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DETERMINATION OF SELECTED PHYSICAL PROPERTIES OF SOME VARIETIES OF ONIONS IN NIGERIA

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ABSTRACT
Polar and equatorial diameters, thicknesses, arithmetic mean diameters, frontal surface, cross sectional and total surface areas, sphericities, shape indexes, roundnesses, true and bulk densities, porosities and rolling angles on two surfaces of five varieties of popularly cultivated onions in Nigeria were determined. Analysis of variance (ANOVA) at 1 and 5% level of significance and least significant difference at 5% level probability were used to compare the data. The equatorial diameter, polar diameter and thickness for Light Red onion were the largest among the varieties evaluated and gotten as 6.53 ± 0.94, 5.12 ± 0.59 and 2.53 ±0.24 cm respectively. The ari thmetic and geometric mean diameters of White onion were 4.36 ± 0.42 and 4.0 ± 0.34 cm respectively; those of Red Creole were 4.42 ± 0.40 and 4.11 ± 0.33 cm and those o f Dark Red onions are 4.48 ± 0.48 and 4.18 ± 0.38 cm accordingly. Brow n onion had the least frontal, cross-sectional and total surface areas of 17.74 ± 3.43, 12.52 ±2.28 and 27.60 ± 3.99 cm ^{2}respectively. All the varieties evaluated were oval with shape index range of 1.65 ± 0.21 to 1.87 ± 0.21. The solid densities wer e obtained as 0.94 ± 0.04, 0.91 ± 0.0, 1.07 ± 0.08, 0.95 ± 0.04 and 0.95 ± 0.06 for Red Creole, Brown, Dark Red, White and Light Red varieties of Nigerian onions respectively. Rolling angles of the varieties ranged from 25 ± 2˚ to 29 ± 1˚ and 30.7 ± 1.5˚ to 33.7 ± 2.1˚ on galvanized steel and plywoo d surfaces respectively. The ANOVA showed that the thicknesses, total surface areas, solid densities, and rolling angles on galvanized sheet and plywood were not significant for the varieties while all other evaluated parameters were highly significant.
***Keywords**: Polar diameter, equatorial diameter, frontal surface area, shape index, rolling angle, onions.*

Nomenclature

A_c	Cross-sectional surface area (cm^2)	P_o	Porosity (%)
A_f	Frontal surface area (cm^2)	R_g	Rolling angle on galvanised steel (˚)
A_o	Area of smallest circumscribing circle (cm^2)	R_n	Roundness
A_p	largest projected area of bulb on screen (cm^2)	R_p	Rolling angle on plywood (˚)
CV	Coefficient of Variation	S_I	Shape index
D_a	Arithmetic mean diameter (cm)	SD	Standard Deviation
D_e	Equatorial diameter (cm)	T_h	Thickness (cm)
D_g	Geometric mean diameter (cm)	T_s	Total surface area (cm^2)
D_p	Polar diameter (cm)	W_1	Mass of sample before oven drying (g)
M_W	Moisture content (%)	W_2	Mass of sample after oven drying (g)
LSD	Least Significant Difference	ρ_b	Bulk density (g cm^{-3})
$Ø_c$	Sphericity	ρ_s	Solid density (g cm^{-3})

INTRODUCTION
Onion (*Allium cepa L*) belongs to the genus *Allium* of the family *Alliaceae*. It is naturally packed vegetable consisting of fleshly connective scales enclosed in paper-like wrapping leaves. Onion, as a plant, has short root and leafy stem and is normally planted in nursery for 6 to 8 weeks before being transplanted into the field. Onions requires well-drained flat surface and climatic temperature range of 15 to 25^{o}C for a good yield (NAERLS, 2008).

Onion is demanded world over, with China, Japan and India ranked topmost in its production. In 2004, the world dry onion production was 56.8 million metric tonnes and Africa, West Africa and Nigeria had dry onion productions of 4.26, 1.06 and 0.62 metric tonnes respectively (FAOSTAT, 2004). Thus, Nigeria alone accounted for 1.1 and 14.6% of world and Africa production. The average yield of dry onion production for the globe, Africa and Nigeria were 18.3, 15.2 and 15.0 tonnes/ha respectively (FAOSTAT, 2004). In 2009, global production of onion was 64.5 million tonnes (FAO, 2009). In 2012, 0.24 metric tonnes of green onions and 1.35 metric tonnes of dry onions were produced in Nigeria. States which produce onions in commercial quantity in Nigeria include Kebbi, Sokoto, Borno, Jigawa, Bauchi, Kaduna and Kano States (Inuwa, 2001).

