International Journal of Science, Environment and Technology, Vol. 3, No 3, 2014, 966 – 975

ISSN 2278-3687 (O)

MOISTURE-DEPENDENT MECHANICAL PROPERTIES OF PIGEON PEA GROWN IN NIGERIA

Okey Francis Obi*, Chinenye C. Anyadike and Charles O. Onyeke
Agricultural and Bioresources Engineering Department, Faculty of Engineering,
University of Nigeria, Nsukka, Nigeria
E-mail: profran6@gmail.com (**Corresponding Author*)

Abstract: The effects of different moisture content levels of 10, 15, 20 and 25% (wb) on some mechanical properties of pigeon pea (*cajanus cajan*) was investigated. These properties are important in the design of appropriate machines for harvesting, processing, transporting, packaging and storage of pigeon pea. The mechanical properties were significantly dependent ($p<0.05$) on the moisture content. The properties – rupture force, compressive strength, maximum displacement, strain at maximum load and the Young's modulus, - had an inverse relationship with the moisture content. As the moisture content increased, the mean value of the mechanical properties decreased. The mean values recorded as the moisture content decreased from 10 – 25% (w.b) were from 159.10 – 69.30 N for the rupture force, 981.26 – 437.57 N/mm^2 for the compressive strength, 4.86 – 2.75 for strain at maximum load, 3.25 – 1.82 mm for maximum displacement and 457.05 – 254.68 N/mm^2 for the Young's modulus.
Keywords: Pigeon pea, moisture content, mechanical properties, Nigeria.

Introduction

Pigeon pea (*Cajanus cajan* (L.) millsp.) is a multipurpose leguminous crop that can provide food, fuel wood and fodder in subsistence agriculture and is widely cultivated in Nigeria (Remanandan and Asiegbu, 1993; Egbe and Kalu, 2006). In most locations in Nigeria agro-ecological zones, resource-poor farmers have through evolutionary history incorporated pigeon pea production into their indigenous cropping systems as field crops, backyard or as field border crops (Egbe and Kalu, 2006). Egbe and Adeyemo (2006) reported that pigeon pea could be intercropped with maize without negative effects on the yield and yield components of maize. Farmers, however, maintain varying degrees of sole and mixed culture with crops such as as sorghum, millet, yam, cassava and sweet potatoes (Egbe and Vange, 2008). Egbe and Vange (2008) further noted that Pigeon pea should play an important role in developing new strategic approaches to ensure food security and sustainable increase in agricultural productivity in Nigeria. It is a rich source of protein, carbohydrate and certain minerals. Pigeon pea seeds contain about 57.3 - 58.7% carbohydrate, 1.2 - 8.1% crude fibre and 0.6 - 3.8% lipids (Sinha, 1977).

*Received Apr 26, 2014 * Published June 2, 2014 * www.ijset.net*

In spite of the numerous importance of pigeon pea in human nutrition (Torres et al., 2007; Aiyeloja and Bello, 2006; Onu and Okongwu, 2006; Amaefule and Obioha, 2001; Agwunobi, 2000; Eneche, 1999), pigeon pea production in Nigeria is still characterized by low production. The processing operations are predominantly done manually. Scientific data on their physical and mechanical properties are not readily available and this has caused low mechanization of their technological processes especially as regards to harvesting and production line processes (Anna and Julitta, 2003). Bhatia et al. (2009) noted that the effective planting, handling, processing and storage of legumes is largely dependent on the knowledge of the engineering properties of the seed, which will in turn aid in better design and fabrication of machines for different stages of their production and processing. The engineering properties of various agricultural products have been studied by some researchers such as hazelnut (Aydin, 2002), almond (Aydin, 2003), cowpea (Davies and Zibokere, 2011), millet (Baryeh, 2002), Guna seed (Aviaral et al., 1999), coffee (Chandrasekar and Viswanathan, 1999), wild plum (Calisir et al., 2005), lentil seeds (Carman, 1996), sunflower seeds (Gupta and Das, 1997), chick pea seeds (Konak et al., 2002), castor seed (Ardebili et al., 2012), soybean (Tavakoli et al., 2009), green gram (Nimkar and Chattopadhyaya, 2001), cotton (Ozarslan, 2002) and white sesame (Darvishi, 2012).

