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The Effects of Moisture Content on the Frictional Properties Of Dika Nut

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ABSTRACT: *The effects of moisture contents on the frictional properties of Dika-nut seeds were investigated at the range of 8.25, 10.14, 13.57, 14.89 and 18.98 % moisture content (dry basis). The moisture dependant handling (dimensions, Sphericity, bulk and true densities, porosity) and flow or frictional properties (angle of repose, angle of internal friction and friction coefficients) were investigated for Dika-nut (Iirvingia Gabonensis) seeds. The equivalent seeds diameter and the Sphericity increased from 32.18mm to 37.56mm and 0.75mm to 0.89mm respectively with increase in moisture contents from 8.25% to l8.98%. The equivalent porosity however decreased from 66.30 to 34.2%, while the angle of repose increased from 22^o to 34^o.Coefficient of static, internal and external frictions increased with moisture content from the range of (0.44 to 0.68), (0.52 to 0.90) and (0.63 to 0.98) respectively. The bulk and true densities decreased with increase in moisture content from (1740kg/rn^3 to 1085 kg/rn^3) and (1071.75kg/rn^3 to 828.0kg/rn^3) respectively. The coefficient of determination, R^2 obtained for the various parameters considered showed a close correlation with increase in moisture content. The results of this study are recommended for use by designers to qualitatively design effective and efficient machines for cracking, processing, handling, and storage of Dika-nut seeds.*

Keywords: *Effects, Moisture content, Frictional properties, Dika Nut seeds.*

I. INTRODUCTION

Dika-nut (*Irvingia Gabonesis*) which is locally called Odika, Manguier, Sauvage or Ogbono is very valuable for its yellow edible mango-like fruit. It is a dicotyledonous plant of the Irvingiaceae and generally found in the moist dense forest of the tropics. Though mainly found wild, it is of high economic importance, Okafor, (1973), hence, its plantations are springing up in many communities. The tree is good for paper manufacture FAO, (1988) and it furnishes termite resistant timers.

The tree grows naturally in the humid, low land forests of tropical Africa, but it is widely planted in central Africa and Western Africa. It is indigenous to the humid forest zone of the gulf of Guinea from western Nigeria east to the central Africa Republic and South to Cabinda (Angola) and the Western most part of DR. Congo and Sao Tome and Principe. The tree is large with drupe of 5-6 cm long. The pulp is eaten while the seed may be ground cooked to make dika bread. Also, it a source of edible oil; dika butter, formerly considered as a substitute for cocoa butter. Its seed oil is used for making soap, Peters et al., 1992.

The kernel constitute an important part of the rural diet in west Africa for controlling dietary lipids and weight gain because it contains about 8.9% protein, l9.7% carbohydrate, 62.8% lipids, 5.3% dietary fiber, and 3.2% ash by weight. Ejofor, (1994), Osagie and Odutuga, (1986).

The frictional properties such as co-efficient of friction and angle of repose are important in designing of storage bins, hoppers, chutes, pneumatic conveyor systems, screw conveyors etc. The rolling resistance or maximum angle of stability in rolling of round shape agricultural materials is useful in designing handling equipment, such as conveying of fruits and vegetables by gravity flow.

To design equipment for the handling, separation, conveying, drying, storing, aeration and processing of Dika nut seeds, determining the physical properties as a function of moisture content is essential. The size and shape of Dika nut seeds are important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery. Mohsenin, (1986); Sahay and Singh, (1994).

The Objectives of study are to evaluate some physical properties of Dika-nut seeds as they are affected by variation in moisture content.

II. MATERIALS AND METHOD

In this section, different equations from different researchers were used in estimating different physical properties of Duka Nut seeds as follows:

2.1 Samples preparation

The Dika-nut seeds used for the study were purchased from the open Jattu market of Etsako West Local Government of Edo state of Nigeria They were cleaned manually to remove all foreign materials. The initial moisture contents of the seeds were determined using ASAE 1998 standard. The initial moisture content of the seeds was found to be 1.68% dry basis. All the weight in this study was determined using a sensitive electronic balance of 0.00lg sensitivity.