Onion is a commercial crop that is eaten for its spiciness, nutritional and medicinal values all over the world. It contains natural sugar, vitamins A, B, C and E, minerals such as calcium, sodium, potassium, iron, magnesium and copper and constituents of fat, carbohydrate and protein. Onion is medicinal and has the potential for reducing the risk to cancer, blood thinning and headache (Haciseferogullari *et al.*, 2005; Jayeeta *et al.,* 2012). In Nigeria, onion is put as condiment in soup, salad and barbecue, and at times eaten raw for its flavour.

The knowledge of physical properties of agricultural materials is essential for the design, improvement, optimization and the proper functioning of machineries for the planting, processing, harvesting, storage, packaging, transportation and handling operations (Mohsenin, 1986). Evaluated physical quantities may be used as design parameters for storage facilities and structures, application of preservative and herbicides and other postharvest processing. But till date in Nigeria, planting, harvesting, sorting, cleaning, packaging, handling, and spraying of onions are done manually by farmers. For machines to be developed for any of these processes, the physical properties of the crop are required.

Physical properties of various agricultural materials have been studies by Mohsenin (1986); Bahnasawy *et al.* (2004) and Bahnasawy (2007). Others have studied the physical properties of garlic (Haciseferogullari *et al.,* 2005), some Egyptian, Indian, Iranian and French onions cultivars (Abdel-Ghaffer and Hindey, 1984; Eweida *et al.,* 1986; Maw *et al.,* 1996; Abhayawick *et al.,* 2002; Ghaffari *et al.*, 2013 and Kaveri and Thirupathi, 2015). However, the physical properties of Red Creole, Brown, Dark Red, White and Light Red onions varieties popularly planted in Nigeria are yet to be evaluated. Thus, the objective of this study is to determine the physical properties of five varieties of onions commonly planted over the years in Nigeria. The study also compared the mean values of the determined physical properties of the crops. The popularly planted onion varieties in Nigeria can be easily described based on colour, namely; White (*Faran Albasa*), Red Creole (*Dan Wurlo*), Brown (*Bobinwa*), Dark Red (*Dan Zarewa*) and Light Red (*Dan Vwaronyo*) onions. It is the physical properties of these popularly cultivated Nigeria onion varieties that are evaluated in this study.

MATERIALS AND METHODS

Samples Procurement

Five varieties of onions were purchased at local market in Karfi, Kano State, Nigeria. The market is a major place where various onions and other vegetables (e.g. tomatoes) farmers from far and wide bring their produces for sale. From the market, onions and other vegetables are transported to almost all parts of the country by middlemen before getting to the final consumers. The five selected varieties were White (*Faran Albasa*), Red Creole (*Dan Wurlo*), Brown (*Bobinwa*), Dark Red (*Dan Zarewa*) and Light Red (*Dan Vwaronyo*) onions. These varieties were selected because they are the widely cultivated varieties in this part of the country. It was ensured that the purchased sample of each variety was not assorted and foreign materials were removed from the samples as soon as they reached the laboratory. The study was carried out at the Processing Laboratory, Agricultural and Bio-Resources Engineering Department, Ahmadu Bello University, Zaria, Nigeria.

Instruments and Materials Used

The following instruments and materials were used to determine the properties of the onion samples:

Vernier calliper

The vernier calliper was used to measure the dimensions of 30 samples of each variety in order to obtain the equatorial and polar diameters and the thicknesses of the samples.

Overhead projector

Overhead Projector (NOBO Quantum 2521 model) was used to project a magnified image of samples of onion on graph sheets for the determination of the sphericity and roundness of each sample.

Electronic meter balance

Electronic meter balance (OPH-T3001 model) with the sensitivity of 0.1g was used to determine the mass of each sample and also used for weighing of sliced samples in the determination of moisture content.

Graduated cylinder

A graduated cylinder (1000 ml) was used for the determination of volume of onions samples by water displacement method.

Planimeter

Planimeter (Aristo No. 1145) was used to measure the total surface areas of onion samples from the spread aluminium foil used to wrap each bulb (Maw *et al.,* 1996; Bahnasawy, 2007; and Kaveri and Thirupathi, 2015).

