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EFFECT OF MOISTURE CONTENT ON PHYSIOCO-MECHANICAL PROPERTIES OF CASHEW-APPLE-NUT VARIETIES RELEVANT FOR ITS PROCESSING

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Abstract:The physioco-mechanical properties of Red and Yellow apple cashew nuts which are essential for the design and fabrications of its processing and storage facilities were studied. The major, minor and intermediate diameter of the cashew nut varied from 21.81–30.43mm,14.01–17.18mm,4.72–10.55mm and 19.83–27.13mm, 16.09–20.27mm, 6.38–13.97mm for Red and Yellow apple respectively. The average values of bulk weight, surface area and volume of the samples were 20.58189.5g, 826.07–342.33g, 137.67–57.05 (mm^3) and 229.8–211.8g,699.97–305.40mm^2,173.13–70.63mm^3.The average values of sphericity, porosity and aspect ratio of the samples were 56.23–50.47%, 73.39–28.83%, 56.19 – 64.05% and 70.08–62.09%,66.82–24.71%,74.60–81.00%. It was observed that all the physical properties studied increased with an increase in moisture apart from bulk density and aspect ratio that decreased across the moisture content. The mechanical properties of Red and Yellow apple cashew nut were found to be moisture content and loading positions dependent. The relationship that existed between moisture content and the mechanical properties was statically significant at ($p < 0.05$) level. It is also economical to load both Red and Yellow apple cashew nut at major axis loading position at 4.26% (wb) moisture content to reduce energy demand required to crack or compress the samples.

Keywords: *Physical property, mechanical property, cashew nut, moisture content, loading position.*

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INTRODUCTION

The effect of moisture content on the engineering properties of biomaterials such as physical and mechanical parameters are essential in the design and adjustment of machines used during harvesting, cleaning, separation, handling and storage [1] The information on the physical and mechanical properties of biomaterials is a prerequisites in the processing of agricultural products into different bio products [2]. It is also necessary in the analysis and investigation of the efficiency of a machine operation, development of a new products and finished quality of products [3]. These properties are not only essential to engineers but also to food processors, plant and animal breeders and other scientist who may exploit them in their various disciplines [4] The physical and mechanical damages that occur in agricultural products are mainly due to external forces under stationary or dynamic conditions [5] .The physical bruises and internal forces that causes physical and mechanical damages in agricultural products include variation in temperature and moisture content and when this physical and mechanical damages occurs, the agricultural products become vulnerable to infection and deterioration [6] Therefore the study of physical and mechanical properties of agricultural materials gives insight on how to withstand these physical and mechanical damages that occur during harvesting, processing and postharvest of the products. Physical and mechanical properties of cashew nut have been reported by some researchers [3]; [7]; [4]; [8]; [9] and many others but there is no literature on effect of moisture content and three axial loading positions on the physical and mechanical properties of two varieties freshly harvested cashew using Instron 3345 Universal Testing Machine with bluehill software. Cashew tree (*Anacardium occidentale Linn*.) is broadly cultivated beyond the coastal regions of the tropics and it is known for its potential benefits [10]. The fruits, the leaves, the bark, the wood and the roots have been investigated to be valuable for commercial uses such as food, medicine, industry and environmental applications. The major commercialized cashew products are raw cashew nut, cashew kernel and cashew nut shell liquid. Cashew nut (*Prunus Dulcis*) is a kidney like shape seeds that is attached to the bottom of the cashew apple [10]. The cashew apple is light reddish to yellow fruit whose pulp can be processed into a sweet, astringent fruit drink or distilled into liquor. It can grow as high as 14m but the dwarf cashew growing up to 6m, has proven more profitable, with earlier maturity and higher yields . [4] .

Cashew nut is very nutritious with high amount of energy as it contains protein, minerals, fats, carbohydrate, vitamins and fibre, all of which contribute enormously to good health from its consumption [3]. Cashew nut kernel can be eaten raw, fried, roasted and sometimes pre-treated with salt or sugar. Other useful products made from cashew are jam, juice, syrup, chutney and beverage [3]. Although the processing of cashew and its products in an old practice for which traditional methods are more available, new methods will not only reduce the drudgery of handling but will expand the areas in which most of the products are effectively being utilized [4]. Data on engineering properties of a biomaterial are dependent on a number of factors such as species, or variety and the climatic environment where it is cultivated [1] and [4]. This makes it desirable that the engineering properties of locally cultivated varieties be determined.

Therefore, the study is concentrated in determining the effect of moisture content and loading positions on the physicomechanical properties of locally harvested Red and Yellow apple varieties of cashew nut relevant to its properties.

MATERIALS AND METHODS

Source of the sample

The Red and Yellow apple cashew nut samples used for this research work were collected from a local farm located Ukehe, Igbo-Etiti LGA Enugu State at a stable harvest moisture.