A review of the literature showed that detailed measurements of the mechanical properties of pigeon pea in Nigerian at various levels of moisture content have not been investigated. The general objective of this study is to provide data on some moisture dependent mechanical properties of pigeon pea necessary for the design of appropriate processing methods and machines. The specific objective of this study was to determine some moisture dependent mechanical properties of pigeon pea grown in Nigeria, namely rupture force, compressive strength, maximum displacement, strain at maximum load and Young's modulus in the moisture content range from 10 to 25% w.b. And to develop predictive models for the properties investigated as a function of moisture content using regression analysis.

Materials and Methods

Samples preparation

The pigeon pea grains used for the study were purchased from a local market in Enugu state, South Eastern Nigeria and cleaned to remove foreign materials and impurities. The moisture content of the grains as brought in from the market was determined by drying samples in an air circulating oven set at 105^{O}C (±2) for 24 h as described by Zewdu and Solomon (2007). The moisture content was determined using equation 1:

$$M_{DB} = \frac{M_W - M_D}{M_D} \times 100 \quad (1)$$

Where,

M_{DB} = Moisture content in dry basis of the grains; M_w = Initial weight of the grain;

M_D = weight of the grain after drying

Because of the significant effect of moisture content in the properties of grains (Singh et al., 1990; Tabatabaeefar, 2003; Zewdu and Solomon, 2007), the mechanical properties of the grain was accessed at four different moisture content levels of 10%, 15%, 20% and 25% in wet basis in order to relate the property to moisture content. In order to attain the desired moisture levels for the study, moisture levels lower than the initial moisture content of the sample were attained by drying the grains at low temperature (40^{o}C) to give a sample mass *B* as calculated below (Viswanathan et al., 1996):

$$B = A(100 - a)/(100 - b) \quad (2)$$

And moisture levels higher than the initial moisture content of the sample were attained by adding the required amount of distilled water, *Q* as calculated from equation 3. The samples were kept in refrigerator at 5^{o}C (±1) for 5 days for the moisture to distribute uniformly throughout the sample. Before using the samples for the study, the required quantity of seeds was taken out of the refrigerator and allowed to warm up to room temperature for about two hours (Nimkar and Chattopadhyay, 2001). The moisture content after equilibration was determined at the time of each experiment using the method described above (Zewdu and Solomon, 2007). The mechanical properties described below were determined at each moisture content level.

$$Q = A(b - a)/(100 - b) \quad (3)$$

Where,

A is the initial mass of the sample in kg, *B* the final mass of the sample after drying in kg, *a* the initial moisture content of sample in % w.b., *b* the final (desired) moisture content of sample in % w.b., *Q* the mass of water to be added in kg.

Determination of mechanical properties

The Monsanto Universal Testing Machine was used for the determination of mechanical properties. The test was based on force-deformation characteristics of the grain. The individual grain was loaded between two parallel plates of the machine and compressed along its length until rupture occurred as is denoted by a rupture point in the force–deformation curve. The rupture point is a point on the force–deformation curve at which the loaded specimen shows a visible or invisible failure in the form of breaks or cracks (Tavakoli et al., 2009). This point is detected by a continuous decrease of the load in the force-deformation diagram. Once the rupture point was detected, the loading was stopped. These tests were carried out at the loading rate of 5 mm/min for all moisture levels (ASAE, 2006).

Statistical analysis

Descriptive statistics were used to analyze the data obtained for each of the properties studied at different moisture content level using GenStat Discovery Edition 4. Predictive models were developed to establish relationship between the properties and moisture content using regression analysis. Each test was performed four times and the mean value determined.

Results and Discussions

The result of the rupture force, compressive strength, maximum displacement for crushing, strain at maximum load and the Young's modulus of pigeon pea are presented in Table 1. It was observed that the mechanical properties investigated had an inverse relationship with the moisture content. That is, as the moisture content increased from 10 – 25% (w.b), the mean values of the mechanical properties decreased.