Graph sheet

Images of the onion bulb samples of each variety from the overhead projector were traced on graph papers for the purpose of obtaining roundness of the bulb.

Aluminium foil

Aluminium foil was used to wrap the bulb samples of each variety in order to determine the total surface area. The used foil was neatly spread on plane and the planimeter used to measure the required total surface area.

Determination of Moisture Content

The oven dried method was adopted in the determination of moisture content of each variety of onions studied. Sample of each variety was peeled using kitchen knife to remove the dried outermost layer of the onions, and the fresh layers were sliced into small pieces of 3 x 3 x 5 mm. The masses of the samples were determined using the electronic balance before and after oven drying for 24 hours at 105 ˚C (Abhayawick *et al.,* 2002). The moisture content of the samples was calculated from the equation given by AOAC (1990) as:

$$M_W = \frac{W_1 - W_2}{W_1} \times 100 \qquad (1)$$

where, M_W = moisture content (% wet basis)
W_1 = mass of sample before oven drying (g)
W_2 = mass of sample after oven drying (g).

Determination of Axial Dimensions

The polar and equatorial diameters and thicknesses of 30 randomly selected samples of each variety of onions were measured using the vernier calliper. The polar diameter was taken as the linear length between the crown and root of an onion bulb. The equatorial diameter was the maximum width of the bulb and perpendicular to the polar diameter of the bulb. The thickness was taken as a length perpendicular to the both the equatorial and polar diameters of the bulb but smaller than either diameter (Bahansawy *et al.,* 2004; and Ghaffari *et al.,* 2013).

Determination of Mean Diameters

From the measured dimensions of each bulb, its arithmetic and geometric mean diameters were determined as follows:

Arithmetic mean diameter

The arithmetic mean diameter was calculated from the measured equatorial and polar diameters and thickness for each bulb from the equation given by Mohsenin (1986) and Bahnasawy *et al.* (2004) as:

$$D_a = \frac{D_p + D_e + T_h}{3} \qquad (2)$$

Where D_a= Arithmetic mean diameter (cm),
D_p = polar diameter (cm)
D_e = equatorial diameter (cm) and,
T_h = thickness (cm).

Geometric mean diameter

The geometric mean diameter was calculated from the three measured dimensions of each bulb from the equation given by Bahnasawy *et al.* (2004) and Kaveri and Thairupathi (2015) as:

$$D_g = (D_p \times D_e \times T_h)^{1/3} \qquad (3)$$

D_g = geometric mean diameter (cm) and other parameters as previously defined.

Determination of Onions Areas

Three forms of surface areas were determined from the dimensions of the onion samples.

Frontal surface area

The frontal surface area of a 3-dimensional object is its appearance when cut at an intersecting plane so that its internal structure is displayed. It is calculated from the equation given by Bahnasawy *et al.*(2004) and Kaveri and Thairupathi (2015)as:

$$A_f = \frac{\pi}{4} D_p D_e \qquad (4)$$

Where A_f = frontal surface area (cm^2) and other parameters as previously defined.

Cross sectional area

The cross sectional area is the area of the section exposed by a plane cutting a 3-dimensional object transversely at right angle to the longest axis. According to Bahnasawy (2007) and Kaveri and Thirupathi (2015), cross sectional area is given as:

$$A_c = \frac{\pi}{4} \frac{(D_p + D_e + T_h)^2}{9} \qquad (5)$$

where A_c = cross sectional area of onion bulbs (cm^2)

Total surface area

Total surface area (T_s) is the total area of the exposed outermost layer of an onion bulb with the root and top leaves removed. The total surface area of three randomly selected samples of each variety studied was determined. Each of the selected bulbs was wrapped completely in an aluminium foil and the rest part of the foil cut off. The foil which wrapped the bulb was then neatly spread on a plane and its surface area measured with the planimeter (Maw *et al.,* 1996; and Kaveri and Thairupathi, 2015).

Determination of Sphericity, Shape Index and Roundness

The sphericity, shape index and roundness of the onions bulb were determined to ascertain the shape of the varieties.

