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EFFECT OF VARYING MOISTURE CONTENT ON CASTOR SEEDS

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Abstract:A study was conducted to investigate the effect of varying moisture content levels on the physical properties of castor seeds namely, these physical properties include; seed dimensions, surface area, sphericity, geometric diameter, bulk and true density, repose angle, static coefficient of friction at varying moisture contents on glass, aluminium and plywood surfaces. The physical properties of Castor seeds were evaluated at moisture contents of 10 %, 12 % and 14 % d.b. The average major, minor and intermediate diameters were 15.509 mm, 12.4992 mm and 7.093 mm respectively at moisture content of 10 % d.b. The geometric mean diameter, sphericity and surface area increased from 11.116 to 11.8497 mm, 0.717 to 0.719 and 388.635 to 441.935 mm^2 as moisture content increased from 10 to 14 % d.b. At the same moisture range, bulk density decreased from 0.4944 to 0.4632 g/cm^3, true density decreased from 2.6632 to 2.5626 g/cm^3, and the corresponding porosity increased from 0.0081 to 0.0082 %. The repose angle was found to increase from 29.67^o to 33.76^o and as the moisture content increased from 10% to 14% d.b., the static coefficient of friction increased on all three structural surfaces, from 0.364 – 0.445 for glass, 0.42868 – 0.52282 for aluminium and from 0.518 – 0.615. Knowledge of these properties constitute essential engineering data in the design of equipment, machineries, processes and controls for castor seeds.

Keywords: castor seeds, surface area, sphericity, geometric diameter, bulk and true density

1.0 INTRODUCTION

1.1 Background of the Study

The castor plant, scientifically known as Ricinus communis, is a member of the Euphorbiaceae family and belongs to the spurge family. It is also referred to as castor beans and Palma christi. The castor plant is classified within the monotypic genus Ricinus and the sub-tribe Ricininae. Castor seeds contain oil ranging from 40 % to 60 %. This oil is utilized in the production of paints, varnishes, lacquers, protective coatings, lubricants, greases, hydraulic fluids, soaps, printing inks, linoleum, oil loth, and as a raw material for manufacturing chemicals like sebacic acid and undecylenic acid. It is also used in the production of plasticizers and nylons (Oyeyemi et al., 2007, Fahmy et al., 2024). Currently, the untapped potential of castor oil in Nigeria remains mostly unexplored. However, it has been determined that there are four common kinds of the crop. According to Oluwole (2010) and Rabelo et al. (2024), the aforementioned categories have been designated as White Big Size (WBS), Black Big Size (BBS), Grey Medium Size (GMS), and Grey Small Size (GSS).

Castor, once found in the southeastern Mediterranean Basin, Eastern Africa, and India, is now widely distributed in tropical regions. Castor readily establishes itself as a seemingly indigenous plant and is frequently encountered in barren areas. It is frequently observed around roadsides and on landfill sites or piles in tropical and subtropical regions. When unripe seed capsules are harvested, they are often spread on the ground to undergo a drying process. Subsequently, these capsule clusters crack open, allowing the seeds to fall out (Oyeyemi et al., 2007; Wei et al., 2019). The understanding of the density and specific gravity of agricultural goods is essential for the computation of thermal diffusivity in heat transfer scenarios, the determination of Reynolds's Number in pneumatic and hydraulic handling of materials, and the prediction of physical structures and chemical composition. The storage and transportation of agro-materials require a high bulk density. In order to accurately anticipate the freezing and thawing rate, it is crucial to consider the shape factor and surface area in the heating and cooling process. The concept of porosity is also employed in the process of shrinkage, namely during the drying phase (Sahin and Summu, 2006; Khater et al., 2023).

Ahmadi et al. (2009) identified several distinct technological quality attributes of seeds that have the potential to impact their behavior during processing. These traits encompass seed size, shape, weight, geometric mean diameter, sphericity, angle of repose, surface area, density, and porosity. The assumption regarding the shape of solid materials is a crucial design component in the transportation of those materials by air or water.

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Physical qualities are necessary for various handling and processing processes, such as heat transmission, heating, cooling, and oil press, in castor seed processing, which involves roasting, heating, and cracking. According to Alamu and Durowoju (2003) and Cesca et al. (2022), castor oil exhibits greater viscosity and density when compared to fossil fuels. The physical characteristics of Castor seed play a crucial role in the development of equipment for various applications.

Processing castor seeds may require certain inductrial processes such as roasting, heating and crack processes, the determination of physical properties of these seeds will come in handy in the handling and processing operations such as heat transfer, hearing, cooling and oil press.

