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Paper No. CSBE15-096

Some Mechanical Properties of Mucuna Bean (*mucuna Crens)* relevant to its cracking

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Written for presentation at the
CSBE/SCGAB 2015 Annual Conference
Delta Edmonton South Hotel, Edmonton, Alberta
5-8 July 2015

ABSTRACT

Some mechanical and frictional properties of Mucuna Bean seed were studied at different moisture content as a panacea for developing processing machines for the seed. The mechanical properties namely; force, deformation, stress and energy to crack both on the seed's major and minor axis were determined by use of a Universal Testing machine (UTM), while the coefficient of friction of the seed was obtained using an incline plane. At moisture level 4.79 to 18.53 % (d.b.), the coefficient of friction increased from 0.205 to 0.277, 0.231 to 0.298, 0.205 to 0.287, 0.218 to 0.313 and 0.249 to 0.329 with plywood, aluminium, glass, galvanized steel and rough wood as structural materials. The force to crack the seed on its major axis decreased from 1595.1 to 244.9 N as moisture level increased from 4.79 to 18.53% (d.b.). Similar trend was recorded for the minor axis. The deformation on both axes decreased as moisture level increased. The stress to break the seed ranged from 2.79 to 21.61 N/mm^2 and 5.12 to 21.01 N/mm^2 on the major and minor axis respectively, while required to break the seed decreased as moisture level increased. Regression equations were used to establish relationships between the mechanical and frictional properties with moisture content.

Keywords: Mucuna Bean, Mechanical Properties, Frictional Properties, Moisture Content, Processing Machines, Stress, Energy

INTRODUCTION

Mucuna bean seeds are derived from the cluster of pods of velvet bean which predominantly grows between (3-18 m) in height. It is dominant in tropical regions particularly Africa and Asia. Mucuna Bean pods are covered with reddish-orange hairs which are prone to itching. Mucuna grows wild in the tropics. The bean, seed, and hair of the bean pod have been widely used traditionally and commercially for various purposes in India, West Africa and Central America. The seed contains 40mg/g of L-Dopa which is a direct precursor to the neurotransmitter dopamine (Amstrong, 2010).

Traditionally, Mucuna bean can be harvested and consumed by humans for the following purpose; prevention of kidney stones, blood cleansing, treatment of urinary tract infection, expulsion of excessive gases from the body system, stimulation of the central nervous system, reduction of blood pressure in humans, menstrual cycle stimulation and also as a warm expeller (Zak, 2009). A research on some mechanical properties mucuna bean is essential considering the high demand for the seed in the market for consumption as food by humans and its applications in the medical field. After harvesting, mucuna bean seeds are being soaked for a period of two to four days in water before they can be manually cracked and used. This has led to gradual loss of interest and utilization of the oil seed. It is necessary to evaluate these properties at various moisture levels as a means of optimizing the effect of moisture content in the cracking process.

Figure 1: Mucuna Bean Seeds

The frictional properties of agricultural bio-materials include: Angle of repose, coefficient of friction etc. It's an essential component in the design of hoppers for agricultural and food processing machines. Many authors have reported values for the coefficient of friction of agricultural biological materials on different structural mediums; Heidargbeigi *et al;*(2008); wild pistachio, Ozarslan (2002); cotton, botton, Dursun and Dursun (2005); caper seed, Baryeh and mangope (2003); pigeon pea. The flow of agricultural materials during processing is largely dependent on the moisture content of the material some of these frictional and flow properties are; coefficient of friction, angle of repose, terminal velocity, drag coefficient amongst others. Several authors have analyzed these properties as a function of moisture levels; Adejumo *et al.* (2009) for okra, Akintunde *et al.* (2007) for melon, Shaifee *et al*. (2009) for dragon head seed, Esref (2007) for lentil and Ozturk and Esen (2008) for barley.