Preparation of the Sample.

The cashew samples were properly cleaned and sorted to select viable seeds. After that, the sample was wrapped with polythene bag and covered in plastic containers to avoid change in moisture contents. Then the sample were taken to the laboratory where the physical and mechanical properties were carried out. The apparatus used include; veneer caliper, for measuring the axial dimensions; Mettler -Toledo Electric digital weighing balance with model number XP204 and 0.001 sensitive, for weighing the samples at intervals; Multi- Purpose Oven Dryer, drying the sample; and Instron Universal Testing Machine, for force-deformation characteristics.

Determination of Physical properties of the samples.

The physical dimensions suchlike major, minor and intermediate diameters of the cashew nut were determined from randomly selected 30 seeds from the bulk sample using a digital Vernier caliper with accuracy of 0.001mm. The geometric mean diameter, arithmetic mean diameter, equivalent mean diameter, harmonic mean diameter, square mean diameter of the cashew nut seeds were calculated using the following equations (1 - 5) reported by [11].

$$\mathrm{AMD} = \frac{\mathrm{a+b+c}}{3} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

$$\mathrm{GMD} = \frac{(\mathrm{axbxc})}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where; a = Major diameter; b = Minor diameter; c = Thickness; AMD = Arithmetic Mean Diameter (mm); GMD = Geometric Mean Diameter (mm).

According to [11], Harmonic Mean, Square mean, and Equivalent Mean Diameters were calculated using;

$$H\mathrm{MD} = \frac{1}{\mathrm{a}} + \frac{1}{\mathrm{b}} + \frac{1}{\mathrm{c}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\mathrm{SMD} = \sqrt{\boldsymbol{axb}} + (\boldsymbol{bxc}) + (\boldsymbol{c}\mathrm{x}\boldsymbol{a}) \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\mathrm{EQMD} = \frac{\mathrm{SMD+GMD+AMD}}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where is:
a = major diameter (mm);
b = minor diameter (mm);
c = thickness (mm);
HMD = harmonic mean diameter (mm);
SMD = square mean diameter (mm);
EQMD = equivalent mean diameter (mm)

Bulk Volume

The following mathematical equation (6) stated by [12] and [13] can be used to calculate the volume of the seeds.

$$V = \frac{\pi B a^2}{6(2a - B)} \quad \ldots\ldots\ldots\ldots(6)$$

Where, $B = (ba)^{1/2}$, a and b are major and minor diameter of the sample (mm), V = volume (m^3).

Surface Area

Surface area of the sample was calculated using equation (7) reported by [3].

$$\text{Surface Area} = \frac{\pi B a^2}{(2a - B)} \quad \ldots\ldots\ldots.7)$$

Where $B = (bc)^{1/2}$, a and b are major and intermediate diameter of the sample (mm)

Sphericity

Sphericity is used in fluid flow and heat and mass transfer calculations and in the design of aerodynamic, sorting and separating machine. It can be calculated using the equation (8) reported by [14].

$$\text{Sphericity } (\%) = \frac{GMD}{a} \quad \ldots.\ldots.(8)$$

GMD = geometric mean diameter of sample (mm), a = major diameter (mm).

Aspect ratio

It is used to calculate aerodynamic, sorting, separation, thermal load and size characteristics of agricultural materials. It is calculated using the equation (9) reported by [15].

$$R_a = \frac{b}{a} \times 100 \quad \ldots\ldots.(9)$$

Where b and a are minor and major diameter of the sample respectively in (mm)

Bulk weight of 30 seeds.

Bulk weight of agricultural material describes its market value. To obtain the 30 seed weight, the seed was weighed using a precision electronic weighing balance with accuracy of 0.001g. It is used to measure the moisture content of agricultural materials.

Bulk density

The bulk density, ρb was calculated as the ratio of weight of the material to the volume of the cylinder using the equation (10) reported [16] and [17]

$$\boldsymbol{\rho_b} = \boldsymbol{W_S} / \boldsymbol{V_C} \quad \text{... ...(10)}$$

Where is:
$W_S = weight\ of\ the\ sample\ (kg)$,
$V_C = Volume\ (m^3)$

True density

True density, ρt (kg m^3) of the samples was calculated by dividing the unit mass of each s ample by its true volume. It is determined using the equation (11) reported by [18].

$$\boldsymbol{\rho_t} = \boldsymbol{M_u} / \boldsymbol{V_u} \quad \text{....(11)}$$

Where is;
ρ_t = true density (kg/m^3), M_u= unite mass of the sample (kg), V_u = unite volume of the sample (m^3)

Porosity

Porosity (ρ), was determined in terms of bulk density (ρb) and true density (ρt) using the following equation (12) reported by [19]

$$\rho = \left(1 - \frac{\rho_b}{\rho_t}\right) x\ 100 \quad \text{.... (12)}$$

Where p = porosity, p_b = bulk density (kg/m^3) and p_t = true density (kg/m)

Determination of the Mechanical Properties.