Sphericity

Sphericity is defined as the ratio of the surface area of a sphere having the same volume as that of a biomaterial to the surface area of the biomaterial. It measures how spherical an object is and ranges from 0 to 1. Sphericity can be expresses according to Mohsenin (1986) and Loghavi *et al.* (2011) as:

$$\emptyset_c = \frac{(D_p \times D_e \times T_h)^{1/3}}{D_e} \qquad (6)$$

where $Ø_c$ = sphericity, other parameters as previously defined.

Shape index

Shape index is the ratio of the equatorial diameter and the root of the product of polar diameter and thickness of biomaterial and express by Bahnasawy *et al.* (2004) and Bahnasawy (2007) as:

$$S_I = \frac{D_e}{\sqrt{D_p \times T_h}} \qquad (7)$$

where S_I =shape index

Shape index is dimensionless. Bodies are said to be oval if shape index > 1.5 and said to be spherical if shape index < 1.5 (Abd alla, 1993; Kaveri and Thirupathi, 2015).

Roundness

Roundness measures the sharpness of the corners of an object (Mohsenin, 1986).The roundness of a randomly selected onion bulb was determined by projecting a magnified image of the bulb on a graph screen using the overhead projector. The image of the onions bulb was traced on the graph sheet. The largest projected area and the area of the smallest circumscribing circle were then measured from the drawn images on the sheet for three samples of each variety of onions. The procedure was repeated three times for each sample and the average of the result was calculated for roundness from the expression given by Mohsenin (1986) and Kaveri and Thairupathi (2015) as:

$$R_n = \frac{A_p}{A_o} \qquad (8)$$

where R_n = roundness,
A_p = largest projected area of the bulb on screen (cm^2) and
A_o = area of smallest circumscribing circle (cm^2).

Determination of Densities and Porosities

The solid and bulk densities and the porosity of samples of the varieties of onions were determined as follows:

Solid density

Solid density of the onion bulbs was determined from the actual volume and mass of the materials. True volume of the bulbs of each variety was determined by dropping samples in a graduated cylinder filled with water. The volume of the displaced water from the container was the volumes of the onions immersed. The mass (g) of the immersed samples was divided by the displaced volume (cm^3) to obtain solid density of each variety. The procedure was repeated three times and the average value calculated as the solid density of the variety (Bahnasawy *et al.,* 2004; Ghaffari *et al.,* 2013).

Bulk density

Bulk density for each variety of onion was determined by pouring samples of the variety in a bucket of known volume and mass to fill to brim. The mass of the poured bulbs was then measured on the electronic balance and divided by the volume of the container to get the bulk density of the variety. The procedure was repeated three times for each variety and average bulk density calculated for each variety (Kaveri and Thairupathi, 2015)

Porosity

Porosity is the percentage void spaces in a material and is a fraction of the volume of pores to the total volumes of the solid materials within a space. Thus, indicating the amount of void in the bulk material. Porosity was calculated using the relationship Mohsenin (1986) and Kaveri and Thairupathi (2015) gave as:

$$P_o = \left(1 - \frac{\rho_b}{\rho_S}\right) \times 100 \quad (9)$$

where P_o = porosity (%),
ρ_b = bulk density (g cm^{-3})
ρ_s= solid density (g cm^{-3}).

Rolling Angles on Surfaces

Rolling angle of each sample was determined on two surfaces, namely galvanised steel and plywood. These two materials were selected for evaluation of rolling angle of onions because they are the mostly used materials for the construction of rack for storage of the crop. To determine the rolling angle, a sample was placed in its most stable position (to avoid toppling over) in a box platform which can be rotated vertically. The platform was then gradually tilted vertically until the bulb just began to roll. At the point, the angle of inclination of the box was read from attached protractor (Buyanov and Voronyuk, 1985 and Bahnasawy *et al.,* 2004). The procedure was repeated three times for each variety and the average value calculated as the rolling angle of the variety.

Analysis of Result

Statistical Analysis Software (SAS) version 9.0 was used for the data analysis. The evaluated parameters of the varieties of onions were compared by Analysis of Variance (ANOVA) at 5% and 1% level of confidence to test for significant difference. Least Significance Difference (LSD) at 5% level of probability was used to classify the means of the parameters by varieties.