The 796.34g of the sample was divided into 5 parts of 170.37g, 140.23g 187.07g, 186.12g and 112.55g. The desired moisture contents were obtained by adding distilled water calculated from equation (1).

$$Q = A(b - a)/(100 - b) \quad (1)$$

(Akinoso, *et al*., 2006)

Where,
A= Initial mass of the sample
a= Initial moisture content of the sample, % dry basis (d.b)
b= Final (desired) moisture content of sample % (d.b)
Q= Mass of distilled water to be added in g.
The samples were then transferred to separate high density polyethylene bags and sealed tightly and labeled. The samples were kept at 5°C in a refrigerator for a week to enable the moisture to be distributed uniformly throughout each sample. This rewetting technique to attain the desired moisture content in seeds and grains has frequently been used (Coskun,
et al., (2005), Garnayak, *et al*., (2008); Sacilink, *et al*., (2003). Five moisture content levels were prepared for the samples and they were 8.25%, 10.14%, 13.57%, 14.98% and 18.98% on dry basis with an average of five replications each. The quantity of distilled water added to obtain the required moisture content is presented in Table 1.

Table 1: The amount of distilled water (g) added to the Dika-nut seeds to obtain the desired moisture content

Moisture content (%) dry basis	Quantity of water added to the seeds (g)
8.25	**12.20**
10.14	**13.20**
13.57	**23.81**
14.89	**28.90**
18.98	**24.00**

Source: Experimental data, (2012)

Before starting the test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to the room temperature for about 2 hours. All the physical properties of the seeds were assessed at moisture levels of 8.25%, 10.14%, 13.57%, 14.89% and 17.89% (d.b.). Five (5) replications each from each sample. 20 Dika nut seeds were randomly selected and their orthogonal lengths were measured using a digital caliper with an accuracy of 0.01mm and used to calculate the equivalent seed diameter, d_e using the relationship in equation (2).

$$d_e = \frac{F_1 + F_2 + F_3}{3} \quad (2)$$

(Ciro,1997)

Where,

F_1 = Arithmetic mean diameter = $\frac{L_1 + L_2 + L_3}{3}$ (3)

F_2 = Geometric mean diameter = $(L_1 + L_2 + L_3)^{1/3}$ (4)

F_3 = Square mean diameter = $\left(\frac{L_1L_2 + L_{2}L_3 + L_{3}L_1}{3}\right)^{1/2}$ (5)

L_1, L_2 and L_3 = the three orthogonal lengths of the seeds measured with a digital Vernier Caliper with an accuracy of 0.01mm.
The sphericity (F) of the seeds was estimated using equation (5)

$$\emptyset = \frac{F_2}{L_2} = \frac{Geometrical\ \ mean\ \ diameter}{major\ \ diameter} \quad (6)$$

(Singh, *et al*., 2010)

2.2 Bulk Density

The bulk density (ρ_b) was determined by filling a 500m1 beaker with seeds (v) dropped from a height of I 50mm to produce a tapping effect in the container reproducing the setting effect during storage and weighing the seed (w) as performed by kaleemullah (1992). It was calculated from:

$$\rho_b = \frac{W}{V} \qquad (7)$$

2.3 True Density

The true density (Q_t) was determined by the water displacement method (Amin, *et al*., 2004). 300 ml of water was placed in a l000ml graduated measuring cylinder and 42.87g seeds were immersed in that water. The recorded immersion 'time was about 10s which was too small to absorb water. The amount of displaced water (V_t) was recorded from the graduated scale of the cylinder. The ratio of weight of seeds (W_i) to the volume of displaced water gave the kernel density as shown in Eqn.8.

$$\rho_t = \frac{W_i}{V_t} \qquad (8)$$

2.4 Porosity (ϵ)

Porosity (ϵ) was determined in terms of bulk density (ρ_b) and true kernel density (ρ_t) by using the formula in Egn.9.

$$\epsilon = (\frac{1 - l_b}{l_t} \times 100) \qquad (9)$$

(Mohsenin, 1986)

2.5 Angle of Repose (Θ_r)

The angle of repose (Θ_r) was determined by using a flat tilting drafting wooden table as described by Sahay and Singh (1994). Sample of the seeds were dropped on the tilted table and the table top was tilted till the seed start moving over the inclined surface. The angle of inclination was now measured as the angle of repose of the seeds.

2.6 Coefficient of Static Friction (μ_s)

The Coefficient of static friction (μ_S) was obtained with respect to galvanized iron commonly used for the construction of hopers, storage and drying bins using the inclined plane apparatus constructed for this study (Figure 1), as described by Dutta, *et al.*, (1988).

