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ORIGINAL ARTICLE

Effect of Moisture Content on Some Selected Physical Properties of Pigeon Pea (*Cajanus cajan*)

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Abstract

Knowledge of physical and mechanical properties of pigeon pea grains are necessary for the design of equipments to handle, transport, process and store the crop. The moisture content of pigeon pea is different at the harvest than at milling or storage; thus affecting different physical and mechanical properties of the pigeon pea. The physical properties of pigeon pea i.e. length, width, thickness, bulk density, particle density, porosity, surface area, volume, angle of repose and hardness have been evaluated as a function of grain moisture content varying from 6.2 to 30.2 % (wb). The length, width, thickness, grain surface area, volume and angle of repose increased non-linearly from 5.37 to 6.24 mm, 4.97 to 5.67 mm, 4.06 to 4.60 mm, 33.73 to 45.22 mm^2, 322.68 to 556.07 mm^3, and 22.7° to 50.45°, respectively, while bulk density, particle density, hardness and sphericity decreased nonlinearly from 1032.49 to 835.35 kg/m^3, 1398.09 to 1242.85 kg/m^3, 484.22 to 10.27 N and 0.89 to 0.87, respectively when moisture content was increased from 6 to 30 % (wb).

Keywords: Pigeon pea, moisture content, hardness, dimension, angle of repose, density.

Introduction

Pulses along with cereals play a vital role in human nutrition, especially for the vegetarian population as a cheap source of protein (Mangaraj *et al.*, 2013). Pigeon pea (*Cajanus cajan*) is the most commonly consumed pulse in the Indian subcontinent. These are cultivated in more than 25 tropical and subtropical countries, either as a sole crop or intermixed with cereals, such as sorghum, pearl millet or maize or with other legumes, such as peanuts. Pigeon peas are cultivated for both as food crop (dried peas, flour or green vegetable peas) and forage/cover crop. They contain high levels of protein and important amino acids like methionine, lysine, and tryptophan (Nwokolo, 1987). Sprouting enhances the digestibility of dried pigeon peas via the reduction of indigestible sugars that would otherwise remain in the cooked dried peas. The annual production and yield of pigeon pea in India in 2012 were 2650000 tonnes, with an average yield of 686.5 kg/h from 3860000 ha areas (FAO, 2013).

The study of physical, aerodynamic and mechanical properties of food grain is important and essential in the design of processing machines, storage structures and processes. The shape and size of grains are important in the design and development of grading and sorting machineries for the separation of foreign material as well as for the thermal processing calculations. Rupture force can be used in design of dehuller. Bulk density and particle density are important factors in designing of storage structures. The angle of repose of the grains can be used for designing the bins, silos, hoppers and storage structures.

The effect of moisture content on physical properties like bulk density, particle density, hardness and angle of repose of different grains such as sunflower, neem nut, pumpkin, gram, pigeon pea, soya bean, karingda, canola seed, paddy, mung bean, corn, pistachio nut (Shepherd and Bhardwaj, 1986; Dutta *et al.*, 1988; Desphande *et al.*, 1993; Gupta and Das, 1997; Chowdhury *et al.*, 2001; Reddy and Chakraverty, 2004; Unal *et al.*, 2008; Seifi and Alimardani, 2010;

Galedar *et al.*, 2010; Maghsoudi *et al.*, 2010) have been investigated. The knowledge of moisture dependence of these properties is important during equipment design in order to construct the equipment that can be used for processing pigeon pea whether seeds are dried or freshly harvested. The objective of this study was to evaluate the effect of moisture content on the physical properties of pigeon pea.

Materials and Methods

Sample preparation and moisture content determination

Pigeon pea grains (*variety: BDN-2*) were procured from the Model Farm, Anand Agricultural University, Baroda. The initial moisture content of the grain was determined using the infrared moisture meter (Citizen, Mumbai) and standard air oven method (AOAC) to correlate. Average initial moisture content was found to be 6.2 % (wb). Then the moisture content of the grains was adjusted to 10.3 %, 14.3 %, 18.1 %, 22.2 %, 26.3 % and 30.2 % (wb) by the addition of calculated amount of distilled water and sealed in polythene bags.

