Original Research Article

MODELING OF PHYSICAL AND COMPRESSIVE TEST PROPERTIES OF TIGERNUT USING RESPONSE SURFACE APPROACH

Abstract

This study was carried out to determine and model the physical and compressive test properties of tiger nuts as influenced by size, moisture level and loading pattern. Tiger nuts were cleaned of all foreign materials and sorted into three different sizes of 6mm, 9mm and 12mm each of 24 runs, and conditioned into four different moisture levels of 7%, 10%, 13% and 16% each of 18 runs respectively following standard method. A total of 72 runs were used for the experiment using a factorial response surface design. The results shows that the arithmetic mean diameter (AMD) ranged from 7-14.867 (mm), geometric mean diameter (GMD) ranged from 6.982-14.853 (mm), sphericity (S) ranged from 0.931-1.011, surface area (SA) ranged from 153.216 -693.382 (mm^2) and the aspect ratio (AR) ranged from 0.926-1.106. The mass (M) of 1000 tiger nut ranged from 201-1061 (g), volume (V) ranged from 25-96 (cm^3), bulk density (BD) ranged from 0.634 -0.979 (g/cm^3), solid density (SD) ranged from 0.712-0.989 (g/cm^3) and porosity (P) ranged from 11.08-21.45. The angle of repose ranged (AOR) from 20.58^o -28.85^o while the coefficient of friction (CF) on galvanized steel and stainless-steel surfaces ranged from 0.222-0.352 and 0.201-0.02 respectively. It was observed that, as sizes and moisture level increases, AMD, GMD, S, SA, AR, M, V, BD, SD and CF all increases respectively while both P and AOR decreases as the size and moisture level increases. It was revealed that the maximum compressive stress ranged from 0.26392-2.12026 (MPa), compressive strain at maximum compressive stress ranged from 1.20168-4.58292 (mm/mm). Energy at maximum compressive stress ranged from 0.02298-0.50274 (J), the compressive load at maximum compression stress ranged from 27.5937-232.257 (N), the extension at maximum compressive stress ranged from 0.30271-4.01056 (mm). The compressive stress at break ranged from 0.20376-1.75422 (MPa). The compressive load at break ranged from 25.2221-200.257 (N). The compressive strain at break ranged from 1.39935-5.79384 (mm/mm). The compressive extension at break ranged from 0.24417-3.55188 (mm). The energy at break ranged from 0.02113-0.33018 (J). The compressive stress at yield ranged from 0.24918-2.37054 (MPa) while the compressive load at yield ranged from 15.9373-210.693 (N). ANOVA result reveals that moisture level and tiger nut sizes have significant effects on the physical properties of tiger nut measured except on sphericity. Moisture level, tiger nut sizes and loading pattern have significant effects on the compressive test properties of tiger nut tested at $p<0.05$ except for Energy at maximum compressive stress and Energy at break where loading have no significant effect at $p>0.05$. Empirical models were developed for the measured Engineering properties. The experimental data generated from this study serves as strong tools for the design and development of tiger nut postharvest machineries such as an oil and milk extractor among others.

Key words: Tiger nut, Physical properties, compressive test, moisture level, sizes, and lording pattern.

1 INTRODUCTION

Tiger nut (Cyperus esculentus) is a magic tuber of the sedge family which can mistakenly considered a weed by most people. According to Awulu *et al.*, (2018), Tiger nut is favourably cultivated in temperate climatic condition within low or no swampy area. Bamishaiye and Bamishaiye, (2011), reported that in Nigeria, tiger nut is cultivated more in the northern region, and it is available in its dried and fresh state. Tiger nut is highly nutritious and important in the health and food industries as reported by Omale *et al*., (2020) and are of three varieties namely, yellow, brown, and black, although the black is not as popular as the others. In Africa, tiger nut can be considered underutilized because it is known mostly for direct (fresh or dried) consumption. Recently, Africans have enjoyed the locally prepared tiger nut milk but are still not aware of other usefulness of tiger nut such as cake, bread, oil, biscuits among others.

Engineering Properties such as Physical and mechanical properties of tiger nut among others are strong tools needed in the design and development of diverse machineries for its mechanization as applied in other plants (Ahmet *et al.*, 2017), Gursor and Guzel, 2010) and (Balami *et al.*, 2014). It is reported by Wang (2021) that tiger nut cultivated across different countries have different engineering properties. Agricultural Engineers are encouraged to generate abundance of engineering data of tiger nut cultivated in Africa to support the facilitation of the design of machineries for effective and efficient tiger nut cultivation, processing, handling, storage, and postharvest activities in general. Agricultural Engineering Researchers have worked on several physical and mechanical engineering properties of some crops cultivated in Nigeria. Few research reports are available on tiger nut engineering properties influenced by higher moisture contents as applied to many areas of tiger nut processing as reported by Oyerinde and Olalusi (2013), and Emurigho *et al*., (2020), but none has been investigated at very low moisture levels which is mostly needed for application such as development of tiger nut oil extraction machine. Tiger nut are of different varieties which are of different sizes and as such, there's every need to determine the physical and mechanical properties of tiger nut as affected by sizes, moisture and loading patterns. This will help with data generation to facilitate development of machineries such as tiger nut oil expeller that can handle tiger nut processing.