According to Alamu and Durowoju (2003) and Cesca et al. (2022), castor oil exhibits greater viscosity and density when compared to fossil fuels. The assessment of Castor seed's physical properties holds significance in the development of equipment utilized for various stages such as harvesting, cleaning, sorting, grading, packaging, and processing. Conversely, the examination of its mechanical properties is crucial for conducting texture analysis and gaining a comprehensive grasp of product quality. Instrumental methods are commonly employed to assess the firmness of horticultural goods, enabling the determination of their maturity and ripeness. This assessment is crucial for the proper handling, storage, and processing of these products (Ali et al., 2012, Hasssnnejed et al., 2023).

Plate 1: Castor Seeds. Source: Vinay et. al. (2016).

2.0 MATERIALS AND METHODS

2.1 Moisture Content Determination

The moisture content determination was carried out by distillation method. The castor seeds were poured into a vegetable oil bath which maintains a temperature of 134 ºC. Moisture is driven off at this temperature and the dry weight of the nut remains. The experiment was conducted in 15-20 minutes according to Monteiro *et al.*, (2016).

Weight of oil bath – W_1 (Kg)

Weight of quantity of Nut – N_1 (Kg)

Weight of oil bath + Nut = $W_1 + N_1$ (Kg)

After moisture is driven off in 15 minutes;

Weight of oil bath + Nut = $W_1 + N_2$ (Kg)

$$M_w = (W_1 + N_1) - (W_1 + N_2) \text{ (Kg)}$$

Therefore;

$$\text{MC (wb)} = \frac{M_w}{N_1} \text{ X } 100 \quad \ldots\ldots (1)$$

3.1.2 Moisture Content Conditioning

The desired moisture contents of the seeds were prepared by adding distilled water. The distilled water was calculated from the relationship according to Coskun *et al.*, (2005):

$$Q = W\,\frac{Mf - Mi}{100 - Mf} \quad \ldots\ldots (2)$$

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Where
Q= the mass of distilled water added, Kg,
W=Initial Mass of the sample in Kg,
Mi= Initial Moisture Content of the Sample in d.b. % and
Mf= Final Moisture Content of the sample in d.b. %.
The samples were kept in a refrigerator at 5 °C (±5 °C) for 7 days for the moisture to distribute uniformly throughout the seed (Carman 1996).

3.2.1 Determination of Geometric Diameter and Sphericitiy

The geometric mean of a castor seed was determined by measuring the dimensions of the principal diameter on three axes – major (a), intermediate (b) and minor (c) – for fifty (50) seed that were randomly selected at the varying moisture contents. Digital Vanier Caliper was used to determine these dimensions. The geometric mean diameter (Dg) was calculated using equation 10 and the Sphericity of Castor seed was determined as well by using equation 4 by Davies and El-Okene (2009).

$$D_g = (abc)^{1/3}\ mm \text{ ……………………………………. (3)}$$

Where: Dg = Geometric Diameter, a = Major Diameter (mm), b = Minor Diameter (mm)
c = Intermediate Diameter (mm)

$$\varphi = \frac{D_g}{a} \text{ ……………………………………………….. (4)}$$

Where; φ = sphericity, D_g=Geometric Diameter (mm) and a= Major Diameter (mm)

3.2.2 Determination of Surface Area of Castor Oil Seeds

Equation 5 by Deshpande *et al.*, (1993) was used to determine the surface area:

$$S = \pi\left(D_g\right)^2 \text{ ………………………………………………. (5)}$$

Where; S = Surface area (mm^2), Dg = Geometric Diameter (mm).

3.2.3.1 Bulk Density

The seeds were poured into a 250 ml measuring cylinder after it had been weighed empty. From a height of 15 cm at a constant rate the seeds were poured into a container and weighed as well. The bulk density was calculated from the mass of bulk seeds divided by the volume of cylinder (Hosain 2012. and Garnayak *et al.*, 2008).

$$\rho_b = \frac{w_s}{V_b} \text{ ……………………………………………………………………….. (6)}$$

Where; Pb= Bulk Density (g/cm^3), Ws= Weight of Solid (g), Vb= Volume of dry Solid (cm^3)

3.2.3.2 True Density

A known weight (50 g) of sample was poured into a 250 cm^3 fractionally graduated cylinder containing 50 cm^3 Toluene. The volume of Toluene displaced by the seeds was observed. The true density by Hosain (2012), was calculated as:

$$\text{True Density } (g/cm^3) = \frac{\text{Weight of Seeds (g)}}{\text{Volume Occupied } (cm^3)} \text{ ………………………….…….…. (7)}$$