Fig. 1: Experimental Frictional box developed for this study

The Table was gently raised and the angle of inclination to the horizontal at which the sample started sliding was read off the protractor attached to the apparatus. The tangent of the angle was reported as coefficient of static friction as given in (Eqn. 10)

$$\mu_2 = \text{Tan}^{-1} Ø_s \qquad (10)$$

Where $Ø_s$ = angel at which sample started sliding. Adjustable tilting table method has been used for other grains and seeds by previous researchers to obtain static co-efficient of friction, Omobuwajo, et al.,(200b), Mijinyawa and Falayi (2000) and Molenda, *et al*., (2000).

Coefficient (μ_1) and angle of internal friction ($\emptyset_1$) were determined using the method developed by Irtwange and Igbeka, (2002).
Dimensions of the guide frame = 20 X 30 X 9mm, of cell= 30 x 30 x 11mm, of the surface = 40 x 30 x 14mm. The coefficient of internal friction, μ_i was estimated using the arrangement in Fig 1 and calculated using equation (11).

$$\mu_i = \frac{W_2 - W_1}{W_a} \qquad (11)$$

Where,

μ_i = coefficient of internal friction,
W_1 = weight to cause sliding of the cell when empty (g),
W_2 = weight to cause sliding of the cell filled with seeds (g),
W_a, = weight of the seed in the cell = volume of cell (mm) x bulk density (g/mm^3)

The angle of internal friction was calculated as shown in equation 12.

$$\emptyset_i = T \qquad (12)$$

2.7 Coefficient of External Friction (μ_e)

For the coefficient of external friction (μ_e) between the seeds and the galvanized metal sheet, use was made of the method by Stepanoff (1969) and Irtwange and Igbeka (2002a). The calculation equation is given by equation13.

$$\mu_e = \frac{W_2 - W_1}{W_a} \qquad (13)$$

Where,

μ_e = coefficient of external friction
W_1 = weight to cause sliding of cell when empty (g)
W_2 = weight to cause sliding of the cell filled with seeds (g)
W_a = weight due to the material in the cell (g) =
Volume of cell (mm^3) x bulk density (kg/mm^3).

The coefficient of friction between the chord and pulley was assumed to be 0.5 (Sethi, *et al*.,1992). Regression equations were developed using Microsoft excel to relate interaction between moisture content and the investigated physical properties of Dika nut seeds.

III. RESULTS AND DISCUSIONS

The amount of distilled water (g) added to the Dika-nut seeds to obtain the required moisture content is shown in Table 1. The effects of moisture content variation on the frictional (flow) and handling properties of Dika nut seed were carried out in this study. It was observed that most of the parameters were affected by increased moisture content.
Regression models with R^2 were developed for each parameter using a spreadsheet software program, Microsoft Excel (2007).

3.1 Orthogonal Dimensions and equivalent Diameter, d_e.

The orthogonal dimensions and the equivalent seed diameter of Dika nut seed increased with an increase in moisture content as shown in **Fig 2.**

$d_e = 46.6x+29.269 \qquad R^2 = 0.898 \qquad (14)$

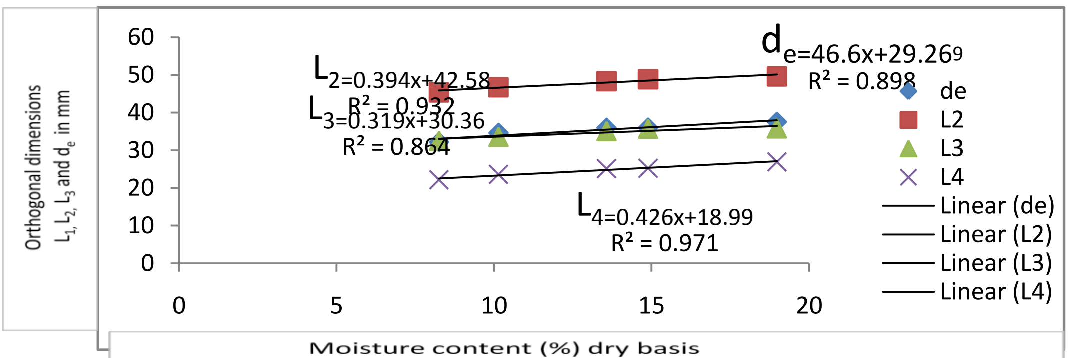

Fig.2: Effect of moisture content on seed equivalent diameter(d_e), major diameter(L_1), intermediate diameter(L_2) and minor diameter(L_3)

The increases in L1, L2, L3 and Le with increase in moisture from 8.25% dry basis to 10.14%dry basis were 34.62, 46.72, 33.60 and 23.56% respectively. These values also increased as the moisture contents were increased through 18.98% dry basis. Karimi *et al.*,(2009) and Sadeghi *et al.*, (2010) found similar trends for wheat, rice and rough rice respectively. Such dimensional changes are important in determining aperture size in the design of handling and processing equipment.