Table 1: Mechanical properties of Pigeon pea at different moisture contents

MC, w.b. (%)	Rupture Force (N)	Compressive Strength (N/mm^2)	Maximum Displacement (mm)	Strain at Maximum Load	Young's Modulus (N/mm^2)
10	159.10 (20.05)	981.26 (53.25)	3.25 (0.35)	4.86 (0.63)	457.05 (23.11)
15	135.45 (13.36)	769.78 (45.82)	3.13 (0.53)	4.61 (0.87)	434.66 (33.80)
20	105.53 (20.23)	764.13 (66.79)	2.38 (0.18)	3.63 (0.31)	368.49 (35.01)
25	69.30 (14.45)	437.57 (55.26)	1.82 (0.45)	2.75 (0.62)	254.68 (16.55)

Standard deviations are in parentheses

Rupture force

The force required to initiate grain rupture for loading along the thickness axis at different moisture contents are presented in Table 1. It can be observed that the rupture force decreased as the moisture content increased from 10% to 25% w.b. The rupture force values ranged from 159.10 to 69.30N. As shown in Table 1, the lower rupturing forces were obtained at higher moisture contents. This might have resulted from the fact that the pigeon pea grain might have softer texture at higher moisture content (Altuntaş and Yildiz, 2007). The relationship between the moisture content (*Mc*) and rupture force (*F*) of pigeon pea grain as expressed using regression equation is shown in equation 4. Figure 1 shows the measured and the predicted values of the rupture force.

$$F = -5.9864Mc + 222.107 \qquad R^2 = 0.991 \qquad (4)$$

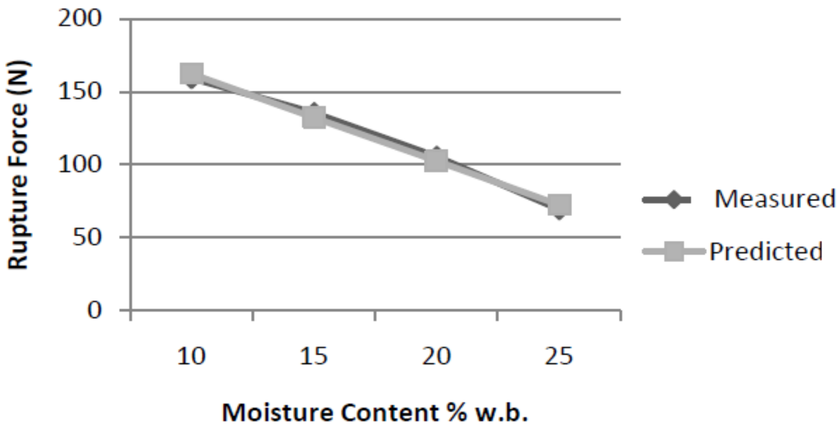

Figure 1: Rupture force of Pigeon pea as a function of moisture content

Compressive strength

The results of the compressive strength of pigeon pea grains are presented in Table 1. It was observed that the compressive strength decreased from 981.26 to 437.57 N/mm^2 as the moisture content increased from 10 to 25% w.b. The relationship between the moisture content (Mc) and compressive strength (Cs) of pigeon pea grain can be expressed mathematically as using equation 5. Figure 2 presents the measured and the predicted values.

$$Cs = -32.7344Mc + 1311.037 \qquad R^2 = 0.886 \qquad (5)$$

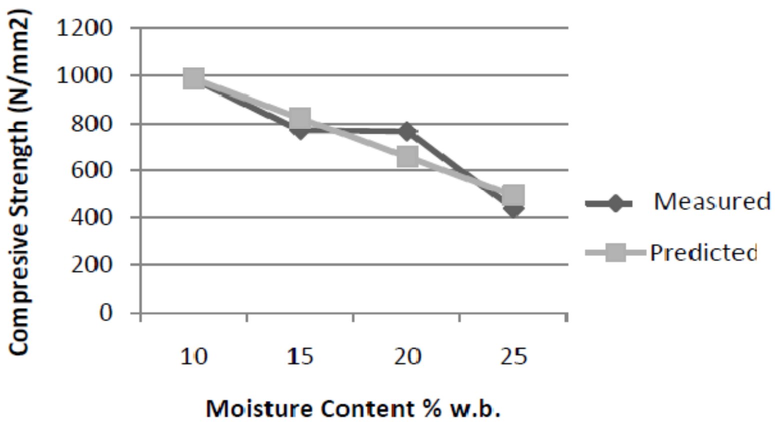

Figure 2: Compressive strength of Pigeon pea as a function of moisture content

Maximum displacement

The result of the maximum displacement of pigeon pea grains are presented in Table 1. It can be observed that the maximum displacement decreased from 3.25 to 1.82 mm as the moisture content increased from 10 to 25% w.b. The relationship between moisture content (Mc) and maximum displacement (Dm) of pigeon pea grain can be expressed mathematically using equation 6. Figure 3 presents the measured and the predicted values of the maximum displacement.

