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Seed moisture dependent on physical and mechanical properties of *Jatropha curcas*

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The moisture-dependent physical and mechanical properties of *Jatropha curcas* were studied. Five levels of moisture content ranging from 5.85 to 25.85 % d.b. were used. Standards methods were used to determine the physical properties, while Instron Testing Machine was used to determine some of the mechanical properties. The average length, width, thickness, thousand grains mass increased as the moisture content increased and coefficient of friction of jatropha increased linearly against various surfaces with increased in moisture content. The bulk density and true density were found to increase from 428 to 474 kg/m^3 and 863 to 1035 kg/m^3 respectively, while the porosity was found to increase from 50.3 to 54.2 %. The maximum rupture force was 113.99 N in the horizontal loading position, while the minimum of 26.83 N was in the transverse loading position. The maximum deformation of 2.5 mm was in the horizontal position and minimum of 0.40 mm in the vertical position. Moisture content was found to affect the properties.

Key words: Jatropha, Moisture content, mechanical and physical properties, rupture force, hardness.

Introduction

Jatropha curcas is a perennial poisonous shrub belonging to the Euphorbiaceae family. It is an uncultivated non-food wild-species, a perennial shrub, easy to adapt in marginal areas and resistant to a medium-long periods of dryness. The seeds contain 28-36% oil that can be processed to produce a high-quality biodiesel fuel, usable in a standard diesel engine. The seed production is around 3.5 tons / hectare. The *curcas* fruit contains 37.5% shell and 62.5% seed (Singh *et al.*, 2007). Seeds are said to resemble castor in seed shape and black in color. They are 42% husk and 58% kernel (Singh *et al.*, 2007).

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To design equipment used in planting, harvesting, transportation, storage, processing and oil extraction of agricultural oil seeds, there is need to know various physical and mechanical properties. The size, shape and mechanical behaviour of those seeds are important in designing of harvesting, separating, sizing, grinding and oil extraction machines. Bulk density, true density and porosity (the ratio of inter granular space to the total space occupied by the grain) are used in design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products. The angle of repose is important in the design of storage and transporting structures. The static coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting and storing structures.

In the recent years, physical properties have been studied for various crops such as groundnut kernel (Olajide and Igbeka, 2003); lentil seed (Amin *et al.,* 2004); jatropha seed (Garnayak *et al.,* 2008) and karanja kernel (Pradhan *et al.,* 2008). Change in moisture level due to pre-treatment was found to have significant effect on the physical properties of cashew nuts (Ogunsina and Bamgboye, 2007). The physical properties of Roselle seeds were found to increase as the moisture content increases with the exception of the bulk density that decreased (Bamgboye and Adejumo, 2009). For optimizing equipment design, oil extraction and handling in Nigeria, physical and chemical properties of J. curcas have to be known. Hence, objective of this study was to investigate physical and mechanical properties of jatropha seed from Nigeria.

Materials and methods

Material and sample selection

Dried J. curcas seeds were obtained at Moniya in Ibadan, Oyo State of Nigeria. The climate of seed's origin is characterized by an annual precipitation of 2000–2400mm and a temperature of 28–35 °C. The seeds were cleaned manually to remove all foreign matter. The initial moisture content of the seeds was determined by oven drying at 105±1^{o}C for 24 h (Ozarslan, 2002). The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following relation (Sacilik *et al*., 2003):

$$Q = \frac{W_i(M_f - M_i)}{(100 - M_f)} \quad (1)$$

Where:

W_i, is the initial mass of sample in kg;

M_i, is the initial moisture content of sample in % d.b.; and
M_f, is the final moisture content of sample in % d.b.
All the physical mechanical and chemical properties of the seeds were determined at five moisture contents. The following methods were used in the determination of some physical and mechanical properties of jatropha seed.

Size and shape

A vernier caliper was used to measure the axial dimensions of randomly selected 100 seeds; length, width, and thickness. From the average of axial dimensions the geometric mean diameter was determined using equation 2 (Joshi et al., 1993):

$$D_g = (abc)^{1/3} \tag{2}$$

where:
D_g is Geometric Mean Diameter, mm
a, the length is the dimension along the longest axis in mm;
b, the width is the dimension along the longest axis perpendicular to a in mm; and
c, the thickness, is the dimension along the longest axis perpendicular to both a and b in mm.

