INFLUENCE OF MOISTURE CONTENT ON SOME PHYSICAL PROPERTIES OF RUBUS *fruticosus*

ABSTRACT

Some engineering properties of *Rubus fruticosus* fruits and nuts and were characterized in order to provide fundamental information about their properties that will aid in designing modern technology for their handling, processing, storage, preservation, quality evaluation, distribution and marketing. The engineering properties studied are some physical property of Rubus Fructicosus fruits and nuts, (moisture content, size and shape of the fruits and nuts) The fruits and nuts were conditioned to five and three different moisture and three and four different temperature levels, respectively before testing. American Standards for Testing and Materials (ASTM) and American Society of Agricultural and Biological Engineers (ASABE) standard procedures were used to test all the properties considered. Genstat, Mathlab, JMP in SAS, Duncan in SPSS and Microsoft excel statistical packages were used to analyze the generated data and the means were compared using the analysis of variance (ANOVA) at 5% level of probability. The results obtained revealed that the major, intermediate and minor diameters of the fruits range 35.14 – 34.09 mm, 22.44 – 20.25 mm and 22.03 – 19.92 mm respectively for long and, 26.66 – 23.05 mm, 16.69 – 13.99 mm and 16.17 – 13.48 mm respectively for short fruits. The average geometric mean diameter (GMD) of the fruit ranged from 25.90 to 23.95 mm for long and 19.13 to 16.27 mm for short fruits at moisture range of 40.91 – 11.03% wet basis. The nuts also ranged from 36.75 – 37.36 mm, 13.19 – 13.66 mm and 12.89 – 13.18 mm respectively for long nuts, 23.26 – 23.87 mm, 10.93 – 11.24 mm and 10.76 – 11.04 mm respectively for short nuts at 10.2% - 25.06 % wet basis. The fruits and nuts are oblong in shape.

Keywords: Moisture content, shape and size, biomaterial, physical properties.

1.0 INTRODUCTION

Since man started discovering and cultivating various types of food, there has never been food without work or work for abundant food without machines. The effectiveness of these machines for mechanizing agricultural production depends on adequate knowledge of engineering properties of the products to be mass produced. Mechanization involves replacing human and animal labour with mechanical devices in crop production, processing, storage and distribution. It reduces production cost, ensures timeliness, and optimizes and protects product quality (Adamade and Jackson, 2014).

In handling and processing of agricultural products, some fundamental information about their characteristics is essentially needed. These information can be obtained through the knowledge of engineering properties of the products which constitutes essential data in designing and developing modern technologies for their production, handling, processing, storage, preservation, quality evaluation, distribution and marketing.

Engineering properties of agricultural product are profitably used for mechanizing their planting, harvesting, drying, processing and storage. They improve working efficiency of processing equipment, reduces losses and waste of constructional materials and, saves time and money. It also helps to maintain quality even in adverse storage and handling conditions and offer ways in which products can be utilized effectively.

In recent time, strong growing interest on tree crop for food, money and medicine has been ongoing. This is because there is high demand of food due to effects of development and increasing population, besides, many economic tree crops are fading away without being harnessed and replaced.

Tree crops are those perennial woody plants with a single elongated stem of about 3m high and above (Orwa *et al.,* 2009) and, have head of branches and foliage on which fruits grow. The fruits of tree crops are of great interest to food scientists, food producers and other scientists who work towards achieving food security. Modern agriculture has led to handling and processing of agricultural products into more useful product through various unit operations like cleaning, grading, sorting, drying, dehydration, storage, milling and transportation. *Rubus fruticosus* fruit is an edible fruit from *Rubus fruticosus* tree. It is eaten boiled or fresh for its nutritional and medicinal values.

Processing of this important fruit is still by conventional method which encourages losses of both oil and kernel, is unhygienic and subjects the fruits to vagaries of heat treatment which results in poor quality oil. Olawale (2012) reported that the extraction of oils from elemi pulp and kernel is not being carried out at commercial level at present, despite ready availability of the fruit in large quantity in Nigeria and elsewhere in Sub-Sahara Africa. This situation would improve if data needed for the design and operation of the oils' extraction plants are available. *Rubus fruticosus*
nuts which house the kernel are usually thrown away after eaten the mesocarp, causing environmental pollution and loss of biomass resources for alternative energy generation. These are as a result of limited knowledge of engineering characteristics of this important fruit and nuts that will promote mechanization of its processing into other useful products.