3.2.3.3 Porosity

The porosity (g) of the bulk seed was computed from the values of the true density (S_t) and bulk density(ρ_B) of the seeds by using the equation given by Mohsenin (1980).

$$Porosity = \frac{1-(Bulk\ Density/True\ Density)}{100} \text{ …………………………………………. (8)}$$

3.2.4 Determination of Angle of Repose

The tilting or static angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined using a topless and bottomless cylinder of initial: 5 cm, diameter and 40 cm height. The cylinder was placed at the centre of a raised circular plate and filled with the castor seeds. The cylinder was then raised slowly until it formed a cone on a circular plane. The height of the cone was measured and the tilting angle of repose was calculated based on the following relationship established by (Karababa, 2006).

$$\Phi = \tan^{-1} 2H/D \text{ ………………………………………………………………. (9)}$$

Where: H = Height of seeds, D = Diameter of the seeds

3.2.5 Determination of Coefficient of Static Friction

The static coefficient of friction (μ) of castor oil seeds was determined on three surfaces namely aluminum, plywood and glass. A topless and bottomless metal box of 150 mm x

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150 mm x 40 mm was filled with the seeds and placed on an adjustable tilting table onto which the material to be tested was fastened. The box was placed on one side of the surface and raised slightly so that it does not touch the material. A screw jack was used to gently tilt the table until friction force between the seeds and the material was overcome by gravity and moves down the slope. The angle of inclination was read from a graduated protractor attached to the tilting table. This was repeated five times to get an average value.

The Coefficient of Static Friction was calculated based on equation 17 (Moshenin, 1980).

$$\mu = \tan(\alpha) \quad \text{.......... (10)}$$

Where;

α = angle of inclination.

RESULTS AND DISCUSSIONS

Seed Moisture Content

The initial moisture content of the seed was found to be 10 % d.b. Two moisture levels were obtained after conditioning the seeds to 12 % and 14 % d.b., respectively indicating that castor seeds are water absorbent. The investigations were carried out at the above moisture levels to determine the effect of moisture content on the physical castor seeds.

The results gained were subjected to statistical analysis using SPSS 20 (SPSS Inc., USA) software.

Determination of Physical Properties of the Castor Seeds

Table 1: Dimensional Characteristics of Castor seeds

Moisture content (%)	**Major Diameter (mm)**	**Minor Diameter (mm)**	**Intermediate Diameter (mm)**	**Geometric Diameter (mm)**	**Sphericity (%)**	**Surface Area (mm^2)**
10	15.50920	12.49920	7.09340	11.116	0.717	388.635
12	16.26080	13.18440	7.41680	11.666	0.718	427.956
14	16.49940	13.41200	7.52620	11.8497	0.719	441.935

Values are mean of 50 measurements.

Table 2: Physical Properties of Castor Seeds

Moisture Content (%)	Bulk Density (g/cm^3)	True Density (g/cm^3)	Porosity	Angle of Repose (^{O})	Coefficient of Friction		
					Glass	Plywood	Aluminium
10	0.494400	2.66318	0.008126	31.104	0.36404	0.51838	0.42868
12	0.463200	2.56260	0.008182	29.670	0.39596	0.52282	0.46636
14	0.465920	2.63490	0.008242	33.764	0.44528	0.61530	0.52282

Values are the mean of 5 measurements

Table 3: ANOVA for dimensional Properties

			Sum of Squares	df	Mean Square	F	Sig.
Major Diameter (mm) * Samples	Between Groups	(Combined)	26.705	2	13.353	33.055	.000
	Within Groups		59.381	147	.404		
	Total		86.086	149			
Minor Diameter (mm) * Samples	Between Groups	(Combined)	22.575	2	11.288	30.518	.000
	Within Groups		54.370	147	.370		
	Total		76.945	149			
Intermediate Diameter (mm) * Samples	Between Groups	(Combined)	5.065	2	2.532	21.457	.000
	Within Groups		17.348	147	.118		
	Total		22.413	149			
Geometric Diameter (mm) * Samples	Between Groups	(Combined)	14.557	2	7.278	46.143	.000
	Within Groups		23.187	147	.158		
	Total		37.744	149			
Sphericity * Samples	Between Groups	(Combined)	.000	2	.000	.105	.901
	Within Groups		.046	147	.000		
	Total		.046	149			