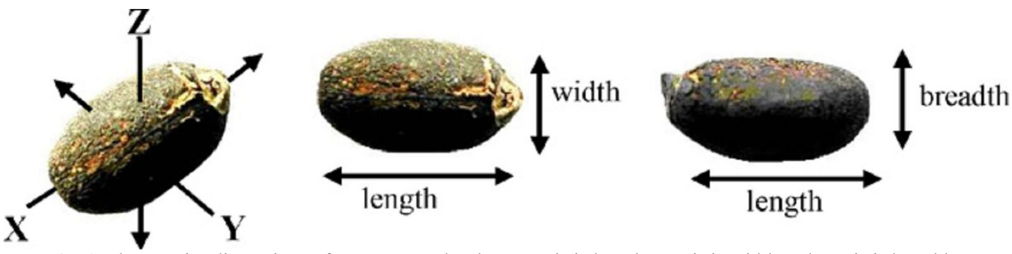

Fig. 1. Three major dimensions of J. curcas seeds where x-axis is length, y-axis is width and z-axis is breadth.

The sphericity was determined using equation 3 (Mohsenin, 1970):

$$\varphi = \frac{(abc)^{1/3}}{(a)} \tag{3}$$

Thousand Seed weight

The thousand grains mass was determined using a digital electronic balance which an accuracy of 0.001 g. To evaluate the thousand grain mass, 100 grains were randomly selected from the bulk sample and then multiplied by 10 to give mass of 1000 seeds.

Bulk and true densities

The bulk density was determined by filling an empty 250 ml graduated cylinder with the seed and weighed (Mohsenin, 1970). The weight of the seeds was obtained by subtracting the weight of the cylinder from the weight of the cylinder and seed. To achieve uniformity in bulk density the graduated cylinder was tapped 10 times for the seeds to consolidate. The volume occupied was then noted. The process was replicated five times and the bulk density for each replication was calculated from the following relation:

$$\gamma_b = \frac{(W_s)}{(V_s)} \qquad (4)$$

where:
γ_b is the bulk density, kg m^{-3};
W_s is the weight of the sample, kg; and
V_s is the volume occupied by the sample, m^3.

The true density was defined as the ratio between the mass of jatropha seeds and the true volume of the seeds, and was determined using the solvent displacement method. The volume of solvent displaced was found by immersing a weighted quantity of jatropha seeds in the measured solvent (Tavakkoli *et al.,* 2009).

Porosity

This was calculated from the values of bulk and true densities using the following relationship (Mohsenin, 1970):

$$\varepsilon = \left(1 - \frac{\gamma_b}{\gamma_t}\right) \times 100 \qquad (5)$$

where
ε is the porosity and γ_b is bulk density γ_t is true density.

Angle of repose

The static angle of repose (θ_s) was determined by using the apparatus shown in Figure 3 consisting of plywood box of 140 x 160 x 35 cm and two plates: fixed and adjustable. The box was filled with the sample and then the adjustable plate was inclined gradually allowing the kernels to follow and assume a natural slope (Tabatabaeefar, 2000; Heidabeigi *et al.,* 2009).

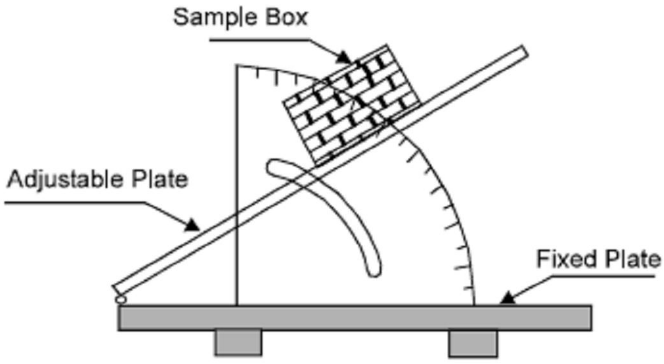

Fig. 2. Determination of angle of repose.

Coefficient of friction

Coefficient of static friction of jatropha seed on three surfaces such as wood, galvanized steel, and glass was determined by using standard method of Baryeh (2002).