Tavokili *et al.* (2009) in studying moisture dependent physical properties of barley observed that the static coefficient of friction of the grains increased linearly against various structural surfaces (plywood, glass and galvanized iron steel) as moisture content increased. This was in consonant with findings of Koocheki *et al.*(2007) for watermelon seed and Karimi *et al.*(2009) for tiger nut, Bamboye and Adejumo (2011) worked on the mechanical properties of roselle seed. The behaviour of the grain due to compression was analyzed using a software texture analyzer. It was also observed that the mechanical properties of the seed increased with increase in moisture content. As moisture level increased from 8.8 to 19% (dry basis), the compressive force, yield stress and young's modulus increased from 23.45 to 49.05N, 17.0 to 38.15Nmm^{-2} and 216.03 to

374.11Nmm^{-2}. Similar trend was obtained by Ahmadi *et al.* (2009) for apricot. Garavand *et al*. (2010) reported that the rupture force and energy of hemp seed decreased from 36.65 to 18.67N and 10.25 to 5.4/mJ respectively as moisture level changed from 5.39 to 27.12% (dry basis).

MATERIALS AND METHODS

A large quantity of the seed was obtained from a local market in Uyo, Akwa Ibom State Nigeria. The seeds were manually clean to remove foreign matter and dirt. Hundreds of samples were randomly selected for various experiments by employing a random sampling method, as utilized by Alonge and Etim (2011) in their study on African Oil Bean Seed and Falaye and Atere (2009) for Cowpea. Experiments were conducted at the National Center for Agricultural Mechanization (NCAM), Ilorin, department of Agricultural and Food Engineering and department of Mechanical Engineering of the University of Uyo, Uyo, Nigeria. The coefficient of friction of the seed was measured with use of an inclined plane. The mechanical properties were determined by use of digital Universal Testing Machine (UTM – Instron 3382, 100 KN Floor Model).

The moisture content of the seed was determined using the ASABE (2006) standard which involved oven drying at six different levels to allow for the analysis of the effect of moisture content on the engineering properties of the seed. The samples were refrigerated at 5^{o}C for 24 hours and later removed and allowed to warm at a room temperature of 27^{o}C for up to 5 hours before experimentation to achieve even moisture distribution and avoid moisture loss (Oje *et al.* 1993) and Alonge and Etim (2011). The initial weight (W_1) of the seeds was determined and recorded using an electronic weighting balance of 0.0lg sensitivity. The seeds were further dried using an air convection oven at a temperature of 105^{o}C for a period of six (6) hours and removed, before being placed in desiccators for five minutes to cool for each moisture level. The final weight (W_2) of the seeds was obtained and the moisture content was determined from the relationship:

$$\text{Moisture Content (M.C.)} = \frac{\text{Initial Weight (g)} - \text{Final Weight (g)}}{\text{Final Weight (g)}}\ (\%)$$

$$m.c.(\%) = \frac{(w_1 - w_2)}{w_2} \qquad - \quad - \quad - \qquad (1)$$

The moisture content was determined at six levels.

The coefficient of friction of the seed on different structural surfaces was determined using the inclined plane method as described by Gupta and Das (1997) and Ogunsinya *et al.*(2009).

The five structural surfaces used were; galvanized steel, plywood, glass, aluminum and rough wood. The seeds were placed on each of the structural surfaces, the incline plane will be gently raised and the angle of inclination at which the seed began sliding was read off the protractor with the sensitivity of one degree.

The tangent of the tilt angle was reported as the coefficient of friction of the seed.

$$\mu = \tan \theta \qquad - \quad - \quad - \quad - \quad - \qquad (2).$$

where, μ = Coefficient of friction, and

θ = tilt angle of the friction device in degrees.

The mechanical properties of the seed were determined by employing a Universal Testing Machine connected to a display monitor. The resistance of the seed to compression was determined by employing uniaxial compression analysis using the ASABE (2006) standard. The method involved subjecting an individual seed from the sample population to compression in its natural resting position on the major and minor axis. Individual seeds at the considered moisture level were dropped at a height of 10cm from a flat surface to allow the seed to fall freely and rest in its natural position, which served as the loading surface. The seeds were loaded between two parallel flat plates at a compression speed set at 3mm/min. This was in consonance with the methods used for other oil seeds (Wandkar *et al*. 2000).