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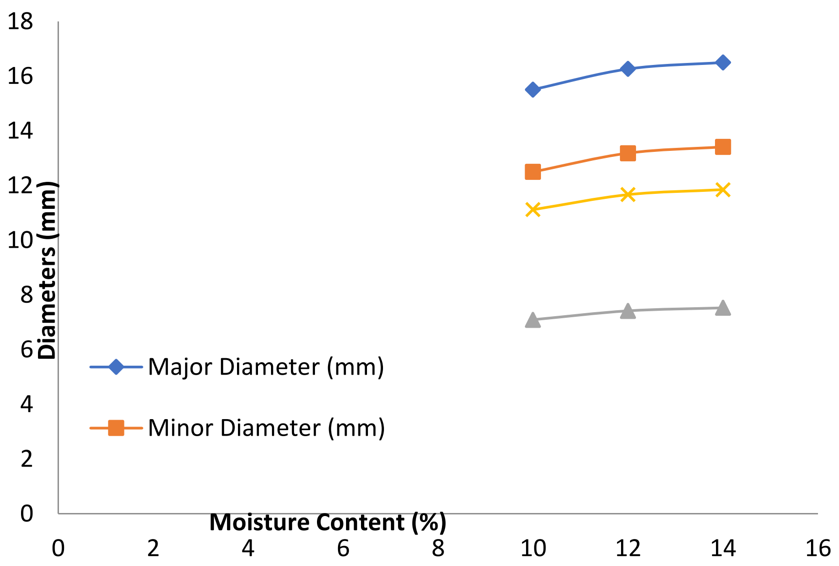
Surface Area (mm2) * Samples	Between Groups	(Combined)	76375.265	2	38187.633	44.648	.000
	Within Groups		125731.020	147	855.313		
	Total		202106.286	149			

(P ≤ 0.05, Sphericity ≥ 0.05).

Table 4: ANOVA for Physical Properties

		Sum of Squares	df	Mean Square	F	Sig.
Bulk Density (g/cm)	Between Groups	.003	2	.001	32.952	.000
	Within Groups	.001	12	.000		
	Total	.004	14			
True Density (g/cm)	Between Groups	.027	2	.013	5.635	.019
	Within Groups	.029	12	.002		
	Total	.056	14			
Porosity	Between Groups	.000	2	.000	15.677	.000
	Within Groups	.000	12	.000		
	Total	.000	14			
Angle of Repose (Degrees)	Between Groups	43.155	2	21.577	41.758	.000
	Within Groups	6.201	12	.517		
	Total	49.355	14			
Coefficient of Friction (Wood)	Between Groups	.030	2	.015	95.868	.000
	Within Groups	.002	12	.000		
	Total	.032	14			
Coefficient of Friction (Aluminium)	Between Groups	.022	2	.011	50.178	.000
	Within Groups	.003	12	.000		
	Total	.025	14			
Coefficient of Friction (Glass)	Between Groups	.017	2	.008	46.912	.000
	Within Groups	.002	12	.000		
	Total	.019	14			

(P ≤ 0.05)



4.2.2 Castor Seed Dimensions

In the moisture range of 10% to 14% d.b., the Major, Minor, Intermediate, and Geometric diameter, Sphericity, and Surface Area were measured. The average of the three axial dimensions rose as the moisture content increased, as shown in Table 2. The findings indicated that there was a linear relationship between each axial dimension and the moisture content. The augmentation in the dimensions is ascribed to the process of expansion or swelling, which

