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Effect of ratooning process on the engineering properties of NERICA rice varieties

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RESEARCH ARTICLE

Abstract

Rice ratooning is the practice of harvesting grain from tillers originating from the stubble of previously harvested crop. Comparative assessment of the engineering properties of main and ratooned NERICA rice varieties was investigated in this study. The length, width, thickness, arithmetic mean diameter, geometric mean diameter, equivalent diameter and surface area ranged from 8.21 to 10.62 mm, 2.31 to 3.60 mm, 1.67 to 2.28 mm, 13.10 to 22.67 mm, 3.26 to 3.87 mm, 6.35 to 9.98 mm, 23.15 to 42.02%, 34.20 to 51.31 mm and from 0.35 to 0.48 mm^2, respectively. Bulk density, true density, porosity, thousand grain weight and volume ranged from 0.63 to 1.14 g/cm^3, 0.55 to 0.67 g/cm^3, 1.48 to 45.91%, 21.66 to 27.41 g and from 0.023 to 0.031 mm^3, respectively. Coefficient of static friction on polished wood, plywood, metal and glass ranged from 0.35 to 0.47, 0.34 to 0.44, 0.26 to 0.34 and 0.14 to 0.21, respectively. Filling and emptying angle of repose ranged from 34.79 to 42.00 and from 46.57° to 67.74°, respectively. There were significant differences ($P<0.05$) in the physical properties of the main and ratooned rice grains except bulk density, filling and emptying angle of repose. This study concluded that significant varietal differences existed among the different rice varieties and that the engineering properties of the main NERICA rice were significantly different from the ratooned crops.

Keywords: engineering properties, rice, ratooning

1. Introduction

Rice (*Oryza sativa*) is a cereal belonging to the Poaceae, a large monocotyledon family of some 600 genera and about 10,000 species (Abulude, 2004). Rice is the staple food for more than 3 billion people (about half the world's population) providing 27% of dietary energy and 20% of dietary protein in the developing world (http://faostat3.fao.org). Rice is cultivated in about 114 countries, most of which are developing countries and it is the primary source of income and employment for more than 100 million household in Asia and Africa (http://faostat3.fao.org; Gharekhani *et al.*, 2013). In developing countries, rice is one of the main dietary sources of macro nutrient (carbohydrate and protein) as well as micronutrient such as calcium and zinc (Lieng *et al.*, 2008).

The New Rice for Africa Lowland (NERICA-L) is a research result of Africa Rice Center (formerly known as West Africa Rice Development Association), which is a new lowland rice variety that is perfectly adapted to the rain fed lowland ecology. The NERICA rice variety seeds offers hope to millions of poor farmers and countless others who struggle in urban areas, spending most of their meagre income on rice (Caulibaly, *et al.*, 2006). Today, rice is no longer a luxury food to millions of Nigerians but has become the cereal that constitutes a major source of calories for the rural and urban poor with demand growing at an annual rate of 5% (Bzugu, *et al.*, 2010).

Rice ratooning is the practice of harvesting grain from tillers originating from the stubble of previously harvested crop. This method utilises the rice stubbles from the previous harvest, allowing the apical buds on the stubbles to develop into full-grown plants which would later flower and produce seeds for another harvest. There are many positive effects of this method. There is neither the need to burn the paddy fields, re-till the soil nor buy new seeds. It also reduces the amount of water needed and other production factors. It enhances rice grain yield without increasing land area because it provides higher resources use efficiency per unit land area per unit time (Jason *et al.*, 2005). This study was conducted to determine some engineering properties of main and ratooned NERICA rice varieties.

2. Materials and methods

Nine NERICA rice varieties, namely NERICA-L 19, NERICA-L 20, NERICA-L 41, NERICA-L22, NERICA-L 24, NERICA-L 26, NERICA-L 42, NERICA-L 44, NERICA-L 47, and OFADA (both the main and ratoon), were obtained from the Department of Plant Physiology and Crop Production of the Federal University of Agriculture, Abeokuta, Nigeria. The rice varieties were planted during the 2008-2009 cropping seasons at the bottom of the inland valley of the Federal University of Agriculture, Abeokuta (7°20`N, 3°23`E), Nigeria. The experiment was laid out in a randomised complete block design with three replicates. The plot size was 3×2 m. Rice was planted using the dry seeded dibbling method by sowing 4-6 seeds per hole at a spacing of 20 cm between and within rows. Missing stands were filled with transplants 14 days after planting (DAP) while thinning stands in excess of three plants. This gave a population of 250,000 stands/ha. Fertiliser was applied as a split application according to fertiliser recommendations for lowland rice based on the soil test of south-western Nigeria (Enwezor *et al.*, 2002). The first application of fertiliser for the main crop was 30 kg N/ha, 15 kg P/ha and 15 K/ha in the form of compound fertiliser (NPK 20:10:10) at 21 DAP, while the second was 55 kg N/ha (urea) applied at 80 DAP. The level of N applied at 80 DAP (prior to heading) was intended to keep the culms green for ratooning after harvesting. The rainfall and temperature data during the study period are presented in Figure 1 and 2 (Adigbo *et al.*, 2012). Rice was harvested by cutting the rice culms at 5-10 cm above the soil when the rice grains had turned straw colour. After the harvest of lowland rice, the ratooned rice crop was treated with a single dose of 60 kg/ha fertiliser in the form of NPK 20:10:10 at 14 days after rationing. The life cycle of main crop stretched across the two peaks of rainfall with the associated cloudy weather, low light intensity and low temperature, which are below the optimum level for the performance of the rice plant. However, the life cycle of ratooned rice commenced at the peak of the second rainy season (September), and it matured in the dry season (December) when there is little or no rain but sufficient residual moisture for optimum growth (Adigbo *et al.*, 2007).