3.2 Bulk Density, True Density and Porosity

The Bulk Density decreased from 1740 to 1258kg/m3

While the true (seed) density decreased from 1071.75kg/m^3 to 828kg/m^3 as moisture content increased from 8.25 to 18.98% (dry basis). A similar decreasing trend in bulk density has been reported by Dursun and Dursun (2005) for caper, Abalone et al. ,(2004) for Amaranth, Kiani et al., (2008) for red bean seed. The bulk density of seed was found to bear the following relationship with moisture content:

$\rho_b = 3.344x^2 - 115.4x + 2276 \quad (R^2 = 0.175)$ (15)

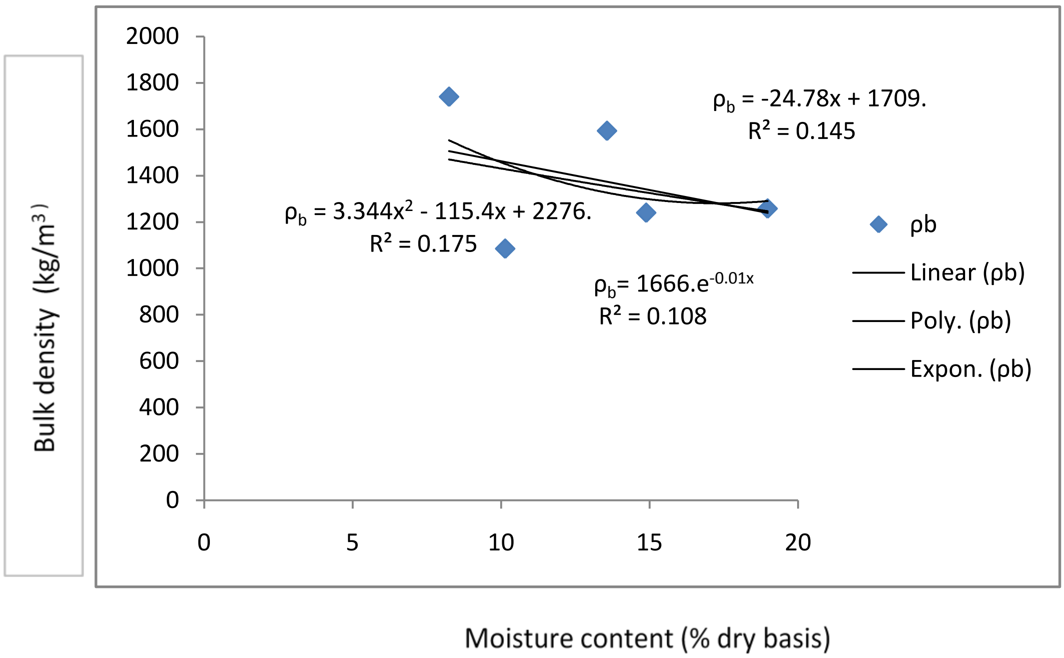

Fig. 3: Effect of moisture content on bulk density of Dika nut seeds.

This decreasing relation is due to the fact that an increasing in mass owing to moisture gain in the grain sample was lower than the accompanying volumetric expansion of the bulk (Tabatabaeefar, 2003). The negative relationship of bulk density with moisture content was also observed by various other research works (Carman, 1996; Duttas *et al.*, 1988; Gupta and Prakash, 1990; Shepherd and Bhardwaj, 1986).

The true density decreased with an increase in moisture content. This decrease in true density of unshelled seed may be as a result of the hardness of the shell which does not permit as much moisture migration into the embeded seed. This same effect was observed in lentil seed and squash seeds by Amin *et al.*, (2004) and Paksoy and Aydin, (2004).