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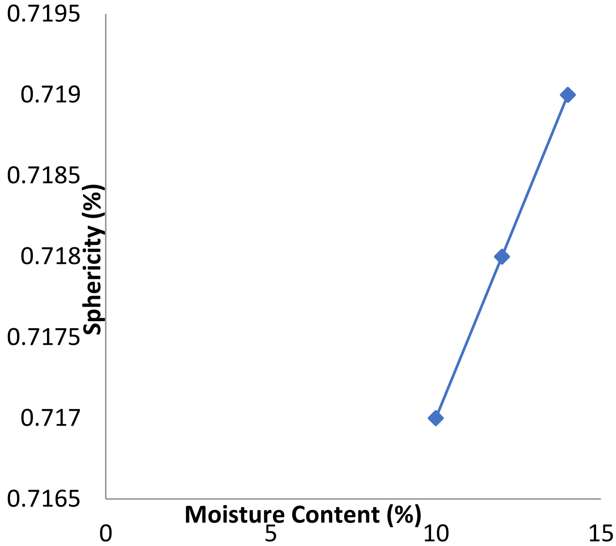
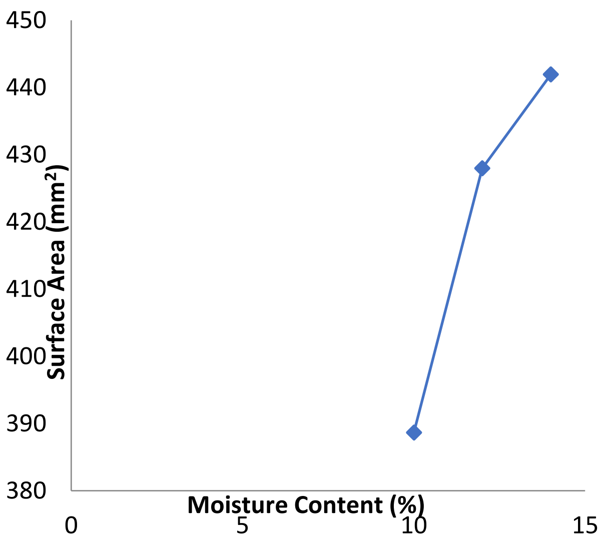
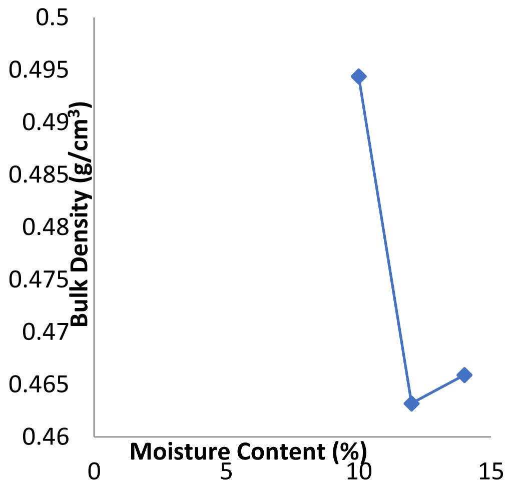
occurs as a consequence of moisture absorption within the intracellular spaces of the seeds. The primary axis, specifically the length, has been identified as a reliable indicator of the inherent resting position of castor seeds. Consequently, it can be utilized to apply compressive stress in order to induce mechanical breakage. Additionally, the inclusion of this dimension is necessary in order to apply shearing force during the process of slicing (Owolarafe and Shotonde, 2004,Parvathy et al.,2021). The dimensional parameters of castor seeds are presented in Table 1.



4.2.3 Sphericity

The sphericity values of the Castor seeds were determined individually using Equation 4. The findings revealed that the sphericity of the castor seeds exhibited an increase from 0.7169 to 0.7186% when the moisture content was raised from 10% to 14% dry bulk. The observed high sphericity of castor seeds suggests a propensity for their shape to resemble a sphere. Consequently, it may be inferred that castor seeds exhibit a preference for rolling rather than sliding on their flat surfaces. Aydin et al. (2002) have documented comparable patterns in the case of Turkish Mahaleb, while Sahoo and Srivastava (2002) have seen similar trends in the case of okra seeds. Table 2 displays the average values of Sphericity at various moisture content levels, whereas Figure 2 illustrates a graph depicting the relationship between Sphericity and moisture content. The analysis of variance (ANOVA) findings shown in Table 8 suggest that there was no statistically significant impact of moisture content on Sphericity ($p \geq 0.05$).





Equation 5 was utilized to determine the surface area of the castor seeds. Table 2 and figure 3 demonstrate that the moisture content increased from 10 to 14% d.b., resulting in an increase in the area from 388.635 to 444.936 mm2.