Sample preparation

The rice grains were cleaned manually to remove all stones, weed seeds, straw and damaged or unhealthy grains. The clean paddy was used for the analysis. The moisture content of the paddy rice ranged between 8.49 and 10.77%. The grains were packaged inside zip-lock polyethylene sample bags and stored at 4 °C for analysis.

Determination of linear dimensions

Linear dimensions i.e. length (L), width (W) and thickness (T) were measured using a micrometer screw gauge with an accuracy of 0.01 mm (Mohsenin, 1986). The arithmetic mean diameter (D_a) and the geometric mean diameter (D_g) were then calculated using the following relationship as described by Mohsenin (1986):

$$D_a = \frac{L \times W \times T}{3} \quad (1)$$

$$D_g = (L \times W \times T)^{1/3} \quad (2)$$

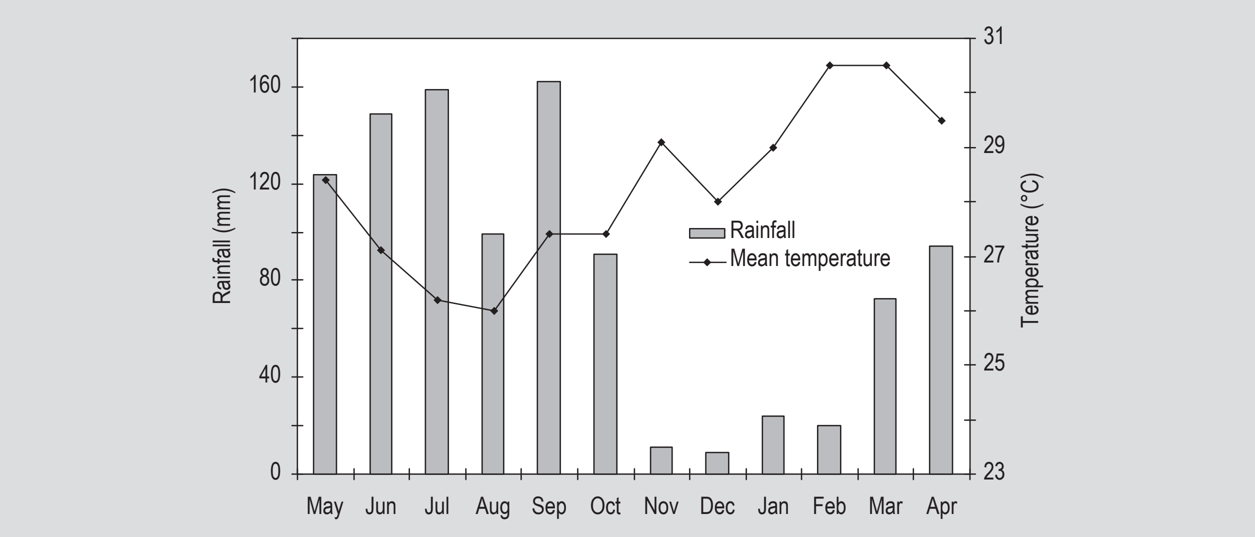

Figure 1. Rainfall and mean temperature of the agricultural calendar for 1982-2008 at Abeokuta, Nigeria (Adigbo *et al.*, 2012).

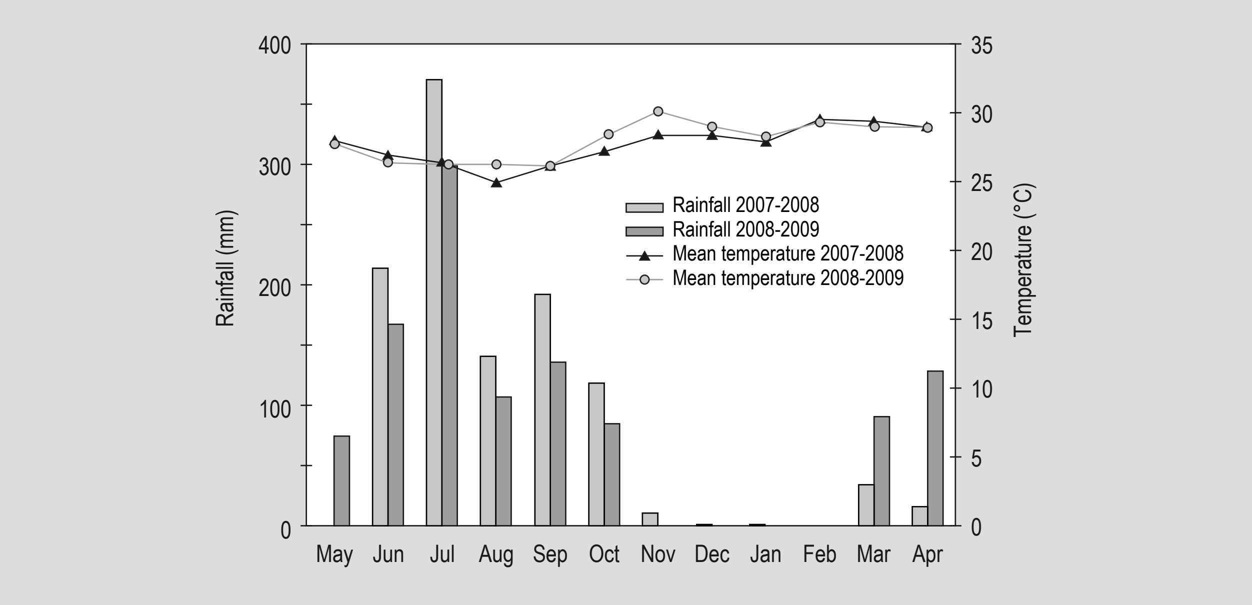

Figure 2. Rainfall and mean temperature for 2007-2008 and 2008-2009 cropping seasons at Abeokuta, Nigeria (Adigbo *et al.,* 2012).

