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ORIGINAL ARTICLE

Effect of variety and moisture content on some engineering properties of paddy rice

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Abstract The effect of variety and moisture content on some engineering properties of five improved paddy rice varieties was investigated within moisture content range of 10% and 30% dry basis (d.b.). Increase in moisture content was found to increase the linear dimensions, mass of 100 seeds, surface area, apparent volume, true volume, arithmetic mean diameter, effective geometric diameter, sphericity, angle of repose, porosity and static coefficient of friction while bulk density and true density decreased with increase in moisture content. Static coefficient of friction was found to increase as moisture content increased from 0.34–0.46, 0.35–0.59, 0.36–0.46 and 0.34–0.45, respectively on plywood, galvanized steel, mild steel and glass structural surfaces. The highest static coefficient was found on galvanized steel. Angle of repose was found to increase as moisture content increases. The study concludes that variety and changes in moisture content significantly ($P<0.05$) affected most of the engineering properties determined.

Keywords Rice · Variety · Improved · Moisture content · Engineering properties

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Introduction

Rice (*Oryza sativa L*) is a cereal foodstuff, which is an important part of the diet of many people worldwide, and a staple food for many (Sujatha et al. 2004). It is cultivated in many countries such as India, Thailand, Argentina, Pakistan, China, Brazil, United State of America, Nigeria, Egypt and Cambodia. China, India, Indonesia and Thailand are the main producers and exporters of rice (FAO 2008a) while Egypt, Nigeria, and Madagascar are the main rice producing nations in Africa (FAO 2008b). Among the major cultivated cereals worldwide, rice stands out, constituting the basic food for large number of human beings (Zhout et al 2002). It is one of the staple foods in Nigeria. The domestic rice production in Nigeria is much lower than the required amount thus, the balance is imported from major rice producing countries mainly Thailand (FAO 2008a). Paddy rice, after harvesting, is either used as milled raw rice or further processed into parboiled rice (Sujatha et al. 2004).

According to FAO (2008b) total world production of rice increased from 429.6 million tonnes in the period 2006/2007 to 433.7 million tonnes in the period 2007/2008 (FAO 2008a). But there was a drop of 7.4% in volume of rice available for international trade (from 31.0 million tonnes in 2006/2007 to 28.7 million tonnes in 2007/2008 trade volume), this reduction in trade volume is caused mainly by the imposition of stringent restrictions on external sales by the main rice exporting counties (FAO 2008b). The reduction in trade volume caused by the imposition of some stringent restrictions on external sales as well as swelling in international rice prices (price of rice per tonne increased from $325 in November 2007 to $567 in March 2008) has created a global food crisis with devastating effect on the Nigerian economy (FAO 2008a). FAO (2008b) stated that

3.9 million tonnes was produced in 2007 compared to 4.0 million tonnes produced in 2006 by Nigeria.

As a result of increase in human population in Nigeria, rice consumption has surpassed its production. It was estimated that rice production in Nigeria between 2001 and 2003 was estimated as 2.03 million tones while consumption was 3.96 million tones. The balance of 1.93 million tones was obtained by importation (FAO 2004). The economic situation with its consequent shortage of foreign exchange has made it necessary for Nigerian government to initiate national strategies to enhance local rice production. Measures taken include breeding and cultivation of high yielding, early maturing and nutritious rice varieties. This has lead to significant increase in local rice production and yield (FAO 2008a). To be able reap the maximum benefits from breeding and agronomical improvement there is the need for the development of processing equipment and techniques to add value to paddy rice.

Therefore there is the dare need to study the engineering and mechanical properties of the common improved paddy rice varieties in Nigeria. Engineering properties have great influence on the behaviour of agricultural crops when subjected to various postharvest handling and processes (Simonyan et al. 2007). These properties are needed to adequately design appropriate equipment and systems for planting, harvesting and post harvest operations such as cleaning, conveying and storage for agricultural crops (Asoegwu et al. 2006). Weight, diameter, surface area, bulk density, thickness, length and width are some of the engineering properties required and necessary in the design and optimal performance of grain threshing units (Simonyan et al. 2007). Therefore, the objective of this study was to investigate the effect of variety and initial moisture content on the engineering and mechanical properties of common improved paddy rice varieties in Nigeria.