The grains were mixed thoroughly to ensure uniform distribution of moisture and were kept in BOD for 24 h for soaking at 25 °C to reach equilibrium. For each test, required quantity of sample was taken out and allowed to warm up for approximately 2 h (Joshi *et al.*, 1993). The moisture content of the sample was checked again using infrared moisture meter (Citizen, Mumbai) after the equilibration and further tests were carried out.

Measurement of spatial dimensions

Three linear dimensions namely, length (L), width (W) and thickness (T), of 50 seeds, randomly selected from the bulk, were measured using digital venire caliper (Mitatoyo, Japan, least count= 0.05mm).

The geometric mean diameter, D_g and equivalent diameter, D_e, in mm was calculated by the following expressions (Mohapatra and Bal, 2012).

$$D_g = \mathrm{LWT}^{1/3} \qquad (1)$$

$$D_e = \left[\mathrm{L}\frac{(\mathrm{W}+\mathrm{T})^2}{4}\right]^{\frac{1}{3}} \qquad (2)$$

The sphericity (ϕ) defined as surface area of the sphere having the same volume as that of the grain to the actual surface area of the grain, was determined using the following formula (Mohsenin, 1986).

$$\text{ø} = \frac{\mathrm{LWT}^{1/3}}{\mathrm{L}} \qquad (3)$$

Where, L is the major diameter (length), W is the intermediate diameter (width) and T is the minor diameter (thickness) in mm.

The surface area and volume of the pigeon pea at different moisture level was calculated using the following expression (Jain and Bal, 1997):

$$V = \frac{\pi B^2 L^2}{6(2L-B)} \qquad (4)$$

$$\mathrm{S} = \frac{\text{ø}\mathrm{BL}^2}{(2\mathrm{L}-\mathrm{B})} \qquad (5)$$

Where, $\mathrm{B} = \sqrt{WT}$ (6)

Particle density and bulk density and porosity determination

The true volume of the grains was determined using the liquid displacement method. Toluene was used instead of water because it is absorbed by the grain to a lesser extent. In addition, its surface tension and dissolution power is low, so that it fills up even shallow dips and does not solubilize the chemical content of the grain (Mohsenin, 1986). Particle density (ρ_t, kg/cm^3) of samples was also calculated by dividing the unit mass of each sample by its true volume.

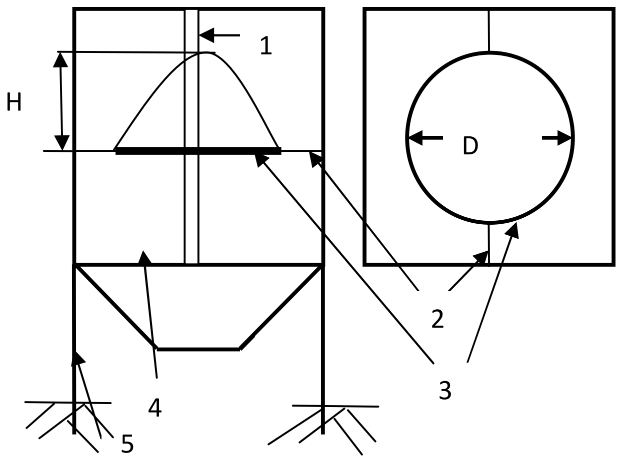
In order to determine the bulk density at given moisture content, a cubical container of length 10 cm m, 9.6 cm height and 10 cm width was filled with pigeon pea grains up to the top surface of the container, and the top was leveled. No separate or additional manual compaction was done. An electronic balance was used for weighing, and the samples' bulk density (ρ_b, kg/cm^3) was defined as the ratio of the mass of the bulk sample to the volume of the container (Suthar and Das, 1996).