2 METHODOLOGY

2.1 Sample acquisition and preparations

The tiger nut was purchased directly from a tiger nut farm in the northern part of Nigeria and was cleaned of all foreign materials and sorted into three principal sizes of 12mm, 9mm and 6mm using an existing tiger nut sorting machine in the department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi-Nigeria. The initial moisture level was investigated following the standard of ASAE (ASAE, 1998) to be 8% wet basis.

Two kilogram (2kg) each of the sample was prepared to a moisture level of 7%, 10%, 13% and 16% (wb) each in 24 runs by including an estimated quantity carbonated H_2O applying Equation (1) below.

$$Q = W_i \left[\frac{M_f - M_i}{100 - M_f}\right] \qquad 1$$

Where, Q is the mass of water to be added in kg, W_i is the preliminary mass of the sample in kg, M_i is the preliminary water level of the sample in % d.b and M_f is the final H_2O level (d.b.) in percentage.

The samples prepared were preserved in a fridge using a closed plastic bag at 5°C for 10,080 minutes to enhance simultaneous circulation of water in the samples. The water level of the prepared samples was verified at the seventh day before being use for the estimation of the physical and compressive test properties selected.

2.2 Moisture content determination

Moisture content of the sample were determined on dry basis (db) using equation 2 and six replications were carried out and the moisture content calculated and recorded.

$$MC_{db} = \frac{w_o - w_f}{w_o} \times 100\,\% \qquad 2$$

Where; $M.C_{db}$= H_2O level, dry basis (%), W_o = initial weight before drying (g), W_f = final weight after drying (g),

2.3 Estimation **of arithmetic mean diameter**

The arithmetic mean diameters were estimated applying equation 3:

$$D_a = \frac{L+W+T}{3} \qquad 3$$

L= major diameter (mm), W= minor diameter (mm) and T = intermediate diameter (mm)

2.4 Estimation of **geometric mean diameter**

The geometric mean diameters were estimated using equation 4 given by Mohsenin, (1986)

$$D_g = (LWT)^{\frac{1}{3}} \qquad 4$$

D_g= geometric mean diameter, (mm), L= major diameter (mm), W= minor diameter (mm) and T= intermediate diameter (mm)

2.5 Determination of sphericity

The sphericity of a tiger nut seed was calculated using equation 5 as given by Mohsenin, (1986)

$$\phi = \frac{D_g}{L} \qquad 5$$

ϕ = spherecity (no unit), Dg= geometric mean diameter (mm), L= length or major diameter (mm)

2.6 Surface area of seeds

The surface area (S) were calculated and obtained from equation 6 given by Baryeh, (2001).

$$S = \pi (D_g)^2 \qquad 6$$

S = Surface area (mm^2), D_g = Geometric mean diameter (mm).

2.7 Estimation of aspect ratio

Aspect ratios were calculated using the ratio of width to length as presented in equation 7.

$$AR = \frac{T}{L} \qquad 7$$

AR= aspect ratio (dimensionless ratio), T= intermediate diameter (mm)
L= length or major diameter (mm)

2.8 Determination of 1000-seed mass of tiger nut

The mass of hundred (100) pieces of tiger nut were determined using a digital weighing scale. The mass was multiplied by 10 and recorded. The process was carried out in six replications for accuracy of results.

2.9 Determination of volume of tiger nut

A 1000 cm^3 measuring cylinder was used to determine the volume of a random sample of tiger nuts. 100 cm^3 of water (V_1) was discharged within the measuring cylinder. The tiger nut sample was poured into the cylinder. The rise in water level (V_2) was noted from the calibration on the measuring cylinder. The volume (V) of tiger nut was calculated using equation 8.

$$V = V_2 - V_1 \qquad 8$$

V= the volume of tiger nut (cm^3), V_1= initial volume of water (cm^3), V_2= volume of water and tiger nut (cm^3)

The process was carried out in six replications and the mean determined and recorded.

2.10 Estimation of the bulk density of tiger nut

The bulk density of tiger nut sample was obtained by filling a 100 cm^3 measuring cylinder to the brim with tiger nut. The weight of the tiger nut alone was gotten by deducting the total weight from the weight of the measuring cylinder and tiger nut. Uniform density was gotten by striking the container ten times in the same pattern in all measurements (Mohsenin, 1970). The bulk density was calculated using equation 9.

$$\rho b = \frac{Ws}{Vs} \qquad 9$$

ρb= bulk density (g/cm^3), Ws= weight of sample in (g), Vs= volume of the container (cm^3)

2.11 Determination of the solid (true) density of tiger nut

The true or solid density is the fraction of a given mass to volume and it was estimated by the water movement method. 20g weight (Mo) of tiger nut was discharged into a 100cm^3 fractionally calibrated cylinder with 50cm^3 carbonated H_2O. The volume of H_2O is observed as it moves by the nuts (V_o). The true density was estimated using equation 10.

$$Sd = \frac{Mo}{Vo} \qquad 10$$

Sd= true density, (g/cm^3), Mo= Weight of the sample (g), Vo= Volume of distilled water displaced (cm^3)

The representative values of bulk and true densities were taken as the average of six replications.

