and 149.3 BU for FARO 11 and FARO 46, respectively. This result indicates that the controls possess the highest ability to remain undisrupted when subjected to long period of constant high temperature.

Final viscosity (FV) ranged from 190.3 BU (*ofada* 3) to 261.1 BU (*ofada* 9) with a mean value of 223.2. There was a significant ($p \leq 0.05$) difference observed among the samples and the control (Table 2). The FV is the most commonly used parameter to determine a particular starch-based sample quality. It gives an idea of the ability of starch to gel after cooking. The gelatinization temperature (GT) indicates the range of temperature wherein at least 90% of starch granules swell irreversibly in hot water with loss of crystallinity and birefringence (Cruz and Khush, 2000). There was no significant ($p \leq 0.05$) difference observed among the *ofada* rice varieties and the control (Table 2). This ranged from 64.1 to 64.7^{o}C and fell within the reported 55 to 70^{o}C final GT range for rice (Cruz and Khush, 2000). This therefore indicates that *ofada* rice varieties are of low GT. The GT and cooking time of milled rice are positively correlated (Juliano, 1967), but does not correlate with texture of cooked rice (IRRI, 1968).

Correlation studies between physical properties and pasting characteristics revealed a significantly ($p \leq 0.05$) negative correlation between grain length and GT ($r = -0.65$) which indicates that GT decreases with increase in grain length (Table 3). Same relationship was also observed between GT and grain shape (L/W Ratio). There was also significantly ($p \leq 0.05$) positive correlation between PV and BDV indicating that as the gelatinization of starch reaches its peak, during heating or cooling, retrogradation of amylose and amylopectin sets in and results in an increase in viscosity until a gel is formed at the end of the test. Significantly ($p \leq 0.05$) negative correlation was recorded between SBV and GT, indicating the dependency of increase in viscosity from the minimum to the final value (SBV) on heating temperature. The significantly positive correlation between grain length with length/width ratio (r = 0.96**) and negative association between

Table 3: Correlation analysis of the relationship between morphological properties and pasting characteristics of *ofada* rice

Properties	L	W	L/W	GW	HL	PV	MV	BDV	FV	SBV	PT	GT
L	1.00											
W	– 0.01	1.00										
L/W	0.96**	– 0.26	1.00									
GW	0.91**	0.07	0.87**	1.00								
HL	0.48	0.04	0.45	0.44	1.00							
PV	0.15	– 0.19	0.16	0.31	– 0.08	1.00						
MV	– 0.27	– 0.17	– 0.21	– 0.13	– 0.40	0.63*	1.00					
BDV	0.27	– 0.07	0.26	0.48	0.27	0.86**	0.31	1.00				
FV	0.47	– 0.31	0.50	0.60*	0.12	0.76**	0.15	0.76**	1.00			
SBV	0.48	0.09	0.38	0.52	0.49	0.19	– 0.59*	0.41	0.57*	1.00		
PT	0.50	– 0.07	0.46	0.27	0.40	– 0.54	– 0.79**	– 0.44	– 0.07	0.52	1.00	
GT	– 0.65*	– 0.19	– 0.57*	– 0.62*	– 0.26	0.08	0.58*	– 0.10	– 0.45	– 0.67*	– 0.53	1.00

L = Grain length, W = Grain width, L/W = Length/width ratio, GW = Grain weight, HL = % hull, PV = Peak viscosity, MV = Minimum viscosity, BDV = Breakdown viscosity, FV = Final viscosity, SBV = Setback viscosity, PT = Peak time, GT = Gelatinization temperature.

kernel length and weight (r = 0.91**) (Table 3) indicates that, when grain size increases, its shape also increases but its boldness decreases. These results confirm the report of Hussain *et al.* (1987) and Vanaja and Babu (2003).

Conclusion

The results of this study indicate variability in the grain physical characteristics and therefore *ofada* could be classified as medium to long grains with medium shape, hence better milling yield return. Grain weight and hull (%) was also within the reported values for modern improved varieties. Two colours, straw and golden were the hull colours. The endosperm were either white or red or mixture of the two colours, confirming the name *ofada funfun* and *pupa* for white and red coloured *ofada* generally used in the South-west Nigeria. *Ofada* good pasting attributes also make it a good material for the production of stiff dough products, better palatability and water binding capacity. These attributes should be exploited for the development of new varieties and utilization in novel food development, branding and the development of the *ofada* rice value-chain.

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References

Afonso, J.P.C. (2001). Coffee physical, physiological aspects and coffee quality in function of drying and storage. Doctorate Thesis in Agricultural Engineering (351 pp). Agricultural Engineering Department, Federal University of Vicosa, Vicosa, MG, Brazil.

Cagampang, G.B., Perez, C.M. and Juliano, B.O. (1973). A gel consistency test for quality of rice. *J. Sci. Food Agric.* 24: 1589 – 1594.

Cruz, N.D. and Khush, G.S. (2000). Rice grain quality evaluation procedures. In Singh, R.K., Singh U.S., and Khush, G.S. (eds). *Aromatic Rices*. Oxford and IBH Publishing Co Pvt. Ltd, New Delhi, pp. 15 – 28.

CMDG (2006). Communication and Marketing Research Group Limited. Draft Report on Project Delicacy (*Ofada* Rice Attributes Evaluation Study) submitted to PrOpCom, Abuja.

Danbaba, N., Anounye, J.C., Gana A.S., Abo, M.E. and Ukwungwu, M.N. (2011). Grain quality characteristics of *Ofada* rice (*Oryza sativa L.*): Cooking and eating quality. *International Food Research Journal* 18: 619 – 624.

