

PHYSICAL PROPERTIES OF SOME RICE VARIETIES AS INFLUENCED BY MOISTURE CONTENT FOR DESIGN OF THRESHING MACHINE

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ABSTRACT

Mechanization of machines for sowing, harvesting, processing, packaging and transportation have been limited by lack of data on physical properties of agricultural products to facilitate design of equipment for its postharvest processing. Therefore, in this study physical properties of three rice varieties were studied as a function of moisture content of grain at four moisture levels. The physical properties of rice considered were bulk density, true density, sphericity, porosity, angle of repose, angle of internal friction and coefficient of friction at 10, 12, 14 and 16% moisture content (wet basis). The average length, width, thickness and thousand grain weight of the three rice grains were, 6.94, 2.19, 1.98 mm and 22.00g respectively. Sphericity, aspect ratio, surface area, bulk density, true density, porosity and repose angle were 3.63, 30.04 mm², 750.21 kgm⁻³, 1250.11 kgm⁻³, 43.5% and 33° respectively. The static coefficients of friction were 0.4425 and 0.3942 for plywood and galvanized iron sheet respectively. Higher friction coefficient values were observed on wood surface and the lowest on galvanized iron surface. It was recommended that galvanized iron sheet be used for construction of processing equipment due to its low friction coefficient.

Keywords: Sphericity, bulk density, coefficient of friction, physical properties, porosity

1 INTRODUCTION

Varietal differences and differences in methods of processing are two important factors that influence quality of rice and rice products. Some of the tests used in the United States of America to determine quality of rice include the alkali spreading value, amylography, amylose content, protein content, size, appearance and hardness of grain. Most of the tests are adapted from methods for evaluation of other cereals [1]. Separation of materials other than grain is essential to upgrade the quality of food material. There are numerous factors that determine the final quality of rice produced by the rice mill. These factors include the milling degree, the level of grain breakage, and level of impurities, colour, and presence of off type kernels such as chalky or damaged kernels [2]. Designers of modern rice mills follow basic principles to enable the machine perform sub-system unit operations such as pre-cleaning, husking, husk aspiration, paddy separation, destoning, whitening, polishing, sifting, length grading, blending, weighing and bagging. Each step in the milling process has a specialized auxiliary device to achieve the best result [3]. Therefore, the aim of this research is to investigate the effect of moisture content on three rice varieties and the possible impact it would have on rice processing (milling and destoning).

2 MATERIALS AND METHODS

2.1 Estimation of average diameter

The average diameter of rice was calculated using the arithmetic mean and geometric mean of the three axial dimensions. The average diameter was determined by considering it as an effective diameter in terms of the thousand seed mass and the true density as given by [2] in equation (1).

$$d_e = \left[\frac{6000m_{1000}}{\pi\rho_t} \right]^{\frac{1}{3}} \quad (1)$$

Where, d_e is the diameter of a sphere of the same volume as the seed in mm; m_{1000} is the thousand seed mass in g and ρ_t is the true density of the seed in kg/m³.

2.2 Geometric mean diameter

The geometric mean diameter D_g in mm was determined using the relation given by [2] in equation (2).

$$D_g^3 = LWT \quad (2)$$

Geometric mean diameter was determined by measuring the average size of the grain, 100 grains were picked at random and their three linear dimensions namely, length (L), width (W), and thickness (T) were measured using a micrometer reading to 0.01mm. The geometric mean diameter D_g was then calculated from the relationship by [2] in equation (3).

$$D_g = (LWT)^{1/3} \quad (3)$$

Where, L is the major diameter of grain in mm; W is the intermediate diameter of the grain in mm, and T is the minor diameter in mm.