The behavior of the seed to compression was analysed with the aid of the software texture analyzer. The software graphic interface produced force deformation curves for various treatments and showed eventual collapse of the seed with the variation of force during deformation. The height of the seed on the machine was considered as the major and minor diameters of the seed as obtained using a venier caliper. The mechanical properties of the seed namely: peak force (cracking force), rupture stress, deformation, yield stress, rupture force, energy to break and young's modulus were obtained from the graphical display on the texture analyzer. This method was utilized by Bamgboye and Adejumo (2011) for roselle seed.

Figure 2: Cracking of mucuna bean seed by compression using a UTM

All experiments were conducted at six different moisture levels and repeated severally. Analysis of variance (ANOVA) and comparison of means were performed using EXCEL Program (SAS, 2001). The relationship between the properties of the seed and moisture levels was established. Model coefficients were determined by using EXCEL routines, The coefficient of multiple determination (R^2) and the mean square error (MSE) of the models and the variations of predicted values with respect to measured values as well as distribution of the residual with respect to the estimated coefficients was used to evaluate the models for fitness of the experimental data. The effect of moisture content on these properties was analysed.

RESULTS AND DISCUSSIONS

The Table below show values obtained for coefficient of friction of the seed at various moisture levels on different structural material.

Table 1: Coefficient of friction of the seed at various moisture levels on different structural materials

Moisture Content	Plywood	Aluminium	Glass	Galvanized Steel	Rough Wood

4.79	0.205	0.231	0.205	0.218	0.249
7.31	0.224	0.253	0.209	0.242	0.271
12.65	0.245	0.261	0.247	0.268	0.293
15.34	0.260	0.270	0.272	0.290	0.305
16.97	0.271	0.291	0.277	0.298	0.311
18.53	0.277	0.298	0.287	0.313	0.329

Table 2: Analysis Of Variance on Coefficient of Friction of the seed

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	0.008	4	0	2.18	0.101	2.76
Within Groups	0.024	25	0			
Total	0.032	29				

The coefficient of friction of the seed increased as moisture level increased. The values ranged from 0.25 to 0.277 (plywood), 0.231 to 0.298 (alumunium), 0.205 to 0.287 (glass), 0.218 to 0.313 (galvanized steel) and 0.249 to 0.329 (rough wood). Plywood and alumunium as structural surfaces had the friction coefficient of 0.205, while rough wood recorded the highest as 0.329.Mathematical relationships linking the coefficient of friction on different structural surfaces with moisture level were established as below:

$$\mu_p = 0.005m + 0.183 \ (R^2 = 0.992) \quad - \quad - \quad - \quad (3)$$

$$\mu_a = 0.004m + 0.213 \ (R^2 = 0.93) \quad - \quad - \quad - \quad (4)$$

$$\mu_g = 0.006m + 0.17 \ (R^2 = 0.983) \quad - \quad - \quad - \quad (5)$$

$$\mu_s = 0.006m + 0.19 \ (R^2 = 0.993) \quad - \quad - \quad - \quad (6)$$

$$\mu_w = 0.005m + 0.228 \ (R^2 = 0.972) \quad - \quad - \quad - \quad (7)$$

where μ_p, μ_a, μ_g, μ_s and μ_w are coefficient of friction of the seed on plywood, aluminium, glass, steel and rough wood as respective structural surfaces. The results obtained were not in close variation with what was obtained by Gowda *et al.* (1995), Paksoy and Aydin (2006), Ozarslan (2002), Adejumo *et al.* (2009) and Coskuner (2005) for soybean, pea, cotton, okra and flaxseed respectively. The coefficient of friction of the seed on the different structural surfaces showed positive correlation with moisture content (dry basis).