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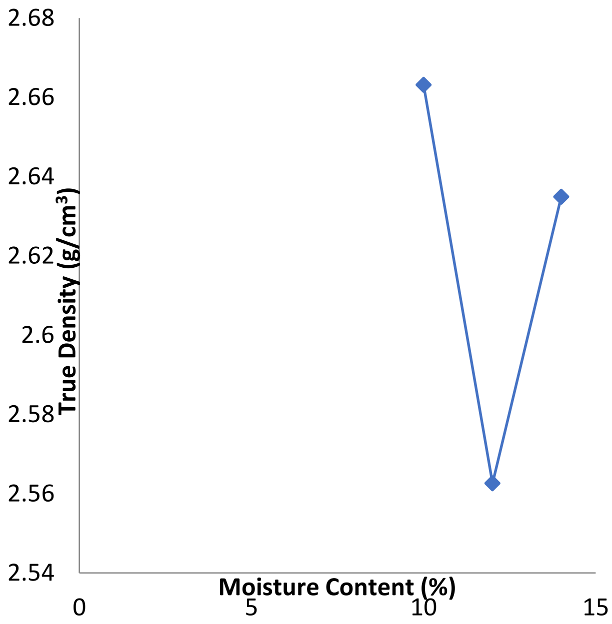
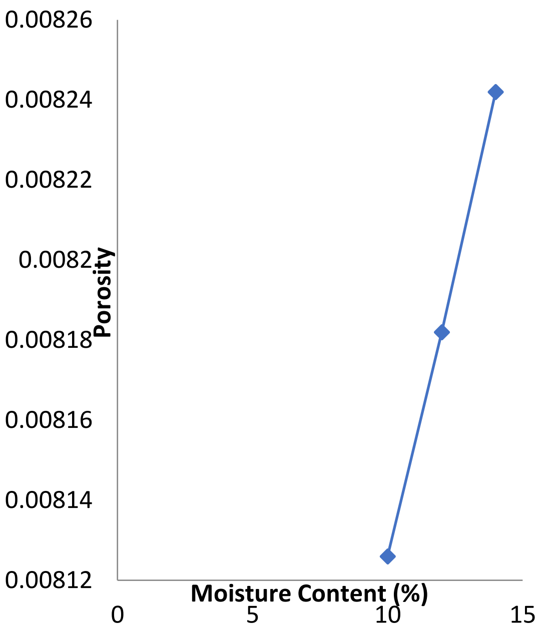
There appears to be a linear relationship between moisture content and surface area (S). Baryeh (2002) has also documented comparable patterns of growth in millet seeds. The analysis of variance (ANOVA) findings presented in Table 8 demonstrate that moisture content had a statistically significant impact ($p \geq 0.05$) on Surface Area.

4.2.4 Bulk density and true density:

The average bulk density values exhibited a decline from 0.4944 at a moisture content of 10% to 0.4632 at a moisture content of 12%. However, they experienced an increase to 0.4659 g cm-3 at a moisture content of 14%, as depicted in Table 3 and Figure 4. The correlation between moisture content and bulk density indicates that the increase in mass due to moisture gain in the sample is less significant than the corresponding volumetric expansion of the bulk. The actual density values exhibited a drop from 2.6632 to 2.5626 g cm-3 at 10% and 12% dry bulk (d.b.), whereas an increase to 2.6349 g cm-3 was observed with a rise in moisture level from 12% to 14% d.b. This information is presented in Table 3 and the accompanying figure (Figure 5). According to the actual density measurement, Castor seeds have a propensity to be partially immersed in water. These qualities have the potential to be advantageous in the process of separating and transporting fruit by hydrodynamic methods. The analysis of variance (ANOVA) findings shown in Table 4 demonstrate that moisture content had a statistically significant impact ($p \geq 0.05$) on both Bulk and True Densities.





4.2.5 Porosity

This characteristic is contingent upon the densities, specifically true and bulk, and varies among different seeds. According to the data shown in Table 3 and Figure 6, it can be observed that the porosity of castor seed exhibited an increase from 0.00813 to 0.00824% when the moisture content increased from 10% to 14% dry basis. The observed phenomenon can be ascribed to the enlargement of seeds, perhaps leading to an increase in the number of empty spaces between the seeds and subsequently augmenting the overall volume. Gupta and Das (1997) observed a positive correlation between moisture content and porosity value in sunflowers, whereas Carman (1996) found a similar relationship in lentils. The analysis of variance (ANOVA) findings shown in Table 9 demonstrate that moisture content had a statistically significant impact ($p \geq 0.05$) on Porosity.

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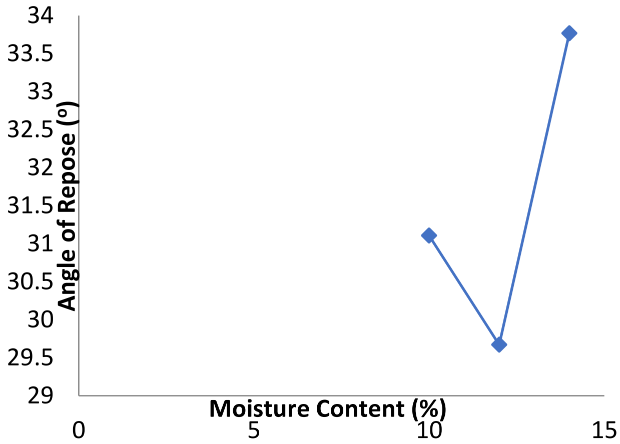