$$Dm = -0.1008Mc + 4.409 \qquad R^2 = 0.939 \qquad (6)$$

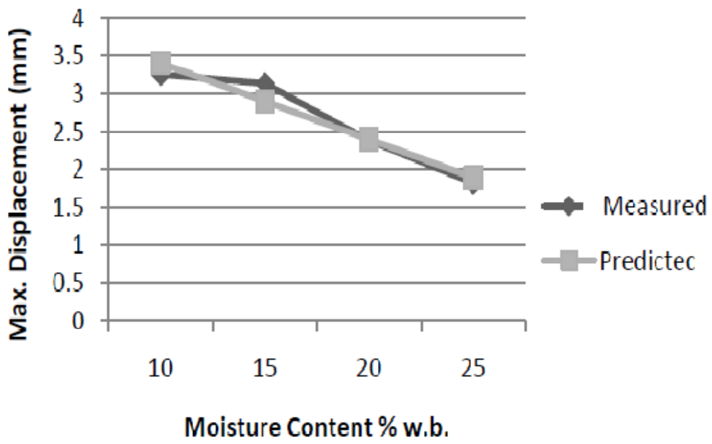

Figure 3: Maximum displacement of Pigeon pea as a function of moisture content

Strain at maximum load

As shown in Table 1, as the moisture content increased from 10 – 25% (wb), the strain at maximum load decreased from 4.86 to 2.75. The relationship between moisture content (Mc) and strain at maximum load (Sm) of pigeon pea grain can be expressed mathematically as follows (Equation 7). Figure 4 shows the graph of the measured and the predicted values of the strain at maximum load obtained using the regression equation.

$$Sm = -0.1462Mc + 6.521 \qquad R^2 = 0.952 \qquad (7)$$

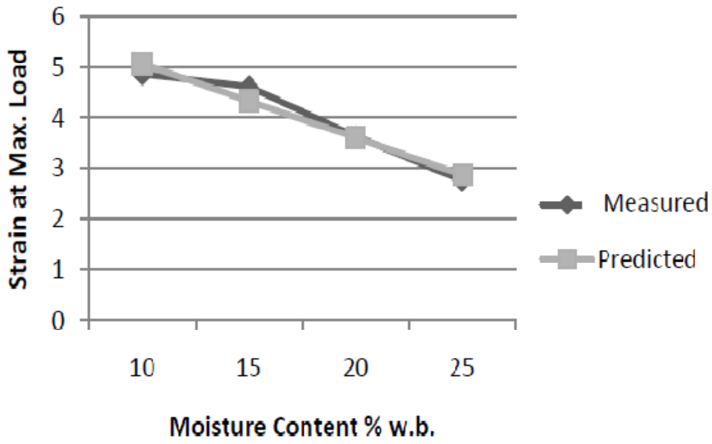

Figure 4: Strain at maximum load of Pigeon pea as a function of moisture content

Young's modulus

The Young's Modulus of the grains was observed to decrease with increase in moisture content level. The Young's Modulus decreased from 457.05 to 254.68 N/mm^2 as the moisture content increased from 10 to 25% w.b. The values of the Young's Modulus (YM) for pigeon pea grain bear the following relationship with its moisture content (Mc) as expressed using the regression equation (8) having a correlation coefficient of 0.916. Figure 5 shows the predicted values from the regression equation and the measured values.