RESULTS AND DISCUSSION

Moisture Contents

The average moisture contents of the five varieties of onions were81.5, 83.2, 83.7, 81.2 and 84.6% for Red Creole (*Dan Wurlo*), Brown (*Borinwa*), Dark Red (*Dan Zerawa*), White (*Faran Albasa*) and Light Red (*Dan Vwaronyo*) onions respectively. Thus, the moisture contents of onions evaluated were found to range from 81.5 to 84.7% (wet basis). The ANOVA result showed that there was no significant difference in the moisture contents of the varieties. Kaveri and Thirupathi (2015) evaluated a variety of Indian onion within the moisture content range of 80.8 to 84.6 %. Abhayawick *et al.* (2002) obtained moisture contents of 82 to 93% for onions in France. While Bahanasawy *et al.* (2004) evaluated the physical properties of three cultivars of onions at 81.3, 80.9 and 79.7% moisture contents.

Linear Dimensions

Table 1 shows the summary of the ANOVA for the linear dimensions and some of the other evaluated parameters of the varieties of onions studied. It shows that there is a high significant difference in the five varieties for both the equatorial and polar diameters, while there is no significant difference in the varieties' thicknesses. This implies that the size and shape of the onions are unique based on variety.

Table 2 shows mean values, Standard Deviations (SD) and Coefficient of Variation (CV) of some evaluated parameters for each of the varieties and the Least Significant Difference (LSD) results. For equatorial and polar diameters, the Light Red onion has the largest mean equatorial and polar diameters of 6.53 ± 0.94 and 5.12 ± 0.59 cm respectively. However, there was no significant difference in the equatorial diameters of Light Red, Dark Red and Red creole onions as shown by the LSD result. Also there was no significant difference in the equatorial diameters of Red Creole, Dark Red and White onions as indicated on Table 2. The Brown onion has the least value of equatorial and polar diameters of 5.25 ± 0.69 and 4.30 ± 0.54 cm respectively among the onions varieties. The polar diameter of Red Creole onion of 4.53 ± 0.62 cm was not statistically different from that of the Brown onions of 4.30 ± 0.54 cm; and the polar diameters of Dark Red, White and the Red Creole onions of mean values of 4.75 ± 0.66, 4.71 ± 0.46 and 4.53 ± 0.62 cm respectively were at par as shown by the LSD results. On the thicknesses of the varieties, the Light Red and the Dark Red onions have the mean values of 2.53 ± 0.24 and 2.54 ± 0.19 cm respectively, while Brown onion has the least value of 2.39 ± 0.26 cm. Table1shows that there was no significant difference in thicknesses of the varieties, and Table 2 confirms it. From the ANOVA results for thicknesses of the varieties, the F value was 2.08, while F tabulated value was 2.37 at 5 % (level of confidence, α). Brown onion has the least value of mean thickness of 2.39 ± 0.26 cm and Light Red onion has the highest mean value of 2.53 ± 0.24 cm but the thicknesses of the varieties were statistically at par. Bahnasawy *et al.* (2004) obtained mean equatorial and polar diameters ranges of 5.17 ± 0.55 to 5.75 ± 0.86 cm and 5.71 ± 0.70 to 6.20 ± 1.59 cm respectively. This implies that the Egyptian cultivars have larger polar and smaller equatorial diameters than the Nigerian cultivars. The results of the equatorial and polar diameters of the evaluated varieties were also in agreement with the result of Amer-Essa and Gamea (2003) which had means of 6.34 and 5.64 cm for equatorial and polar diameters respectively for *Giza 20* onion bulbs studied in Egypt.

Table 1: Summary of ANOVA results for some evaluated parameters

		F values calculated								F tabulated	
Source	DF	D_e	D_p	T_h	D_a	D_g	A_f	A_c	T_s	5%	1%
Variety	4	9.23**	8.02**	2.08^{NS}	11.86**	11.35**	11.84**	11.32**	1.85^{NS}	2.37	3.32
Error	145										