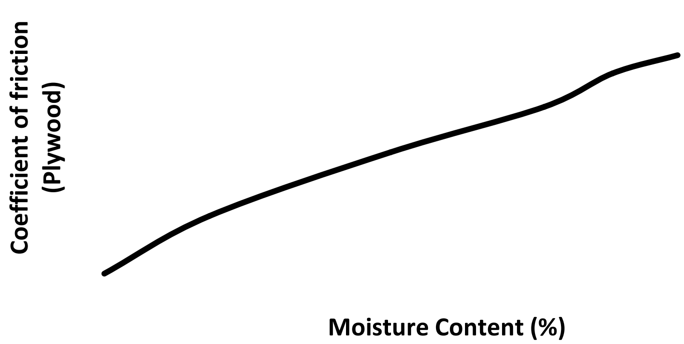

Figure 3: Relationship between moisture content and coeffiecient of friction of the seed with plywood as structural surface.

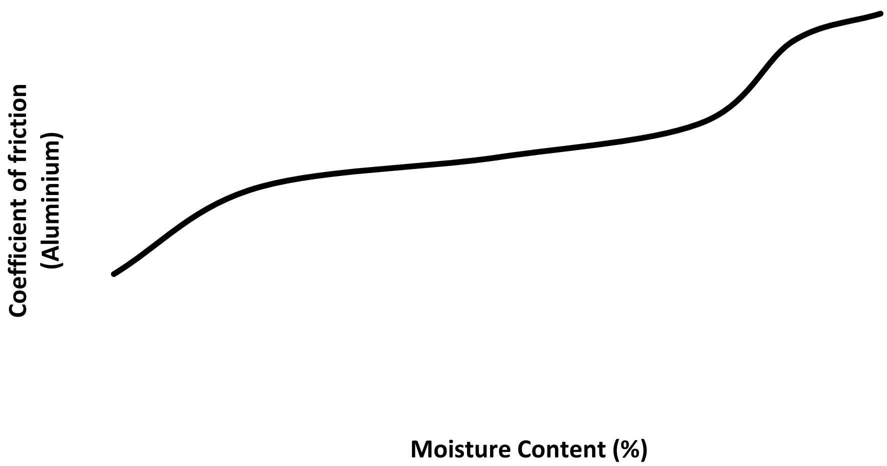

Figure 4: Relationship between moisture content and coeffiecient of friction of the seed with aluminium as structural surface

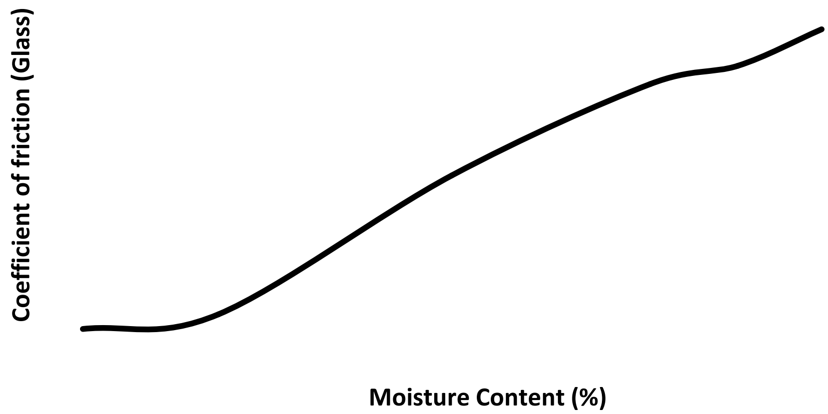

Figure 5: Relationship between moisture content and coeffiecient of friction of the seed with glass as structural surface.

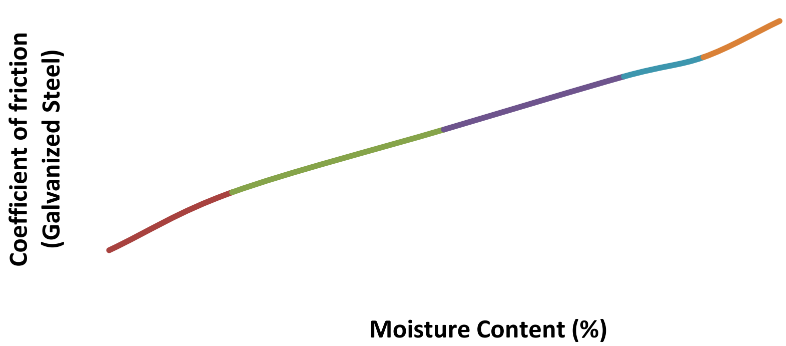

Figure 6: Relationship between moisture content and coeffiecient of friction of the seed with galvanized steel as structural material