2.12 Porosity

The porosity of tiger nut was estimated applying the relationship provided by Mohsenin (1986) in equation 11.

$$\varepsilon p = \left(1 - \frac{\rho b}{Sd}\right) \times 100 \qquad 11$$

εp = porosity (no unit), Pb= bulk density (g/cm^3), Sd= solid density (g/cm^3)

2.13 Estimation of repose angle

The repose angle was estimated applying a topless and baseless cylinder of 73 mm diameter and 100 mm height. The cylinder was placed above the centre of a raised circular plate having a diameter of 350 mm. The cylinder was filled with tiger nut after which the cylinder was raised slowly till it formed a cone on the circular plate. The height of the cone was estimated and the filling repose angle, (θ) was estimated based on equation 12 (Mohsenin, 1986).

$$\theta = Tan^{-1}\left(\frac{2H}{D}\right) \qquad 12$$

θ = repose angle (°), H= height of cone (mm), D= diameter of the cone formed in (mm)
Six replications were carried out and the mean determined.

2.14 Coefficient of static friction

The coefficients of static friction of 200g of tiger nut tubers were estimated applying the sliding box method. Two test surfaces namely galvanized steel and stainless steel were used. A galvanized steel flat sheet of length 250 mm and thickness 2 mm, without base or lid was filled with tiger nut sample and placed on an adjustable tilting box, faced with the test surface. The sample container was slightly raised (5 mm) so as not to touch the test surface. The inclination of the test surface was gradually increased with a screw device until the seeds started to slide down and the angle of tilt (θ) was measured from a graduated protractor attached to the side of the tilting box. The procedure was repeated using glass and wood as test surfaces and the coefficient of static friction will be calculated using equation 13.

$$\mu = Tan^{-1}\theta \qquad 13$$

μ= coefficient of Static friction (dimensionless), θ= angle of tilt (°).

2.15 Determination of the mechanical properties of tiger nut

The compressive test properties of the prepared tiger nut samples were determined considering two loading patterns using a universal testing machine at the Obafemi Awolowo University, Nigeria in six replications.

3.0 RESULT AND DISCUSSION

3.1 Physical Properties of tiger nut tuber

The experimental results shows that the AMD ranged from 7-14.867 (mm) and GMD ranged from 6.982-14.853 (mm) as presented on table 1. The S ranged from 0.931-1.011, SA ranged from 153.216-693.382 (mm^2), AR ranged from 0.926-1.106. The M of 1000 tiger nut ranged from 201-1061 (g), V ranged from 25-96 (cm^3). BD ranged from 0.634-0.979 (g/cm^3), SD ranged from 0.712-0.989 (g/cm^3), P ranged from 11.08-21.45. The AOR ranged from 20.58^o - 28.85^o while the CF on galvanized steel and stainless-steel surfaces ranged from 0.222-0.352 and 0.201-0.02 respectively. It was observed that, as sizes and moisture level increases, AMD, GMD, S, SA, AR, M, V, BD, SD, and CF all increases respectively while both P and AOR decreases as the size and moisture level increases. The observations here is similar to the report given by Ahmet et al., (2017) and (Usman *et al*., 2019).

The model recommended for modeling the physical properties of tiger nut by the design expert software is the quadratic model for AMD, GMD, S, SA, AR, M, V, BD, SD, P and CF on galvanized steel and stainless steel while the linear model was recommended for angle of repose and their respective Std. Dev., Mean, C.V.%, Press, R-Squared, Adj R-Squared, Pred R-Squared, Adeq Precision among others are presented on table 2 and 3. Statistical data from the modeling analysis shows that all models used were significant and ANOVA result reveals that moisture level and tiger nut sizes have significant effects on the physical properties of tiger nut measured except on sphericity at p = 0.05. The "Pred R-Squared" of all the physical properties model is in reasonable agreement with their "Adj R-Squared".

Table: 1. Experimental Mean Results of the Physical Properties of Tiger nut Influenced by Sizes and Moisture Level

Sizes (mm)	Moisture Level (%)	AMD (mm)	GMD (mm)	Sphericity	Surface Area (mm^2)	Aspect Ratio	Mass of 100 seeds (g)	Volume (cm3)
6	7	7.02050	6.9950	1.00800	153.78733	1.10250	201.83333	24.33333
6	10	9.19433	9.1797	.93117	264.84917	.92867	252.83333	31.00000
6	13	10.28333	10.7138	1.01567	363.76667	.99850	271.33333	39.66667
6	16	11.44767	11.4423	.97350	411.50383	.99050	290.66667	42.83333
9	7	9.55783	9.5575	.99933	287.09700	1.01017	550.16667	52.50000
9	10	11.42217	11.4057	.96200	408.87067	.99950	622.33333	63.66667
9	13	12.30600	12.2977	.95750	475.32383	.96850	653.00000	71.16667
9	16	13.11333	13.1110	.97467	540.27683	.99283	688.50000	77.50000
12	7	11.85067	11.8180	.93417	438.96767	.96883	812.66667	71.50000
12	10	12.94183	12.9208	.93317	524.71783	.93417	1012.33333	82.50000
12	13	13.78950	13.7775	.94083	596.60317	.92617	1031.00000	90.50000
12	16	14.85350	14.8395	.94900	692.12267	.95000	1058.50000	95.00000