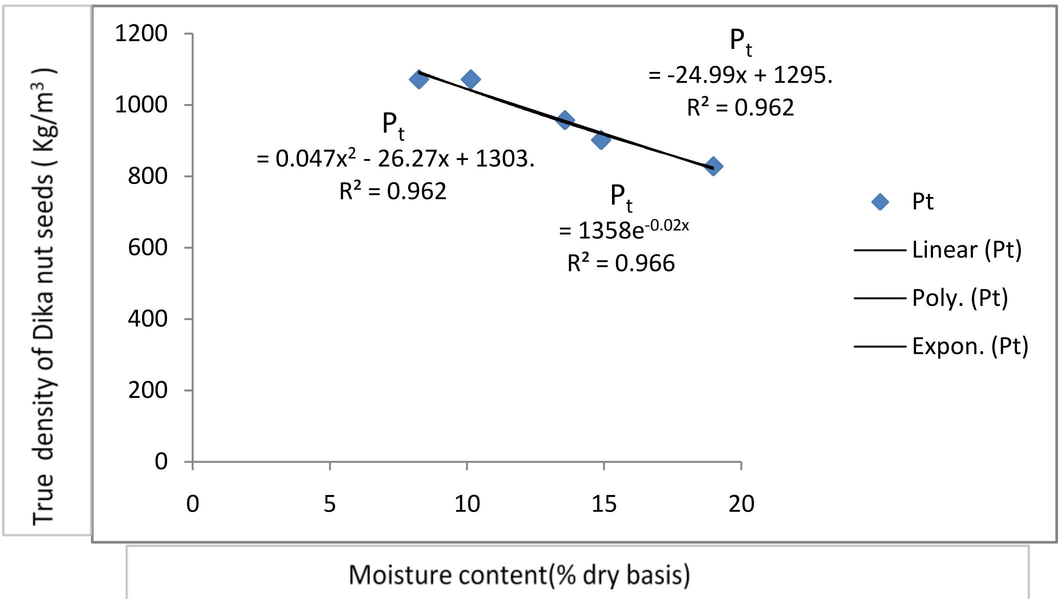

Fig. 4: The effect of moisture content on True density of Dika nit seeds.

The true density varied from 1071.75 to 901.80kg/m^3 when the moisture level increased from 8.25 to 18.98% (dry basis) Figure. 4 The true density and the moisture content of seed can be correlated as follows

$P_t = 0.047x^2 - 26.27x + 1303$ $\qquad R^2 = 0.962$ $\qquad$ (16)

Singh and Goswami (1996), Gupta and Das (1997) and Yalçın and Özarslan (2004) reported similar trends in the case of cumin, sunflower and vetch, respectively. Since the porosity depends on the bulk and true densities, the magnitude of variation in porosity depends on these densities only.

The porosity (*Pt*) calculated from experimental data decreased from 66.30 to 34.2 %. This decrease in porosity with increase in moisture content was also observed for other grains, for example for pumpkin seed and pigeon pea as reported by Joshi *et al*. (1993) and Shepherd and Bhardwaj (1991).The porosity decreases because an increase in moisture content results in a more significant increase/swelling of the linear dimensions, thus reducing the airspaces and giving a more compact arrangement of seeds, invariably reducing the porosity of the grain bulk. The R^2 was found to be 0.920, 0.920 and 0.939 for linear, exponential and polynomial respectively Figure 5.