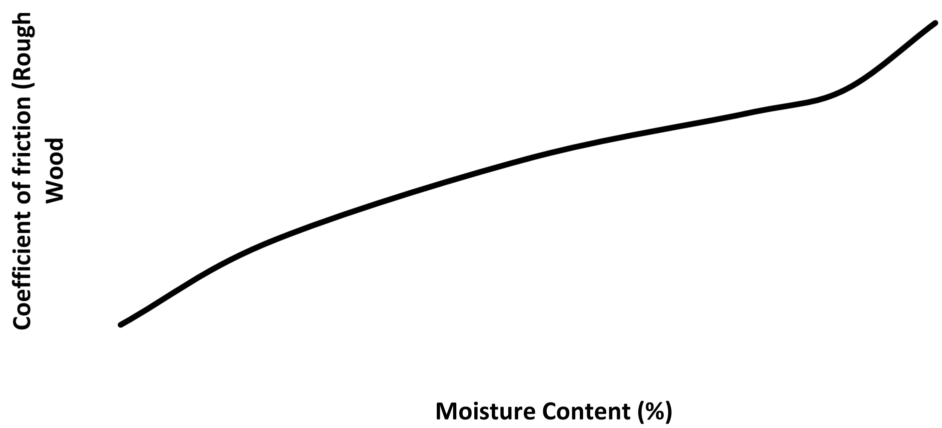

Figure 7: Relationship between moisture content and coeffiecient offriction of the seed with wood as structural surface

Mechanical Properties

The force required to crack the seed and deformation as relative to the various moisture levels and orientations were obtained as given in the table below.

Table 3: Mechanical properties of mucuna bean seed at moisture level range (4.79 to 18.53%) dry basis (major Orientation).

Moisture Content (%)	*Height(mm)*	*Force(N)*	*Deformation(mm)*
4.79	*30.22*	*1595.10*	*8.77*
7.31	*29.68*	*1380.50*	*7.44*
12.65	*29.03*	*938.00*	*6.47*
15.34	*28.59*	*576.90*	*2.84*
16.97	*27.88*	*364.40*	*0.50*
18.53	*27.22*	*244.90*	*0.05*

Table 4: Mechanical properties of mucuna bean seed at moisture level range (4.79 to 18.53%) dry basis (minor Orientation)

Moisture Content (%)	*Height (mm)*	*Force (N)*	*Deformation (mm)*
4.79	*19.69*	*1054.10*	*5.43*
7.31	*19.64*	*916.60*	*4.46*
12.65	*19.45*	*829.30*	*4.29*
15.34	*19.31*	*725.90*	*2.96*
16.97	*19.29*	*677.30*	*0.79*
18.53	*19.20*	*567.10*	*0.69*

Table 5: Table Analysis of variance on mechanical properties – major orientation

Source of Variation	SS	df	MS	F	P-value	F Crit
Between Groups	2780073	2	1390036.55	13.71	0.0004	6.36
Within Groups	1520961	15	101397.38			
Total	4301034	17				

Table 6: Analysis of variance on mechanical properties – minor orientation

Source of Variation	SS	df	MS	F	P-value	F crit.
Between Groups	2458065	2	1229032.47	119.96	5.93×10^{-10}	3.68
Within Groups	153682.40	15	10245.49			
Total	2611747	17				