Compression tests were carried out on the sample at three different moisture levels under three different loading orientations namely; major, minor and intermediate, using an INSTRON Universal Testing Machine (IUTM), of BlueHill 3 software, and Dell computer system of windows 8 software. The samples were compressed at the cross-head load of 5KN at speed of 5mins. As the compression began and progressed, a load deformation curve was plotted automatically in relation to the response of each sample under compression. Thirty randomly selected samples were tested at each loading orientation and at three different moisture contents. The load-deformations curves and its parameters were obtained. At the end of the compression test, maximum load, compressive extension, energy at maximum load and slope at maximum load were tabulated.

Compressive strength (N/mm)

This measures the strength at which each sample under compressive test will crack. It was calculated as the ratio of applied force to the area of the sample, it is denoted as δc, calculated by adopting equation (13) reported by [15].

$$\delta c = \frac{f_c}{A} \qquad \dots \dots \dots (13)$$

Where; ∂c = compressive strength (N/mm^2);
fc = $maximum\ load\ at\ fracture$ (N);
A = $crosssectional\ area\ of the sample$ (mm^2).

Stiffness (N/mm^2)

Stiffness is rigidity of a material and the extent at which it resists deformation in response to applied force. The stiffness, St, o f a material is measure of the resistance offered by an elastic material to deformation. It is the ratio of the stress to strain (δ/ε), [1]

$$S_t = \frac{f}{\partial} \qquad \dots\dots(14)$$

Where is:
St = stiffness (N/mm^2);
F = force on the material;
δ = deformation on the material.

Toughness (J/M^3)

This is the amount of energy per unit volume that a material can absorb before rupturing occur. It is also defined as a material's resistance to fracture when stressed. It is approximated under the stress–strain curve. Mathematically, toughness can be calculated using equation (15) as reported by [1];

$$\text{Toughness} = \frac{\text{Rupture energy}}{\text{Volume of material}} \qquad \dots \dots \dots (15)$$

Deformation Energy (N/MM)

This is the total spent energy of a sample under compressive test at which deformation occur. It is given as;

$$\text{Deformation energy} = \text{Rupture force X deformation at rupture} \qquad \dots \dots \dots \dots (16)$$

RESULTS AND DISCUSSION

Physical properties of cashew nut

The mean value of the three axial dimensions of two varieties (Red and Yellow apple) of cashew nut seeds such as major, minor and intermediate were studied at three different moisture content and they are presented in table 1. From fig.1, it was observed that the three dimensions displayed linear trend apart from minor dimeter both Red and Yellow apple that showed logarithm trend dependent on the moisture content.

Eminent correlation was observed among the axial dimensions of the samples and moisture content which indicated that as the sample absorbs water, the cashew nut swells in all the main dimensions (major, minor and intermediate) within the moisture range of 4.226 % to 11.69% (wb). The major, minor and intermediate diameter of the cashew nut varied from 21.81 - 30.43mm, 14.01 – 17.18mm, 4.72 – 10.55mm and 19.83 – 27.13mm, 16.09 – 20.27mm, 6.38 – 13.97mm for Red and Yellow apple respectively as the moisture content increased from 4.29 – 11.69% (wb). The arithmetic and geometric mean were also fund to increase with corresponding increase in moisture content from 19.37 -13.18mm, 17.16 -11.02mm and 20.45 – 14.10mm, 19.15 – 12.35mm for Red and Yellow apple cashew nut respectively and these were similar with what [20]; [1]; [14]; [23], [24]; [25] and [24] reported on different agricultural materials. It was observed that major, minor, intermediate, arithmetic mean and geometric mean diameters are statically significant at $p < 0.05$. The relationship that existed among the cashew nut dimensions and moisture content range are shown below with their values for coefficients of determination (R^2)

Major (Red) = 8.5876ln (mc) + 9.5791 $R^2 = 0.9909$
Major (Yellow) = 7.2267ln (mc) + 9.3349 $R^2 = 0.9999$
Minor (Yellow) = 4.1984ln (mc) + 10.261 $R^2 = 0.9487$
Minor (Red) = 0.4298mc + 12.087 $R^2 = 0.9925$
Intermediate (Yellow) = 1.0233mc + 1.9681 $R^2 = 0.9996$
Intermediate (Red) = 0.7943mc + 1.0565 $R^2 = 0.9799$

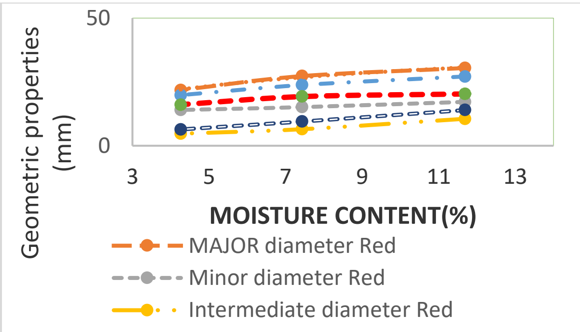

Figure.1. Effect of moisture content on some geometric properties of Red and Yellow apple cashew nut

Bulk weight, surface area and volume of cashew nut.