Continuation of Table 1,

Sizes (mm)	Moisture Level (%)	Bulk density (g/cm^3)	Solid Density (g/cm^3)	Porosity	Angle of repose (degree)	Coefficient of friction Galvanized steel	Coefficient of friction Stainless steel
12	7	.63500	.71383	16.14167	28.83000	.22350	.20283
9	10	.81400	.73483	13.16500	27.74167	.22733	.20533
6	13	.84267	.77500	11.85333	26.53833	.23650	.21550
12	16	.92250	.81517	11.04833	25.26333	.26217	.24600
9	7	.64500	.75483	17.44167	26.38167	.24183	.20517
6	10	.85283	.81583	15.05833	25.27167	.25567	.21483
12	13	.87183	.87500	13.65333	24.65000	.26517	.24533
9	16	.96200	.92683	12.45167	23.44000	.32450	.26317
6	7	.65500	.83350	21.39167	24.64167	.29499	.23300
12	10	.88350	.86500	17.84833	23.65167	.30217	.24650
9	13	.89217	.90550	15.52167	22.05167	.31550	.26250
6	16	.97550	.98550	13.83167	20.54667	.35283	.30250

Table 2: Model Summary Statistics for Physical Properties of Tiger nut

STATISTICS INFORMATION	PHYSICAL PROPERTIES						
	AMD	GMD	Sphericity	Surface	Aspect	Mass	Volume

				Area	Ratio		
Model	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic
Std. Dev.	0.20	0.20	0.015	10.94	0.029	23.36	1.73
Mean	11.44	11.42	0.96	424.17	0.99	614.88	62.19
C.V. %	1.75	1.77	1.56	2.58	2.92	3.80	2.79
PRESS	1.48	1.49	5.535E-003	4756.65	0.019	15068.20	81.19
R-Squared	0.9943	0.9943	0.7570	0.9963	0.7960	0.9958	0.9961
Adj R-Squared	0.9915	0.9915	0.6355	0.9944	0.6940	0.9938	0.9941
Pred R-Squared	0.9792	0.9792	0.3993	0.9852	0.5257	0.9885	0.9894
Adeq Precision	60.105	60.009	8.279	76.929	9.860	61.525	68.064
BIC	3.13	3.29	-79.95	131.08	-58.87	155.35	72.11
AICc	7.83	7.99	-75.25	135.78	-54.17	160.05	76.81

Continuation of Table 2

STATISTICS INFORMATION	Bulk Density	Solid Density	Porosity	Angle of Repose	Coefficient of Friction on Galvanized steel	Coefficient of Friction on Stainless Steel
Model	Quadratic	Quadratic	Quadratic	Linear	Quadratic	Quadratic
Std. Dev.	0.034	5.105E-003	0.22	0.25	7.159E-003	4.568E-003
Mean	0.83	0.83	15.13	25.01	0.28	0.23
C.V. %	4.10	0.61	1.43	1.01	2.60	1.95
PRESS	0.028	7.751E-004	1.35	1.25	1.620E-003	4.389E-004
R-Squared	0.9461	0.9972	0.9966	0.9888	0.9788	0.9825
Adj R-Squared	0.9192	0.9958	0.9949	0.9870	0.9682	0.9738
Pred R-Squared	0.8698	0.9918	0.9902	0.9832	0.9329	0.9632
Adeq Precision	15.602	87.010	76.298	71.115	31.636	35.570
BIC	-53.67	-114.36	5.58	6.50	-103.54	-117.92
AICc	-48.97	-109.66	10.28	6.18	-98.84	-113.22

Table: 3. Developed models for physical properties of tiger nut in relation to moisture level and tuber sizes

PHYSICAL PROPERTIES	FINAL EQUATIONS IN TERMS OF ACTUAL FACTORS
AMD	$= -6.41891 + (1.50078\times D) + (1.11807\times ML) - (0.027472\times D\times ML) - (0.029665\times D^2) - (0.021040\times ML^2)$
GMD	$= -6.58411 + (1.50896\times D) + (1.13570\times ML) - (0.027825\times D\times ML) - (0.029919\times D^2) - (0.021532\times ML^2)$
S	$=1.14941+(9.61241E\text{-}003\times D) - (0.035620\times ML) + (8.87255E\text{-}004\times D\times ML) - (1.44170E\text{-}003\times D^2) + (1.17303E\text{-}003\times ML^2)$
SA	$= -466.21079 + (63.89729\times D) +(45.52314\times ML) - (0.15452\times D\times ML) - (0.91472\times D^2) - 90.75228\times ML^2)$
AR	$=1.41190 + (0.032973\times D0 - (0.085603\times ML) + (1.58170E\text{-}003\times D\times ML) - (93.46326E\text{-}003\times D^2) + (2.79080E\text{-}003\times ML^2)$
M	$= -725.94517 + (97.82203\times D0 + (51.56928\times ML) + (3.11928\times D\times ML) - (0.77887\times D^2) - (2.68032\times ML^2)$
V	$= -93.77024 + (20.70395\times D) + (2.90423\times ML) + (0.13562\times D\times ML) - (0.77268\times D^2) - (0.072612\times ML^2)$
BD	$=-0.15635 + (0.052299\times D) + (0.10394\times ML) + (6.74837E\text{-}004\times D\times ML) - (2.90106E\text{-}003\times D^2) - (3.44047E\text{-}003\times ML^2)$
SD	$=0.49090 + (0.059891\times D) - (0.019229ML) + (8.82353E\text{-}004\times D\times ML) - (2.59691E\text{-}003\times D^2) + (1.12962E\text{-}003\times ML^2)$
P	$= 21.99267 + (0.59010\times D) - (1.69232\times ML) - (0.046601\times D\times ML) + (0.034697\times D^2) + (0.062585\times ML^2)$
AOR	$= 35.87633 - (0.71967\times D) - (0.38795\times ML)$
CFGS	$=0.24318 + (0.013760\times D) - (0.023211\times ML) + (3.54575E\text{-}004\times D\times ML) - (2.64012E\text{-}004\times D^2) + (1.13527E\text{-}003\times ML^2)$
CFSS	$= 0.29053 - (0.014378\times D) - (0.012216\times ML) + (5.016340E\text{-}004\times D^2) + (6.01459E\text{-}004\times ML^2)$