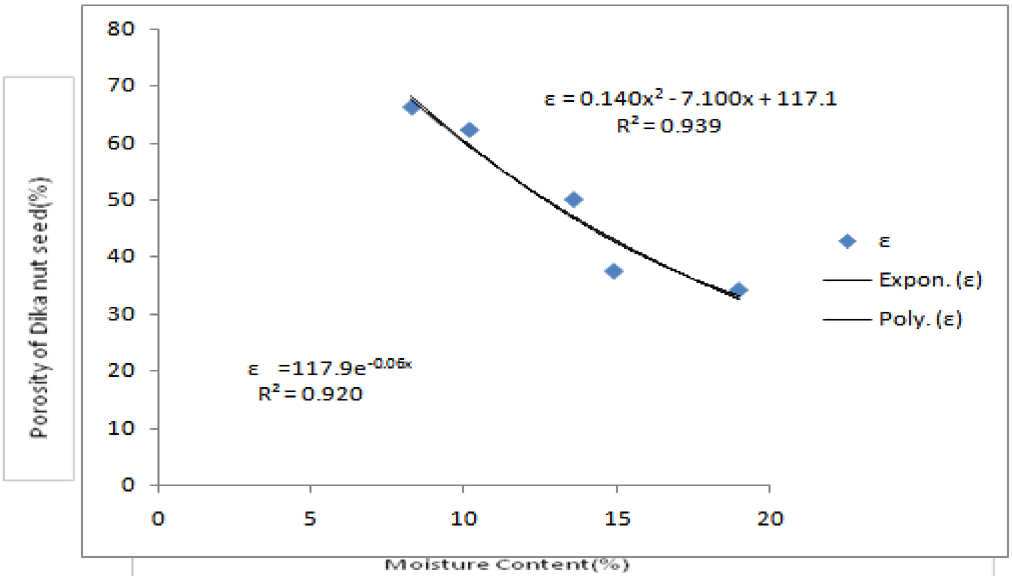

Fig.5: Effect of moisture content on porosity of Dika nut seeds

The porosity and the moisture content of seed can thus be correlated as follows

$\varepsilon = 0.140x^2 - 7.100x + 117.1$ $R^2 = 0.939$ (17)

The sphericity of Dika nut seed increased from 0.75 to 0.89 with the increase in moisture content (Figure 5). The relationship between sphericity and moisture content Mc in % d.b. can be represented by the equation

$\phi = -9E\text{-}05x^2 + 0.015x + 0.636$ $R^2 = 0.964$ (18)

Similar trends have been reported by Altunta *et al*., (2005) for Fenugreek seed, Baümler *et al*., (2006) for safflower and Solomon and Zewdu (2009) for Niger seed.

Angle of repose (Θ_r) of Dika nut seeds increased from 22.0^0 to 34.0^0 as the moisture content increased from 8.25% to 18.98% dry basis. This may be due to the fact that an increase in moisture content increased the cohesion between the seeds, thus increasing the friction the seed experiences during its flow/movement. Similar trend has been reported by Nimkar and Chattopadhyay, (2001) for green gram; Amin *et al*., (2004) for Lentil seeds and Kingsley *et al*., (2006) for dried pomegranate seeds.

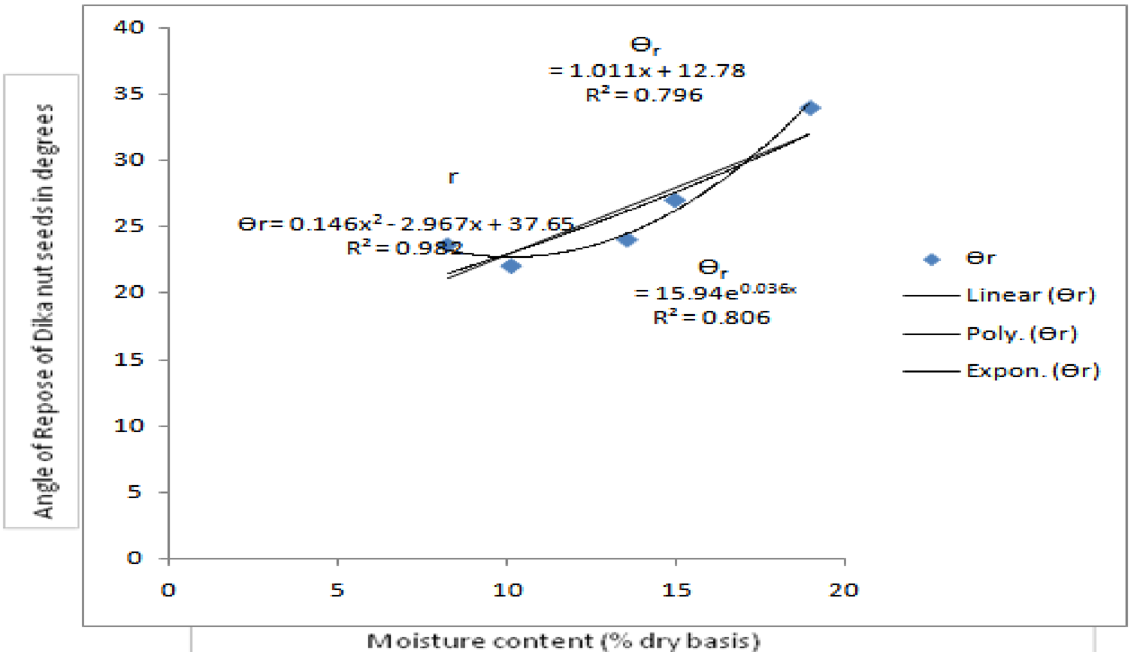

Fig.6: The effect of moisture content on angle of repose of Dika nut seeds

The angle of repose of the Dika nut seeds and the moisture content of seed can be correlated as follows:
$\Theta_r = 0.146x^2 - 2.967x + 37.65$ $R^2 = 0.982$ (19)