** means highly significant, * means significant and ^{NS} means not significant

Arithmetic and Geometric Mean Diameter

From Table 1, the results of the ANOVA for both the arithmetic and geometric mean diameters were highly significantly different for the varieties evaluated. The arithmetic and geometric diameter are used to describe the shapes of materials for the purpose of designing equipment for handling, processing or storage of the materials. In Table 2, the LSD result followed the same trend for both the arithmetic and geometric mean diameters. In both, the Brown onion had the least values of 3.98 ± 0.35 and 3.76 ± 0.32 cm respectively. And the Light Red onion had the largest mean values of 4.73 ± 0.48 and 4.38 ± 0.41 cm in stated order. The other three varieties have values of arithmetic and geometric means diameters which are ranked as equal by LSD. Bahnasawy *et al.* (2004) obtained mean arithmetic diameters of 5.74 ± 1.06, 6.01 ± 1.28 and 5.50 ± 0.59 cm for *Giza* 6, *Beheri* and *Giza* 20 onions varieties respectively. While the corresponding mean geometric diameters are 5.72 ± 1.05, 5.89 ± 1.26 and 5.48 ± 0.58 cm. This implies that the Egyptian cultivars of onion have larger mean diameters than the Nigerian cultivars, which are due to cultivar differences, agronomical practices and climatic factors.

Frontal, Cross Sectional and Total Surface Areas

The results of the ANOVA (Table 1) show that frontal and cross sectional areas were significantly different for the varieties. This implies that the volume of convective air and spray material that are required for processing, drying and preserving the varieties are not same. The LSD result, Table 2, shows a common trend in the LSD ranking of the varieties for frontal and cross sectional areas as obtained for arithmetic and geometric diameters. From Table 2, the Red Creole, Dark Red and White onions have statistically the same frontal areas of 22.39 ± 4.83, 23.05 ± 5.39 and 22.00 ± 4.76 cm^2 respectively. Brown and Light Red onions have the lowest and highest values of the cross sectional areas of 12.52 ± 2.28 and 17.72 ± 3.65 cm^2 respectively, which are statistically different from one another and from the other varieties classified as equal in cross-sectional and frontal areas. Bahnasawy *et al.* (2004) had the mean values of 26.68 ± 9.35, 29.52 ± 12.46 and 23.96 ± 4.95 cm^2 for the cross-sectional areas and 26.29, 28.81 and 23.33 cm^2 for frontal surface areas of *Giza* 6, *Beheri* and *Giza* 20 varieties of Egyptian onions respectively. Thus, the surface areas of the Egyptian onions were larger when compared to the Nigerian varieties due to the same reasons stated for mean diameters. The larger thicknesses of the Egyptian cultivars account for its larger areas as compared with the Nigerian cultivars.

From Table 1, it was that observed the total surface areas of the evaluated varieties have no significant difference. And the mean values of the varietal total surface areas were all ranked as statistically equal by the LSD result in Table 2. The mean total surface area of the Light Red onion was 269.3 ± 99.78 cm^2 and that of Brown onion was 278.3± 28.28 cm^2. The lowness of the means of total surface area of Light Red onion was due to one of the randomly selected varieties being rather small as reflected by its SD of 98.78 and CV. Bahnasawy (2007) obtained 136.37 ± 313.58 cm^2 for large size garlic, and Amer-Essa and Gamea (2003) obtained 166.34 ± 6.21 cm^2 surface area of *Giza 20* onion.

Sphericity, Shape Index and Roundness

Table 3 shows the summary of the ANOVA of the other evaluated parameters of the onions varieties ranging from shape index to rolling angles on surfaces. And Table 4 shows the means values, SD, CV and LSD of the same parameters. From Table 3, the sphericity of the varieties was highly significant. In Table 4, the sphericity of four of the varieties was classified as statistically equal. Only Brown onion was found to have a sphericity of 0.72 ± 0.06 and classified as statistically different from and higher than those of the other varieties. The varieties of the onion bulb were 66 to 72% spherical. Table 3 shows that like sphericity, shape index was also highly significant for the varieties. The LSD ranking in Table 4 shows that four varieties of the onions were classified as equal in shape index. Brown onions with mean value of 1.65 ± 0.21 was classified differently and lower in shape index than three of the varieties and same with White onion with mean shape index of 1.74 ± 0.93. The mean shape indexes for all varieties of onion evaluated were each > 1.5. This implies that the varieties are all oval shape according to Abd Alla (1993). Bahanasawy *et al.* (2004) found *Giza 6 and Beheri* onions to be oval in shape and *Giza 20* onion as spherical in shape. Kevari and Thirupathi (2015) and Ghaffari *et al.* (2013) found Iranian onions as spherical. The roundness of the varieties was not significant from Table 3 and Table 4 shows that LSD ranked roundness of all the varieties as equal. However, Light Red onion has the lowest value of roundness of 0.83 ± 0.03, and Red Creole has the highest mean roundness of 0.90 ± 0.08. It implies that all the varieties have 83 to 90% roundness. Kaveri and Thirupathi (2015) got the mean roundness of 0.87 ± 0.04 and 0.84 ± 0.08 for fresh and stored onions respectively.