Engineering properties of agricultural products includes physical, thermal, electrical, optical and mechanical properties. Here physical properties – moisture content, shape and size are treated in this paper. Physical properties are those attributes that reveal the physical features of agricultural product, which can affect mechanization of their handling, processing and storage. Such properties are moisture, shape and size, solid and bulk density, porosity, surface area and volume, angle of repose and absorption which determine the behaviour of the products during handling and processing operations (Mohsenin, 1986, Stroshine, 1998). These properties do change during processing operation and should be considered during design to avoid processing failure.

The objective of this study is to determine the physical: moisture content, size and shape of *Rubus fruticosus* fruit and nuts and to establish relationship between samples size, shape, moisture content of the bio-material.

2.0 MATERIALS AND METHODS

2.1 Crop Materials (*Rubus fruticosus*)

The *Rubus fruticosus* products used for this experiment are the long and short *Rubus fruticosus* fruits and nuts. They were sourced from Tropical environment of Ebonyi State of Nigeria and harvested from August to October. The fruits and nuts are shown in Plate 1.

Plate 1: *Rubus fruticosus* short nuts

2.2 Physical Properties of *Rubus fruticosus* Fruits And Nuts

2.3 Moisture content

The moisture content of the fruits was determined by oven drying method for the fruits and rewetting methods and oven drying for the nuts. The initial moisture content of the fruits was allowed to be uniform by placing them in a refrigerator at $5^{o}C$ for about 18 hours. The moisture content of the fruits was determined at average environmental temperature and relative humidity of $38^{o}C$ and 77% respectively. The fruit samples were put in a clean moisture can and weighed using digital balance (Model APX-1502, Denver Instrument US) of 0.01g accuracy before putting them in the oven. The oven was

set at temperature of 105°C for 8 hours. The difference between the initial and final weight of each sample was used to calculate the moisture content of the sample as Equation 1 (Mohsenin 1986):

$$\% M_{wb} = \frac{W_1 - W_2}{W_1} \times \frac{100}{1} \qquad 1$$

Where: M_{wb} = moisture content wet basis (%), W_1 = initial weight (g). W_2 = final weight (g).

2.4 Moisture content of agricultural products

This is the amount of water present in any material which can be expressed as a percentage of the material weight either in wet basis or dry basis. It is calculated as, Equation 2 (Mohsenin, 1986):

$$\% M_{wb} = \frac{w_1 - w_2}{w_1} \times \frac{100}{1} \qquad 2$$

where: M_{wb}= moisture content wet basis (%), w_1= dry weight (g), w_2 = final weight (g).

2.5 Shape and size of agricultural products

Shape is a physical attribute of agricultural products that is used to differentiate between cultivars, study the heritage shape trait, evaluate the consumer decision performance, package and transport product (Jahns *et al*., 2001, Sadrnia *et al*., 2007). Shape can be described objectively (depending on the nature of the product) using indices calculated from geometrical characteristics of the product. Such indices include roundness, roundness ratio (RR), sphericity and axial ratio (AR) (Mohsenin, 1986, Wilhelm *et al*., 2005, Venora *et al*., 2007). Roundness measures the consistency of the product diameter at a number of different orientations).Roundness ratio is non-dimensional physical parameter that uses the geometrical attribute of the product to determine its shape (Rashidi and Seyfi, 2007). Sphericity is defined as the ratio of the volume of a triaxial ellipsoid with diameters equal to the major, intermediate and minor diameters to the volume of sphere which circumscribed the object. Aspect ratio is also a dimensionless physical quantity that describes the shape of an object (Sadrnia *et al*., 2007).

For nuts and nutshells, a predetermined amount of distilled water was added to the sample before placed it in a refrigerator set at 5 °C for about 20 hours to equilibrate. The quantity of water added was calculated as in Equation 3 (Mohsenin, 1986):

$$W_2 = W_1 \left(\frac{M_1 - M_2}{100 - M_1}\right) \qquad 3$$

Where W_1 = sample weight, W_2 = amount of distilled water to be added, M_1 = final moisture content, M_2 = initial moisture content.

Five different moisture content (M_1, M_2, M_3, M_4 and M_5) wet basis were obtained for the fruits but the nuts and nutshell were conditioned to three moisture levels (M_1, M_2, M_3). Each moisture content was replicated three times.

2.6 Size and Shape of Fruits and Nuts

Size was determined by measuring the principal dimensions of the products such as length, width and thickness which are also known as major, intermediate and minor diameters, Fig. 1.