Determination of volume, bulk density, true density and porosity

The volume of the rice grains was determined by water displacement method as described by Oje and Ugbor (1991). The bulk density (ρ_b), and true density (ρ_t) of the rice grains were determined using the method described by Mohsenin (1986). The bulk density of grain was calculated as the ratio of the bulk weight and the volume of the container:

$$\rho_b = \frac{m}{v} \tag{3}$$

Where m is the mass of rice grain in g and v container volume in m^3.

The true density (ρ_t) was calculated as:

$$\rho_t = \frac{m}{vm} \tag{4}$$

Where m = grain weight and vm= volume of displaced water (m^3).

Porosity (ε) was determined using an expression described by Jain and Bal (1997):

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

Determination of 1000 grains weight and sphericity

The weight of 1000 grains was determined using a method described by Varnamkhasti *et al.* (2007) while the sphericity (Φ) was determined according to Mohsenin (1986) method:

$$\Phi = \frac{(L \times W \times T)^{1/3}}{L} \tag{6}$$

Size and shape

A micrometer screw gauge with least resolution counts 0.01 mm was used to determine the diameter of the rice grains. Three groups of 50 rice grain samples were drawn randomly from each sample. From each group, 20 grains were picked randomly and were thoroughly mixed together from which 30 rice grains were randomly selected. Its square mean diameter (D_s) and equivalent diameter (D_e) were calculated using the following equations given by Aseogwu *et al.* (2006):

$$D_e = \frac{D_a + D_g + D_s}{3} \tag{7}$$

$$D_s = \left[\frac{(L \times W) + (W \times T) + (L \times T)}{3}\right]^{1/3} \tag{8}$$

Aspect ratio (AR) was determined using the relationship given by Maduako and Faborode (1990):

$$AR = \frac{W}{L} \times 100 \tag{9}$$

Surface area

Surface area (*S*) was determined using the expression described by Jain and Bal (1997):

$$S = \frac{\pi \times B \times L^2}{(2L - B)} \tag{10}$$

Where $B = WT^{½}$.

Angle of repose

This was determined using the method described by Razavi *et al.* (2007). The filling angle of repose (f) was calculated using the equation:

$$f = \arctan\left(\frac{2 - H}{D}\right) \tag{11}$$

Where H is the height of the cone and D is the cone diameter.

The method described by Joshi *et al.* (1993) was used to determine the funnelling angle of repose. The emptying angle of repose (e) was calculated from the measurement of the depth of the free surface of the sample at the centre using the equation (Paksoy and Aydin, 2004):

$$e = \arctan\left(\frac{2 \times H}{x}\right) \tag{12}$$

Where x = radius of the heap.

Coefficient of static friction

The coefficient of static friction (μ) was determined with respect to four surfaces: polished wood, plywood, galvanised iron and glass. These are common materials used for handling and processing of grains and construction of storage and drying bins. A hollow metal cylinder 5 mm diameter and 50 mm high and opened at both ends was filled with the grains and placed on an adjustable tilting table such that the metal cylinder does not touch the table surface. The tilting surface was raised gradually by means of a screw device until the cylinder just starts to slide down. The angle of the surface was read from a scale and the static coefficient of friction was taken as the tangent of this angle (Singh and Goswami, 1996).

Statistical analysis

The data were subjected to statistical analysis of variance (ANOVA) and means separated with Duncan Multiple Range Test using SPSS version 16.0 (IBM SPSS, Inc., Chicago, IL, USA).

3. Results

Linear dimensions

The values of the linear dimension of the main NERICA lowland rice varieties and their ratoons are shown in Table 1. The length, width, and thickness varied between 8.21 and 10.62 mm, 2.31 and 3.35 mm, and 1.67 and 2.28 mm, respectively. The lengths of the grains of all the varieties were significantly different ($P<0.05$) from each other. For the main crop, the OFADA variety had the shortest length of 8.21 mm while the NERICA-L 19 variety had the longest length of 10.62 mm. Of the ratoon samples, the OFADA ratoon had the shortest length of 8.61 mm while that of NERICA-L 42 and 20 were the longest and had the same length with its main crop. Apart from the NERICA-L 42, OFADA and NERICA-L 26 varieties, the ratoons of the other varieties were significantly shorter in length than their corresponding main crop.

The ratoon of the OFADA variety had the highest width of 3.60 mm and significantly wider than its main crop, while the ratoon sample of NERICA-L 26 had the lowest width of 2.31 mm. All the grains from the ratoon samples were lower in width than those from the main crop except for those of NERICA-L 42 and 47 which were not different from their main crop and ratooned OFADA which was higher. The OFADA variety had the highest thickness and its ratoon was not significantly different from it at 95% confidence limit. The ratoon crop of variety NERICA-L 24 had the lowest thickness and differed significantly from its main crop at 95% confidence limit. The thickness of all the ratoon samples differed significantly ($P<0.05$) from their main crops except for those of the OFADA and NERICA-L 47.

The arithmetic mean diameter, geometric mean diameter (GMD) and equivalent diameter (EqD) were in the range 13.10-22.67 mm, 3.26-3.87 mm and 6.35-9.98 mm, respectively. The arithmetic mean diameter was highest for the ratooned OFADA crop and it differed significantly ($P<0.05$) from its main crop, which was lower. The ratoons of the NERICA varieties were significantly lower than their main crop counterparts with the exception of NERICA-L 47 which had the same value as the main crop. The ratoon of NERICA-L 22 and NERICA-L 26 had the least arithmetic mean diameter. The ratoon of the OFADA variety had the highest geometric mean diameter and differed significantly from that of its main crop. The ratoon of NERICA-L 22, NERICA-L 24, and NERICA-L 26 had the least geometric mean diameter. All the GMDs of the ratooned crops were considerably lower than their main crops except for that of NERICA-L 44, which was the same with that of its main crop, and the OFADA ratoon which was higher.