Note: AMD (arithmetic mean diameter), GMD (geometric mean diameter), S (sphericity), AR (aspect ratio), SA (surface area), M (mass), V (volume), BD (bulk density), SD (solid density), P (porosity), AOR (angle of repose), CFGS (coefficient of friction on galvanized steel) and CFSS (coefficient of friction on stainless steel).

3.2.2 Mechanical Properties

The experimental results revealed that the maximum compressive stress ranged from 0.26392 - 2.12026 9MPa) as shown in table 4. The compressive strain at maximum compressive stress ranged from 1.20168-4.58292 (mm/mm). Energy at maximum compressive stress ranged from 0.02298-0.50274 (J), the compressive load at maximum compression stress ranged from 27.5937-232.257 (N), the extension at maximum compressive stress ranged from 0.30271-4.01056 (mm). The compressive stress at break ranged from 0.20376-1.75422 (MPa). The compressive load at break ranged from 25.2221-200.257 (N). The compressive strain at break ranged from 1.39935-5.79384 (mm/mm). The compressive extension at break ranged from 0.24417-3.55188 (mm). The energy at break ranged from 0.02113-0.33018 (J). The compressive stress at yield ranged from 0.24918-2.37054 (MPa) while the compressive load at yield ranged from 15.9373-210.693 (N). It was observed that the compressive test parameters all increased as the size and moisture level increases. It was also observed that the compressive test parameters all decreased as the loading pattern was changed from lateral (horizontal) to transverse (vertical) loading. The result trend is like what was reported by Zareiforoush *et al*., (2010) and Sunmonu *et al*., (2015)

Table: 4. Experimental Mean Results of the Mechanical Properties of Tiger nut Influenced by Sizes, Moisture Level and Loading pattern.

Sizes (mm)	Moisture Level (%)	Loading	MCS (MPa)	CSNMCS (mm)	EYMCS (J)	CLMCS (N)	CEMCS (mm)	CSB (MPa)
6	7	Lateral	.3528	1.4955	.0321	51.9783	.6130	.3660
6	7	Transverse	.3113	1.2487	.0248	28.5333	.3285	.2176
6	10	Lateral	.8646	1.9361	.0761	95.2370	1.0451	.5518
6	10	Transverse	.7206	1.2255	.0326	52.7681	.7160	.3101
6	13	Lateral	1.1425	2.5166	.1193	117.3566	1.6588	.6185
6	13	Transverse	.7035	2.0694	.0417	80.8312	1.2371	.3829
6	16	Lateral	1.2424	3.5215	.1327	135.0342	1.5144	.9589
6	16	Transverse	.9044	2.8308	.0798	108.1606	1.8342	.7168
9	7	Lateral	.7346	1.8984	.0819	102.4647	1.6207	.7728
9	7	Transverse	.5021	1.4011	.4301	85.3389	1.0476	.5206
9	10	Lateral	1.1910	2.4310	.1171	146.9729	2.0826	1.0081
9	10	Transverse	1.0589	1.4823	.0719	134.2380	1.4397	.7315
9	13	Lateral	1.6216	3.1008	.1638	161.3648	2.4611	1.2279
9	13	Transverse	1.3252	2.5409	.1091	145.1742	2.0525	.9945
9	16	Lateral	2.1513	4.2370	.2134	208.0026	3.4407	1.6291
9	16	Transverse	1.5262	3.5033	.1605	158.3741	3.1763	1.2161
12	7	Lateral	1.1748	2.5594	.1335	169.8040	2.2460	1.2178
12	7	Transverse	1.0421	1.6533	.0935	133.2174	1.5025	.8455
12	10	Lateral	1.7941	2.9231	.1906	204.0296	3.0550	1.4895
12	10	Transverse	1.3297	2.2587	.1071	156.8929	2.0692	1.2221
12	13	Lateral	2.0861	3.8619	.2664	233.6885	3.5302	1.7228
12	13	Transverse	1.6939	3.1081	.2115	174.1697	2.5176	1.4880
12	16	Lateral	2.8337	5.8457	.3567	287.9321	4.7830	2.3674
12	16	Transverse	2.0571	4.5317	.2550	206.9715	3.9488	1.7078