The mean value of the bulk weight, surface area and volume of two varieties (Red and Yellow apple) of cashew nut seeds such as major, minor and intermediate were studied at three different moisture content and they are presented in table 1. From fig.3, it was observed that Bulk weight, surface area and volume of the samples showed linear trend apart from bulk weight of Yellow sample that displayed logarithm trend with corresponding increase in moisture content.

The average values of bulk weight, surface area and volume of the samples were 205.8 -189.5g, 826.07 – 342.33g, 137.67 – 57.05 (mm^3) and 229.8 – 211.8g, 699.97 – 305.40mm^2, 173.13 – 70.63mm^3 at moisture range of 4.26 – 11.69% (wb).
This is similar to what [27] reported in effect of moisture content on the physical properties of sesame seeds . From the findings it was observed that bulk weight, surface area and volume are statically significant at $p < 0.05$. The relationship that existed among bulk weight, surface area and volume of the cashew nut and moisture content range are shown below with their values for coefficients of determination (R^2)

Area (Red) = 65.513mc + 51.444	$R^2 = 0.9947$
Area (Yellow) = 52.882mc + 86.583	$R^2 = 0.9975$
Bulk weight (Yellow) = 17.743ln (mc) + 185.69	$R^2 = 0.9929$
Bulk weight (Red) = 2.154mc + 181.48	$R^2 = 0.9546$
Volume (Yellow) = 13.756mc + 13.162	$R^2 = 0.9989$
Volume (Red) = 10.918mc + 8.5737	$R^2 = 0.9947$

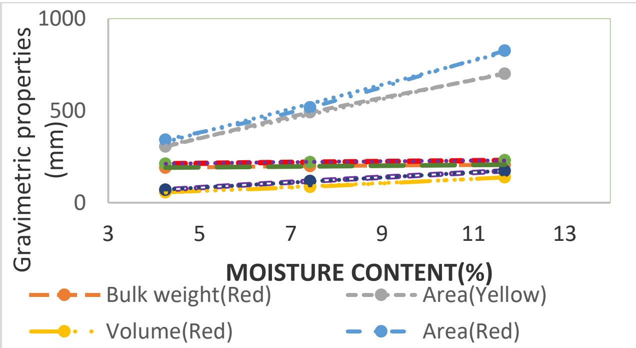

Figure.2. Effect of moisture content on some gravimetric properties of Red and Yellow apple cashew nut

Sphericity, Porosity and Aspect ratio

The average value of the sphericity, porosity and aspect ratio of two varieties (Red and Yellow apple) of cashew nut seeds samples were studied at three different moisture content and they are presented in table 1. From fig.2, it was observed that sphericity, porosity and aspect ratio of the samples displayed linear trend apart from sphericity of Yellow sample that displayed logarithm trend with corresponding increase in moisture content. The average values of sphericity, porosity and aspect ratio of the samples were 56.23 – 50.47%, 73.39 – 28.83%, 56.19 – 64.05% and 70.08 – 62.09%, 66.82 – 24.71%, 74.60 – 81.00% at moisture range of 4.26 – 11.69% (wb). From the findings it was observed that sphericity, porosity increased with corresponding increase in moisture content despite aspect ratio that displayed negative sign in the regression equation and this is due that the aspect ratio decrease down the line as moisture content increases across the properties.

The relationship that existed among sphericity, porosity and aspect ratio of the cashew nut and moisture content range are shown below with their values for coefficients of determination (R^2)

Aspect ratio (Yellow) = -0.8946mc + 85.602 $R^2 = 0.9006$
Sphericity (Yellow) = 7.9055ln (mc) + 50.59 $R^2 = 0.9996$
Porosity (Red) = 5.9691mc + 4.2208 $R^2 = 0.9969$
Porosity (Yellow) = 5.5718mc + 3.7534 $R^2 = 0.9605$
Aspect ratio (Red) = -0.9892mc + 66.269 $R^2 = 0.598$
Sphericity (Red) = 0.8241mc + 45.541 $R^2 = 0.6713$