Mechanical properties

Instron Universal Testing Machine (Model Santam STM-5), equipped with a 25 kg compression load cell and integrator, was used to determine some of the mechanical properties. The measurement accuracy was 0.001 N in force and 0.001 mm in deformation (Mohsenin, 1970).The individual seed was loaded between two parallel plates of the machine and compressed at the present condition until rupture occurred as is denoted by a bio-yield point in the force-deformation curve. Once the bio-yield was detected, the loading was stopped. Rupture force, deformation at rupture point, and hardness were measured at a speed of 5 mm/min, which is suitable for highly oil bearing materials (Olaniyan and Oje, 2002).

Results and discussions

Physical properties, size and shape

The variation of the seed length, width, thickness and geometric mean diameter with seed moisture content is shown in Table 1. The table showed that the three axial dimensions increased with moisture content in the moisture range of 5.85 to 25.85%. The Length increased from 17.01 to 17.71 mm, the width from 10.74 to 11.23 mm, and the thickness from 8.19 to 8.96 mm. The geometric mean diameter increased with increased in moisture content. These could be of important consideration in the theoretical determination of the seed volume at different moisture contents. Similar results of increased in the physical properties with moisture content are reported by Tavakkoli *et al.* (2009) for soybean grains and Bamgboye and Adejumo (2009) for Roselle seeds.

Table 1. Variation of principal dimensions with seed moisture content

Seed moisture content, % d.b.	Length, mm	Width, mm	Thickness, Mm	Geometric mean diameter, mm	Sphericity %
5.85	17.01(0.92)*	10.74(1.13)	8.19(0.43)	11.43(0.76)	67.20(0.83)
10.85	17.40(1.07)	10.99(0.54)	8.46(0.36)	11.74(0.59)	67.47(0.55)
15.85	17.54(1.06)	11.17(0.41)	8.67(0.36)	11.93(0.54)	68.02(0.51)
20.85	17.67(0.74)	11.19(0.45)	8.69(0.38)	11.97(0.50)	68.24(0.68)
25.85	17.71(1.11)	11.23(0.38)	8.96(0.82)	12.12(0.70)	68.44(0.63)

*Values in parenthesis are the standard deviations.

The sphericity was found to increase from 67.20% at the moisture content of 5.85 % to a maximum value of 68.44 % at the moisture content of 25.85 %. The result was different from what obtained for other seeds. A decreased in the sphericity with increased in moisture content was observed for pigeon pea (Baryeh and Mangope, 2002). The relationship between sphericity and moisture content is shown in Table 2.

Table 2. Equations showing the relationship between physical properties and moisture content of Jatropha seed

Moisture content % db	Equation	R^2
	$\varphi = 0.065M + 66.844$	0.966
	$M_{1000\ wt} = 8.812M + 456.440$	0.988
5.85–25.85	$\gamma_b = 0.002M + 0.414$	0.988
	$\gamma_t = 8.300M + 811.645$	0.987
	$P = 8.300M + 811.645$	0.991
	$\mu_{pl} = 0.007M + 0.365$	0.978
	$\mu_{st} = 0.006M + 0.334$	0.987
	$\mu_g = 0.005M + 0.271$	0.994
	$\theta_s = -0.39M + 38.282$	0.983

Thousand seed weight

The thousand seed weight variation with seed moisture content is shown in figure 3. The thousand seed mass increased linearly with increased in seed moisture content. The relationship between the thousand seed weight and seeds moisture content is shown in Table 2.