Materials and methods

Five improved rice varieties namely: FARO55, FARO44, FARO52, FARO49 and NERICA L34 were sourced from the National Cereal Research Institute, Badeggi, Niger state and National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, Oyo State, Nigeria. Some genotypic and phynotypic characteristics of the improved paddy rice varieties are shown in Table 1. The initial moisture content of the seeds was determined using ASAE standards (2003) and the average moisture content was determined. The amount of water that was added (Q) to condition the samples to the desired moisture contents was determined by making use of the following expression.

$$Q = \frac{A(b - a)}{100 - b} \tag{1}$$

Where

- Q Mass of water to be added, in Kg
- A Initial mass of sample in Kg
- a Initial moisture content of sample in % d.b.
- b Final (desired) moisture content of sample % d.b.

The conditioned rice samples were packed separately in polyethylene bags and stored in a refrigerator at a low temperature of 4–5°C. For each test, the required quantity of sample were taken and allowed to warm up for approximately 2 hr (Joshi et al. 1993).

Size, shape and sphericity A micrometer screw gauge was used to measure the linear dimensions namely; length (L), width (W) and thickness (T) of the paddy rice varieties (Tunde-Akintunde and Akintunde 2007). The effective diameter (D_e), sphericity (Q) and surface area (S) were calculated from the three linear dimensions according to the following expression (Jain and Bal 1997).

$$De = (LWT)^{1/3} \tag{2}$$

$$Q = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{3}$$

$$S = \pi De^2 \tag{4}$$

given by McCabe et al. (1986).

Mass and volume The mass of one hundred seeds was determined using an electronic balance to an accuracy of 0.0 l g. The method described by Dutta et al (1988) was used to determine the volume of each paddy rice variety. A group of 100 seeds of known average weight was packed in water resistant polyethylene bag and dropped into a can filled with water. The displaced water was collected and weighed. It was then used to calculate equivalent volume of water and hence volume of the seeds.

Bulk density, true density and porosity The true density of the paddy rice varieties was obtained using the method described by Tunde-Akintunde and Akintunde (2007). Bulk density was measured using the AOAC method, in which a 50 ml cylinder was filled with paddy rice from a height of 15 cm. The excess paddy rice was removed and the weight recorded. The bulk density was then calculated as the ratio of paddy rice weight to the volume occupied (Omobuwajo et al. 1999). Porosity (P) was calculated from the relationship

Table 1 Some genotypic and phynotypic characteristics of the improved paddy rice varieties

New name	Cultivar name	Ecology	Days to maturity	Plant height (cm)	Yield range (tonnes/ha)	Grain shape	Reaction to blast	Year of release
FARO 44	SIP1692033	Shallow swamp	150	95	4.0–6.0	Long	R	1992
FARO 49	ITA 315	Upland	120	100	2.0–4.5	Medium	R	1992
FARO 52	WITA 4	Lowland	125	100	Average 3.8	Long	R	NA
FARO 55	NERICA 1	Upland	130	75	Average 2.1	Long	R	NA
	NERICA L34	Lowland	120	90	N/A	Long	R	N/A

IRRI 1995; Anonymous 1996; Erenstein et al. 2004

NA data not available

between bulk (ρ_b) and true (ρ_t) densities according to Mohsenin (1986) as follows.

$$P = \frac{1 - \rho_b}{\rho_t} \times 100 \tag{5}$$

Angle of repose Angle of repose was measured using a specially constructed wooden box measuring 300×300×300 mm with a detachable front panel (Ogunjimi et al. 2002). The box was filled with the paddy rice varieties at the different desired moisture content and the front panel was removed quickly. The paddy rice was allowed to flow according to their natural flow pattern. The angle of repose was calculated by measuring the distance between the end of the flow and the end of the box

$$Angle\ of\ repose = \frac{\tan^{-1}(\text{horizontal distance})}{height\ of\ box} \tag{6}$$