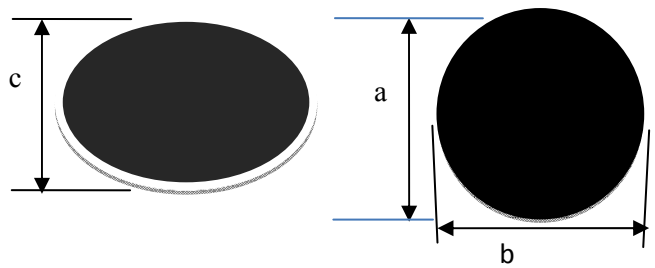

Figure 1: Principal dimensions of *Rubus fruticosus fruits* (a) major diameter, (b) intermediate diameter and (c) minor diameter.

Digital venier caliper (Mitutoyo, Japan) of 0.01g accuracy was used to measure the principal dimensions of the fruits and nuts at various moisture levels. Fifty replications

Various mean diameters and shapes of the fruits and nuts were calculated using Equations 4 – 8 Mohsenin (1986) and Ehiem *et al.*(2012):

$$GMD = \sqrt[3]{abc} \qquad 4$$

$$AMD = \frac{a+b+c}{3} \qquad 5$$

$$SMD = \sqrt{\frac{(a \times b)+(b \times c)+(c \times a)}{3}} \quad (6)$$

$$\text{EQD} = \frac{SMD+GMD+AMD}{3} \quad (7)$$

$$AR = \frac{b}{a} \quad (8)$$

Where: a = major diameter, b = intermediate diameter, c = minor diameter, GMD = geometric mean diameter, AMD = arithmetic mean diameter, SMD = square mean diameter, EMD = equivalent diameter; AR = aspect ratio.

Roundness of the fruits were determined by tracing the edges of the fruits with sharp pencil on a white paper. The diameter of the sharp projected areas were measured with a pair of divider and digital venier caliper while roundness of each fruit and nut was calculated as Equation 9.

$$Roundnes = \frac{(A_p)}{(A_c)} \quad (9)$$

Where; A_p= Largest projected area of the product when in natural rest position; A_c = Area of smallest circumscribed circle.

Roundness ration (RR) was determined as shown in Equation 10.

$$RR = \frac{a}{\sqrt{bc}} \quad (10)$$

Sphericity was determined by applying the data of principal dimensions to Equation 11.

$$Sphericity = \sqrt[3]{abc}/a \quad (11)$$

Where a = major diameter, b = intermediate diameter, c = minor diameter

The roundness and sphericity of each of the five and three moisture content studied were replicated fifty times.

3.0 RESULTS AND DISCUSSIONS

3.1 Physical Properties Of *Rubus fruticosus* Fruits And Nuts

3.2 Size of *Rubus fruticosus* fruits and nuts

The principal dimension of long and short *Rubus fruticosus* fruits and nuts is presented in Table 1. The principal dimensions of long and short fruits evaluated decreased as moisture content decreased from 40.91 to 11.03% (*w.b.).*The major, intermediate and minor diameters decreased by 2.65%, 15.71% and 15.24% respectively for long fruit and, 11.56%, 16.18% and 16.64% respectively for short fruit. Behise *et al.* (2013) and Aghajani *et al.* (2012) observed 10.74%, 6.44% and 11.52% and, 2.76%, 13.38% and 9.29% decrease in major, intermediate and minor diameters of sunflower seeds and barley fruits (Sahra) respectively as moisture content decreased from 18% - 10% and 42.17% - 10.12% wet basis.

Major, intermediate and minor diameters of the nuts increased by 1.63%, 3.51% and 2.20% respectively for long nut and 2.56%, 2.76% and 2.54% respectively for short nut as moisture content increased from 10.20% - 25.06% wet basis. Major, intermediate and minor diameters of tiger nut, pistachio nut and dika nut were also reported to increase by 15.16%, 14.13% and 12.89% respectively; 18.04%, 20.10% and 5.930% respectively and, 1.21%, 6.62% and 30.81% respectively as moisture content increased from 17% - 27% (wb); 3.70% - 30% (wb) and 8.74% - 13.75% (wb) respectively (Abano and Amoah, 2011, Peyman *et al*., 2013 and Orcheba *et al*., 2013 respectively). The observed increase in principal dimensions could be because the cells of the fruits and nuts expanded at higher moisture content.

Table 1: Principal dimensions of *Rubus fruticosus long and short* fruits and nuts at different moisture content.