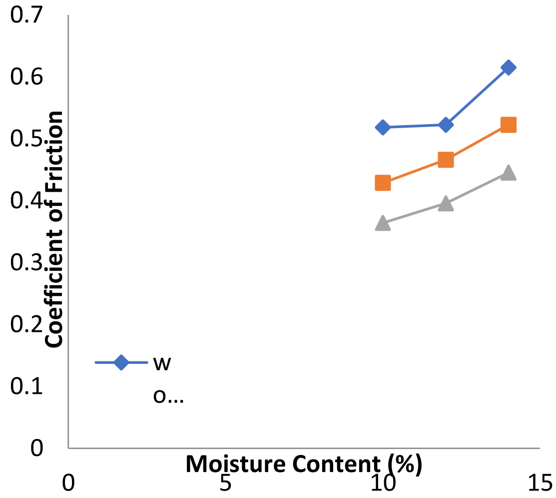

4.2.6 Angle of repose

In the 10%–14% d.b. moisture range, the angle of repose ranged from 31.1 to 33.8º. Table 3 and Figure 7 demonstrate a rise in moisture content from 12 to 14% and a decrease in moisture content from 10 to 12%. The adhesive force between the castor seeds and the material is shown to rise at greater moisture concentrations, which results in poorer castor seed flowability. Comparable Victor et al. (2011) noted a similar pattern with melon seeds. Table 9's ANOVA result shows that the angle of repose was significantly impacted by moisture content at a significance level of ($p < 0.05$).

4.2.7 Static coefficient of friction

In the experiment, three distinct surfaces were used: aluminum sheet, glass, and plywood. On all surfaces, the static coefficient of friction rose as the moisture content rose. Higher moisture values cause the seed and surface to adhere to one another more. According to the data shown in Table (3), the surfaces of plywood and glass had the highest and lowest coefficients of friction, respectively, measuring 0.518 to 0.615 and 0.364 to 0.445. As the moisture content rises from 10% to 14% d.b., the aluminum surface also exhibits the second lowest coefficient of friction values (0.429 - 0.523), as seen in figure 8. For this reason, it is advised to build seed hopper hoppers in planters and decorticators using aluminum sheet material. According to Dutta et al. (1988), Carman (1996), and Aydin (2002), the coefficient of static friction rose in proportion to the moisture content. This is depicted in Figure 8. According to Table 9's ANOVA result, the static coefficient of friction was significantly impacted by moisture content at a significance level of ($p < 0.05$).

5.1 CONCLUSION

A research was carried out to study the effect of change in moisture content level on some of the physical properties of castor seeds in Nigeria. These properties encompassed linear dimensions, sphericity, bulk and true density, geometric mean diameter, surface area, porosity, angle of repose, and coefficient of friction. Based on the findings, it was observed that there was an increase in the various physical properties measured as the moisture content level increased. The analysis of variance (ANOVA) revealed that moisture content had a statistically significant impact ($p \leqq 0.05$) on the Dimensional and Physical Properties of Castor Seeds, with the exception of the Sphericity of the seed. The provided data will aid in the development of equipment and machinery for the transportation, sorting, cleaning, handling, drying, and storing of castor seeds.

5.2 RECOMMENDATIONS

The following recommendations are therefore made for further research:

i. The generated data should be utilized in the design and fabrication of planter hoppers, processing machines and storage facilities for Castor Seeds.

ii. Further work can be done on the Mechanical Properties of castor seeds at higher range of varying moisture content.

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REFERENCES

[1]. Ahmadi, H., Fotwhollahzadeth, H & Hossein, M. (2009). Post-harvest physical and Mechanical Properties of Apricot fruits, pits and kernels (*C.V. Sonnati salmas)* cultivated in Iran. *Parkistan journal of Nutrition*, 8(3):264-268.

[2]. Alamu O.J. and Durowoju M.O (2003) "Effect of Conduit Dimension on Economic Pipeline Distribution of Highly Viscous Liquids". Journal of Applied Scineces. 6(2) 3651-3661.

[3]. Ali Nejat Lorestani, Farzad Jaliliantabar & Rashid Gholami (2012). Physical and mechanical properties of castor seed, Quality Assurance and Safety of Crops & Foods 2012, Volume 4, PP 29–32.