For the EqD, there was significant difference ($P<0.05$) among the rice varieties. The ratoons also differed significantly

Table 1. Effect of ratooning processes on some linear dimensions of NERICA lowland rice varieties.[1]

Variety	Cropping system[2]	Length (mm)	Width (mm)	Thickness (mm)	AMD (mm)[3]	GMD (mm)[3]	EqD (mm)[3]	AR (%)[3]	SA (mm^2)[3]	Sphericity
NERICA-L 19	MC	10.62^{k}	2.70^{efg}	2.19^{h}	20.43^{h}	3.87^{i}	9.13^{h}	25.43^{bc}	47.33^{h}	0.37^{cd}
	RC	9.76^{hi}	2.40^{b}	2.20^{ef}	15.23^{b}	3.52^{bc}	7.27^{b}	24.65^{b}	39.53^{b}	0.37^{bc}
NERICA-L 20	MC	10.54^{k}	2.68^{efg}	2.21^{hi}	20.27^{h}	3.86^{hi}	9.10^{h}	25.42^{bc}	47.39^{gh}	0.37^{cde}
	RC	10.14^{j}	2.34^{ab}	1.93^{cd}	14.90^{b}	3.48^{b}	7.12^{b}	23.15^{a}	38.73^{b}	0.35^{a}
NERICA-L 41	MC	9.51^{fg}	2.81^{i}	2.03^{ef}	17.47^{cde}	3.68^{def}	8.10^{cde}	29.63^{hi}	43.20^{cde}	0.39^{ij}
	RC	9.25^{cde}	2.65^{efg}	1.88^{bc}	14.87^{b}	3.48^{b}	7.12^{b}	28.72^{gh}	38.83^{b}	0.38^{gh}
NERICA-L 22	MC	9.89^{ij}	2.71^{fgh}	2.10^{fg}	18.23^{def}	3.72^{efg}	8.36^{ef}	27.43^{ef}	44.40^{def}	0.38^{gh}
	RC	9.02^{c}	2.39^{b}	1.88^{bc}	13.10^{a}	3.33^{a}	6.45^{a}	26.48^{cde}	35.73^{a}	0.38^{defg}
NERICA-L 24	MC	9.61^{gh}	2.91^{j}	2.11^{g}	19.17^{fg}	3.79^{gh}	8.70^{fg}	30.34^{i}	45.87^{fg}	0.40^{j}
	RC	9.11^{cd}	2.50^{c}	1.67^{a}	12.27^{a}	3.26^{a}	6.14^{a}	27.50^{ef}	34.20^{a}	0.36^{bc}
NERICA-L 26	MC	9.32^{def}	2.63^{def}	1.98^{de}	15.70^{b}	3.56^{c}	7.45^{b}	28.29^{fg}	40.23^{b}	0.39^{hi}
	RC	9.40^{efg}	2.31^{a}	1.83^{b}	12.83^{a}	3.33^{a}	6.35^{a}	24.62^{b}	35.17^{a}	0.36^{b}
NERICA-L 42	MC	10.04^{j}	2.76^{hi}	2.20^{h}	19.87^{gh}	3.82^{hi}	8.95^{h}	27.56^{ef}	46.83^{gh}	0.39^{hi}
	RC	10.06^{j}	2.70^{fgh}	2.09^{fg}	18.40^{ef}	3.74^{fg}	8.43^{ef}	26.87^{de}	44.63^{ef}	0.38^{defg}
NERICA-L 44	MC	10.38^{k}	2.81^{i}	2.18^{h}	20.63^{h}	3.66^{de}	9.26^{h}	27.20^{ef}	48.13^{h}	0.38^{efgh}
	RC	9.92^{ij}	2.72^{gh}	2.07^{fg}	18.10^{de}	3.71^{ef}	8.32^{de}	27.48^{ef}	44.10^{de}	0.38^{fgh}
NERICA-L 47	MC	9.95^{ij}	2.57^{cd}	2.08^{fg}	17.23^{cd}	3.87^{i}	7.98^{cd}	25.80^{cd}	42.77^{cd}	0.37^{cdef}
	RC	9.54^{fgh}	2.62^{de}	2.09^{fg}	16.97^{c}	3.64^{d}	7.89^{c}	27.56^{ef}	42.17^{c}	0.39^{hi}
OFADA	MC	8.21^{a}	3.35^{k}	2.28^{i}	20.47^{h}	3.52^{bc}	9.13^{h}	40.99^{j}	47.70^{h}	0.48^{k}
	RC	8.61^{b}	3.60^{l}	2.24^{hi}	22.67^{i}	4.00^{j}	9.98^{i}	42.02^{j}	51.13^{i}	0.47^{k}
Variety[4]		***	***	***	***	***	***	***	***	***
Ratooning[4]		***	***	***	***	***	***	***	***	***
Variety × Ratooning[4]		***	***	***	***	***	***	***	***	***

[1] Means (n=30) followed by different superscript letters within the same column are significantly different (*P*<0.05).

[2] MC = main crop; RC = ratoon crop.

[3] AMD = arithmetic mean diameter; GMD = geometric mean diameter; EqD = equivalent diameter; AR = aspect ratio; SA = surface area.

[4] *** = significant at *P*<0.05.

from the main crop ($P<0.05$). The ratoon of NERICA-L 24 had the least value which was not significantly different ($P>0.05$) from the ratoon of NERICA-L 22 and NERICA-L 26. The ratoon of OFADA variety had the highest EqD. The EqD of all the ratooned rice grains were significantly lower than those of the main crop except NERICA-L 47 and OFADA.