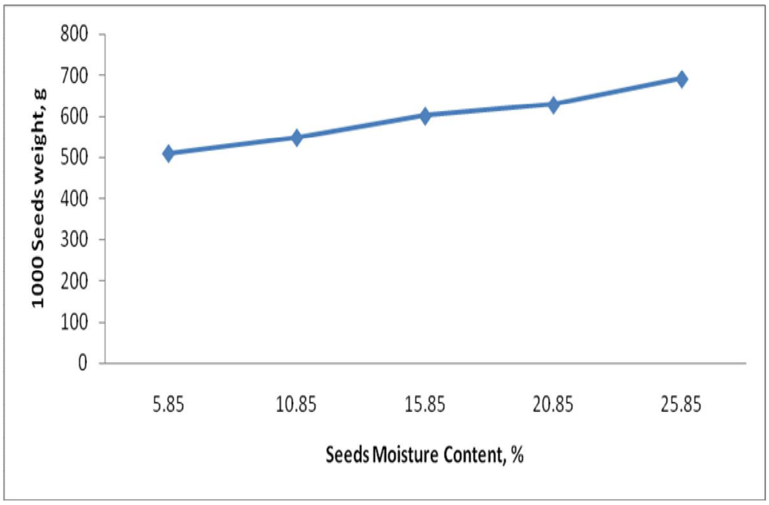

Fig. 3. Variation of 1000 seeds weight with moisture content

Bulk Density

An increased in the bulk density with moisture content from 428 kg/m^3 to 474 kg/m^3 is shown in figure 4. This was due to increase in the mass as a result of moisture gained in the sample which was higher than the accompanying volumetric expansion of the bulk as stated by Pradhan *et al*. (2008). However, the values were slightly higher than the bulk density obtained using India grown crop as reported by Karaji *et al.* (2008). A similar increasing trend in bulk density was reported by Baryeh and Mangope (2002) for QP-38 variety pigeon pea and Kingsly *et al*. (2006) for dried pomegranate seeds. The relationship between bulk density and moisture content is shown in Table 2.

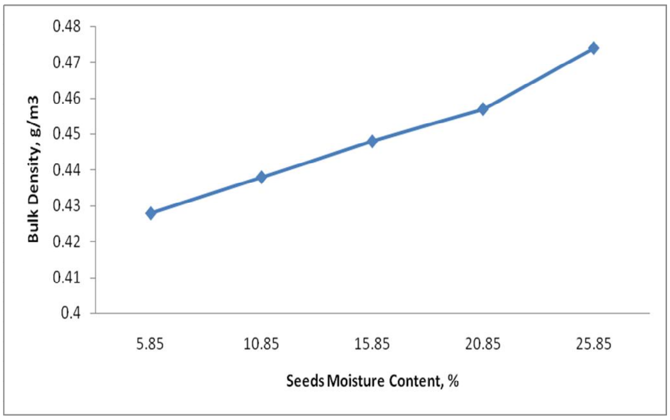

Fig. 4. Variation of bulk density with moisture content

True or Kernel Density

The effect of moisture content on true density of jatropha seeds showed significantly increased with increasing moisture content (Figure 5). The results were similar to those reported by Bart-Plange and Baryeh (2003) for Category B cocoa beans, Selvi *et al*. (2006) for linseed and Pradhan *et al*. (2008) for karanja kernel. The values were higher than what obtained (510 – 980 kg/m^3) from India variety (Karaji *et al.,* 2008). The relationship between true density and moisture content is shown in Table 2.

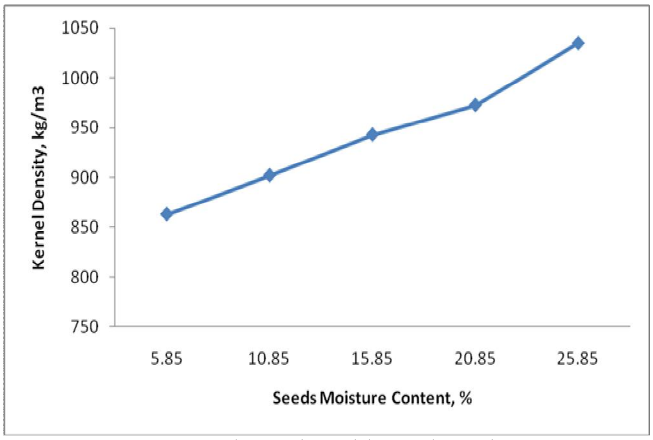

Fig. 5. True or Kernel Density with Seeds Moisture Content.

Porosity

The porosity variation with seed moisture content that the porosity increases with increase in seed moisture content from 50.3% to 54.2% is shown in figure 6. An increased in porosity with moisture content were reported for chickpea seeds stated by Konak *et al.* (2002), and green gram (Nimkar and Chattopadhyay, 2001). The relationship existing between porosity and seed moisture content was found to be linear and can be seen in Table 2.