	Fruits					
	Long			Short		
M. C.	a	b	c	A	b	c
40.91%	42.86 ± 0.91	20.05 ± 0.66	19.56 ± 0.65	26.06 ± 1.09	16.69 ± 0.59	16.17 ± 0.27
	(2.13)	(3.27)	(3.33)	(4.18)	(3.52)	(1.98)
34.92%	42.59 ± 0.88	18.54 ± 0.63	18.06 ± 0.64	25.08 ± 1.37	15.89 ± 0.56	15.36 ± 1.54
	(2.09)	(3.41)	(3.56)	(5.47)	(3.56)	(1.05)
23.44%	42.36 ± 0.93	18.44 ± 0.51	17.89 ± 0.53	24.20 ± 2.08	15.05 ± 0.78	14.57 ± 1.54
	(2.09)	(2.77)	(2.97)	(8.62)	(5.24)	(1.05)
18.5%	42.02 ± 0.97	17.39 ± 2.38	17.18 ± 0.98	23.87 ± 2.24	14.45 ± 0.84	13.94 ± 1.59
	2.30	(1.36)	(3.74)	(9.39)	(5.80)	(1.14)

11.03%	41.71 ± 1.36 (3.27)	16.90 ± 2.43 (1.44)	16.58 ± 1.13 (3.82)	23.05 ± 2.73 (1.18)	13.99 ± 0.96 (1.20)	13.48 ± 1.62 (1.20)
			Nuts			
10.20%	36.75 ± 1.27 (3.46)	13.19 ± 0.45 (3.41)	12.89 ± 0.39 (3.03)	23.26 ± 0.92 (3.96)	10.93 ± 0.38 (3.48)	10.76 ± 0.35 (3.25)
17.23%	36.91 ± 1.73 (4.69)	13.26 ± 0.37 (2.79)	12.99 ± 0.36 (2.77)	23.59 ± 0.89 (3.77)	11.18 ± 0.45 (4.03)	10.98 ± 0.42 (3.83)
25.06%	37.36 ± 1.27 (3.39)	13.67 ± 0.46 (3.37)	13.18 ± 0.39 (2.96)	23.87 ± 0.92 (3.84)	11.24 ± 0.45 (4.04)	11.04 ± 0.43 (3.89)

The values in bracket are the coefficient of variation (%CV); a = major diameter (mm); b = intermediate diameter (mm); c = minor diameter (mm); M .C. = moisture content wet basis.

Lower percentage variation of principal dimensions of the nuts with moisture content when compared with that of tiger nut and pistachio nut could be because the cell of the *Rubus fruticosus* nuts have less void spaces and shrinking behavior during moisture loss than tiger nut and pistachio nut. The principal dimensions of both fruits and nuts had low coefficient of variation which indicates evenly distributed values about their means. The mean diameters also decreased as moisture content decreased from 40.91 to 11.03% (*w.b.)*for fruits and 25.06% - 10.20% wet basis for nuts (Table 2).The geometric mean diameter (GMD), arithmetic mean diameter (AMD), square mean diameter (SQMD) and equivalent mean diameter (EQD) of the fruits decreased by 7.73%, 6.75%, 7.03% and 7.17% respectively for long fruit and, 14.95%, 14.26%, 14.66% and 14.60% respectively for short fruit. Long and short *Rubus fruticosus* nuts also decreased in GMD, AMD, SQMD and EQD by 2.44%, 2.10%, 2.37% and 2.29% respectively and 2.65%, 2.69%, 2.64% and 2.63% respectively. Davies and Zibokere (2011) has also reported 26.79%, 22.09% and 20.11% increase in GMD of Ife Brown, IAR-339-1 and IT86G-1010 cowpea varieties, respectively as their moisture content decreased from 30% - 15% wet basis. The ANOVA in Table 3 revealed that moisture content had significant (5%) effect on the principal dimensions of both fruits and nuts while the effect of interaction is not significant (5%). Besides, the differences between the principal dimensions of long and short fruits are highly significant (5%). Regression equations of the principal dimensions in Table 4 showed high values of coefficient of determination (R^2) indicating good relationship between the parameters evaluated.

Table 2: Mean diameters of long and short *Rubus fruticosus* fruits and nuts at different moisture content.