The aspect ratio (AR), surface area and sphericity ranged from 23.15 to 42.02%, 34.20 to 51.31 mm^2 and from 0.35 to 0.48, respectively. Two-way analysis of variance of these physical characteristics showed that the NERICA varieties differed significantly ($P<0.05$) from each other and also the main crops differed significantly from the ratooned grains. For the AR, the varieties differed significantly from each other at 95% confidence limit. The ratoons did not differ significantly from their corresponding parent plant except for those of varieties NERICA-L 24, 26 and 47. The ratoon of NERICA-L 24 had the lowest surface area value while the ratooned OFADA had the highest value. The surface area of the main crop differed significantly ($P<0.05$) from each other, the ratooned samples also differed significantly from their parent grains except for that of NERICA-L 47 which did not differ from its parent crop. The sphericity of the ratooned samples differed significantly ($P<0.05$) from their main crops except for NERICA-L 19, 22, 44 and OFADA varieties.

Bulk grain properties

The bulk grain properties of the main and ratooned crop of the NERICA rice varieties are presented in Table 2. True density, bulk density, and porosity ranged between 0.63 and 1.14 g/m^3, 0.55 and 0.67 g/m^3, and between 1.48 and 45.91%, respectively. The 1000 grains weight and grain volume ranged from 21.66-27.49 g and 0.023-0.031 mm^3, respectively. The main effect of variety was generally found to be significant ($P<0.05$) on the bulk density. There were no significant differences in the bulk densities of the ratooned crop ($P>0.05$). NERICA-L 44 had the lowest bulk

Table 2. Effect of ratooning processes on some bulk grain properties of NERICA lowland rice varieties.[1]

Variety	Cropping system[2]	True density (g/m^3)	Bulk density (g/m^3)	Porosity (%)	TKW (g)[3]	Single kernel volume (mm^3)
NERICA-L 19	MC	0.79^{cde}	0.58^{c}	26.74^{de}	27.49^{k}	0.028^{efg}
	RC	1.04^{gh}	0.60^{def}	42.45^{ghi}	24.04^{bcdef}	0.026^{bcde}
NERICA-L 20	MC	0.77^{cd}	0.59^{cde}	33.71^{cd}	27.35^{k}	0.032^{i}
	RC	1.04^{gh}	0.60^{ef}	42.38^{ghi}	24.87^{defghi}	0.026^{bcde}
NERICA-L 41	MC	0.83^{def}	0.61^{fg}	26.60^{de}	24.18^{bcdefg}	0.026^{bcde}
	RC	1.00^{g}	0.60^{def}	40.59^{ghi}	23.59^{bcde}	0.027^{cdef}
NERICA-L 22	MC	0.86^{ef}	0.59^{cd}	31.94^{ef}	26.17^{ijk}	0.027^{def}
	RC	1.02^{g}	0.62^{hijk}	39.09^{gh}	21.66^{a}	0.026^{cdef}
NERICA-L 24	MC	0.63^{a}	0.61^{ghi}	12.27^{a}	25.33^{fghi}	0.028^{defg}
	RC	1.00^{g}	0.55^{a}	44.97^{hi}	22.71^{ab}	0.024^{ab}
NERICA-L 26	MC	0.74^{bc}	0.59^{cde}	19.50^{bc}	23.22^{bc}	0.023^{a}
	RC	1.14^{i}	0.62^{hij}	45.91^{i}	23.51^{bcd}	0.026^{bcde}
NERICA-L 42	MC	1.00^{g}	0.62^{hij}	38.40^{g}	24.81^{hij}	0.031^{i}
	RC	0.87^{f}	0.63^{k}	26.56^{de}	25.43^{ghi}	0.029^{fgh}
NERICA-L 44	MC	0.90^{f}	0.57^{b}	37.20^{fg}	24.98^{defghi}	0.025^{abc}
	RC	1.00^{g}	0.61^{gh}	39.11^{gh}	24.44^{cdefgh}	0.028^{def}
NERICA-L 47	MC	0.74^{bc}	0.62^{ijk}	15.01^{b}	23.72^{bcde}	0.026^{bcd}
	RC	1.10^{hi}	0.63^{jk}	42.71^{ghi}	23.81^{bcdef}	0.027^{cdef}
OFADA	MC	0.66^{ab}	0.67^{l}	11.48^{a}	27.14^{jk}	0.031^{hi}
	RC	1.00^{g}	0.61^{gh}	38.99^{gh}	25.10^{efghi}	0.030^{ghi}
Variety[4]		***	***	***	***	***
Ratooning[4]		***	ns	***	***	*
Variety × Ratooning[4]		***	ns	***	***	*

[1] Means (n=3) followed by different superscript letters within the same column are significantly different ($P<0.05$).

[2] MC = main crop; RC = ratoon crop.

[3] TKW = 1000 grains weight.

[4] ns = not significant; *** = significant at $P<0.01$; * = significant at $P<0.05$.

density while OFADA had the highest value. The interactive effect of variety and ratooning were found to be significant ($P<0.05$) on the true density of the main and ratooned rice. It was observed that the true densities of the ratoons were higher than their main crop except for that of NERICA-L 42 that was lower than its main crop. There was significant difference ($P<0.05$) in the 1000 grains weight of the main crop and ratooned rice samples. For some of the varieties, the corresponding ratoon did not differ significantly from the main crop. These varieties were NERICA-L 21, 26, 42, 44 and 47. The ratoons of varieties NERICA-L 19, 20, 22, 24 and OFADA differed significantly from their main crops. OFADA variety had the least porosity while the ratoon of NERICA-L 26 had the highest. The interactive effect of variety and ratooning were found to be significant ($P<0.05$) on the porosity of the main and ratooned crops.