Continuation of Table 4,

Sizes (mm)	Moisture Level (%)	Loading	CLB (N)	CSNB (mm/mm)	CEB (mm/mm)	EYB (J)	CSY (MPa)	CLY (N)
6	7	Lateral	40.6723	1.8159	.6098	.0469	.4720	35.2835
6	7	Transverse	26.3574	1.4591	.2575	.0225	.2521	17.8329
6	10	Lateral	72.4921	2.6789	1.2837	.0937	.7351	53.6672

6	10	Transverse	42.3870	2.0771	.6128	.2688	.3483	36.2447
6	13	Lateral	89.1588	4.0716	1.5170	.1307	.8868	73.6163
6	13	Transverse	54.7147	3.4041	.8834	.0414	.4867	50.6722
6	16	Lateral	113.9608	5.1331	1.8290	.1768	1.2268	96.2883
6	16	Transverse	106.9233	4.1643	1.0936	.0709	.6164	71.8220
9	7	Lateral	89.2993	2.2913	1.3762	.1068	.9435	61.1650
9	7	Transverse	51.5819	1.6909	1.0382	.0826	.5069	40.5660
9	10	Lateral	125.5942	3.0992	2.0456	.1830	1.2382	91.1057
9	10	Transverse	71.5758	2.6334	1.3333	.1037	.8048	53.1291
9	13	Lateral	138.9275	4.5836	2.3789	.2180	1.4549	117.1594
9	13	Transverse	99.7098	3.3855	1.8066	.1179	1.0349	99.5041
9	16	Lateral	180.1444	5.8505	3.1052	.3138	2.1646	184.1163
9	16	Transverse	152.1840	4.7274	2.3559	.2301	1.4121	131.7998
12	7	Lateral	139.6323	3.0818	2.2929	.1624	1.5046	106.1401
12	7	Transverse	131.2791	2.0657	1.4978	.1027	1.0997	88.0943
12	10	Lateral	177.9828	3.8316	3.3523	.2822	2.0387	175.9395
12	10	Transverse	140.7031	3.3335	2.0586	.1431	1.5012	133.4058
12	13	Lateral	196.6495	5.2571	3.8190	.3305	2.4056	207.9836
12	13	Transverse	152.9424	4.5403	2.5292	.2061	1.5914	164.0914
12	16	Lateral	262.1530	6.5366	4.3326	.4163	3.4698	223.2716
12	16	Transverse	182.5161	5.4653	3.4628	.3042	2.1603	204.7908

The model recommended for modeling the mechanical properties of tiger nut by the design expert software includes quadratic model for CSMCS, CSNMCS, CLMCS, CEMCS, and CLY. The 2FI model for MCS, CSB, CSNB, CEB, while the linear model was recommended for ENMCS, CLB, ENB and CSY, and their respective Std. Dev., Mean, C.V.%, Press, R-Squared, Adj R-Squared, Pred R-Squared, Adeq. Precision among others is all presented on table 5 and 6. Statistical data from the modeling analyses shows that all models used were significant which indicated that the models are good and ANOVA result reveals that moisture level, tiger nut sizes and loading pattern have significant effects on the mechanical properties of tiger nut tested at $p = 0.05$ except for Energy at maximum compressive stress and Energy at break where loading have no significant effect on at $p = 0.05$. The "Pred R-Squared" of all the mechanical properties model is in reasonable agreement with their "Adj R-Squared".

Table: 5. Model Summary Statistics for Mechanical Properties of Tiger nut

STATISTICAL INFORMATION	MECHANICAL PROPERTIES					
	MCS	CSNMCS	EMCS	CLMCS	CEMCS	CSB
Model	2FI	Quadratic	Linear	Quadratic	Quadratic	2FI
Std. Dev.	0.14	0.071	0.92	8.23	0.054	0.082
Mean	1.17	2.63	3.30	132.40	2.05	0.96
C.V. %	11.87	2.69	27.85	6.22	2.64	8.46
PRESS	0.87	0.21	18.77	3192.24	0.12	0.24
R-Squared	0.9686	0.9981	0.6588	0.9908	0.9989	0.9844
Adj R-Squared	0.9529	0.9965	0.5906	0.9834	0.9980	0.9766
Pred R-Squared	0.8812	0.9918	0.4951	0.9566	0.9956	0.9537
Adeq Precision	21.261	67.838	8.786	36.104	97.169	31.650
BIC	-9.28	-32.40	58.02	148.33	-42.53	-29.45
AICc	-5.71	-20.90	57.10	159.83	-31.03	-25.88