The force required to crack the seed on the major and minor axes decreased as moisture content increased. The deformation on the major and minor axes increased with increasing moisture content (dry basis). At 18.53% moisture level (dry basis), more than fifty percent of the seeds loaded into the UTM were partially cracked. This was as a result of the near bone drying attained by the seed after twenty four hours of oven drying at 105^0c. This however revealed that when the moisture content of the seed exceeds 18.53% (dried over 24 hours in an oven), the seed will attain bone drying and greater percentage of its nutritional constituents will be lost. These findings were necessary considering the toughness of the pod of bean seed. A mathematical expressions relating the moisture level of the seed with force required to crack the seed on its major axis was obtained as below:

$$F = 2029 - 100.1m \ (R^2 = 0.998) \qquad - \quad - \qquad (8)$$

where: F = Force required to crack the seed (N) and
m = Moisture content

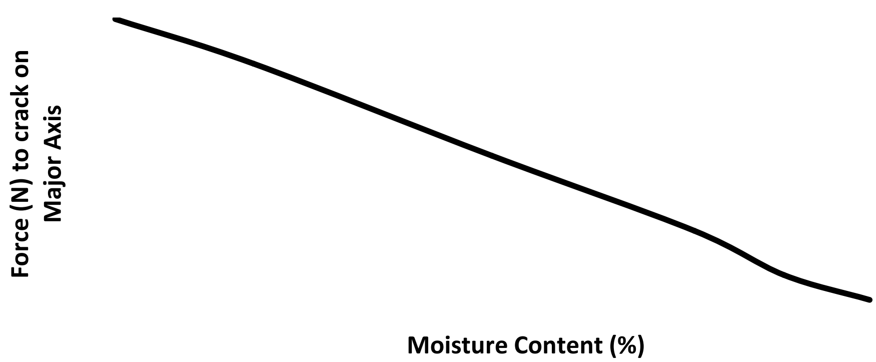

Fig. 8:Relationship between force to crack the seed on the major axis with moisture content.

These findings were in consonant with results obtained by Darvishi (2012),Ezeoha(2012) and Ahmadi *et al.* (2009) for white sesane, palm kernel and fennel seed respectively. For design purposes, the minor orientation will be preferred to guarantee efficient cracking of the seed. A mathematical expression linking the peak force on the minor axis with moisture content was developed as thus:

$F = 1185 - 31.38m \; (R^2 = 0.971)$ - - (9)

where: F = Force required to crack the seed on the minor axis and
m = Moisture content

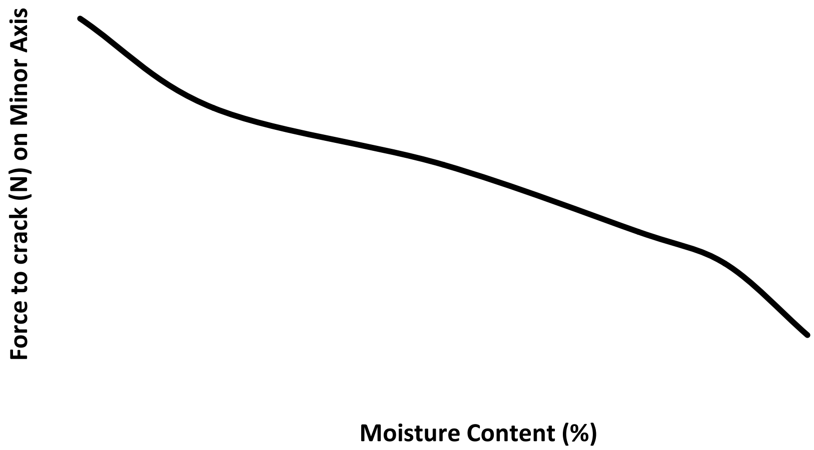

Figure 9: Relationship between force to crack the seed on the minor axis with moisture content

The cracking force recorded on the minor axis (567.1N) at moisture level 18.53% (dry basis) was greater than what was obtained on the major axis (244.9N). This clearly illustrated that, when the seeds are dried over a period of time, cracking tends to likely be more efficient on the major axis than the minor axis. Similar trends were reported by Bamboye and Adejumo (2001), Sadiku and Bamboye (2014) and Akintunde *et al.* (2007) for roselle, locust bean and melon seed respectively.