Static coefficient of friction The static coefficient of friction for the paddy rice at different moisture content on different structural surfaces (mild steel, galvanized steel, glass, and plywood) was obtained by the inclined plane method which involved using a hollow metal cylinder (50 mm diameter and 50 mm height) open at both ends and filled with paddy rice. The cylinder was then placed on an adjustable tilting plate without allowing the metal cylinder to touch the inclined surface. The tilting surface was raised slowly and gradually until the grains started to slide down and the angle of inclination was read from the graduated scale (Dutta et al. 1988; Suthar and Das 1996).

$$\mu = \tan \alpha \tag{7}$$

μ static coefficient of friction
α angle of inclination

Statistical analysis The experimental data was subjected to statistical Analysis of Variance (ANOVA), Pearson's Correlation and Regression Analysis using SPSS version 15.0.

Results and discussion

Table 2 shows the effect of variety and moisture content on the physical dimensions of improved paddy rice varieties. The effect of variety and moisture content on the physical dimensions of the paddy rice was significant ($P<0.05$). As the moisture content increased from 10% to 30% (d.b), the three linear dimensions of all the improved paddy rice varieties increased due to the swelling of the seeds. This increase in linear dimensions has also been reported for millet in which the length and thickness increased from 2:18 to 2.788 mm for a moisture content range of 5–22.5% (d.b.) (Baryeh 2002), while a similar increase was reported in length, width and thickness of soybean from 6.32–6.75 mm, 5.23–5.5 mm and 3.99–4.45 mm, respectively (Deshpande et al. 1993). Similar findings were also reported by Al-Mahasneh and Rababah (2007) for green wheat, Aydin (2002) for grains hazelnuts, Calisir et al (2005) for rapeseed, and Tunde-Akintunde and Akintunde (2007) for sesame seeds. Linear dimensions are important in determining aperture size in design of grain handing machinery (Al-mahasneh and Rababah 2007). Mass of 100 seeds was found to increase from 2.86–3.6 mm, 2.69–3.17 mm, 2.30–2.87 mm, 2.48–3.15 mm and 3.14–3.77 mm, respectively for FARO 55, FARO 44, FARO 52, NEGICA L34 and FARO 49, respectively. Similar results were reported by Tunde-Akintunde and Akintunde (2007) for sesame seeds.

The effective mean diameter, sphericity, arithmetic mean diameter and surface area also increased with increase in moisture content. This is because they are dependent on the three linear dimensions, which were observed to increase. Effective mean diameter was observed to increase from 2.59–3.86 mm, 3.63–3.73 mm, 3.60–3.72 mm 3.53–3.69 mm and 5.89–4.12 mm, respectively for FARO 55, FARO 44, FARO 52, NERICA L34 and FARO 59, respectively. Arithmetic mean diameter also increased as the moisture content increases. The arithmetic mean diameter and effective mean diameter is useful in determining the diameter of sieve holes (Simonyan et al. 2007).

Table 2 The effect of variety and moisture content on the physical dimensions of improved paddy rice varieties

Variety	Moisture content	Mass of 100 seeds(g)	Length (mm)	Width (mm)	Thickness (mm)	Arithmetic mean diameter (mm)	Effective geometric diameter (mm)	Sphericity (%)	Surface area (mm^2)
FARO55	10%	2.9	9.2	2.4	2.1	15.4	3.6	0.39	40.5
	20%	3.2	9.1	2.7	2.2	18.3	3.8	0.42	45.4
	30%	3.6	9.7	2.7	2.2	19.2	3.9	0.40	46.8
FARO44	10%	2.7	9.4	2.3	2.3	15.9	3.6	0.39	41.4
	20%	2.9	9.7	2.5	2.0	16.9	3.7	0.38	43.1
	30%	3.2	9.8	2.5	2.1	17.3	3.7	0.38	43.7
FARO52	10%	2.3	9.3	2.4	2.1	15.7	3.6	0.39	40.9
	20%	2.6	9.7	2.5	2.2	17.1	3.7	0.39	43.4
	30%	2.9	9.7	2.6	2.2	16.3	3.7	0.38	42.1
NERICA L34	10%	2.5	9.5	2.2	2.1	14.7	3.5	0.37	39.1
	20%	2.9	9.7	2.4	2.1	16.4	3.7	0.37	42.2
	30%	3.2	9.9	2.4	2.2	16.8	3.7	0.38	42.9
FARO49	10%	3.1	9.3	3.0	2.1	19.6	3.9	0.42	47.5
	20%	3.4	9.7	3.2	2.2	22.7	4.1	0.42	52.2
	30%	3.8	9.9	3.2	2.2	23.4	4.1	0.42	53.4
Mean		3.0	9.6	2.6	2.1	17.7	3.8	0.49	44.3
Standard deviation		0.41	0.26	0.32	0.05	2.53	0.17	0.02	4.13
SE		0.11	0.07	0.08	0.01	0.65	0.04	0.00	1.07
CV		13.57	2.76	12.53	2.50	14.26	4.58	4.44	9.33
P of variety		[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
P of initial moisture content		[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
P of variety X initial moisture content		[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]