3.3 Coefficient of static, internal and external friction

These coefficients were found to increase with increase in moisture content; coefficient of static friction from 0.44 to 0.68; coefficient of internal friction from 0.52 to 0.90 and coefficient of external friction from 0.63 to 0.98.

The result showed that coefficient of external friction was higher than that of internal friction which in turn is higher than the static friction. Several researchers had found the same trend, Nimkar and Chattopadhyay, (2001); Gezer *et al.*, (2002); Isik,(2007); Seifi and Alamardani, (2010). From figure 7, it is observed that the coefficient of external friction had R^2 highest for using logarithmic regression model followed by coefficient static and internal in that order. The models are represented in equations 20, 21 and 22 respectively.

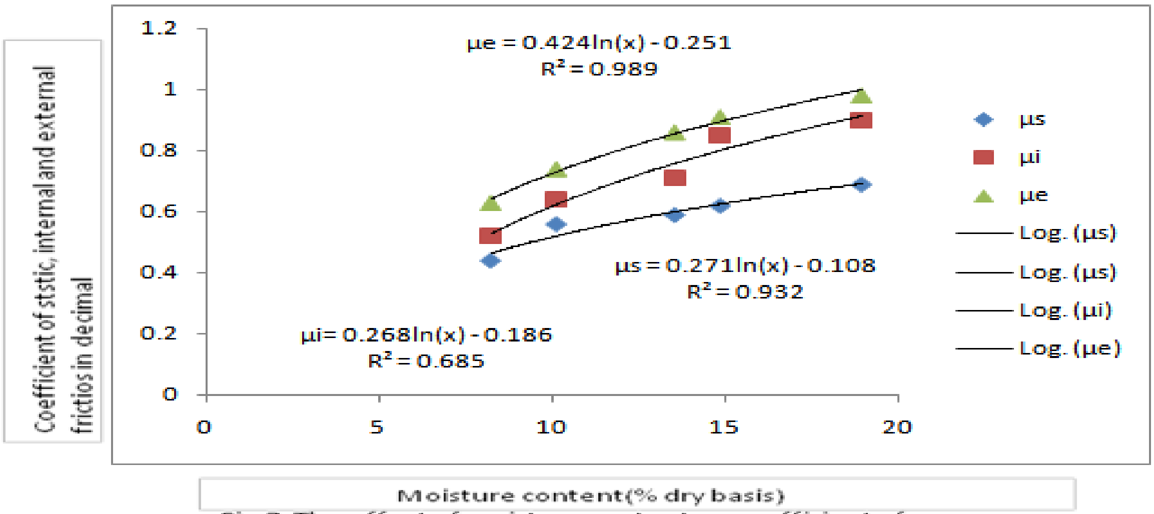

Fig.7: The effect of moisture content on coefficient of static, internal and externalfriction on Dika nut seeds

$\mu_e = 0.424\ln(x) - 0.251$ $R^2 = 0.989$ (20)

$\mu_s = 0.271\ln(x) - 0.108$ $R^2 = 0.932$ (21)
$\mu_i = 0.268\ln(x) - 0.186$ $R^2 = 0.685$ (22)

The increase in static friction with increase in moisture content (Altuntas and Dermirtola, (2007) may be due to increase adhesion between the seeds and the surface at higher moisture levels.

IV. CONCLUSION

The conclusions of this study can be summarized as follows:
1) The average equivalent diameter (major, intermediate and minor seed diameters), angle of repose, the coefficients of static, internal and external frictions also increased as the moisture content increased while there was a decrease in bulk and true desities , porosity and sphericity as the moisture content increased from 8.25 to 18.98% dry basis
2) The physical properties of Dika nut seeds were expressed by the regression equations as a function of moisture content.
These properties would provide important and essential data for efficient process and equipment design.

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