Deformation on the major axis

As moisture level of the seed increased, deformation of the seed due to cracking on its major axis decreased. The value ranged from 0.054 to 8.774mm at the different moisture levels. A mathematical expression relating the pair was developed as thus:

$D = 12.5 - 0.655m \; (R^2 = 0.942)$ - - (10)

where: D = Deformation (mm) and
m = Moisture content

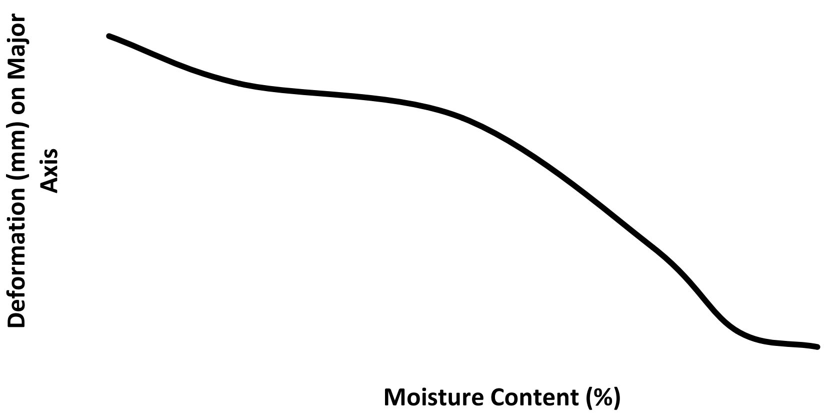

Figure 9: Relationship between deformation on the major axis with moisture content

Deformation on the minor axis

The deformation of the seed on its minor axis decreased with increasingmoisture content. The values ranged from 0.694 to 5.426 at the various moisture levels. The values were not in line with what was obtained for the major axis of the seed. A mathematical expression was developed for the two variables and given as below:

$d = 7.295 - 0.337m$ (R^2 = 0.878) - - - (10)

where d=Deformation on minor axis and

m = Moisture content

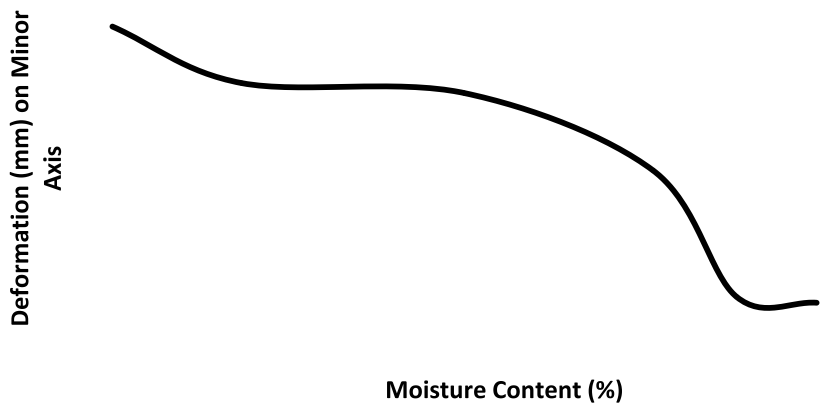

Figure 10: Relationship between deformation on the minor axis with moisture content

At the various moisture levels, an increase of 81% was recorded as against the 160% obtained for the major orientation. Similar analysis was reported by Afzalinia and Roberge (2007) for some selected forage materials.

Relationship between Force and Deformation

The relationship between force and deformation on both the major and minor axes of the seed was determined. A positive correlation was obtained between force required to break the seed and deformation on the major axis. A mathematical model linking the two variables was established as below:

$F = 238.1 + 143.2d$ ($R^2 = 0.953$) - - (11)

where F = Force required to crack the seed on the major axis

d = deformation (mm)

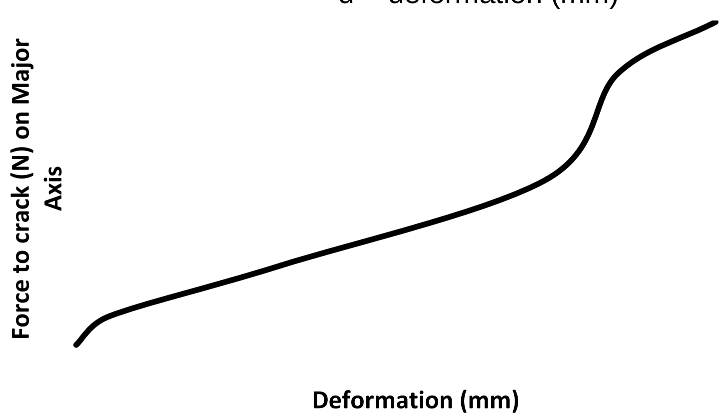

Figure 11: Relationship between force to crack the seed on the major axis with deformation.