Coefficient of static friction

The effect of variety and ratooning on the coefficient of static friction of NERICA rice varieties is shown in Table 3. This was determined on four different surfaces namely polished wood, plywood, metal and glass for all the main crops and their ratoons. The coefficients on polished wood, plywood, metal and glass ranged between 0.35 and 0.47, 0.34 and 0.44, 0.26 and 0.34, and between 0.14 and 0.21, respectively. The coefficients of static friction of the main crops were significantly different from the ratooned crops ($P<0.05$) for all the NERICA varieties. For the coefficient on polished wood, the ratoons were lower than their main crops and differed significantly ($P<0.05$) except for NFRICA-L 26, which was significantly ($P<0.05$) higher than its parent and OFADA that did not differ from its parent crop. As with the polished wood, the ratoons have lower coefficients than the main crops on plywood except for varieties NERICA-L 26 and 42, which did not differ significantly from their main crop, and OFADA that was

Table 3. The effect of ratooning processes on coefficient of static friction (μ) of NERICA lowland rice varieties.[1]

Variety	Cropping system[2]	Polished wood	Plywood	Metal	Glass
NERICA-L 19	MC	0.44^{fgh}	0.41^{fg}	0.33^{l}	0.18^{cd}
	RC	0.42^{def}	0.38^{bc}	0.31^{ghij}	0.14^{a}
NERICA-L 20	MC	0.47^{i}	0.41^{defg}	0.34^{l}	0.20^{g}
	RC	0.36^{ab}	0.37^{bc}	0.32^{jk}	0.18^{cd}
NERICA-L 41	MC	0.44^{gh}	0.41^{efg}	0.32^{ijk}	0.19^{fg}
	RC	0.37^{abc}	0.37^{b}	0.30^{cdef}	0.18^{cd}
NERICA-L 22	MC	0.42^{efg}	0.41^{efg}	0.31^{fghij}	0.20^{fg}
	RC	0.38^{bc}	0.39^{bcdef}	0.28^{b}	0.18^{cde}
NERICA-L 24	MC	0.41^{de}	0.43^{gh}	0.33^{kl}	0.19^{fg}
	RC	0.35^{a}	0.37^{b}	0.26^{a}	0.18^{bc}
NERICA-L 26	MC	0.36^{ab}	0.38^{bc}	0.32^{jk}	0.21^{h}
	RC	0.39^{cd}	0.38^{bc}	0.30^{cde}	0.19^{efg}
NERICA-L 42	MC	0.43^{efg}	0.39^{bcde}	0.29^{c}	0.20^{fg}
	RC	0.36^{ab}	0.37^{b}	0.29^{cde}	0.20^{g}
NERICA-L 44	MC	0.41^{de}	0.44^{h}	0.31^{fghij}	0.19^{fg}
	RC	0.37^{abc}	0.39^{bcde}	0.30^{efghi}	0.19^{defg}
NERICA-L 47	MC	0.45^{h}	0.37^{b}	0.29^{cd}	0.19^{cdef}
	RC	0.41^{def}	0.40^{cdef}	0.30^{defg}	0.18^{bc}
OFADA	MC	0.38^{bc}	0.34^{a}	0.31^{hij}	0.17^{b}
	RC	0.38^{bc}	0.38^{bcd}	0.31^{efghi}	0.18^{cde}
Variety[3]		***	***	***	***
Ratooning[3]		***	***	***	***
Variety × Ratooning[3]		***	***	***	***

[1] Means (n=3) followed by different superscript letters within the same column are significantly different ($P<0.05$).

[2] MC = main crop; RC = ratoon crop.

[3] *** = significant at $P<0.05$.

higher than its main crop. The result of the coefficient on galvanised steel also showed that the ratoons were significantly lower than the main crop except for those of varieties NERICA-L 42, 44, 47 and OFADA, which did not show any significant difference ($P>0.05$). On glass surface, the coefficient of static friction for the ratooned samples were lower and differed significantly ($P<0.05$) from the main crop except for NERICA-L 26 and 42 which did not differ significantly. The ratoons of NERICA-L 47 and OFADA were however higher than their main crops.

Angle of repose

The result of the varietal and ratooning effects on the angle of repose is shown in Table 4. The filling angle of repose varied between 34.79 and 42.00 while the emptying angle of repose varied between 46.57 and 67.74. The ratoon sample of variety NERICA-L 47 had the lowest filling angle of repose while that of variety NERICA-L 19 had the highest. Among the main crop, NERICA-L 19 had the highest filling angle of repose while NERICA-L 26 had the least. The analysis of variance for the filling angle of repose showed that the effect of variety on the samples was not significant ($P>0.05$) but the ratooning effect was significant ($P<0.05$). Among the main crop, NERICA-L 20 had the highest emptying angle of repose while NERICA-L 24 had the least. Among the ratooned crops, OFADA had NERICA-L 24 had the highest emptying angle of repose. The effect of variety and ratooning were found to be insignificant ($P>0.05$) on the emptying angle of repose.