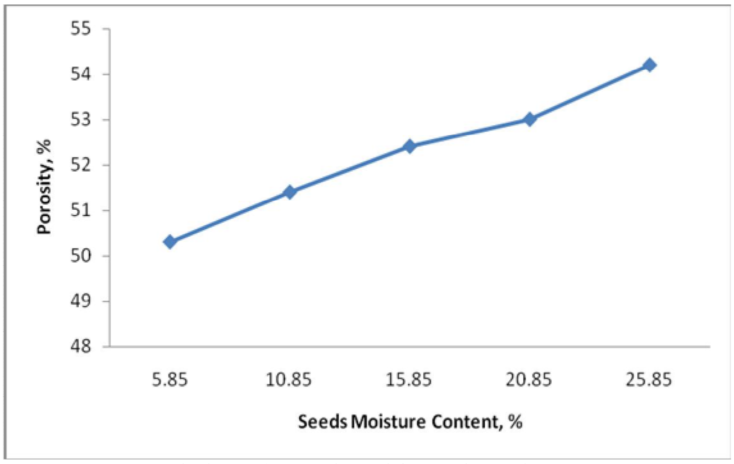

Fig. 6. Variation of Porosity with Seeds Moisture Content

Coefficient of friction

The coefficient of friction of jatropha seed increased with increased in moisture content in all contact surfaces (Figure 7). The maximum value of 0.55 was obtained on the surface of plywood and the minimum value of 0.30 was on the surface of glass. Similar findings were reported for millet (Baryeh, 2002), and pumpkin seeds (Joshi *et al.,* 1993). The relationship between coefficient of friction on different contact surfaces with moisture content is shown in Table 2.

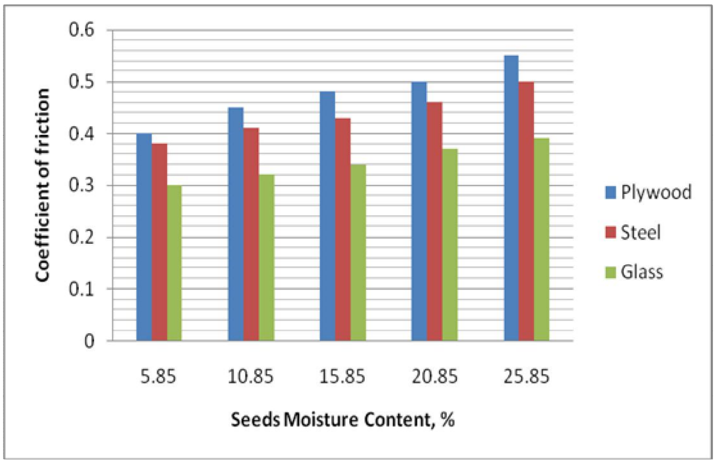

Fig. 7. Coefficient of friction on different contact surfaces with moisture content

Angle of repose

The variation dynamic angle of repose with seed moisture content is shown in figure 8. It can be seen that the dynamic angle of repose decreased in the moisture range of 5.85 to 25.85%. This showed that the amount of dynamic angle of repose was higher at lower moisture content. The angle of repose of seeds was decreased with increasing unit mass. This was due to smaller seeds showed higher cohesion than larger ones. The relationship between static angle of repose and the moisture content is shown in Table 2.