Values are means of ten replicates for mass of 100 seeds and twenty replicates for others

[a] Significantly different ($P<0.05$)

The sphericity of the five paddy rice varieties increased as moisture content increases. The mean value was 0.39 which is lower than that of green wheat (Al-Mahasneh and Rababah 2007), sesame seeds (Tunde-Akintunde and Akintunde 2007), Soyabean seeds (Deshpande et al. 1993; Gupta and Das 1997), and millet (Baryeh 2002). This is because the shape of paddy rice is cylindrical. This implies that the grains cannot be treated as a sphere for analytical prediction of their drying behaviour. Such low sphericity suggests that the paddy rice grain may be expected to slide rather than roll on their surface, which is a property that is quite important in design of grain hoppers (Al-Mahasneh and Rababah 2007). The surface area increased from 40.45–45.81 mm^2, 41.36–43.70 mm^2, 40.87–43.71 mm^2, 39.10–42.86 mm^2 and 47.45–53.41 mm^2, respectively for FARO 55, FARO 44, FARO 52, NERICA L34 and FARO 49, respectively. Similar finding were reported by Tunde-Akintunde and Akintunde (2007); Balasuramanian and Vismanathan (2010). Knowledge of grain surface is important during modelling of grain drying, aeration, heating and cooling (Al-Mahasneh and Rababah 2007). The effect of variety and moisture content on the physical dimensions of all the five rice varieties were significant ($P<0.05$). The interactive effect of both variety and moisture content was also significant ($P<0.05$). This implies that the three linear dimensions depend on the variety and moisture content of paddy rice studied.

The effect of variety and moisture content on some engineering properties of five improved paddy rice varieties is presented in Table 3. Apparent volume was observed to increase as moisture content increased. The ratio between apparent volume and surface area is usually called the characteristic length. Characteristic length has important role in handling irregularly shaped objects. Some of its application includes determination of projected area of particles moving in turbulent air stream, which can be useful in designing grain cleaners, separators, and pneumatic conveyors. As the ratio between surface area and volume increases, the rate of heat and mass transfer from kernel increases, which affects several unit operations such as drying, cooling and heating (Al-Mahasneh and Rababah 2007). The true volume was also found to increase as

Table 3 The effect of variety and moisture content on some engineering properties of improved paddy rice varieties