	Fruits							
	Long				Short			
M. C.	GMD	AMD	SQMD	EQD	GMD	AMD	SQMD	EQD
40.91%	25.90 ± 0.64 (1.61)	26.54 ± 0.66 *(1.62)*	26.19 ± 0.65 *(1.61)*	26.21 ± 0.65 *(1.61)*	19.13 ±1.09 *(5.09)*	19.64 ± 0.92 *(4.67)*	19.37 ± 0.98 *(5.05)*	19.38 ± 0.99 *(5.10)*
34.92%	25.23 ± 0.63 *(2.48)*	25.91 ± 0.63 *(2.44)*	24.54 ± 0.63 *(2.47)*	25.56 ± 0.63 *(2.46)*	18.26 ±1.06 *(3.81)*	18.78 ± 0.63 *(3.33)*	18.49 ± 0.96 *(3.18)*	18.51 ± 0.83 (4.16)
23.44%	24.69 ± 0.57 *(2.33)*	25.41 ± 0.59 *(2.31)*	25.01 ± 0.58 *(2.31)*	25.04 ± 2.32 *(2.32)*	17.41 ± 1.25 *(4.17)*	17.94 ± 0.80 *(4.47)*	17.65 ± 1.18 *(4.39)*	17.67 ± 1.00 *(4.68)*
18.50%	24.36 ± 0.55 *(2.25)*	25.11 ± 0.55 *(2.18)*	24.69 ± 0.55 *(2.21)*	24.72 ± 0.55 *(2.21)*	16.84 ± 1.34 *(4.92)*	17.42 ± 0.87 *(4.98)*	17.10 ± 1.26 *(4.36)*	17.12 ± 1.08 *(4.28)*
11.03%	23.95 ± 0.54 *(2.24)*	24.75 ± 0.54 *(2.17)*	24.31 ± 0.54 *(2.20)*	24.33 ± 0.54 *(2.19)*	16.27 ± 1.47 *(3.04)*	16.84 ± 1.41 *(3.62)*	16.53 ± 1.43 *(3.65)*	16.55 ± 1.26 *(3.62)*
	Nuts							
10.20%	18.42 ± 0.47 (2.55)	20.95 ± 0.57 (2.72)	19.39 ± 0.49 (2.50)	19.59 ± 0.51 (2.60)	13.98 ± 0.43 (3.08)	14.98 ± 0.48 (3.20)	14.39 ± 0.45 (3.20)	14.45 ± 0.45 (3.11)
17.23%	18.52 ± 0.53 (2.86)	21.05 ± 0.71 (3.37)	19.50 ± 0.59 (3.03)	19.69 ±0.61(3.10)	14.25 ± 0.47 (3.29)	15.25 ± 0.49 (3.21)	14.67 ± 0.48 (3.27)	14.72 ± 0.48 (3.26)
25.06%	18.88 ± 0.52 (2.75)	21.40 ± 0.61 (2.85)	19.86 ± 0.55 (2.77)	20.05 ± 0.56 (2.79)	14.36 ± 0.48 (3.34)	15.38 ± 0.51 (3.32)	14.78 ± 0.49 (3.32)	14.84 ± 0.49 (3.30)

The values in bracket are the coefficient of variation (%CV);

Table 3: ANOVA summary of physical parameters of *Rubus fruticosus* fruit studied at moisture range of 40.91% - 11.03% wet basis.

	Fruits					Nut				
Source of variation	df	a	b	c	5%	df	a	b	c	5%
Size	1	15094.87**	713.12**	1438.55**	3.86	1	7796.08**	2145.59**	2301.78**	3.87
Moisture content	3	23.78*	79.26**	151.40**	2.39	2	7.57*	23.56*	18.28*	3.03
Interaction	4	6.59*	0.8593ns	0.6308ns	2.39	2	0.2544ns	1.99ns	0.4459ns	3.03

*a = major diameter (mm); b = intermediate diameter (mm); c = minor diameter (mm); ** Highly significant; * Significant; ns Not significant*

Table 4: Equations representing relationship between principal dimensions and moisture content

Fruit	
Long	Short

Parameters	Regression equation	R^2	Regression equation	R^2
a	3.59 h + 41.39	0.97	9.14 h + 22.13	0.97
b	9.24 h + 15.92	0.99	8.71 h + 13.01	0.99
c	8.48 h + 15.70	0.89	8.64 h+ 12.51	0.99
		Nut		
a	4.14 h + 36.28	0.95	4.09 h + 22.86	0.99
b	3.27 h + 12.80	0.87	0.3533 ln(h) + 11.76	0.94
c	1.96 h + 12.67	0.98	0.3184 ln(h) + 11.50	0.98

a = major diameter (mm); b = intermediate diameter (mm); c = minor diameter (mm); h = moisture content wet basis

In design and development of processing and handling equipment for *Rubus fruticosus* products, moisture content of the fruits and nuts should be specified to avoid waste of money and material due to over /under design.