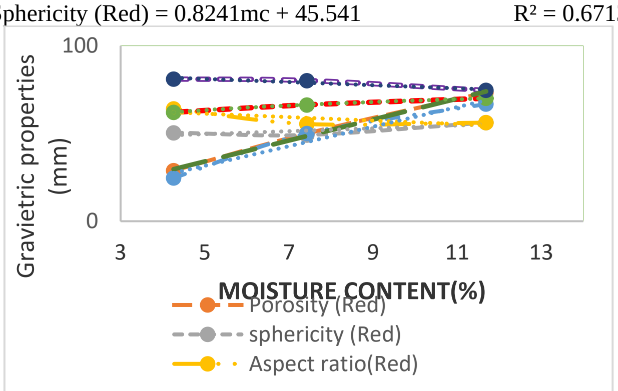

Figure 3. Effect of moisture content on the some gravimetric properties of Red and Yellow apple cashew nut

Bulk density and true density

The average bulk and true density of Red and Yellow apple cashew nuts varied from 321.49–604.15g/mm^3, 1208.30 –847.98 g/mm^3 and 419.16 – 631.21 g/mm^3, 1263.17 – 838.32g/mm^3 respectively at moisture range of 4.26 – 11.69% (wb). It was observed that increase in moisture content decreases the bulk density and increase true density of the samples it is so because the volumetric expansion of the samples was found to be lesser than mass of the sample when it absorbs water, this similar and contrary with [21]; [28]; [29]; [30] [13], [31] and [32] on different biomaterials for bulk and true density. The relationship that existed between bulk and true densities of the cashew nut and moisture content range are shown below with their values for coefficients of determination (R^2), (see fig.4)

True density (Yellow) = 427.08ln (mc) + 246.95 $R^2 = 0.9426$
True density (Red) = 359.19ln (mc) + 342.8 $R^2 = 0.9771$
Bulk density (Yellow) = -29.085mc + 770.95 $R^2 = 0.9533$
Bulk density (Red) = -38.88mc + 794.09 $R^2 = 0.9393$

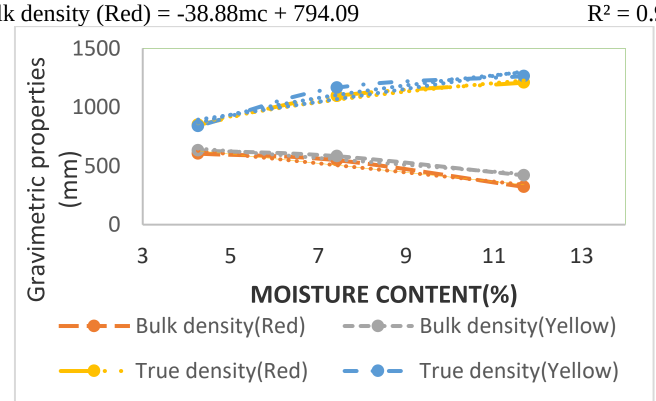

Figure 4. Effect of moisture content on some gravimetric properties of Red and Yellow apple cashew nut

Table 1.Effect of moisture content on Physical properties of Red and Yellow apple cashew nut

Properties	Moisture content/ Samples					
	11.69%		7.43%		4.26%	
	Red apple cashew nut	Yellow apple cashew nut	Red apple cashew nut	Yellow apple cashew nut	Red apple cashew nut	Yellow apple cashew nut
Major Diameter (mm)	30.43 (0.81)	27.13 (0.82)	27.28 (2.34)	23.78 (1.09)	21.81 (2.13)	19.83 (0.27)
Minor Diameter (mm)	17.18 (1.35)	20.27 (1.32)	15.12 (0.98)	19.25 (0.45)	14.01 (0.32)	16.09 (0.88)
Intermediate diameter(mm)	10.55 (2.13)	13.97 (1.36)	6.47 (0.92)	9.48 (0.82)	4.72 (0.76)	6.38 (2.16)
Arithmetic mean diameter (mm)	19.37 (0.94)	20.45 (0.94)	16.29 (0.32)	17.49 (0.97)	13.18 (0.64)	14.10 (3.13)
Geometric mean diameter (mm)	17.16 (1.43)	19.15 (1.82)	13.51 (0.86)	15.86 (1.97)	11.02 (1.84)	12.35 (1.09)
Harmonic mean diameter (mm)	0.18 (0.01)	0.15 (2.31)	0.25 (0.91)	0.19 (2.13)	0.32 (0.05)	0.26 (2.09)
Square mean diameter (mm)	32.11 (0.68)	34.81 (3.05)	26.20 (0.21)	29.42 (3.09)	21.25 (2.43)	23.41 (0.29)
Equivalent mean diameter (mm)	22.88 (0.99)	24.80 (0.03)	18.66 (0.076)	20.92 (0.21)	15.15 (0.63)	16.62 (0.02)
Bulk weight (g)	205.8 (0.18)	229.8 (0.97)	199.5 (2.08)	220.4 (2.04)	189.5 (0.12)	211.8 (0.76)
Volume (mm^3)	137.67 (5.01)	173.13 (4.06)	86.27 (1.05)	117.35 (1.65)	57.05 (2.64)	70.63 (1.65)
Sphericity	56.23 (0.12)	70.08 (0.07)	49.19 (2.23)	66.35 (1.97)	50.47 (3.06)	62.09 (2.09)
Porosity (%)	73.39 (1.04)	66.82 (0.97)	50.00 (3.65)	50.00 (0.65)	28.83 (1.74)	24.71 (0.28)
Bulk density (g/mm^3)	321.49 (1.13)	419.16 (0.05)	547.60 (1.82)	582.46 (0.92)	604.15 (1.73)	631.21 (0.92)
True density (g/mm^3)	1208.30 (2.13)	1263.17 (0.81)	1095.21 (2.34)	1164.92 (3.04)	848.98 (0.45)	838.32 (2.03)
Surface area (mm^2)	826.07 (1.17)	699.97 (0.27)	517.62 (4.12)	490.77 (0.98)	342.33 (1.95)	305.40 (0.03)
Aspect ratio	56.19 (0.18)	74.60 (0.06)	55.44 (3.04)	80.23 (0.91)	64.05 (1.12)	81 (0.06)