$$YM = -13.4656Mc + 614.368 \qquad R^2 = 0.916 \qquad (8)$$

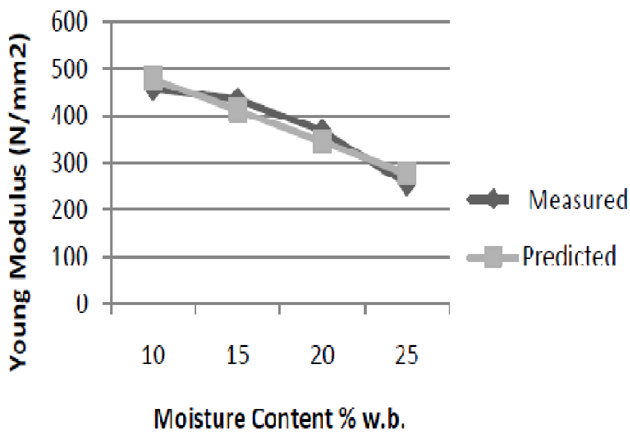

Figure 5: Young's modulus of Pigeon pea as a function of moisture content

Conclusion

The following conclusions were drawn from the investigation on moisture-dependent mechanical properties of pigeon pea grains for moisture content levels of 10 to 25% w.b. The mechanical properties were found to decrease with increasing moisture content level. The mechanical properties were significantly dependent on the moisture content with high coefficient of correlation ranging from 0.886 to 0.991.

References

[1] Adejumo, O.I., Alfa, A.A. and Mohammed A., 2007. Physical properties of Kano white variety of Bambara groundnut. Nigerian Academic Forum, (12)1: 68-77.

[2] Agwunobi, L.N., 2000. Effect of feeding heat treated soybean (Glycine max) and pigeon pea (Cajanus cajan) as major sources of protein on layer performance. Global Journal of Pure and Applied Science, 6: 1–3.

[3] Aiyeloja, A.A. and Bello, O.A., 2006. Ethnobotanical potentials of common herbs in Nigeria: A case study of Enugu state. Educational Research and Review, 1: 16–22.

[4] Altuntas, E. and Yildiz, M., 2007. Effect of moisture content on some physical and mechanical properties of faba bean *(Vicia faba L.)* grain. Journal of Food Engineering, 78:174-183.

[5] Amaefule, K.U. and Obioha, F.C., 2001. Performance and nutrient utilization of broiler starters feed diets containing raw, boiled or dehulled pigeon pea seeds (Cajanus cajan). Nigerian Journal of Animal Production, 28: 31–39.

[6] Anna, G. and Julitta, B. (2003). Physical properties of selected legumes seeds as indicators of technological suitability of small-seed broad bean. Pol. J. Food Nutri. Sci, Vol. 12/53(2): 9-13.

[7] Ardebili, M.S., Najafi, G., Ghobadian, B., and Hashjin, T.T., 2012. Determination of some mechanical properties of castor seed (Ricinus communis L.) to design and fabricate an oil extraction machine. J. Agr. Sci. Tech. 14: 1219-1227.

[8] ASAE. 2006. Compression test of food materials of convex shape. S368.4, 609-616.

[9] Aviaral N.L., Gwandzag M.I., and Haque M.A., 1999. Physical properties of Guna seeds. J. Agric. Eng. Res., 73, 105-111.

[10] Aydin, C., 2002. Physical properties of Hazel nuts. Biosys. Eng., 82(3): 297-303.

[11] Aydin C., 2003. Physical properties of Almond nut and kernel. J. Food Eng., 60: 315-320.

[12] Baryeh E.A., 2002. Physical properties of millet. J. Food Eng., 51: 39-46.

[13] Bhatia, T., Sharma, R.K. and Prasal, K., 2009. Studies on some physical properties of protein-rich legume (Lens esculantus) splits. Asian Journal of Chemistry 21(10): 103-107.

[14] Calisir S., Haciseferogullari H., Ozcan M., and Arslan D., 2005. Some nutritional and technological properties of wild plum (Prunus spp.) fruits in Turkey. J. Food Eng., 66: 233-237.

[15] CarmanK., 1996. Some physical properties of lentil seeds. J. Agric. Eng. Res., 63(2): 87-92.

[16] Cetin, M., 2007. Physical properties of barbunia bean (*Phaseolus Vulgaris L. cv. burbuniz*) seed. Journal of Agricultural Engineering Research, 80: 353-362.

[17] Chandrasekar V. and Viswanathan R., 1999. Physical and thermal properties of Coffee. J. Agric. Eng. Res., 73: 227-234.

[18] Davies, R.M. and Zibokere, D.S., 2011. Effect of moisture content on some physical and mechanical properties of three varieties of cowpea (Vigna unguiculata (L) Walp). Agricultural Engineering International: CIGR Journal, Manuscript No.1700. Vol. 13, No.1.