Table 2: Mean ranking of the physical properties evaluated

Varieties		**D_e** (cm)	**D_p** (cm)	**T_h** (cm)	**D_a** (cm)	**D_g** (cm)	**A_f** (cm^2)	**A_c** (cm^2)	**T_s** (cm^2)
Red Creole	Means	6.24^{ab}	4.53^{cb}	2.49^{a}	4.42^{b}	4.11^{b}	22.39^{b}	15.47^{b}	287.3^{a}
	SD	0.74	0.62	0.26	0.40	0.33	4.83	2.78	34.53
	CV (%)	11.77	13.63	10.45	9.01	8.13	21.56	17.95	12.01
Brown	Means	5.25^{c}	4.30^{c}	2.39^{a}	3.98^{c}	3.76^{c}	17.74^{c}	12.52^{c}	278.3^{a}
	SD	0.69	0.54	0.26	0.35	0.32	3.43	2.28	28.36
	CV (%)	13.16	12.55	10.75	8.79	8.79	19.34	18.25	10.19
Dark Red	Means	6.16^{ab}	4.75^{b}	2.54^{a}	4.48^{b}	4.18^{b}	23.05^{b}	15.95^{b}	276.0^{a}
	SD	0.11	0.66	0.19	0.48	0.38	5.39	4.78	29.71
	CV (%)	17.85	13.79	7.34	10.67	9.16	23.38	10.67	10.77
White	Means	5.91^{b}	4.71^{b}	2.45^{a}	4.36^{b}	4.07^{b}	22.00^{b}	15.04^{b}	275.0^{a}
	SD	0.93	0.46	0.21	0.42	0.34	4.76	2.83	58.02
	CV (%)	15.75	9.67	3.72	9.64	8.43	21.63	18.85	21.10
Light Red	Means	6.53^{a}	5.12^{a}	2.53^{a}	4.73^{a}	4.38^{a}	26.45^{a}	17.72^{a}	269.3^{a}
	SD	0.94	0.59	0.24	0.48	0.41	5.87	3.65	98.78
	CV (%)	14.43	11.44	9.59	10.21	9.35	22.19	20.62	36.68

Means followed by same letter are not significant. Symbols as defined in text

Table 3: ANOVA results for other physical properties

		F values calculated								F tabulated	
Source	$Ø_C$	S_I	DF	R_n	ρ_b	ρ_s	P_o	R_g	R_p	5%	1%
Variety	4.29**	3.95**	4	0.59^{NS}	35.50**	3.34^{NS}	25.02**	1.42^{NS}	1.51^{NS}	3.48	5.99
Error			10								

** means highly significant, * means significant and ^{NS} means not significant

Table 4: Mean ranking of other physical properties

Varieties		**$Ø_C$**	**S_I**	**R_n**	**ρ_b** ($g\ cm^{-3}$)	**ρ_s** ($g\ cm^{-3}$)	**P_o** (%)	**R_g** (°)	**R_p** (°)
Red Creole	Means	0.66^{b}	1.87^{a}	0.90^{a}	0.53^{c}	0.94^{a}	47.15^{a}	27.67^{a}	33.00^{a}
	SD	0.05	0.21	0.03	0.11	0.04	1.13	1.53	1.50
	CV	17.65	11.35	3.41	2.41	4.59	2.39	5.50	1.50
Brown	Means	0.72^{a}	1.65^{b}	0.84^{a}	0.57^{b}	0.91^{a}	42.36^{b}	27.30^{a}	30.70^{a}
	SD	0.06	0.21	0.06	0.13	0.05	2.12	2.28	3.10
	CV	8.59	12.52	7.68	2.30	5.44	5.00	18.25	10.00
Dark Red	Means	0.69^{b}	1.79^{a}	0.84^{a}	0.61^{a}	1.07^{a}	39.10^{c}	27.33^{a}	33.70^{a}
	SD	0.07	0.11	0.06	0.12	0.08	1.25	3.20	2.10
	CV	10.96	17.85	7.68	2.06	7.86	3.20	11.80	6.20
White	Means	0.69^{b}	1.74^{ab}	0.87^{a}	0.57^{b}	0.95^{a}	42.70^{b}	29.00^{a}	31.00^{a}
	SD	0.07	0.93	0.11	0.07	0.04	0.61	1.00	2.00
	CV	10.39	15.75	12.14	1.06	4.59	1.43	3.40	6.50
Light Red	Means	0.68^{b}	1.82^{a}	0.83^{a}	0.52^{c}	0.95^{a}	48.50^{a}	25.00^{a}	30.70^{a}
	SD	0.05	0.94	0.03	0.10	0.06	1.03	2.00	1.50
	CV	7.83	14.43	3.61	1.99	6.19	2.13	8.00	5.00