Note: the values in brackets are the standard deviation of the three replication of each properties.

Mechanical properties of cashew nut

The compressive force required to crack the cashew nut at major, minor and intermediate loading positions ranged from 302.21 – 158.47N, 307.43 – 148.23N and 856.45 – 221.41N for Red apple cashew nut at moisture content range of 11.6 - 4.26% (w.b) respectively while 769.35 -149.46N, 824.49 – 341.20N and 443.14 – 151.73N for Yellow apple cashew nut at moisture content range of 11.69 – 4.26% (w.b) respectively (see table 2).

It was observed that for the both samples (Red and Yellow apple cashew nut), the compressive force is solely dependent of moisture content because increase in moisture content increased the force required to crack the samples.

From fig.5 – 7, it was observed that force needed to crack the sample were higher at 11.69% moisture content and lower at 4.26% moisture content which is the storage moisture content of cashew nut. For loading positions, it was noticed that intermediate and major diameter recorded highest and lowest rupture force across the moisture content respectively for Red apple cashew nut while minor and major averagely recorded highest and lowest rupture force across the moisture content respectively for Yellow apple cashew nut. It was also observed that the Yellow apple cashew nut displayed the highest rupture force at all conditions than Red apple cashew nut. The values of compressive force show that, the samples required lesser compressive force to crack the samples at storage moisture content (4.26% wb) irrespective of the loading positions and varieties.

Compressive extension presented in table 2, the major, minor and intermediate loading positions the compressive extensions ranged from 10.82 - 2.40mm, 9.76 – 6.82mm and 14.26 – 4.86mm for Red apple cashew nut respectively while 14.68 – 3.72mm, 7.32 – 5.27mm and 6.18 -3.82mm for Yellow apple cashew nut at moisture content range of 11.69 - 4.26% (wb). It implies that as the moisture content increased the compressive extension averagely increased but highest values of compressive extension were recorded at 11.69% (wb) which is harvest moisture content for both samples while lowest compressive extensions were recorded at 4.26% (wb) which is storage moisture content for both samples. The results of compressive extensions in table 2, indicated that the samples is more sticky than brittle at 11.69% (wb) moisture content and this equally resulted the increase in compressive force and toughness of the samples irrespective of the loading positions when moisture content increases.

Deformation energy required to cause rupture on the samples at major, minor and intermediate loading positions are 3.26 – 0.38kJ, 3.00 – 1.33kJ and 12.21 -1.08kJ for Red apple cashew nut while 11.29 - 0.56kJ, 6.04 – 2.34kJ and 2.74 – 0.93kJ for Yellow apple cashew nut sample at moisture content range of 11.69 – 4.26% (wb). It was observed that, the increase in moisture content increased the deformation energy required to initiate cracking in the samples for both loading positions and samples varieties. From the result above, it was noticed that, the Yellow apple cashew nut sample averagely recorded the highest deformation energy while Red apple cashew samples had lowest deformation energy. It implies that at all conditions Yellow apple cashew nut would be tougher and stronger than Red apple cashew nut. It was recommended that when conservation of energy is needed, Red and Yellow apple cashew nut should be loaded at major diameter at 4.26% (wb) moisture content.

The stiffness of the samples are presented in the table 2. The major, minor and intermediate loading positions ranged from 66.02 – 27.93 N/mm, 31.49 – 16.48N/mm and 60.05 -33.86 N/mm for Red apple cashew nut while 70.85 – 40.17N/mm, 119.05 - 49.81 and 84.22 – 24.75 N/mm for Yellow apple cashew nut as the moisture content varied from 4.26 – 11.69% (wb).