Continuation of Table 5

STATISTICAL INFORMATION	MECHANICAL PROPERTIES					
	CLB	CSNB	CEB	EB	CSY	CLY

Model	Linear	2FI	2FI	Linear	Linear	Quadratic
Std. Dev.	11.84	0.14	0.087	0.24	0.070	7.65
Mean	114.14	3.54	1.82	-0.89	1.18	102.73
C.V. %	10.37	3.83	4.78	26.59	5.92	7.45
PRESS	3320.95	0.56	0.18	1.22	0.15	2778.06
R-Squared	0.9660	0.9952	0.9960	0.6542	0.9940	0.9931
Adj R-Squared	0.9592	0.9927	0.9940	0.5850	0.9910	0.9876
Pred R-Squared	0.9463	0.9877	0.9921	0.4941	0.9846	0.9672
Adeq Precision	32.371	55.113	60.417	8.615	51.224	37.030
BIC	155.11	-10.15	-27.01	6.33	-35.35	145.57
AICc	154.19	-6.57	-23.44	5.41	-31.78	157.07

The physical properties and mechanical properties models created using the Design Expert statistical tool are presented on table 5 and table 6.

Table: 6. Developed models for mechanical properties of tiger nut in relation to moisture level, tuber sizes and loading pattern

MECHANICAL PROPERTIES	LOADING	FINAL EQUATIONS IN TERMS OF ACTUAL FACTORS
MCS	Lateral	= -0.62180 + (0.054551×D) + (0.*031621*×ML) + (0.010828×D×ML)
	Transverse	= -0.22938 + (0.021216×D) – (1.28116E-003×ML) + (0.010828×D×ML)
CSNMCS	Lateral	= 5.94533 – (0.46639×D) - (0.64553×ML) + (0.023688×D×ML) + (0.021714×D^2) + (0.029956×ML^2)
	Transverse	= 5.52284 – (0.48426×D) – (0.65574×ML) + (0.023688×D×ML) + (0.021714×D^2) + (0.029956×ML^2)
EMCS	Lateral	= 7.55586 – (0.33390×D) – (0.15474×ML)
	Transverse	= 8.33167 – (0.33390×D) – (0.15474×ML)
CLMCS	Lateral	= -308.13343 + (38.13574×D) + (27.83514×ML) + (0.052378×D×ML) – (1.15685×D^2) – (0.72061×ML^2)
	Transverse	= -294.12293 + (37.16207×D) + (24.64223×ML) + (0.052378×D×ML) – (1.15685×D^2) – (0.72061×ML^2)
CEMCS	Lateral	= 0.16203 + (0.27379×D) – (0.29866×ML) + (0.019038×D×ML) – (0.010713×D^2) + (0.014865×ML^2)
	Transverse	= -0.20956 + (0.24473×D) – (0.29089×ML) + (0.019038×D×ML) – (0.010713×D^2) + (0.014865×ML^2)
CSB	Lateral	= -0.62987 + (0.080714×D) + (0.034628×ML) + (6.25502E-003×D×ML)
	Transverse	= 0.61481 + (0.069392×D) + (0.019110×ML) + (6.25502E-003×D×ML)
CLB	Lateral	= -110.83115 + (15.63369×D) + (9.01383×ML)
	Transverse	= -138.75901 + (15.63369×D) + (9.01383×ML)
CSNB	Lateral	= -1.33072 + (0.081889×D) + (0.31281×ML) + (9.69561E-003×D×ML)
	Transverse	= -1.39135 + (0.075734×D) + (0.25761×ML) + (9.69561E-003×D×ML)
CEB	Lateral	= 8.41228E-003 + (0.010752×D) – (0.030651×ML) + (0.024179×D×ML)
	Transverse	= -0.38183 + (0.022446×D) – (0.063603×ML) + (0.024279×D×ML)
EB	Lateral	= -1.94726 + (0.073636×D) + (0.046763×ML)
	Transverse	= -2.15754 + (0.073636×D) + (0.046763×ML)
CSY	Lateral	= -0.42807 + (0.056440×D) – (2.70061E004×ML) + (0.013769×D×ML)
	Transverse	= -0.31805 + (0.041769×D) – (0.041157×ML) + (0.013769×D×ML)
CLY	Lateral	= 51.13677 – (17.84398×D) – (3.70628×ML) + (1.17049×D×ML) + (1.39355×D^2) + (0.24240×ML^2)
	Transverse	= 82.28632 – (21.43666×D) –(6.69961×ML) + (1.17049×D×ML) + (1.39355×D^2) + (0.24240×ML^2)

Note: MCS (Maximum compressive stress), CSNMCS (Compressive strain at maximum compressive stress), EMCS (Energy at maximum compressive stress) , CLMCS (Compressive length at maximum compressive stress), CEMCS (Compressive extension at maximum compressive stress), CSB (Compressive stress at break), CLB (Compressive load break), CSNB (Compressive strain at break), CEB (Compressive extension at break), EB (Energy at break), CSY (Compressive stress at yield), CLY (Compressive load at yield),

4 CONCLUSION AND RECOMMENDATIONS

This study revealed that, as sizes and moisture level increases, Arithmetic mean diameter, Geometric mean diameter, Sphericity, Surface area, Aspect ratio, Mass, Volume, bulk density, Solid density, and Coefficient of friction all increases respectively while both Porosity and Angle of repose decreases as the size and moisture level increases. It was also observed that the compressive test parameters all increased as the size and moisture level increases. The compressive test parameters all decreased as the loading pattern was changed from lateral loaning to transverse loading. Statistical data from the modeling analysis shows that all models used were significant and ANOVA reveals that moisture level and tiger nut sizes have significant effects on the physical properties of tiger nut measured except on sphericity and moisture level, tiger nut sizes and loading pattern have significant effects on the compressive test parameters of tiger nut tested at $p<0.05$ except for Energy at maximum compressive stress and Energy at break.