2.3 Sphericity

Sphericity was determined following the method of [2] assuming that the volume of the solid is equal to the volume of a triaxial ellipsoid with intercepts L, W, T, and that the diameter of the circumscribed sphere is the longest intercept L of the ellipsoid, the degree of sphericity can then be expressed as in equation (4).

$$\phi = \frac{(LWT)^{1/3}}{L} \quad (4)$$

2.4 The surface area

The surface area S in mm² was determined as given by [2] in equation (5).

$$S = \pi D_g^2 \quad (5)$$

Where D_g = geometric mean diameter (mm)

2.5 Angle of repose

Angle of repose was determined following the method of [4]. An empty cylindrical mold of 15 mm diameter and 25 mm height was filled with rice grains and placed at the center of a galvanized iron plate and raised gradually until it forms a cone of grain. The height of the cone was measured and the filling angle of repose calculated using equation (6).

$$\theta = \tan^{-1} \left(\frac{2H}{D} \right) \quad (6)$$

Where, H and D are the height and diameter of the cone in mm, respectively.

2.6 Static coefficient

The static coefficient of friction for the grains was measured against two frictional surfaces, namely plywood and galvanized iron sheet. A topless and bottomless box of dimension 150×100×40 mm³ was placed on an adjustable sloping surface. The box surface was raised gradually with the intention not to touch the surface. The structural surface with the box resting on it and inclined gradually with a screw device until the box just started to slide down over the surface. The slope angle was then read from a graduated scale [2]. The static coefficient of friction was then calculated following equation (7). The results for this experiment on two different surfaces are presented in result.

$$\mu_s = \tan(\alpha) \tag{7}$$

where, μ_s is static coefficient of friction, α is angle of tilt.

2.7 Bulk density

The bulk density is the ratio of the mass of sample of the seeds to its total volume. It was determined by filling a predefined container from a constant height. The bulk density (ρ_b) was determined by filling a 500 ml beaker with seeds by dropping them from a height of 150 mm and the seeds weighed [5]. It was then calculated using equation (8).

$$\rho_b = \frac{M}{V} \tag{8}$$

2.8 True density

The true density is the ratio of the mass sample of seeds to its pure volume. The true density (ρ_t) was determined by the water displacement method as stated by [2]. Five hundred milliliters of water was placed in a 1000 ml graduated cylinder in which 20g of seeds was immersed. The immersion time was about 10 seconds this is to disallow water absorption by the seeds. The amount of water displaced was then recorded from the graduated scale of the cylinder. The ratio of weight of seeds to the volume of displaced water gave the true density. The displaced water was then collected and weighed and used to calculate equivalent volume of water and hence volume of seed. Due to the short duration of experiment, moisture adsorption was expected to be negligible and therefore seeds were not treated for moisture adsorption prevention.

2.9 Porosity

Porosity is the ratio of free space between kernels to the total of bulk seeds. This was computed using equation (9) for the different rice varieties.

$$\varepsilon = \left(\frac{\rho_t - \rho_b}{\rho_t} \right) \times 100 \tag{9}$$

2.10 Moisture content

Moisture content of samples was determined using the procedure detailed by [3]. The samples were dried at 105⁰C for 18 hours [6]. Weight loss of the samples was then recorded and moisture in percentage determined. This was replicated three times. The moisture content then calculated as:

$$Mc_{wb} = \frac{W_i - W_d}{W_i} \times 100 \tag{10}$$

Mc_{wb} = moisture content, wet basis, %, W_i = initial weight of sample, g, W_d = dried weight of sample, g.

3 RESULTS AND DISCUSSION

The results obtained from laboratory measurements of physical dimensions of rice varieties are presented and discussed here. The means of measured parameters length, width, thickness, aspect ratio (Ra), arithmetic mean diameter, geometric mean diameter, sphericity and Surface area for 300 replications of the three rice varieties are presented in Table 1. The means of the physical properties of three rice varieties major, intermediate and minor diameters and calculated values of aspect ratio, arithmetic mean diameter, geometric mean diameter, sphericity and surface area.