The variation of moisture content and the stiffness of the both samples displayed parabolic trend, it implies that, the stiffness of the samples were not solely dependent on moisture content and loading positions but slightly dependent on the varieties. It was observed that, the Yellow apple sample cashew nut had highest average stiffness values than Red apple cashew nut.

The toughness of the both samples are presented in table 2. The major, minor and intermediate loading positions ranged from 23.67 – 6.66J/mm^3, 23.31 – 16.92J/mm^3 and 18.93 -88.69J/mm^3 for Red apple cashew nut while 65.21 – 7.93J/mm^3, 34.89 -28.21J/mm^3 and 15.83 – 10. 48J/mm^3 for Yellow apple cashew nut at 11.69 – 4.26% (wb) moisture content range. The result also showed that, as moisture content increases the toughness of the samples also increases irrespective of loading positions. The both samples noticed to be tougher at 11.69% moisture content which is an indication that the samples are sticky and elastic at this condition. The result presented in the table 2, showed that the toughness is solely dependent on moisture content but not on loading positions. From the findings, it was obvious that Red apple cashew nut samples are averagely tougher than Yellow apple cashew nut.

Compressive strength of the Red and Yellow apple cashew nut are presented in table 2. The major, minor and intemediate positions ranged from 0.46 – 0.36N/mm^2, 0.43 – 0.37N/mm and 1.04 – 0.5N/mm^2 for Red apple nut samples while 1.10 -0.49Nmm^2, 1.21 – 0.03Nmm^2 and 0.65 – 0.44N/mm^2 for Yellow apple cashew nut at 11.69 – 4.26% (wb) moisture content range. It is observed that the Yellow apple cashew sample recorded higher compressive strength at average which implies that it requires more energy and rupture force to process or to extract the cashew nut kernel than that of Red apple cashew nut. The effect of moisture content and loading positions were not pronounced in compressive strength for the both samples but varieties are effected compressive strength.

Table 2. Effect of moisture content and loading positions on the mechanical properties of Red and Yellow cashew apple nut.

Moist. content (%)	Varieties	Loading position	Comp. force at Rupture (N)	Compr. extension (mm)	Max. Energy at rupture (J)	Stiffness (N/mm)	Toughness (J/mm^3)	Def. Energy (kJ)	Compr. strength (N/mm^2)
11.69 %	Red apple cashew nut	a	302.21	10.82	1.67	27.93	23.67	3.26	0.36
		b	307.43	9.76	1.94	31.49	21.79	3.00	0.37
		c	856.45	14.26	3.64	60.05	88.69	12.21	1.04
	Yellow apple cashew nut	a	769.35	14.68	5.07	52.40	65.21	11.29	1.10
		b	824.49	7.32	4.71	112.63	34.89	6.04	0.03
		c	443.14	6.18	0.14	71.70	15.83	2.74	0.63
7.43%	Red apple cashew nut	a	199.62	5.37	0.21	37.17	12.40	1.07	0.38
		b	214.16	6.82	0.74	31.40	16.92	1.46	0.41
		c	262.14	7.74	1.56	33.86	23.53	2.03	0.5
	Yellow apple cashew nut	a	509.42	7.19	0.84	70.85	31.19	3.66	1.04
		b	627.43	5.27	1.21	119.05	28.21	3.31	1.21
		c	321.73	3.82	2.20	84.22	10.48	1.23	0.65
4.26%	Red apple cashew nut	a	158.47	2.40	0.19	66.02	6.66	0.38	0.46
		b	148.23	8.99	2.04	16.48	23.31	1.33	0.43
		c	221.41	4.86	0.55	45.55	18.93	1.08	0.64
	Yellow apple cashew nut	a	149.46	3.72	0.34	40.17	7.93	0.56	0.49
		b	341.20	6.85	0.37	49.81	33.13	2.34	1.12
		c	151.73	6.13	0.35	24.75	13.17	0.93	0.44

a, b and c are major, minor and intermediate diameters respectively

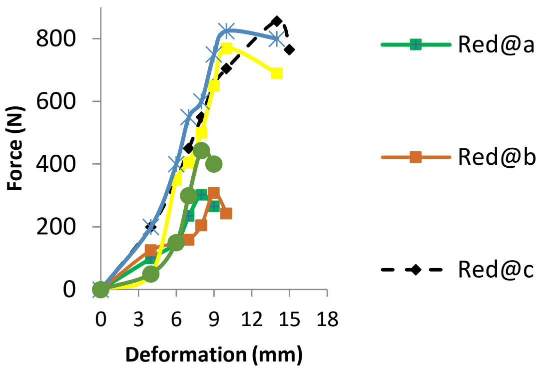

Figure 5. Force-deformation curves of Red and Yellow apple cashew nut at 11.69% (w.b) under three geometric (a,b.c) loading positions