Variety	Moisture content	Apparent volume (cm^3)	True volume (cm^3)	True density (g/cm^3)	Bulk density (g/cm^3)	Porosity (%)	Aspect ratio (%)
FARO55	10%	13.8	3.0	0.95	0.61	37.8	26.1
	20%	16.7	3.2	1.0	0.57	46.1	30.0
	30%	17.3	3.6	1.0	0.54	46.1	28.0
FARO44	10%	14.2	2.7	1.0	0.60	40.9	24.0
	20%	15.1	2.9	1.0	0.58	41.8	25.7
	30%	15.4	3.3	0.97	0.54	44.5	25.3
FARO52	10%	14.0	2.6	0.89	0.61	32.6	26.2
	20%	15.3	2.7	0.98	0.57	41.5	26.0
	30%	14.5	3.0	0.94	0.55	41.2	24.9
NERICA L34	10%	13.0	2.3	1.1	0.62	43.5	23.7
	20%	14.5	2.8	1.0	0.58	42.1	24.1
	30%	14.9	3.2	0.99	0.51	47.5	24.2
FARO49	10%	17.8	3.1	1.0	0.58	42.1	32.6
	20%	20.5	3.6	0.94	0.59	42.8	32.3
	30%	21.2	3.9	0.97	0.55	42.9	32.5
Mean		15.9	3.1	0.99	0.57	41.8	27.1
Standard deviation		2.40	0.43	0.05	0.03	3.85	3.37
SE		0.62	0.11	0.01	0.01	0.99	0.87
CV		15.13	14.12	4.82	5.28	9.19	12.42
P of variety		[a]	[a]	[a]	ns	[a]	[a]
P of initial moisture content		[a]	[a]	[a]	[a]	[a]	[a]
P of variety X initial moisture content		[a]	[a]	[a]	ns	[a]	[a]

Values are means of ten replicates

[a] Significantly different ($P<0.05$) ns = not significantly different ($P>0.05$)

moisture content increased. This is similar to findings reported by Tunde-Akintunde and Akintunde (2007) for sesame seeds. Apparent volume was observed to increase as moisture content increased.

The bulk density and true density of the five paddy rice varieties were found to decrease with increase in moisture content. Similar trend was reported by Al-Mahasneh and Rababah (2007) for green wheat and mash bean. However, true density decreased with increase in moisture content. The decrease in true density with moisture content was greater than the decrease in bulk density. The bulk density was lower than that of true density because the air space in grain bulk increases the volume while the weight is the same. The decrease in bulk and true density was mainly due to the larger increases in kernel volume compared to the increase in kernels mass (Al-Mahasneh and Rababah 2007) as the grains absorbs moisture. Porosity increased with increase in moisture content. These were in accordance with findings reported for millets (Baryeh 2002; Balasuramanian and Vismanathan 2010), rapeseed (Calisir et al. 2005), soybeans (Deshpande et al. 1993) and sun flower seeds (Gupta and Das 1997). The mean value for porosity for the five paddy rice varieties was 41.84%. Higher porosity provides better aeration and water vapour diffusion during drying.

The aspect ratio increased with increase in moisture content. Aspect ratio relates the kernel width and length. It determines whether the grains will slide or roll on their flat surfaces. Higher aspect ratio means that the grains will rather slide than roll (Al-Mahasneh and Rababah 2007). The effect of veriety on the engineering properties was significant ($P<0.05$) except for bulk density while the effect of moisture content was significant ($P<0.05$) for all the engineering properties. The combined effect of both variety and moisture content was significant ($P<0.05$) for all the engineering properties except for bulk density. The values obtained for the bulk and true density of the paddy rice varieties were similar to that of beni seed which is an indication that it will float in water (Tunde-Akintunde and Akintunde 2007) while karingda with a true density of 1148–1004 kg/m^3 will sink in water (Suthar and Das 1996). These properties are useful in the hydrodynamic separation and transportation of grains and seeds (Tunde-Akintunde and Akintunde 2007).

Table 4 shows the effect of variety and moisture content on the mechanical properties of improved paddy rice varieties. As moisture content increased, there was a significant increase in the value of angle of repose. The angle of repose ranged from 21.77–29.06° which was higher than that of beni seed (Tunde-Akintunde and Akintunde 2007) but similar to that of gram seeds 25.5–30.4°; sunflower, 34–41°; and lentil seeds, 24.8–27.78^0 (Dutta et al. 1988, Gupta and Das 1997, Amin et al. 2004). Angles of repose are useful in design of processing and handling equipment. The high value of the angle of repose may be due to the large size of the grains and their relatively rough surface which prevent sliding of the grains on one another easily (Tunde-Akintunde and Akintunde 2007). The mean values for static coefficient of friction for wood, galvanized steel, mild steel and glass were 0.41, 0.42, 0.41 and 0.41, respectively. As the moisture content increased, the static coefficient of friction against the selected surfaces increased. The same increase was observed for sunflower seeds and millet by Gupta and Das (2000) and Baryeh (2002). This may be due to the fact that an increase in moisture content increased the cohesion between the seeds, thus increasing the friction the seed experiences during its flow/movement on the respective surfaces (Balasuramanian and Vismanathan 2010). In this study, galvanized steel had the highest mean value of 0.42 while others had the same mean value of 0.41. The little variation between wood and galvanized steel was similar to that reported for pulse grains by Amin et al. (2004). Tunde-Akintunde and Olajide (2005) also reported low coefficient of friction values on wood for soybeans comparable to that observed for the improved paddy rice varieties. The effect of variety was significant ($P<0.05$) for all the mechanical properties. Also the interactive effect of variety and moisture content on the parameters was significant ($P<0.05$).