Porosity was determined by using the bulk density and particle density data using the following expression (Mohsenin, 1986).

$$Porosity(\%) = \left(1 - \frac{bulk\ density}{particle\ density}\right) \times 100 \qquad (7)$$

Angle of repose determination

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using an angle of repose apparatus as shown in Fig 1. The apparatus is a cube of 16 cm, a circular plate of 6 cm diameter with a sliding gate at the bottom. The apparatus was placed on a table and filled with pigeon pea, and the sliding gate at the



1. Scale
2. Base holder
3. Circular base
4. Transparent face
5. Stand

Fig 1: Schematic diagram of angle of repose measuring tool

bottom was slowly removed until it formed a cone on the circular base. The diameter and height of the cone formed was recorded. The angle of repose (θ) was calculated by using the following equation (Mohsenin, 1986).

$$\theta = \tan^{-1}\frac{2H}{D} \qquad (8)$$

Where H is the height of the cone (cm) and D is the diameter of the cone (cm).

Hardness measurement

Rupture force/hardness of the grain was determined using ‘‘Stable micro system texture analyzer (TAHDi)” of 100 kg compression load cell. The individual grains were loaded between 5 mm cylindrical probe and load cell of the texture analyzer and compressed along with the thickness until rupture occurred. The rupture point is point at which the grain gets break or crack (Fos'hat *et al.*, 2011; Mohapatra and Bal, 2012).

Statistical Analysis

Statistical analysis was done with Microsoft Excel- 2007. Mean and standard deviation were calculated for each parameter. Coefficients of determination (r2) were calculated for all the parameters. Regression models were developed for each parameter with respect to moisture content.

Results and Discussion

The mean values for the length, width and thickness measured at different moisture contents in the range of 6.2 – 30.2 % (wb) are represented in Fig 2(a,b,c). As the moisture content increased, the three linear dimensions increased due to the swelling of the seed. The increase in linear dimensions for length, width and thickness were from 5.38 to 6.24 mm, 4.98 to 5.67 mm and 4.06 to 4.60 mm.

The following regression equations (9), (10) and (11) were developed for thickness (T), length (L) and width (W), with moisture content (M, % wb).

$$T=0.1298M + 4.8351, \qquad r^2= 0.93 \qquad (9)$$

$$L = 0.1572M + 5.1987, \qquad r^2= 0.96 \qquad (10)$$

$$W = 0.0955M + 3.9858, \qquad r^2= 0.91 \qquad (11)$$

The variation of mean geometrical diameter (D_g) and equivalent diameter (D_e) of the grain upon exposure of moisture is shown in Fig. 2(d, e). The mean geometrical diameter and equivalent diameters increased from 4.77 to 5.45 mm and 4.78 to 5.48 mm, respectively with increase in moisture content from 6.2