The deformation of the seed upon cracking on its minor axis increased with cracking force. A mathematical expression was developed for the variables as given below:

$$F = 538.2 + 82.7d \; (R^2 = 0.881) \qquad - \quad - \quad - \qquad (12)$$

where F = Force required to crack the seed on its minor axis
d = deformation on the minor axis

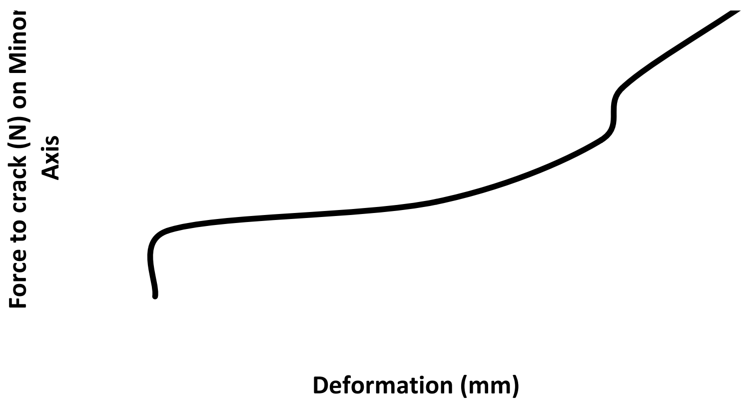

Figure 12: Relationship between force to crack the seed on the minor axis with deformation.

ıe coefficient of determination (R^2) on the major axis (0.953) was higher than that on the minor ‹is (0.881). This showed that the relationship between the cracking force and deformation on the ajor axis was of more positively correlation than that of the minor axis. The stress on the major ıd minor axes of the seed on cracking increases with increasing moisture content. The Energy to ack on the major and minor axes of the seed upon cracking decreased as moisture content creased.

ıble 8: Stress and Energy to crack the seed on both axes

Moisture Content (%)	Stress (N/mm^2) Major Axis	Stress (N/mm^2) Minor Axis	Energy to Crack (N.m) Major Axis	Energy to Crack (N.m) Minor Axis
4.79	2.79	5.12	3.60	2.02
7.31	4.66	8.05	2.58	1.90
12.65	8.99	10.91	2.09	1.63
15.34	12.78	13.74	1.54	1.12
16.97	17.33	16.29	1.06	0.79
18.53	21.60	21.01	0.63	0.47

CONCLUSION

The study was aimed at evaluating the effect of moisture content on some mechanical and frictional properties of mucuna bean seed relevant to the development of its cracking machine. The properties were determined at moisture levels of 4.79 to 18.53% (dry basis). The coefficient of friction of the seed on various structural surfaces namely: plywood, alumunium, glass, galvanized steel and rough wood were determined. The mechanical properties of the seed measured were: drop height, cracking force, deformation, stress and energy to crack on the major and minor axes of the seed. The study revealed that the coefficient of friction of the seed on the different structural surfaces increased with increasing moisture level. The force required to crack the seed on the major axis decreased with increasing moisture level.

The deformation was observed to decrease with increasing moisture level. Tests done with use of a Universal Testing Machine (UTM) revealed that the cracking force and deformation on the major axis of the seed declined as moisture level increased. These findings were in consonance with what was obtained by Bamgboye and Adejumo (2011) for roselle seed. The stress on the major and minor axes, increased with increasing moisture content, while energy to crack the seed, decreased as moisture level increased. The study also illustrated that the design of machines for the processing of the seed is a function of moisture content, given variations obtained in values for properties tested. Processing machines should be developed for the seed based on the engineering properties obtained from the study for a variety of purposes.

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