The correlations between grain moisture content, physical dimension and engineering properties are presented in Table 5. Significant ($P<0.05$) strong engineering correlations existed between grain moisture content and mass of 100 seeds, length, true volume, porosity and angle of repose while a significant ($P<0.05$) negative correlations was found between grain moisture content and bulk density. Mass of 100 seeds, width, arithmetic mean diameter and effective geometric diameter showed significant ($P<0.05$)

Table 4 The effect of variety and moisture content on the mechanical properties of improved paddy rice varieties

Variety	Moisture content	Angle of repose (°)	Coefficient of static friction			
			Plywood	Galvanized steel	Mild steel	Glass
FARO55	10%	25.3	0.41	0.41	0.39	0.42
	20%	24.8	0.42	0.42	0.39	0.41
	30%	29.1	0.41	0.39	0.36	0.36
FARO44	10%	21.8	0.37	0.39	0.37	0.40
	20%	23.1	0.43	0.43	0.40	0.42
	30%	24.3	0.45	0.46	0.42	0.45
FARO52	10%	25.2	0.40	0.41	0.40	0.42
	20%	25.2	0.44	0.59	0.46	0.34
	30%	25.1	0.46	0.40	0.44	0.41
NERICA L34	10%	24.8	0.46	0.46	0.42	0.44
	20%	23.8	0.42	0.38	0.42	0.40
	30%	26.7	0.34	0.35	0.41	0.41
FARO49	10%	24.3	0.41	0.40	0.38	0.42
	20%	26.4	0.40	0.40	0.40	0.37
	30%	27.8	0.40	0.41	0.43	0.42
Mean		25.2	0.41	0.42	0.41	0.41
Standard deviation		1.80	0.03	0.05	0.03	0.03
SE		0.48	0.01	0.01	0.01	0.01
CV		7.16	7.61	13.02	6.48	6.87
P of variety		[a]	[a]	[a]	[a]	[a]
P of initial moisture content		[a]	[a]	[a]	[a]	[a]
P of variety X initial moisture content		[a]	[a]	[a]	[a]	[a]

Values are means of three replicates

[a] significantly different ($P<0.05$)

Table 5 Correlation coefficients between initial moisture content, physical dimensions and engineering properties of improved paddy rice varieties

	MC	Physical dimensions								Engineering Properties						
		M100	Length	Width	Thick-ness	AMD	EGD	Sphe	SA	AV	TV	TD	BD	Poro	AR	AOR
MC	1															
M100	0.665[a]	1														
Length	0.763[a]	0.417	1													
Width	0.243	0.740[a]	0.156	1												
Thickness	0.115	0.386	−0.015	0.241	1											
AMD	0.388	0.811[a]	0.321	0.974[a]	0.343	1										
EGD	0.430	0.834[a]	0.319	0.967[a]	0.318	0.987[a]	1									
Sphe	0.000	0.576[b]	−0.254	0.875[a]	0.422	0.810[a]	0.799[a]	1								
SA	0.400	0.818[a]	0.321	0.974[a]	0.342	0.999[a]	0.989[a]	0.813[a]	1							
AV	0.369	0.809[a]	0.283	0.979[a]	0.348	0.999[a]	0.986[a]	0.834[a]	0.999[a]	1						
TV	0.655[a]	0.960[a]	0.391	0.798[a]	0.374	0.856[a]	0.875[a]	0.648[a]	0.862[a]	0.853[a]	1					
TD	−0.129	−0.025	0.023	−0.232	0.017	−0.194	−0.226	−0.238	−0.197	−0.192	−0.286	1				
BD	−0.904[a]	−0.624[b]	−0.651[a]	−0.202	−0.188	−0.312	−0.362	−0.046	−0.331	−0.299	−0.598[b]	0.081	1			
Poro	0.555[b]	0.475	0.334	−0.026	0.212	0.068	0.088	−0.056	0.083	0.069	0.269	0.633[b]	−0.677[a]	1		
AR	0.058	0.625[b]	−0.095	0.965[a]	0.221	0.893[a]	0.886[a]	0.946[a]	0.893[a]	0.909[a]	0.691[a]	−0.226	−0.046	−0.101	1	
AOR	0.544[b]	0.625[b]	0.364	0.470	0.227	0.536[b]	0.562[b]	0.360	0.530[b]	0.530[b]	0.658[a]	−0.158	−0.471	0.199	0.415	1