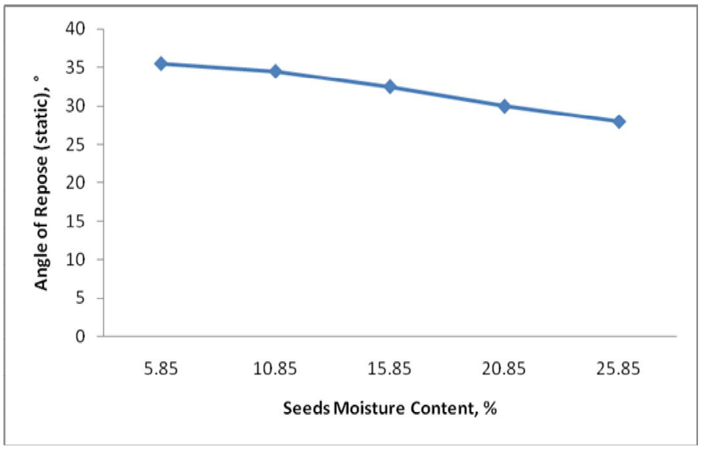

Fig. 8. Angle of Repose with Moisture Content

Mechanical Properties of Jatropha Seed

Rupture force

The force needed to rupture a seed decreased as the moisture content increased from 5.85 to 25.85%. The rupture force of 113.99 N was the highest in the horizontal direction at 5.85% moisture content, while the least rupture force was 26.83 N at the moisture content of 28.85% in the transverse position. This indicated that seeds with lower moisture content needs higher compression load for rupture. Generally, rupture force in the horizontal loading position was highest and lowest for the transverse loading position. This trend was similar to the report of Karaji *et al*. (2008) obtained from Jatropha imported from India, though lower in values. The relationships between rupture forces required at different loading positions with seeds moisture content is shown in Table 4.

Deformation

The deformation at rupture point increased with an increased in moisture content of the seeds. From the equation relating deformation with moisture content (Table 4). The moisture content can only be said to affect deformation in the vertical direction with R^2 of 0.865, while the low values of R^2 in the horizontal (0.382) and transverse (0.207) positions indicated that the moisture content alone cannot be used to describe deformation of jatropha seed in these positions.

Table 3. Mechanical properties of Jatropha seeds with respect to moisture content

Moisture Content %	Loading Position	Rupture Force (N)	Deformation at Rupture Point (mm)	Hardness (N/mm)
5.85	Transverse	29.47(12.50)*	0.43(0.16)	68.78(8.94)
10.85		37.22(8.93)	0.58(0.24)	67.08(8.86)
15.85		31.64(8.81)	0.46(0.18)	64.17(7.21)
20.85		28.15(8.76)	0.44(0.22)	63.98(9.82)
25.85		26.83(8.55)	0.40(0.22)	61.40(8.13)
5.85	Horizontal	113.99(19.24)	2.50(1.10)	67.75(7.02)
10.85		92.14(25.08)	1.36(0.36)	64.62(1.84)
15.85		84.65(27.30)	1.31(0.38)	57.44(8.65)
20.85		89.03(14.61)	1.55(0.51)	56.82(6.57)
25.85		81.86(19.02)	1.44(0.52)	45.50(7.49)
5.85	Vertical	95.48(20.30)	1.72(0.64)	55.51(1.72)
10.85		86.71(7.43)	1.99(0.46)	43.62(4.80)
15.85		86.36(15.31)	1.98(0.44)	43.57(6.15)
20.85		81.16(22.65)	2.21(0.39)	37.62(8.81)
25.85		82.77(17.00)	2.20(0.59)	36.72(8.

*Values in parenthesis are the standard deviation

Table 4. Equations showing the relationship between some mechanical properties and moisture content of Jatropha seed

Moisture content % db	Equations	R^2
5.85 – 25.85	$\text{Deformation}_{ver.} = 0.024M + 1.646$	0.865
	$\text{Deformation}_{hor.} = -0.039M + 2.244$	0.382
	$\text{Deformation}_{trans.} = -0.004M + 0.525$	0.207
	$\text{Rupture energy}_{ver.} = -0.619M + 96.313$	0.779
	$\text{Rupture energy}_{hor.} = -1.347M + 113.690$	0.700
	$\text{Rupture energy}_{trans.} = -0.287M + 35.211$	0.310
	$\text{Hardness}_{hor.} = -1.046M + 75.005$	0.924
	$\text{Hardness}_{ver.} = -0.872M + 57.223$	0.845
	$\text{Hardness}_{trans.} = -0.357M + 70.744$	0.959

The hardness of the seed decreased with increase in the seed moisture content. Hardness in the vertical direction was lowest, whereas hardness in the transverse direction was highest. The hardness of seeds was decreased with increasing moisture content in all directions. The relationship between hardness of seed at different loading directions and moisture is shown in Table 4.

Conclusion

The physical properties of jatropha seed determined as a function of moisture content varied significantly with increased in moisture content. The sphericity, geometric mean diameter, thousand seed mass, angle of repose, surface area, true density, bulk density, porosity, coefficient of static friction and terminal velocity showed an ascending relationship with increased in moisture gain. These properties would provide important and essential data for efficient process and equipment design. The rupture force, deformation and hardness were found to vary with moisture content. More force would be required to rupture the seed at low moisture content.

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