Table 1. Physical properties of three rice varieties

Rice variety	Length (L) mm	Width (W) mm	Thickness (H) mm	Aspect Ratio (Ra)	Arithmetic mean (Da)	Geometric mean (Dg)	Sphericity	Surface area (mm ²)
Kano	6.503	2.24	1.807	3.6094	3.5167	2.9376	0.4524	27.1714
aria	7.235	2.125	1.895	3.8179	3.7517	3.0427	0.4206	29.0881
Mario	7.377	2.216	2.148	3.4344	3.9137	3.2360	0.4387	32.9022
Average	7.038	2.193	1.95	3.6206	3.7273	3.0721	0.4372	29.7206

Means of 300 replications

It can be seen that length of rice is between 6.50 - 7.38 mm, width between 2.13 to 2.24 mm, while thickness is between 1.81 to 2.15 mm for Kano and Mario rice variety respectively. These values are within the published range of 5.25 - 7.49 mm for length, 2.10 - 2.89 mm for width and 1.71 - 2.03 mm for thickness of Abakaliki and Akeze rice varieties respectively as reported by [7]. The measured equivalent diameter ranged between 3.52 to 3.91 mm which are similar to the range of values of 3.48 to 3.90 mm obtained for sadri rice variety by [8]. The sphericity values for Kano, Zaria and Mario rice varieties are 0.45, 0.42 and 0.44 respectively. These values are higher than the value of 0.41 obtained by [5] for local rice variety ITA 257. The surface area ranged between 27.17 - 39.90 mm² for Kano and Mario rice variety respectively, indicating that the larger the grain dimension the larger the surface area. Table 2 presents the dimension and physical characteristics of the three rice varieties, mean values, standard deviation, minimum values and maximum values as obtained from the study. In this study minimum value for length obtained for the three rice varieties was 6.50mm and the maximum value was 7.38mm, width ranged between 2.13 to 2.24mm and thickness between 1.81 to 2.15 mm. [7] determined the dimensions of Abakaliki and Akeze rice, where 72% of grain lengths are between 6.00 mm and 7.24 mm, 23.3 % have lengths between 5.25 mm and 5.99 mm, 5 % have lengths between 7.25mm and 7.99 mm. They found that 99 % of grains have thickness less than 2 mm, which are similar to the range of values obtained in this study.

Table 2. Dimension and physical characteristics of the three rice varieties

Property	No. of observation	Mean value	Standard deviation	Min. value	Max. value
Length (mm)	300	6.94	0.44	6.50	7.38
Width (mm)	300	2.19	0.06	2.13	2.24
Thickness (mm)	300	1.98	0.17	1.81	2.15
Geometric mean diameter (mm)	300	3.09	0.15	2.94	3.23
Sphericity (%)	300	43.65	1.16	42.05	45.24
Aspect ratio	300	3.63	0.20	3.43	3.82
Surface area (mm ²)	300	30.04	2.87	27.17	32.90
Bulk density (kg m ⁻³)	15	750.21	30.21	720.01	780.41
True density (kg m ⁻³)	15	1250.11	31.91	1218.20	1282.01
Porosity (%)	15	43.5	1.5	42.00	45.00
Thousand weight of grains (g)	15	22.00	1.00	21.00	23.00
Angle of repose (degree)	15	33	2	31	35
Terminal velocity	15	5.13	0.065	5.06	5.19

The bulk density of rice ranged between 720 to 780 kg/m³ which is higher than values of 726.06 kg/m³ to 734.60 kg/m³ for Tarom and Farj rice variety reported by [9]. While values of true density lies between 1218.20 to 1282.01kg/m³ whose values are higher than the true density of Tarom and Farj rice varieties with 1108.98 to 1144.68 kg/m³ as reported by [9]. Plywood has higher angle of repose than galvanized iron this may be due to the smooth surface of the galvanized iron sheet relative to plywood. Angle of repose for the three rice varieties lies between 31° to 35° on the galvanized iron surface. Therefore, the data on frictional properties can be used in hopper design for gravity flow, since the angle of inclination of the hopper walls should be greater than angle of repose to ensure continuous flow of the material. Mass of 1000 rice grains for the three rice varieties ranged between 21 to 23g, and are higher than values of 17.84 to 23.61g for Farj and Ramezani rice variety as reported by [10]. Table 3 shows the values of static coefficient of friction of the three rice varieties on two plain surfaces that is the plywood and galvanized iron sheet. It present the values of static coefficient of friction measured on plywood surface and on galvanized iron surface at 10% moisture content wet basis. The static coefficient of friction was higher on plywood surface than on galvanized iron surface. This can be attributed to the surface roughness which was high on plywood. The static coefficient shows that the galvanized iron surface had the minimum amount of static friction coefficient compared to plywood surface. Moisture had a significant effect on friction properties of tested rice varieties with an increase of moisture from 10 to 16%, the friction coefficients of surface materials (plywood and galvanized iron) increased. This is similar to the work of [11] on the effect of