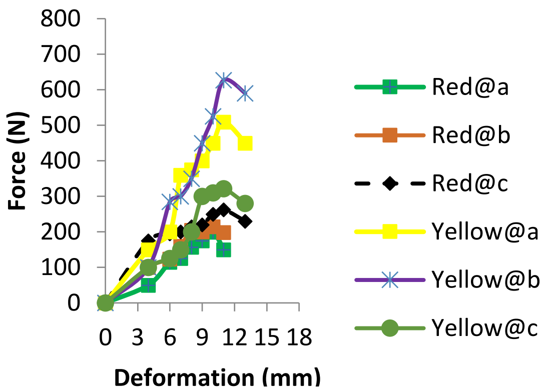

Figure 6. Force-deformation curves of Red and Yellow apple cashew nut at 7.43% (w.b) under three geometric (a,b.c) loading positions

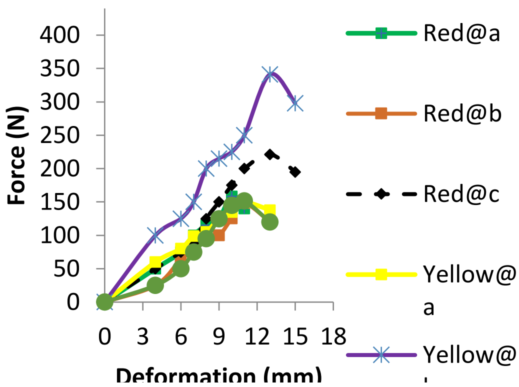

Figure 7. Force-deformation curves of Red and Yellow apple cashew nut at 4.26% (w.b) under three geometric (a,b.c) loading positions

CONCLUSION

It was concluded that physical and mechanical properties of Red and Yellow apple cashew nut are solely dependent on moisture content. The data generated from physical properties of Red apple cashew nut cannot be used in designing of food processing and storage system for Yellow apple cashew nut as the physical properties of both samples varied significantly at ($p<0.05$) with moisture content. Most of the physical properties were found to increase with correspond increase in moisture content (4.26 – 11.69% wb) apart from bulk densities, harmonic mean diameter and aspect ratio that decreased across the moisture content studied. The mechanical properties of Red and Yellow apple cashew nut were found to be moisture content and loading positions dependent. The relationship that existed between moisture content and the mechanical properties was statically significant at ($p< 0.05$) level. It is also economical to load both Red and Yellow apple cashew nut at major axis loading position at 4.26% wb moisture content to reduce both strength and energy demand required to crack or compress the samples.

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UTICAJ SADRŽAJA VLAGE NA FIZIČKO-MEHANIČKA SVOJSTVA SORTI INDIJSKOG ORAHA KOJI JE RELEVANTAN ZA NJIHOVU PRERADU

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Apstrakt: Proučavane su fizičko-mehaničke osobine crvene i žute okrugle (jabučaste) sorte indijskog oraha koje su neophodne za projektovanje i izradu objekata za preradu i skladištenje.

Glavni, manji i srednji prečnik indijskog oraha varirao je od 21.81–30.43 mm, 14.01–17.18mm,4.72–10.55mm i 19.83–27.13mm, 16.09–20.27mm, 6.38–13.97mm za Crvenu i Žutu okrugli oblik , respektivno .

Prosečne vrednosti zapreminske mase, površine i zapremine uzoraka bile su 826.07–342.33g, 137.67–57.05 (mm^3) and 229.8–211.8g, 699.97–305.40 mm^2, 173.13–70.63 mm^3.

Prosečne vrednosti za sferičnost, poroznost i odnos širina/ visina uzoraka iznosili su 56,23–50,47%, 73,39–28,83%, 56,19 – 64,05% i 70,08–62,09%, 66,82–24,71%, 74,60–81,00%.

Primećeno je da se vrednosti parametara za sve proučavane fizičko-mehaničke osobine povećavaju sa povećanom vrednosti sadržaja vlage (w.b), osim nasipne zapremine i odnosa širine i visine koji se smanjuju sa manjim sadržajem vlage.

Utvrđeno je da mehanička svojstva Crvenog i Žutog indijskog oraha zavise od sadržaja vlage i položaja (načina) utovara oraha u skladište.

Odnos koji je postojao između sadržaja vlage i mehaničkih osobina bio je statistički značajan na nivou ($p<0,05$).

Takođe je ekonomično ubaciti zajedno crvene i žute okrugle sorte indijskog oraha po glavnoj osi utovara skladišta, sa sadržajem vlage od 4,26% (wb), kako bi se smanjila potrošnja energije potrebna za lom ili kompresiju uzoraka.

Ključne reči: *Fizička svojstva, mehanička svojstva, indijski orah, sadržaj vlage, položaj* utovara .

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