3.3 Shape of *Rubus fruticosus* fruits and nuts

3.4 Sphericity, roundness and aspect ratio of the fruits and nuts

The sphericity, roundness and aspect ratio of *Rubus fruticosus* long and short fruits decreased with increase in moisture content (40.91% to 11.03% wet basis) while the long and short nuts increased with increase in moisture content (10.20% - 25.06% wet basis).The sphericity, roundness and aspect ratio of short and long fruits reduced by 5.27%, 3.80% and 45.10% and, 4.65%, 6.98% and 4.62%, respectively (Table 5 and Fig 3). Fathollahzadeh *et al.* (2008) and Razavi *et al.* (2009) also reported that the sphericity of barberry fruits and canola seeds (*SLM spp*.) reduced by 40.43% and 2.29% as moisture content reduced from 89.23 – 11.64% and 21 – 6% wet basis respectively. At 40.91% *wet basis*, the sphericity and aspect ratio values showed that short fruits are more spherical and oblong than long fruit; hence, short fruit can roll more easily than the long fruit

Aspect ratio (AR), sphericity and roundness ration (RR) of the nuts at 10.20% moisture content wet basis ranged from 2.8 – 3.09, 1.69 – 1.88 and 0.4700–0.5300 respectively for long nut and, 1.88 – 2.32, 1.20 – 1.45 and 0.5700–0.6600 respectively for short nut. The mean values of shape parameters shown in Table 5 and Fig 3 revealed that AR for both nuts are within the range for oblong shape (1.85 – 2.31) as classified by Şehrali (1988) and Kara *et al.* (2013). The values of RR and sphericity being slightly higher than 50% confirmed the shape. *Rubus fruticosus* nuts had similar shape with Aras-98, Elkoca-05, Noyanbey-98 and Yakutiye-98 bean cultivars as reported by Kara *et al*. (2013) while Tenera and Dura palm nuts are ovate in shape (Akinoso and Raji, 2010).

Table 5: Aspect ratio of long and short *Rubus fruticosus* fruits and nuts at different moisture content

Sizes	Moisture content (wb)				
	40.91 %	34.92 %	23.44 %	18.50 %	11.03 %
Long fruit	46.78 ± 1.67 (3.57)	45.23 ± 1.43 *(3.16)*	43.47 ± 1.43 *(3.29)*	41.36 ± 5.72 *(3.38)*	40.56 ± 5.94 *(3.02)*

Short fruit	64.09 ± 2.14*(3.34)*	63.52 ± 2.97 *(4.68)*	62.49 ± 4.27 (4.83)	60.86 ± 4.32 (0.09)	60.71 ± 4.88 (4.73)
	10.02%	17.23%	25.06%	NS	NS
Long nut	2.79 ± 0.09 (3.23)	2.77 ± 0.13 (4.69)	2.74 ± 0.09 (3.29)	NS	NS
Short nut	2.13 ± 0.09 (4.23)	2.11± 0.08 (3.79)	2.11± 0.09 (4.27)	NS	NS

The values in bracket are the coefficient of variation (% CV); The fruits aspect ratio values are in percentage. NS = not studied

F-LSD (5%) of difference between two sizes of Rubus fruticosus fruit and nuts means respectively = 0.0252 and 0.0418

F-LSD (5%) of difference between moisture levels of Rubus fruticosus fruit nuts means respectively means = 0.0398 and 0.0625

Table 6: ANOVA summary of moisture effect on aspect ratio, sphericity and roundness of *Rubus fruticosus* long and short fruits and nuts

	Fruits				Nuts			
Source of variation	df	Aspect ratio	Sphericity	Roundness	df	Aspect ratio	Sphericity	Roundness

Moisture content	4	< 0.0010**	0.0670ns	0.5410ns	2	0.6770ns	0.4140ns	0.3930 ns
Size	1	< 0.0010**	< 0.0010**	< 0.0010**	1	< 0.0010**	< 0.0010**	0.3660ns
Interactions	4	0.5240ns	0.7850 ns	0.9590 ns	2	0.9070 ns	0.4950 ns	0.3970 ns
Total	29							