moisture on some physical properties of two varieties of rough rice, which reported that moisture had a significant effect on the static friction coefficient. Hence, galvanized iron sheet could be selected for use as machine component due to its lower friction coefficient when compared to plywood to enable free flow of rice grains in the hopper.

Table 3. Static coefficients of friction of the three rice varieties on two surfaces

Surface	No. of observation	Mean	Standard dev.	Min. value	Max. value
Plywood	15	0.4425	0.0150	0.4275	0.4574
Galvanized iron sheet	15	0.3942	0.0247	0.3695	0.4189

Table 4 displays the mass, geometric mean diameter and sphericity of impurities in the rice varieties.

Table 4. Mass, geometric mean diameter and sphericity of impurities in rice

Type of impurities	Mass of impurities			Geometric mean diameter			Sphericity of impurities		
	(g)			of impurities (mm)					
	Kano	Zaria	Mario	Kano	Zaria	Mario	Kano	Zaria	Mario
Millet	0.02	0.01	0.01	2.74	2.88	2.70	0.62	0.65	0.66
Small stone (1-2) mm	0.02	0.004	0.01	1.43	1.55	1.48	0.88	0.96	0.94
Medium stone (2-3) mm	0.03	0.014	0.02	2.58	2.17	2.41	0.73	0.77	0.85
Big stone (3- 4.25) mm	0.05	0.04	0.20	3.18	3.10	3.45	0.80	0.79	0.87

It can be seen that the geometric mean diameter of the impurities ranged between 2.74 – 2.88mm, these values are similar to the geometric mean diameter of rice varieties measured. Though their sphericity values are higher than that of rice, it may present a serious problem during separation of rice from stone. [12] determined the size, shape, density and suspension velocity of admixtures of ITA 257 rice variety and other impurities like stones and sticks and found the sphericity of ITA 257 rice variety to be 0.41. These measurements are important to enable complete separation of rice from its basic impurities. The effect of moisture content on the principal dimensions of the three rice varieties is presented in Table 5. Table 5 present the principal dimensions of the three rice varieties at four levels of moisture content. Indicating that there is an increase in axial dimensions as moisture content is increased. This may be due to the fact that as moisture content increases, rice grains tend to swell due to moisture absorption. The effective diameter of rice was found to be higher than the thickness of the grains. Similar findings were reported for millet by [13], sweet corn [14] and maize by [15]. The linear relationship between the rice dimension lengths, widths and thickness, and moisture levels are shown in Figure 1- 3 respectively for the three rice varieties. The Figures show that all axial dimensions increased linearly with increase in moisture content from 10 to 16%. This is in conformity with result of the study by [16] on the effect of moisture content on desma seeds.

Table 5. Principal dimension of rice varieties at different moisture contents

Rice variety	Kano			Zaria			Mario		
Moisture content (%)	Principal dimensions (mm)			Principal dimensions (mm)			Principal dimensions (mm)		
	length	Width	Thickness	length	Width	Thickness	length	Width	Thickness
10	6.34	1.98	1.68	6.88	2.00	1.69	6.78	1.89	1.96
12	6.50	2.24	1.81	7.24	2.13	1.90	7.38	2.22	2.15
14	7.02	2.44	1.94	7.52	2.34	2.02	7.52	2.52	2.25
16	7.32	2.50	1.98	7.58	2.38	2.26	7.56	2.54	2.30