4. Discussion

The importance of the knowledge of the physical properties of agricultural crops cannot be over emphasised, because it is necessary for optimising the design of equipment and facilities for harvesting, handling, conveying, separation, drying, storing, and processing of such materials (Correa *et al.*, 2007). The physical dimensions of rice kernels are of vital interest in the rice processing industry. These dimensions are important in marketing and grading, design of cleaning and grading equipment as well as in drying operations (DeDatta, 1981; Gharekhani *et al.*, 2013). Rice grains graded uniformly provide uniform germination and

Table 4. The effect of ratooning processes on the filling angle of repose (°) and emptying angle of repose (°) of NERICA lowland rice varieties.[1]

Variety	Cropping system[2]	Filling angle of repose (°)	Emptying angle of repose (°)
NERICA-L 19	MC	42.0^{d}	63.5^{abc}
	RC	40.7^{cd}	53.0^{abc}
NERICA-L 20	MC	41.0^{cd}	67.7^{c}
	RC	40.6^{cd}	52.6^{abc}
NERICA-L 41	MC	41.0^{cd}	58.7^{abc}
	RC	38.5^{bc}	49.5^{ab}
NERICA-L 22	MC	40.1^{bcd}	59.1^{abc}
	RC	35.4^{a}	47.9^{a}
NERICA-L 24	MC	39.4^{bcd}	52.9^{abc}
	RC	39.6^{bcd}	61.4^{abc}
NERICA-L 26	MC	38.4^{bc}	66.7^{bc}
	RC	39.1^{bcd}	53.8^{abc}
NERICA-L 42	MC	39.3^{bcd}	54.5^{abc}
	RC	39.1^{bcd}	58.1^{abc}
NERICA-L 44	MC	41.3^{cd}	55.9^{abc}
	RC	37.2^{ab}	53.2^{abc}
NERICA-L 47	MC	39.6^{bcd}	55.2^{abc}
	RC	34.8^{a}	52.7^{abc}
OFADA	MC	41.0^{cd}	62.2^{abc}
	RC	38.4^{bc}	46.6^{a}
Variety[3]		ns	ns
Ratooning[3]		***	**
Variety × Ratooning[3]		ns	ns

[1] Means (n=3) followed by different superscript letters within the same column are significantly different ($P<0.05$).

[2] MC = main crop; RC = ratoon crop.

[3] ns = not significant; *** = significant at $P<0.01$; ** = significant at $P<0.05$.

usually give increased harvesting yield (Faramandfar *et al.*, 2009). Determination of physical dimensions also form an important part of quality evaluation of newly developed materials in rice breeding programs.

The linear dimensions of the NERICA-L varieties used for this study were similar to some local Nigerian rice varieties as reported by Adewumi (1996), who reported that the length of ITA 150, ITA 128 and Igbemo cultivated in Ondo State, Nigeria varied from 9.70 to 10.40 mm. Shitanda *et al.* (2002) reported 9.81 mm for IR-36 variety. Varnamkhasti *et al.* (2007) reported that Sazandegi variety had a length of 8.54 mm which is close to that recorded for OFADA variety in this study. The values Adewumi (1996) obtained for width (3.37 to 3.43 mm) were higher than those obtained for the NERICA lowland varieties but similar to those obtained for the OFADA variety. Linear dimensions are important in determining aperture size in the design of grain handling machinery (Al-Mahasneh and Rababah, 2007). The differences observed in the linear dimensions from other varieties could be as a result of varietal differences and ratooning efffect.

Farahmandfar *et al.* (2009) reported a much lower arithmetic mean diameter value (3.35-4.16 mm) for Poya, Khazar and Haraz rough rice varieties than those obtained in this study. The arithmetic mean diameter is useful in determining the diameter of sieve holes (Simonyan *et al.* 2007). The importance of these and other characteristic axial dimensions in determining aperture sizes and other parameters in machine design have been discussed by Mohsenin (1986) which was also highlighted by Omobuwajo *et al.* (1999).

The GMD obtained were higher than 2.61-3.14 mm reported by Farahmandfar *et al.* (2009), for Poya Khazar and Haraz varieties, but close to that reported for Sazandegi (3.40 mm) by Varnamkhasti, *et al.* (2007). The differences in the GMD of the different rice varieties could be due to the differences in their genetic makeup (Mohsenin, 1986). The geometric mean is useful in the estimation of the projected area of a particle moving in turbulent or near turbulent region of an air stream, which is generally indicative of its pattern of behavior in a flowing fluid such as air (Omobuwajo *et al.*, 1999). It also indicates ease of separating impurities from the particles during pneumatic cleaning (Omobuwajo *et al.*, 1999).

Farahmandfar *et al.* (2009) reported lower values (2.62-3.14 mm) of equivalent diameter for Poya, Khazar and Haraz varieties. Shittu *et al.* (2009) reported 17.82-25.31 mm for ITA150, ITA301, WAB189 and WAB450 varieties, which are much higher values than those obtained for the NERICA and OFADA varieties in this study. The values obtained for surface area were higher than 25.03-27.98 mm^2 reported by Adewumi (1996), for Igbemo, ITA 150 and ITA 128 varieties and 19.63-28.50 mm^2 reported by Farahmandfar *et al.* (2009) for Poya, Khazar and Haraz varieties. However those obtained by Shittu *et al.* (2009) (39.63-49.69 mm^2) for ITA150, ITA301, WAB189 and WAB450 varieties, were about the same as those obtained in this study.

The AR, an indicator of a tendency towards an oblong shape, obtained for the NERICA varieties was close to values reported by Varnamkhasti *et al.* (2007) for Sazandegi variety, but much lower than those obtained for the OFADA varieties. Values obtained for OFADA were however close to those reported for wheat (Gharekhani *et al.*, 2013; Stroshine and Hamann 1994,) and interestingly their shape look alike.

The sphericity obtained for the NERICA and the OFADA varieties indicated that the shape of the grains makes it difficult to roll on surface (Varnamkhasti *et al.*, 2007). This has to be taken into cognisant in equipment design so that there can be ease of flow of the grains through chutes and other passages during various processing. There were significant differences among the varieties with the OFADA varieties having higher sphericity than the NERICA varieties. These values were close to those obtained by Shittu *et al.* (2009) for ITA150, ITA301, WAB189 and WAB450; by Varnamkhasti *et al.* (2007) for Sazandegi paddy variety; by Shitanda *et al.* (2002) for Delta variety and Adewumi (1996) for Igbemo, ITA 150 and ITA 128 varieties.