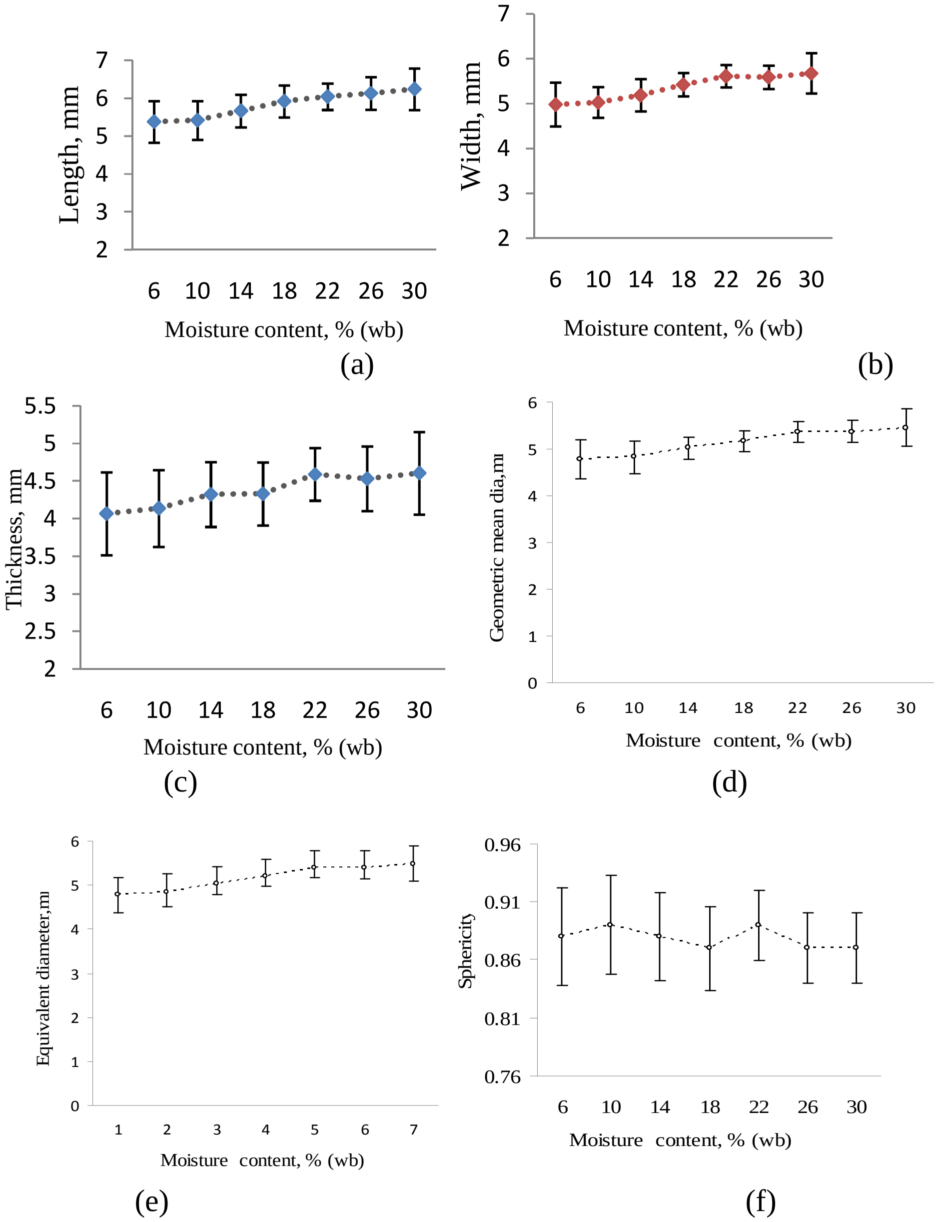


Fig. 2 Effect of moisture content on (a) Length, (b) Width, (c) Thickness, (d) Geometric mean diameter (e) Equivalent diameter (f) Sphericity of pegion pea

to 30.2% (wb). The mean geometrical diameter and equivalent diameters were lower than the length and width, and higher than thickness. It was evident from the figure that mean geometrical diameter and equivalent diameter of pigeon pea grains increased with increase in moisture content; followed a second order polynomial equation (Eqs (12 and 13):

$$D_g = -0.008M^2 + 0.196M + 4.533, \qquad r^2 = 0.968 \quad (12)$$

$$D_e = -0.008M^2 + 0.197M + 4.548, \qquad r^2 = 0.967 \quad (13)$$

The variation of the sphericity, ϕ with seed moisture content is shown in Fig. 2(f). The figure showed that the sphericity reduced from 0.88 to 0.87 and increased to 0.89 for the seed moisture range considered, the minimum occurring at 22% (wb) seed moisture content. The variation was almost linear between 6.2% and 22.2% (wb) seed moisture content.

This suggested that as the seed moisture content increased from 6.2 to 22.2% (wb) its shape deviated more and more from the shape of a sphere and started approaching a sphere again between 18.1 and 22.2 % (wb) seed moisture content. This may be due to the differential dimensional changes of the three major dimensions as the seed absorbed moisture. Similar findings were reported by Baryeh and Mangope (2002) for pigeon pea.

The volume (V) and surface area (S) also increased with increase in moisture content (Fig. 3a, b). Since, volume is dependent on the three linear dimensions, the change in linear dimensions reflected in the change in volume too. The volume of grains was observed to increase significantly following a linear trend from an initial value of 322.68 to 556.07 mm^3 ($P < 0.01$), when the moisture content increased from 6.2 to 30.2 % (wb).. There was a steady increase in surface area from 33.72 mm^2 at 6.2 % (wb) seed moisture content to 45.21 mm^2 at 30.2 % (wb) seed moisture content, as a result of change in major dimensions. These linear trends were represented by the following equations:

$$V = 42.00M + 267.5, \quad r^2 = 0.972 \qquad (14)$$

$$S = 2.087M + 31.30, \quad r^2 = 0.966 \qquad (15)$$

The bulk density (ρ_b) of the pigeon pea decreased from 1032.49 to 835.35 kg/m^3 with an increase in moisture content from 6.2 to 30.2 % (wb) (Fig 3c). This was due to the fact that an increase in mass owing to moisture gain in the grain sample was lower than accompanying volumetric expansion of the bulk. The correlation between the bulk density (ρ_b) and moisture content are as follows:

$$\rho_b = 1055 - 26.20M, \quad r^2 = 0.94 \qquad (16)$$

It was revealed that there was significant difference ($P<0.05$) between the mean values of bulk density, particle density, angle of repose at different moisture contents. A decrease in bulk density with increase in moisture content was reported for soybeans, gram seed, sunflower seed and lentil seeds (Deshpande *et al.,* 1993; Dutta *et al.,* 1988; Gupta and Das, 1997; Amin *et al.,* 2004).

The particle density (ρ_t) varied from 1398.09–1242.85 kg/m^3 with an increase in moisture content (Fig. 3d). Particle density and moisture content can be correlated as follows:

$$\rho_t = 1408 - 16.58M, \quad R^2 = 0.96 \qquad (17)$$

The bulk density was observed to be lower than that of particle density because of the air spaces in grain bulk increases the volume while the weight is the same. Similar observations were reported for lentil seed and squash seeds (Amin *et al.,* 2004; Paksoy and Aydin, 2004).

The porosity (P) was calculated from the bulk density and particle density of the pigeon pea. The porosity was found to increase from 26.14 to 34.33 % with increase in moisture content from 6.2 to 30.2 % (wb). This was due to the fact that with increase in moisture content, volume of grain also increases thereby, influencing the porosity of the grain. The relationship between the porosity (%) and moisture content can be represented by the following polynomial equation:

$$P = -0.2871M^2 + 3.7124M + 22.131, \quad r^2 = 0.9427 \quad (18)$$

The angle of repose (Θ) increased from 22.7 – 50.45 degree with increase in moisture content from 6.2 – 30.2 % (wb) (Fig. 3e). The variations of the angle of repose with moisture content were represented by a power curve:

$$\Theta = 22.18M^{0.328}, \ r^2 = 0.93 \qquad (19)$$

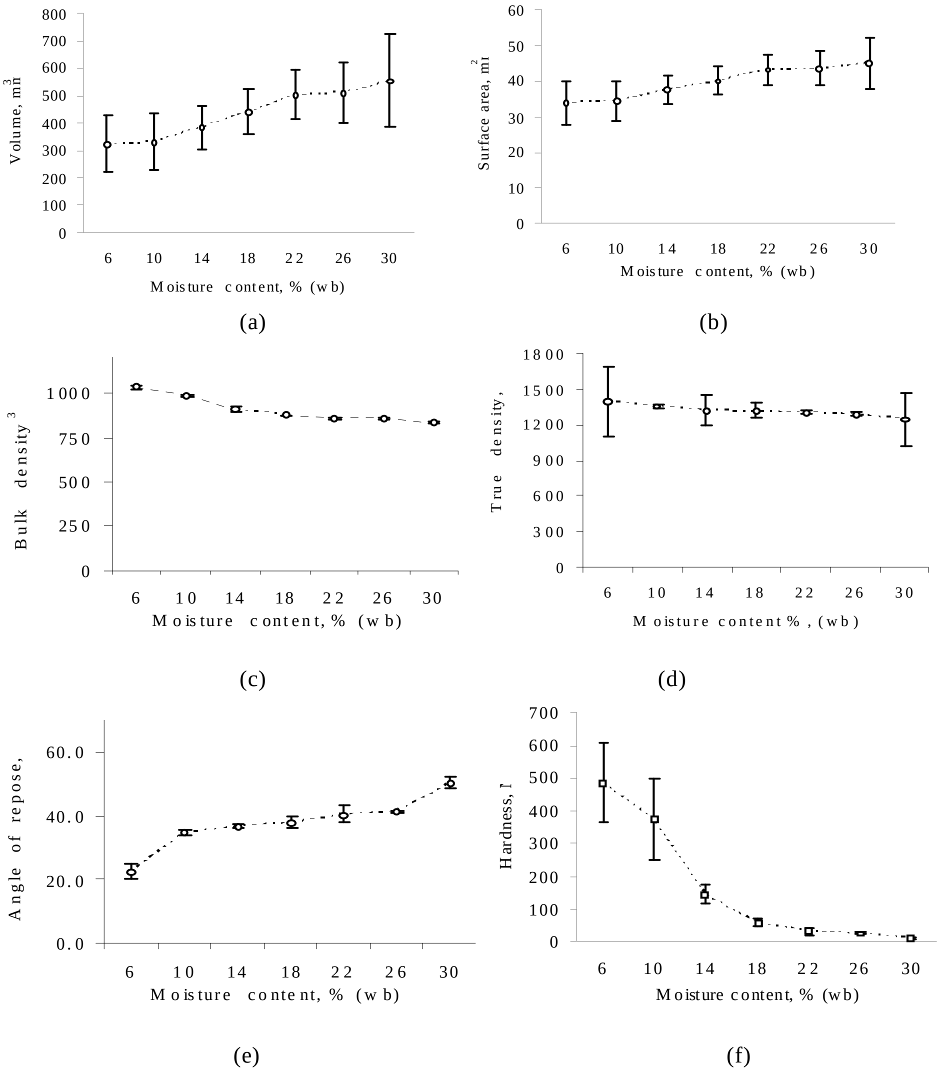
The studies carried out on gram seed, sunflower seed, pumpkin seed and on lentil seeds further confirmed that the angle of repose of agricultural materials increased with increase in moisture content (Gupta and Das, 1997; Amin *et al.,* 2004).