[a] Correlation is significant at the 0.01 level (2-tailed)

[b] Correlation is significant at the 0.05 level (2-tailed)

MC Moisture content; *M100* Mass of 100 seeds; *AMD* Arithmetic mean diameter; *EGD* Effective geometric diameter; *Sphe* Sphericity; *SA* Surface area; *AV* Apparent volume; *TV* True volume; *TD* True density; *BD* Bulk density; *Poro* Porosity; *AOR* Angle of repose

Table 6 Regression equations showing the interdependency of grain moisture content and engineering properties of improved paddy rice varieties

	Improved paddy rice varieties				
	FARO55	FARO44	FARO52	NERICA L34	FARO49
Surface Area (mm^2)	SA=3.15 M+37.93 R^2=0.91	SA=1.15 M+40.433 R^2=0.92	SA=0.6 M+40.933 R^2=0.83	SA=1.9 M+37.6 R^2=0.88	SA=2.95 M+45.133 R^2=0.90
Porosity (%)	*P*=-4.15 M+5.03 R^2=0.75	*P*=1.8 M+38.8 R^2=0.92	*P*=4.3 M+29.83 R^2=0.72	*P*=2 M+40.367 R^2=0.51	*P*=0.4 M+41.8 R^2=0.84
Aspect Ratio (%)	AR=0.95 M+26.133 R^2=0.54	AR=0.65 M+23.7 R^2=0.53	AR=-0.65 M+27 R^2=0.86	AR=0.25 M+23.5 R^2=0.89	AR=-0.05 M+32.567 R^2=0.50
Angle of Repose (°)	*R*=1.9 M+22.6 R^2=0.65	*R*=1.25 M+20.567 R^2=1	*R*=-0.05 M+25.267 R^2=0.75	*R*=0.95 M+23.2 R^2=0.72	*R*=1.75 M+22.667 R^2=0.99
Arithmetic Mean Diameter (mm)	AMD=1.9 M+133.833 R^2=0.92	AMD=0.7 M+15.3 R^2=0.94	AMD=0.3 M+15.767 R^2=0.80	AMD=1.05 M+13.867 R^2=0.89	AMD=1.9 M+18.1 R^2=0.88
Apparent Volume (cm^3)	AV=1.75 M+12.433 R^2=0.87	AV=0.6 M+13.7 R^2=0.92	AV=0.25 M+14.1 R^2=0.50	AV=0.95 M+12.233 R^2=0.90	AV=1.7 M+16.433 R^2=0.90
Length (mm)	L=0.25 M+8.83 R^2=0.60	L=0.2 M+9.2333 R^2=0.92	L=0.2 M+9.1667 R^2=0.75	L=0.2 M+9.3 R^2=1	L=0.3 M+9.0333 R^2=0.96
Effective Mean Diameter (mm)	EMD=0.15 M+3.4667 R^2=0.96	EMD=0.05 M+3.5667 R^2=0.75	EMD=0.05 M+3.5667 R^2=0.75	EMD=0.2 M+3.4333 R^2=0.75	0.1 M+3.8333 R^2=0.75
True Volume (cm^3)	TV=0.3 M+2.667 R^2=0.96	TV=0.3 M+2.3667 R^2=0.96	TV=0.2 M+2.3667 R^2=0.92	TV=0.45 M+1.8667 R^2=1	TV=0.4 M+2.7333 R^2=0.99
Width (mm)	W=0.15 M+2.3 R^2=0.75	W=0.1 M+2.2333 R^2=0.75	W=0.1 M+2.3 R^2=1	W=0.1 M+2.1333 R^2=0.75	W=0.1 M+2.9333 R^2=0.75
Thickness (mm)	T=0.05 M+2.0667 R^2=0.75	T=-0.1 M+2.33 R^2=0.43	T=0.075 M+2.0167 R^2=0.96	T=0.05 M+2.0333 R^2=0.75	T=0.05 M+2.0667 R^2=0.75
True Density (g/cm^3)	TD=0.025 M+0.933 R^2=0.75	TD=−0.015 M+1.02 R^2=0.75	TD=−0.025 M+0.8867 R^2=0.51	TD=−0.055 M+1.14 R^2=0.82	TD=−0.015 M+1 R^2=0.55
Bulk Density (g/cm^3)	BD=−0.035 M+0.6433 R^2=0.99	BD=−0.03 M+0.6333 R^2=0.96	BD=−0.03 M+0.6367 R^2=0.96	BD=−0.055 M+0.68 R^2=0.98	BD=−0.015 M+0.6033 R^2=0.52