Gayin, J., Manful, J.T. and Johnson, P.N.T. (2009). Rheological and sensory properties of rice varieties from improvement programmes in Ghana. *International Food Research Journal* 16: 167 – 174.

Gomez, A.K. and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research*. International Rice Research Institute, John Wiley and Sons Inc., New York, 680 pp.

Ghasemi, V.M., Mobli, H., Jafari, A.A.R., Keyhani, A.M. Heidari S., Rafiee, S. and Kheiralipour, K. (2008). Some physical properties of rough rice (*Oryza sativa*) grain. *Journal of Cereal Science*, 47: 496 – 501.

Hossain, M.S., Singh, A.K. and Fasih-uz-Zaman. (2009). Cooking and eating characteristics of some newly identified inter sub-specific (*Indica/japonica*) rice hybrids. *Science Asia* 35: 320 – 325.

Hussain, A.A, Muarya, D.M. and Vaish, C.P. (1987). Studies on the quality status of indigenous upland rice (*Oryza sativa*). *Indian J. Genet.* 47: 145 – 152.

International Rice Research Institute (1968). Annual Report for 1967. Los Banos, Laguna, Philippines, 303 pp.

IRRI (International Rice Research Institute) (1980). Alkali digestion. In: *Standard Evaluation for Rice: International Rice Testing Program*, 2nd Edn, IRRI, Manila, pp. 43 – 44.

IRRI (1996). *International Rice Research Institute, Standard Evaluation Scales for Rice*. Los Banos, The Phillippines, 40 pp.

Jennings, P.R., Coffman, W.R. and Kauffman, H.E. (1979). Grain quality. In: *Rice Improvement*. Intl. Rice Res. Inst., Los Banos, Laguna, Philippines, pp. 101 – 120.

Jennifer Minh-Chau Dang and Les Copeland (2004). Genotype and environmental influences on pasting properties of rice flour. *Cereal Chem.* 81 (4): 486 – 489.

Jha, N.S. (1999). Physical and hygroscopic properties of makhama. *Journal of Agricultural Engineering Research* 72: 145–150.

Juliano, B.O., Onate, L.U., and Del, M.A.M (1965). Relation of starch composition, protein content and gelatinization temperature to cooking and eating quality of milled rice. *Food Technol.* 19: 1006 – 1011.

Juliano, B.O. (1967). Physicochemical studies of rice starch and protein. *Intl. Rice Comm. Newslt.* (special issue): 93 – 105.

Kunze, O.R. and Wratten, F.T. (1985). Physical and mechanical properties of rice. In: *Rice Chemistry and Technology*. Am. Assoc. Analytical Chem. Minnesota, U.S.A, pp. 207 – 231.

Luh, B.S. (1980). *Rice: Production and Utilization*. AVI Publishing Company Inc. Westport. CI.

Martin, C. and Smith, A.M. (1995). Starch biosynthesis. *Plant Cell* 7: 971 – 985.

Mohsenin, N.N. (1980). *Physical Properties of Plant and Animal Materials*. 2nd edition. Gordon and Breach Science. New York, USA.

Normita, M. and Cruz, D. (2002). Rice Grain Quality Evaluation Procedures. Graham R. A Proposal for IRRI to establish a grain quality and nutrition research centre: IRRI discussion paper series No. 44 Los Banos, Philippines: International Rice Research Institute.

Ogut, H. (1998). Some physical properties of white lupin. *Journal of Agricultural Engineering Research* 69 (3): 273 – 277. doi:1006/jaer.1997.0252.

Sanjiva Rao, B.S., Vasudeva, A.R. and Subrahmanya, R.S. (1952). The amylose and amylopectine content of rice and their influence on cooking quality of the cereal. *Proc. Indian Acad. Sci.*, Sect. B 36: 70 – 80.

Simonyan, K.J., El-Okene, A.M. and Yiljep, Y.D. (2007). Some Physical Properties of Samaru Sorghum 17 Agricultural Engineering International: the CIGR Ejournal Manuscript FP 07 008. Vol. IX.

Silva, J.S. and Corre˘a, P.C. (2000). Estrutura, composic¸a˜o e propriedadesdosgra˜os(Structure,compositionandpropertie softhegrains). In Silva, J.S. (ed.), Secagem e Armazenamento de produtosagrı´colas (Drying and storage of agricultural products) (pp. 21 – 37). Juiz de Fora, Brazil: Maria Institute.

Thomas, D.J., and Atwell, W.A. (1999). *Starches*. Eagan Press Handbook Series. Am. Assoc. Cereal Chem., St. Paul, MN.

Tran, U.T., Okadome, H., Murata, M., Homma, S. and Ohtsubo, K. (2001). Comparison of Vietnamese and Japanese rice cultivars in terms of physicochemical properties. *Food Sci. Technol. Res.* 7: 323 – 330.

Unnevehr, L.J., Duff, B. and Juliano, B.O. (1992). Consumers demand for rice grain quality: Introduction and major findings. In: Unnevehr, L.J., Duff, B. and Juliano, B.O. (eds.). *Consumer Demand for Rice Grain Quality*. IRRI, Philippines and IDRC Canada, pp. 5 – 20.

Vanaja, T. and Babu, L. (2003). Association between physicochemical characters and cooking qualities in high yielding rice varieties of diverse origin. *Genetic Resources IRRN* 28: 28 – 29.

Webb, B.D. (1985). Criteria of rice quality in the United States. In: B.O Juliano (ed.). *Rice Chemistry and Technology*. Am. Assoc. Analytical Chem. Minnesota, U.S.A, pp. 403 – 442.