[19] Darvishi, H., 2012. Moisture-dependent physical and mechanical properties of white sesame seed. American-Eurasian J. Agric. & Environ. Sci., 12 (2): 198-203.

[20] Downes, R.W., 2001. Establishment of legumes in pasture of savanna woodland in North Queensland. Queens l. J. Agric. Anim.Scie., 24:23-29.

[21] Egbe, O.M., and Kalu, B.A., 2006. Farming systems study: Participatory rural appraisal of pigeon pea cropping systems in Southern Guinea Savanna of Nigeria. Abia State University Environmental Review (ASUER) 5(1): 37 – 47.

[22] Egbe O.M., Adeyemo, M.O., 2006. Estimation of the effect of intercropped pigeon pea on the yield and yield components of maize in Southern Guinea Savanna of Nigeria. Journal of Sustainable Development in Agriculture and Environment, 2: 107 – 19.

[23] Egbe O.M., and Vange, T., 2008. Yield and agronomic characteristics of 30 pigeon pea genotypes at Otobi in Southern Guinea Savanna of Nigeria. Life Science Journal, 5(2): 2008

[24] Eneche, E.H., 1999. Biscuit-making potential of millet/pigeon pea flour blends. Plant Foods for Human Nutrition, 54: 21–27.

[25] Gupta R.K., and Das, S.K., 1997. Physical properties of Sunflower seeds. J. Agric. Eng. Res., 66: 1-8.

[26] Konak M., Carman K., and Aydin, C., 2002. Physical properties of Chick pea seeds. Biosys. Eng., 82(1): 73-78.

[27] Milani, E., Seyed, M. Koocheki, A., Nikzadeh, V., Vahedi, N., Moeinfard, M., and Gholamhosseinpour, A., 2007. Moisture dependent physical properties of Cucurbit seeds. Int. Agrophysics, 21: 157-168.

[28] Mohsenin, N.N., 1986. Physical property of plant and Animal Materials. Gordon and Breach Scientific Publishers, New York. Pp. 130-310.

[29] Nimkar, P.M., and Chattopadhyay, P.K., 2001. Some physical properties of green gram. Journal of Agric. Engineering Research.80: 183-189.

[30] Onu, P.N., and Okongwu, S.N., 2006. Performance characteristics and nutrient utilization of starter broilers fed raw and processed pigeon pea (Cajanus cajan) seed meal. International Journal of Poultry Science, 5(7): 693–697.

[31] Ozarslan C., 2002. Physical properties of cotton seed. Biosys. Eng., 83(2): 169-174.

[32] Remanandan P., and Asiegbu, J.E., 1993. Pigeon Pea Germplasm Collection in Nigeria. ICRISAT Genetic Resources Report No.79. ICRISAT, Pantacheru, AP, India. ICRISAT.

[33] Singh, U., Jambunathan, R., Saxena, K., Subrahmanyam, N., 1990. Nutrition quality evaluation of newly developed high-protein genotypes of pigeon pea (Cajanus cajan). Journal of the Science of Food and Agriculture, 50: 201–209.

[34] Sinha, S.K., 1977. Food legumes: Distribution, adaptability and biology of yield, In: Plant production and protection paper 3. FAO, Rome, pp: 102.

[35] Tabatabaeefar, A., 2003. Moisture-dependent physical properties of wheat. Int. Agrophysics, 17: 207-211.

[36] Tavakoli, H., Rajabipour, A., and Mohtasebi S.S., 2009. moisture-dependent some engineering properties of soybean grains". Agricultural Engineering International: the CIGR Ejournal. Manuscript 1110. Vol. XI. February, 2009

[37] Torres, A., Frias, J., Granito, M., and Vidal-Valverde, C., 2007. Germinated Cajanus cajan seeds as ingredients in pasta products: Chemical, biological and sensory evaluation. Food Chemistry, 101: 202–211.

[38] Viswanathan, R., Palaniswamy, P.T., Gothandapani, L., and Sreenarayanan, V.V., 1996. Physical properties of neem nut. Journal of Agricultural Engineering Research, 63: 19-26.

[39] Zewdu, A.D., and Solomon, W.K., 2007. Moisture-dependent physical properties of tef seed. Biosystems Engineering 96(1): 57-63.