The hardness of pigeon pea grain decreased from 484.22 to 10.27 N with increase in moisture content from 6.2 to 30.2 % (wb) (Fig 3f). The results showed that the rupture strength along any major axes was highly dependent on the moisture content, for the range of moisture content investigated (6.2–30.2 % wb). It indicated that greater forces were necessary to rupture the grains with lower moisture level. The trend of decreasing rupture force at higher kernel moisture contents might be due to a gradual change in the integrity of the cellular matrix. Similar results have been reported for sunflower kernel and green gram (Gupta and Das, 2000; Unal *et al.,* 2008). The correlation between hardness with respect to moisture content follows a logarithmic equation as shown below:

$$H = 1138e^{-0.49M}, \ R^2 = 0.96 \qquad (20)$$

Similar trend was observed by Altuntas and Yildiz (2007) for faba bean grain and Tavakoli *et al.* (2009) for soybean grains. A large standard deviation -

was observed in the rupture force for lower moisture content. As moisture content increased the standard deviation decreased gradually, this phenomenon may be explained by the fact that there was large standard deviation in the grain dimensions and hence their absorptibility of moisture. There may be differential moisture diffusion in the grain varying in dimensions which almost stabilized as more moisture was added to the lot to bring them to same moisture level. This indicated that all the seeds did not have same moisture content level at the initial stage. The seeds which were lying at the bottom layer absorbed more moisture content as water would likely to accumulate at the bottom due to gravity. Inspite of frequent stirring uniform moisture absorption by the grains could not be established.



(a) (b)

(c) (d)

(e) (f)

Fig 3. Effect of moisture content on (a) volume (b) Surface area (c) bulk density (d) Particle density (e) Angle of repose and (f) Textural (compressive) hardness of pegion pea

Conclusion

All the linear dimensions of the seed increased linearly as the seed moisture content increased, which was due to the absorption of moisture and expansion. Mean and equivalent diameter of grain increased nonlinearly with increase in moisture content. Seed surface area and seed volume increased linearly as the seed moisture content increased, as they were dependent on the spatial dimensions of the grain. The bulk density and particle density increase linearly with increase in seed moisture content. The increase in angle of repose with pigeon pea moisture content could be attributed to the building up of the adhesion force at the grain water interface. Decrease of compressive hardness with moisture content may be attributed to the lesser resistance of seed due to softening of tissue. The information on moisture dependent properties will aid in developing and designing various post harvest handling and processing equipments for pigeon pea.

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