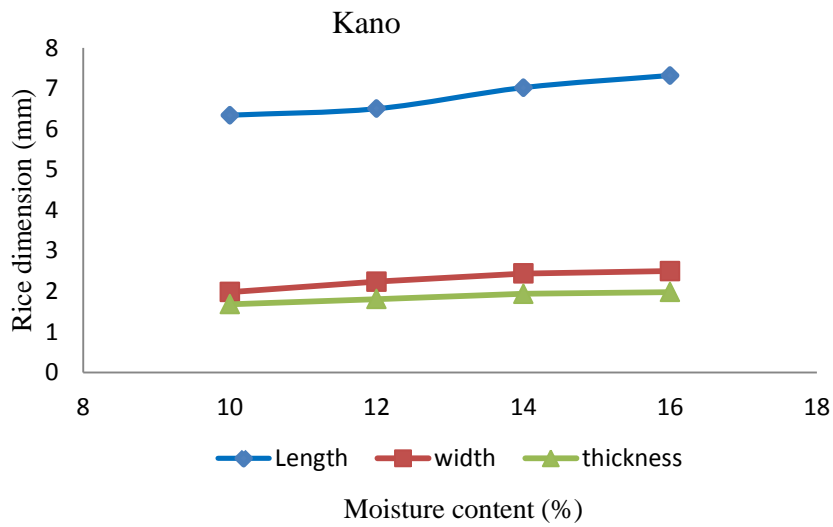


Figure 1. Effect of moisture content variation on Kano rice variety dimensions

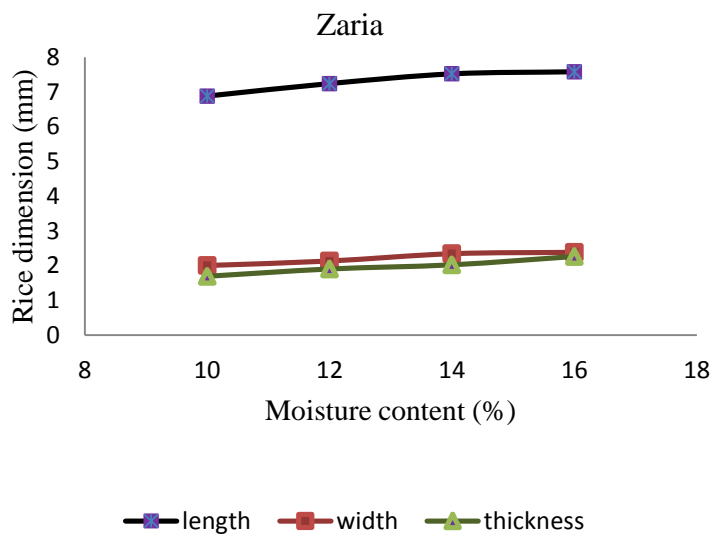


Figure 2. Effect of moisture content variation on Zaria rice variety dimensions

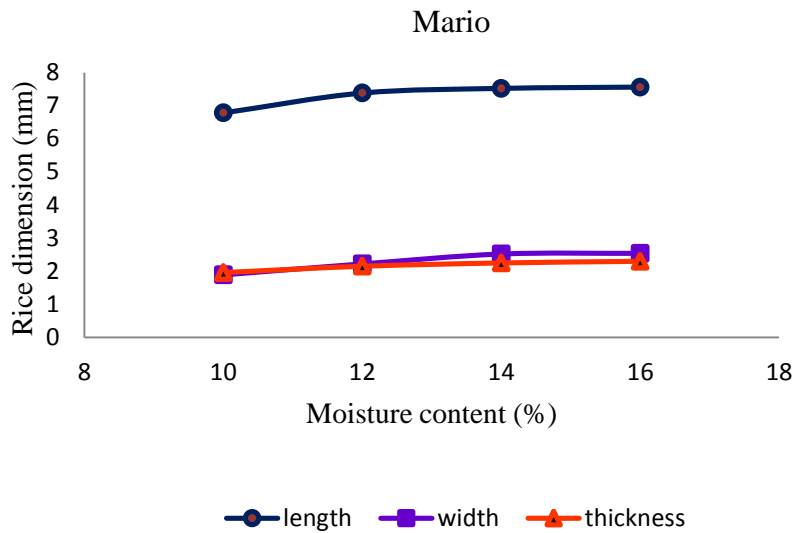


Figure 3. Effect of moisture content variation on Mario rice variety dimensions

Table 6 indicate that as moisture content increases so also are the physical properties like surface area, sphericity and geometric mean diameter. These are some factors that can affect effective processing of rice when done at the wrong moisture content. The surface area increased linearly with increase in moisture content of the rice grains. There was an increase from 27.17 to 32.90 mm²; similar result was reported for popcorn by [14], sweet corn [17]. Surface area is usually called the characteristic length. Characteristic length has important role in the case of irregular shape objects.