The differences and in some instances, similarities in values of these axial dimensions may be due to the varietal differences, level of moisture content of the grains, environmental conditions and some cultural practices (DeDatta, 1981). Generally most of the main crops had higher linear dimensions than the ratooned samples except for some few varieties where there were no differences or where they were lower. Principal axial dimensions of rice grains are useful in calculating power requirements during rice processing (Farahmandfar, *et al.*, 2009). Surface area and volume of grains are important during modelling of grain drying, aeration, heating and cooling (Ghasemi *et al.*, 2008). On the other hand, mass modelling of the agricultural products is a common task and its results are used in designing tools (Tabatabaeefar and Rajabipour, 2005).

Thousand weight of paddy rice is a useful index to 'milling outruns' in measuring the relative amount of foreign material in a given lot of paddy and the amount of shriveled or immature grains (Varnamkhasti *et al.*, 2007). Shittu *et al.* (2009) reported higher values for ITA150, ITA301, WAB189 and WAB450 rice varieties, while Varnamkhasti *et al.* (2007) reported a lower value for Sazandegi variety. These could be attributed to varietal differences and ratooning. The significant interactions between the two factors also indicate that both can collectively affect the measured properties.

The knowledge of bulk density is useful for the design of silos and hoppers for grain handling and storage. Since higher bulk density implies lesser packing space requirement, the rice varieties studied will require less packing space than those reported by Yadav and Jindal (2007) and Varnamkhasti *et al.* (2007). However the same packing space will be required for rice varieties reported by other authors (Correa *et al.*, 2007; Razavi and Farahmandfar, 2008; Shittu *et al.*, 2009). Farahmandfar *et al.* (2009) reported much higher values than those found in this study. The true densities obtained for the ratoons were close to those reported by other researchers but the values obtained for the parent plants were lower. Farahmandfar *et al.* (2009) and Correa *et al.* (2007) reported higher values than those obtained in this study. The differences in the values of the bulk and true densities in relation to these other varieties could probably be due to intrinsic characteristics of each variety (Correa *et al.*, 2007). For the bulk density, the interactions between the two factors indicate that only the varietal differences can affect the measured properties and not the ratooning. While for the true density, the significant interaction between the two factors indicates that both variety and ratooning can collectively affect the measured properties.

The porosity value reported by Shittu *et al.* (2009) for WAB 450 was close to those obtained in this study, so also were those reported by Farahmandfar *et al.* (2009) for Poya, Khazar and Haraz varieties. Shittu *et al.* (2009) however reported a higher value for ITA 301. Varnamkhasti *et al.* (2007) also reported a higher value for Sazandegi variety. The characteristic that these rice grains will sink in water can be used to design separation or cleaning process for grains because lighter fractions will float (Varnamkhasti *et al.*, 2007). Bulk density, true density, and porosity (the ratio of inter granular space to the total space occupied by the grain) can be useful in determining space requirements for design of grain hoppers, grain conveying systems and storage facilities. They can affect the rate of heat and mass transfer of moisture during aeration and drying processes (Varnamkhasti *et al.*, 2007). Interestingly, the ratooned grains have higher porosities, bulk and true densities than the main crop except for some few exceptions but the 1000 kernel weight and volume were lower.

Coefficient of static friction was determined on four different surfaces. These surfaces were polished wood, plywood, galvanised steel and glass. The results showed that glass had the lowest friction coefficient, while polished wood had the highest, with a value slightly higher than twice that of glass. This might be because of the higher surface roughness in case of polished wood compared with glass (Al-Mahasneh and Rababah, 2007). The coefficients on polished wood and plywood were about the same values, probably because they have almost the same surface roughness. Mohsenin (1986) affirmed that the friction and consequently its coefficient are affected mainly by the nature and type of the surface in contact.

For the coefficients on all the surfaces, the main crops however had higher coefficients than the ratooned crops. Varnamkhasti *et al.* (2007), reported about the same value of coefficient of static coefficient on plywood for the paddy of Sazandegi rice variety. Varnamkhasti *et al.* (2007) reported about the same value of coefficient on glass for the paddy of Sazandegi variety. The coefficient of static friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of material through it (Varnamkhasti *et al.*, 2007). These data obtained could also be used in calculation of energy requirements for grain transportation which helps in sizing the motor requirements in grain moving augurs (Al-Mahasneh and Rababah, 2007).

Two types of repose angle were determined; filling and emptying angles of repose. For the filling angle of repose it was discovered that the factors controlling the sample behaviour depend only on the ratooning and not on the variety. This was also the case for the emptying angle of repose. Angle of repose can be useful in specifying the slope of grain discharge hoppers. The angle of grain hopper has to be greater than angle of repose so as to allow free flowing of the grain during grain discharge (Al-Mahasneh and Rababah, 2007). From data obtained for this study, the same angle of grain hopper can be used for all the varieties studied. Adewumi (1996) reported lower values for ITA 150, ITA 128 and Igbemo paddy rice varieties. The angle of repose would also help in predicting the motion of seeds during milling as well as determining the pressure of grains against machine walls so as to decide the choice of materials for fabrication (Joshi *et al.*, 1993).

5. Conclusions

This study showed that significant varietal differences existed among the different NERICA rice varieties and that the engineering properties of the main rice crop were significantly different from the ratooned crops. However, existing equipment used for handling and processing conventional rice varieties could be suitable for the NERICA rice varieties (main or ratooned) with little or no modifications because some of the results obtained for NERICA were similar to existing conventional rice varieties and where there were differences, it was not so significant.

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