Recommendations

I recommend that more research be carried out in Nigeria and other Africa Nations on tiger nut Engineering Properties considering different factors such as harvest time, drying methods, storage duration among others that can influence these properties in general.

REFERENCES

Ahmet İnce1, Kubilay Kazım Vursavuş, Yasemin Vurarak, Pınar Çubukcu, Melih Yavuz Çevik1 (2017). Selected engineering properties of tiger nut as a function of moisture content and variety. Turkish Journal of Agriculture and Forestry Turk J Agric For (2017) 41: 263-271 © TÜBİTAK doi:10.3906/tar-1612-38

America Society of Agric Engineers, (1998). ASAE S352.2 Standards, 45^{th} Ed, DEC.97. Moisture Measurement. Unground grain and seeds. 551. St. Joseph, Mich: ASAE.

Awulu, J.O., Omale, P.A. and Omadachi, J.O. (2018) Characterization of Tiger Nut Oil Extracted Using Mechanical and Chemical Methods. Journal of Science and Multidisciplinary Research Volume 10, No 2, 2018 ISSN: 2277-0135

Balami, A. A., Birma, M., Dauda, S. M. and Adebayo, S. E. (2014). Engineering Properties of Tiger Nut Seeds Relevant to the Design of Cleaning and Sorting Machine. Proc. of the Second Intl. Conf. on Advances in Applied Science and Environmental Engineering - ASEE 2014. Copyright © Institute of Research Engineers and Doctors, USA. All rights reserved. ISBN: 978-1-63248-033-0 doi: 10.15224/ 978-1-63248-033-0-22

Bamishaiye, E.I and Bamishaiye, O.M. (2011). Tiger Nut: As A Plant, Its Derivatives and Benefits. AJFAND African Journal of Food, Agriculture, Nutrition and Development, Volume 11 No.5. ISSN: 16845374.Modeling and Optimization of Some Optical Properties of Tiger nuts (*Cyperus esculentus*) Using Response Surface Approach 6 Published by African Scholarly Science Communication Trust.

Baryeh, E.A. (2001). Effects of palm oil processing parameters on yield. *Journal of Food Engineering*, 48(1): 1-6.

Emurigho, Tega A and Kabuo, Canice O. andIfegbo, Arinze (2020). Determination Of Physical and Engineering properties of Tiger Nut (Cyperus Esculentus) Relevant to Its Mechanization. International Journal of Engineering Applied Sciences and Technology, 2020, Vol. 5, Issue 8, ISSN No. 2455-2143, Pages 82-90. Published Online December 2020 in IJEAST (http://www.ijeast.com)

Gursor, S. and Guzel, E. (2010). Determination of physical properties of some agricultural grains. *Research Journal of Applied Sciences, Engineering and Technology* 2(5). 74-77.

Mohsenin NN (1986). Physical properties of plant and animal materials. Gordon and Breach Science Public, New York.

Mohsenin, N.N (1970). Plant and Animal materials (Physical Characteristics). Gordon and Breach science publisher, New York. 51-83.

Omale, P. A and Omobowale, M.O (2018). Mechanical Properties of Tigernut (*Cyperus Esculentus*) as Influenced by Moisture Content. XII CIGR Section VI Technical Symposium in Ibadan, Nigeria– 22-25 October 2018.

Oyerinde, A. S. and Olalusi, A. P. (2013). Effect of Moiture content on selected Physical and Mechanical Properties of Two Varieties of Tigernut (cyperus spp). Journal of Food Research; Vol. 2, No. 6; 2013. Issn 1927-0887 E-ISSN 1927-0895. Published by Canadian Center of Science and Education

Sunmonu M. O., Iyanda, M. O. Odewole, M. M. and Moshood, A. N. (2015). Determination of Some Mechanical Properties of Almond Seed Related to Design of Food Processing Machines. *Nigerian Journal of Technological Development, vol. 12, No. 1.*

Usman, D.D Adanu, E. O. Jahun B. G. and Ibrahim, K. (2019). Effect Of Moisture Content Variation on Thermo-Physical Properties of Brown Variety Tigernut (Cyperus Esculentus). Azojete, September 2019. Vol. 15(3) 714-724 Published by The Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria. Print ISSN: 1596-2490, Electronic ISSN: 2545-5818

Wang, L., Hu, C., Guo, W., He, X., Wang, X., Jian, J. and Hou, S. (2021). The Effects of Moisture Content and Loading Orientation on some Physical and Mechanical Properties, 17(1), 109-117. https://doi.org/10.3844/ajbbsp.2021.109.117

Zareiforoush, H., Mohtasebi, S.S., Tavakoli, H. and Alizadeh, M.R. (2010). Effect of Loading Rate on Mechanical Properties of Rice Straw. *Australian Journal of Crop Science*, 4: 190–195.