Mass of 100 seeds (g)	MS=0.35 M+2.5333 R^2=0.99	MS=0.25 M+2.4733 R^2=0.99	MS=0.3 M+2 R^2=1	MS=0.5 M+2.1667 R^2=0.99	MS=0.35 M+2.7333 R^2=0.99
Coefficient of static friction (on glass surface)	CG=−0.03 M+0.4667 R^2=0.99	CG=0.25 M+0.3733 R^2=0.99	CG=−0.005 M+0.4 R^2=0.51	CG=−0.015 M+0.4467 R^2=0.52	CG=−0.025 M+0.4533 R^2=0.75
Coefficient of static friction (on galvanized steel surface)	CV=−0.01 M+0.427 R^2=0.43	CV=0.035 M+0.3567 R^2=0.99	CV=0.005 M+0.4767 R^2=0.52	CV=−0.055 M+0.5067 R^2=0.94	CV=0.005 M+0.3933 R^2=0.75
Coefficient of static friction (on mild steel surface)	CM=−0.015 M+0.41 R^2=0.78	CM=0.025 M+0.3467 R^2=0.99	CM=0.02 M+0.39333 R^2=0.73	CM=−0.005 M+0.4267 R^2=0.75	CM=0.025 M+0.3533 R^2=0.99

positive correlations with sphericity, surface area, true volume, apparent volume, and angle of repose; but negatively correlated with bulk density. Table 6 presents regression equations showing the interdependency of grain moisture content and some engineering properties of improved paddy rice varieties. The equations showed linear relationships between grain moisture content and the engineering properties with relatively strong coefficients of determination (R^2) indicating that the equations are suitable for predicting the interactions between grain moisture content and engineering properties of improved paddy rice varieties. Similar relationship had been reported for different minor millets by Balasubramanian and Viswanathan (2010).

Conclusion

The effect of variety and initial moisture content on some engineering properties of improved paddy rice varieties was reported. The linear dimensions, mass of 100 seeds, surface area, apparent volume, true volume, arithmetic mean diameter, effective geometric diameter, sphericity, angle of repose, porosity and static coefficient of friction increased with increase grain moisture content irrespective of variety. Bulk density and true density decreased with increase in moisture content in all the varieties. Static coefficient of friction was increased from 0.34–0.46, 0.35–0.59, 0.36–0.46 and 0.34–0.45, respectively on plywood, galvanized steel, mild steel and glass structural surfaces as moisture content increased. The highest static coefficient was found on galvanized steel. The physical, engineering and mechanical properties of the improved paddy rice varieties were significantly affected by variety and moisture content.

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