[4]. Cesca, S., Stich, D., Grigoli, F. *et al.* Reply to: Multiple induced seismicity mechanisms at Castor underground gas storage illustrate the need for thorough monitoring. *Nat Commun* **13**, 3445 (2022). https://doi.org/10.1038/s41467-022-30904-5

[5]. Coskun, M.B., Yalcin, I. and Ozarslan, C. (2005). Physical Properties of sweet corn seed (Zeamays Saccharata Sturt). Journal of Food Engineering, 74 (4), 523 – 528.

[6]. Davies R.M and A.M. El-Okene (2009). Moisture-Dependent Physical Properties of Soybeans. Int. Agrophysics, 2009, 23, 299-303.

[7]. Desphande S.D., Bal S., and Ojha T.P., (1993). Physical Properties of soybean. J. Agric. Eng. Res., 56, 89 – 98.

[8]. Fahmy, H.M., Amr, A. Synthesis of castor oil/PEG as a textile softener. *Sci Rep* **14**, 7208 (2024). https://doi.org/10.1038/s41598-024-56917-2

[9]. Fan, W., Lu, J., Pan, C. *et al.* Sequencing of Chinese castor lines reveals genetic signatures of selection and yield-associated loci. *Nat Commun* **10**, 3418 (2019). https://doi.org/10.1038/s41467-019-11228-3

[10]. Hassannejad, S., Fadaei, B., Abbasvand, E. *et al.* Early response of *Solanum nigrum* L. to Lumax and castor oil combination in relation to antioxidant activity, osmolyte concentration and chlorophyll ~~*a*~~ fluorescence. *Sci Rep* **13**, 409 (2023). https://doi.org/10.1038/s41598-023-27428-3

[11]. Hosain Darvishi (2012). Moisture-dependent physical and Mechanical properties of white seed American-Eurasian J.Agric and Environ. Sci., 12(2) : 198 – 203, 2012. ISSN 1818 – 6769.

[12]. Garnayak, D.K., Pradhan. R.C., Nalk, S.N and Bhatnagar. N.,(2008). Moisture dependent physical properties of Jatropha seed. Indust. Crops Prod., 27: 127 – 129.

[13]. Karababa E. (2006). Physical Properties of Popcorn Kernerl. Journal of food Engineering, 72:100 - 107.

[14]. Khater, ES.G., Abd Allah, S.A., Bahnasawy, A.H. *et al.* Enhancing bio-oil yield extracted from Egyptian castor seeds by using microwave and ultrasonic. *Sci Rep* **13**, 4606 (2023). https://doi.org/10.1038/s41598-023-31794-3

[15]. Mohsenin, N.N. (1980). Physical Properties of Plants and Animal Materials. Gordon and Breach Science Publishers, New York.

[16]. Monteiro L. M., Nogueira R. M., and Pires E. M. (2016). A Valid Method For Determining The Water Content Of The Brazil Nut (*Bertholletia excelsa*). Bioscience Journal., Uberlândia, v. 32, n. 4, p. 952-959.

[17]. Oluwole, F.A. (2010). Some Physical Properties of Castor Seeds.A non-thesis PhD seminar II, University of Maiduguri, Nigeria.

[18]. Oyeyemi, S.M., Okeniyi, S.O & Olaniyan, I.O. (2007). The effect of physical soil properties on the prospect of castor seed production. *Journal of Engineering and Applied Sciences,* 2(1): 86-89.

[19]. Owolarafe O.K., Shotonde H.O. (2004) Some physical properties of fresh okro fruit. *Journal of Food Engineering*, **63**, 299–302.

[20]. Parvathy, S.T., Prabakaran, A.J. & Jayakrishna, T. Probing the floral developmental stages, bisexuality and sex reversions in castor (*Ricinus communis* L.). *Sci Rep* **11**, 4246 (2021). https://doi.org/10.1038/s41598-021-81781-9

[21]. Rabelo Aparício, R., Machado dos Santos, G., Siqueira Magalhães Rebelo, V. *et al.* Performance of castor oil polyurethane resin in composite with the piassava fibers residue from the Amazon. *Sci Rep* **14**, 6679 (2024). https://doi.org/10.1038/s41598-024-54000-4

[22]. Rao,M.A., Rizvi S.S.H., Datta, A.K & Ahmed,J., (Eds.). (2014). Engineering Properties of Food (4th Edition). Boca Raton: CRC Press.

[23]. Sahin, S., & Summu, S.G. (2006). Physical properties of foods. New York: Springer.

[24]. Vinay R. Patel, Gerard G. Dumancas, Lakshmi C. Kasi Viswanath, Randall Maples and Bryan John J. Subong. (2016). Castor Oil: Properties, Uses, and Optimization of Processing Parameters in Commercial Production.