Means followed by same letter are not significant. Symbols as defined in text

Bulk and Solid Densities and Porosity

Table 3 indicates that the bulk density of the varieties was highly significant. Thus, the weight and cost of transportation of equal containers of the varieties would differ. Table 4 shows that Dark Red onions has the largest bulk density of 0.61 ± 0.12 g cm^{-3}, the bulk densities of Brown and White onions were classified as equal. Those of Red Creole and Light Red onions of mean values 0.53 ± 0.11 and 0.52 ± 0.10 g cm^{-3} respectively were the lowest class. In Table 3, solid density was not significant for the varieties. Table 4 shows that the mean solid densities were 1.07 ± 0.08, 0.95 ± 0.06, 0.95 ± 0.04, 0.94 ± 0.04 and 0.91 ± 0.05 g $cm^{-3}$for Dark Red, Light Red, White, Red Creole and Brown onions respectively and are all statically at par. Bahnasawy *et al.* (2004) obtained 1.09 ±0.12, 1.11 ± 0.15 and 1.04 ± 0.09 g cm^{-3}as solid densities of *Giza 6, Beheri* and *Giza 20* onions respectively. This implies that only Dark Red onion of Nigerian varieties has similar solid density as the Egyptian cultivars. Ghaffari *et al.* (2013) also got true density value of 1.00 ± 0.01 g cm^{-3} for Iranian onions and Amer-Essa and Gamea (2003) got 0.97 ± 0.11g cm^{-3}.

Porosity of the onion varieties were analysed as highly significantly different (Table 3). In Table 4, Light Red and Dark Red onions have the highest and least mean porosities of 48.50±1.03 and 39.10 ± 1.25% respectively. By the LSD ranking, Light Red and Red Creole of are at par and have the highest porosity. These were followed by White and Brown onions with 42.70 ± 0.61 and 42.36 ± 2.12% respectively which are also at par. Kaveri and Thirupathi (2015) got porosity of 42.43 ±4.40% for freshly harvested onions.

Rolling Angles

Table 3 shows that the rolling angles of the varieties on both galvanised steel and plywood were each not significant. Table 4 shows the rolling angle of White onion has the highest numerical mean value of 29.00 ± 1.00˚and Light Red onion has the least numerical mean value of 25.00 ± 2.00˚on galvanised steel. However, the mean rolling angles of all the varieties of onions on the galvanised steel were ranked as statistically at par with one another. For the rolling angles of the varieties on plywood, all the mean values, which ranged from 30.70 ± 1.50˚ to 33.70 ± 2.10˚, were statistically equal. Bahnasawy *et al.* (2004) obtained rolling angle for Egyptian onion on galvanised sheet as a range of 20.3 to 29.3˚ and on plywood obtained a range of 22.7 to 31.30˚. Thus the rolling angles of the varieties studied are within the ranges gotten by Bahnasawy *et al.* (2004).

CONCLUSIONS

The physical properties of commonly cultivated Nigerian onion varieties were determined and compared. It was found that shape and size properties of Light Red onion were the largest for the properties of the varieties studied and Brown onion has the least values for all linear dimensions, diameters and surface areas studied. The means of equatorial diameter, polar diameters, thickness, frontal area and cross-sectional area of Light Red onion are 6.53 cm, 5.12 cm, 2.53 cm, 26.45 cm^2 and 17.72 cm^2 respectively. The corresponding values for Brown onions are 5.25 cm, 4.30 cm, 2.39 cm, 17.74 cm^2 and 12.52 cm^2. All the varieties were found to be oval shaped and the mean roundness values of the varieties were not significantly different. It was also found that the rolling angles on galvanised sheet and plywood for the evaluated varieties were not significantly difference one from another.

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