Level of probability = 5%; ** highly significant; ns = significant

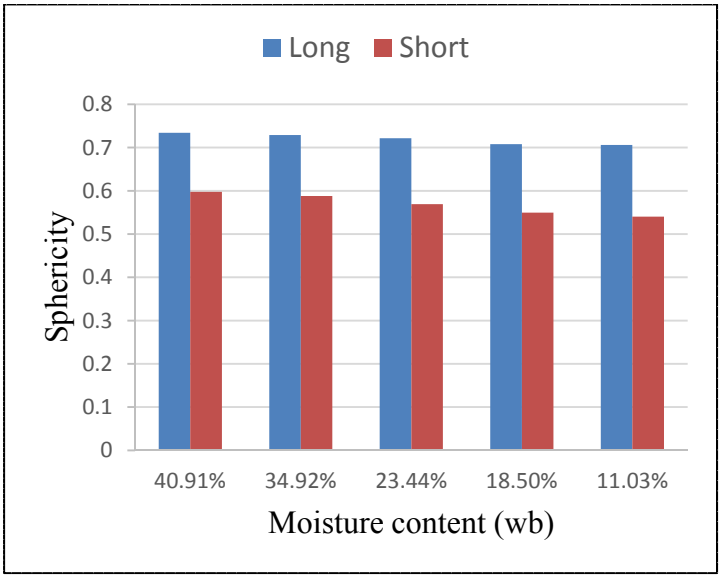

Fig. 3a

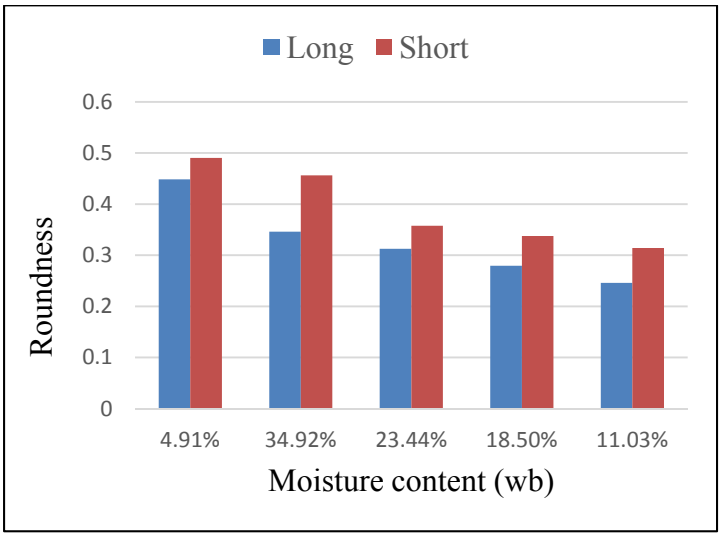

Fig. 3b

Figure 3: The plot of (a) sphericity and (b) roundness of *Rubus fruticosus fruits* against moisture content.