Table 6. Physical properties of rice at different moisture contents

Rice variety Moisture content (%)	Kano			Zaria			Mario		
	S	ϕ	dg	S	ϕ	dg	S	ϕ	Dg
10	23.50	0.43	2.74	25.07	0.41	2.83	26.37	0.43	2.90
12	27.23	0.45	2.94	29.20	0.42	3.05	32.97	0.44	3.24
14	31.73	0.45	3.18	33.17	0.43	3.25	37.40	0.46	3.45
16	33.59	0.45	3.27	36.31	0.45	3.40	38.28	0.46	3.49

Some of its applications include determination of projected area of particles moving in turbulent air stream, which can be useful in designing grain cleaners, separators and pneumatic conveyors. The effect of moisture content on sphericity index is significant however, the rice grain cannot be treated as a sphere so as to roll in the hopper but would rather slide down the side of the hopper and this is a property quite important in the design of grain hoppers. Porosity was found to decrease linearly with increase in moisture level from 10 to 16%. A linear relationship between porosity and varying moisture level was obtained. Similar trend was reported for hazel nut [18] and popcorn [14]. However, porosity was reported to increase with increase in moisture content for millet [19] and soybeans [20]. The geometric mean diameter increased by increasing the moisture content of rice in all the three varieties. The regression equations and R² values for the relationship are shown in Table 7.

Table 7. Regression equations for some physical characteristics of rice varieties

Physical characteristics	Variety	Equation	R ²
Geometric mean diameter (mm)	Kano	$D_g = 0.092Mc + 2.026$	0.972
	Zaria	$D_g = 0.096Mc + 2.082$	0.993
	Mario	$D_g = 0.099Mc + 2.18$	0.897
Porosity (%)	Kano	$\varepsilon (\%) = -1.4Mc + 58.4$	0.982
	Zaria	$\varepsilon (\%) = -1.5Mc + 57$	0.998
	Mario	$\varepsilon (\%) = -1.35Mc + 57.1$	0.990
Sphericity (%)	Kano	$\phi = 0.3Mc + 41.2$	0.600
	Zaria	$\phi = 0.65Mc + 35.6$	0.966
	Mario	$\phi = 0.55Mc + 38.7$	0.896
Surface area (mm ²)	Kano	$S = 1.7385Mc + 9.889$	0.977
	Zaria	$S = 1.885Mc + 10.205$	0.996
	Mario	$S = 2.008Mc + 11.667$	0.907

The type of relationship existing between the physical characteristics, rice variety and moisture content as expressed by regression equations and R² values. It has shown that geometric mean diameter, sphericity and surface area of rice varieties increased as moisture content increased. Similar results were obtained for nigella by [21] and [11] on rough rice. Sphericity of rice seeds changed with increase in moisture content and the relationship between moisture content and sphericity is represented by the regression equation and coefficient of determination R² in Table 7. The porosity of rice decreases with increase in moisture content as shown by the regression equation and coefficient of determination R² in Table 4.7 for the different rice varieties. It was also observed that an increase of moisture content is accompanied by a decreased in bulk density. [22] reported that physical characteristics of sunflower seeds were directly related to the amount of moisture, and an increase of moisture decreased the bulk density of sunflower seeds. [23] investigated the effects of different levels of moisture on the physical characteristics of lentil and reported that bulk density decreases as moisture increases.

4 CONCLUSIONS

All the axial dimensions increased linearly with increase in moisture content from 10 to 16%. The geometric mean diameter, sphericity and surface area increased with increase in moisture content. However, there is a decrease in porosity and bulk density as the moisture increases.

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