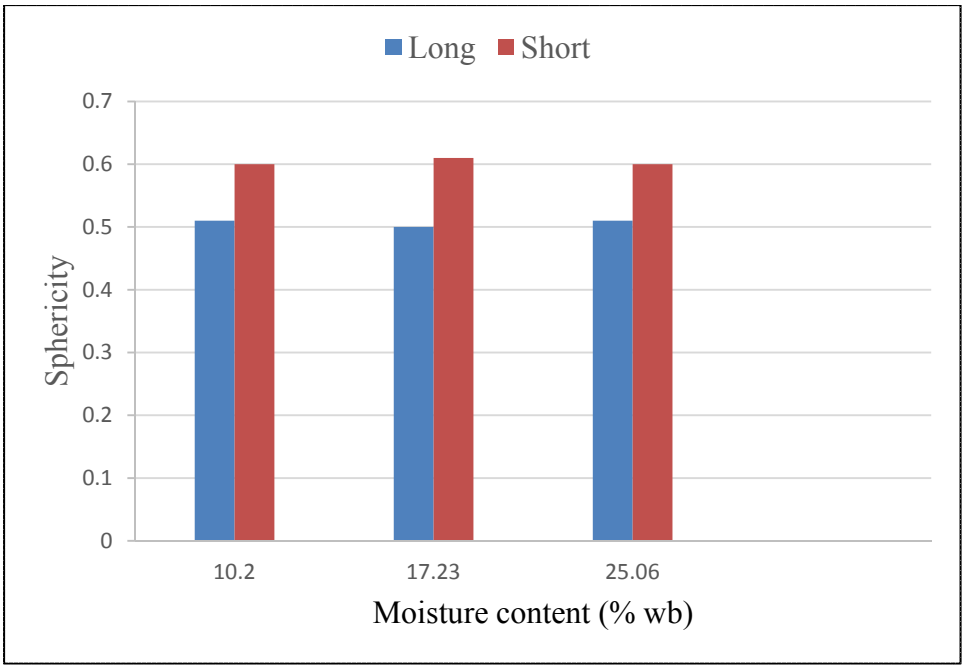

Fig. 4a

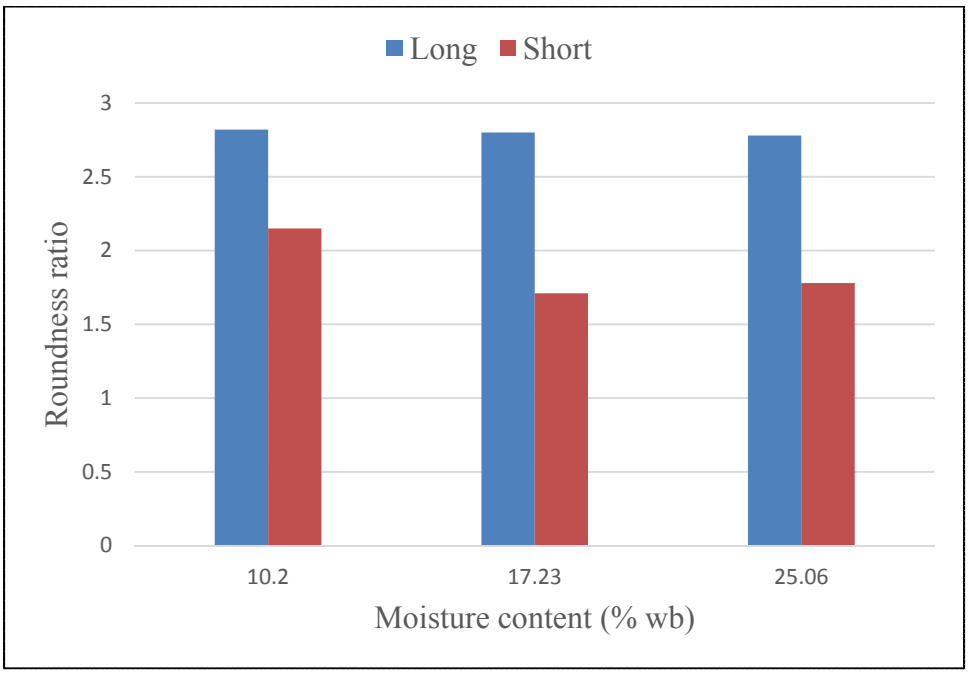

Fig. 4b

Figure 4: The plot of (a) sphericity and (b) roundness of *Rubus fruticosus* nuts against moisture content.

All the shape parameters for short fruits had non-linear relationship with moisture content except RR. Long and short fruits are significantly different (5%) in terms of sphericity and aspect ratio (AR) while the nuts differ in terms of AR and RR (Table 4). Moisture content had no effect on the shape parameters of the nut but significantly (5%) affected the AR of the fruit only. This result could be because the cells of the fruits and nuts are inelastic and could have less pore spaces which resulted in low shrinkage effect during moisture loss. The interaction of both fruits and nuts are not significant (5%). Roundness had low values for both fruits and nuts studied, showing that *Rubus fruticosus* fruits and nuts are not round, therefore, the shape of screen opening for separation purposes must not be round. These results mean that the shape of outlet channel of storage facility for *Rubus fruticosus* fruits and nuts should be oblong or rectangular. The rolling nature of the fruits is an indication that agitator device is not needed in the design.

4.1 Conclusions

Some engineering properties of *Rubus fruticosus* fruits, nut and nutshell were studied and the following conclusions were made:

1. The major, intermediate and minor diameters of the fruits range 35.14 – 34.09 mm, 22.44 – 20.25 mm and 22.03 – 19.92 mm respectively for long and, 26.66 – 23.05 mm, 16.69 – 13.99 mm and 16.17 – 13.48 mm respectively for short fruits at moisture range of 40.91 to 11.03% (wet basis).
2. The nuts also ranged from 36.75 – 37.36 mm, 13.19 – 13.66 mm and 12.89 – 13.18 mm respectively for long nuts, 23.26 – 23.87 mm, 10.93 – 11.24 mm and 10.76 – 11.04 mm respectively for short nuts at 10.2% - 25.06 % wet basis.
3. Both fruits and nuts are oblong in shape and denser than water (with average values of 1.05 g/cm^3 and 1.69 g/cm^3 respectively).

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