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MOISTURE DEPENDENCE OFPHYSICAL PROPERTIES AND SPECIFIC HEAT CAPACITY OF NEEM (*Azadirachta Indica A. Juss)* KERNELS

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Abstract
This study investigated the effect of moisture content on the physical properties and specific heat capacity of Neem *(Azadirachta Indica A. Juss*) nut kernels. The major, intermediate and minor axial dimensions of the kernels increased from 1.04 to 1.23cm, 0.42 to 0.6cm, and 0.32 to 0.45cm respectively, as the moisture content increased from 5.2 to 44.9 % (db). The arithmetic and geometric mean diameters determined at the same moisture level were significantly different from each other, with the arithmetic mean diameter being higher. In the above moisture range, one thousand kernel weight, true density, porosity, sphericity, roundness and surface area all increased linearly from 0.0987 to 0.1755kg, 632 to 733kgm^{-3}, 6.42 to 32.14%, 41.3 to 47.5%, 22 to 36% and 13 to 24cm^2 respectively, while bulk density decreased from 591.4 to 497.4kgm^{-3} with increase in moisture content. Angle of repose increased from 21.22 to 29.8^o with increase in moisture content. The Static coefficient of friction on ply wood with grains parallel to the direction of movement ranged from 0.41 to 0.61, it ranged from 0.19 to 0.24 on on fiber glass, 0.28 to .038 on hessian bag material and 0.25 to 0.33 on galvanized steel sheet. The specific heat of the seed varied from 2738.1-4345.4J/kg/^{o}C in the above moisture range.

Key words: Neem seeds, physical properties, specific heat, Semi-arid region.

1. Introduction

Neem (*Azadirachta indica A. Juss*) tree is a member of the mahogany family Meliaceae and is native to tropical south East Asia (Okonkwo, 2004). Most of the plant's parts such as fruits, seeds, oil, leaves, bark, and roots contain compounds with proven antiseptic, antiviral, antipyretic, anti- inflammatory, antiulcer, and antifungal property. It has great potentials in the fields of pest management, environment protection, and medicine. It is also a natural source of eco-friendly insecticides, pesticides and agrochemicals (Brahmachari, 2004).
Moisture content has a decided influence on the physical and thermal properties of agricultural products. According to Mohsenin (1986), water affects safety, stability, quality and physical properties of food. Addition of moisture affects the adhesion and cohesions properties of agricultural material.

Several authors have worked on the physical properties of agricultural materials. These include Alonge and Adigun (1999) on sorghum, Olaoye (2000) on castor nut; Mijinyawa and Omoikhoje (2005) on palm kernel and Gupta and Das (1997) on sunflower. Paksoy and Aydin (2006) described the size of agricultural materials by measuring three principal dimensions (major, intermediate and minor diameters) using a vernier caliper. Davies and Zibokere (2011) studied the size of three varieties of cowpea (Vigna unguiculata (L) walp), namely Ife Brown, IT86D-1010 and IAR-339-1 at four different moisture contents (15%, 20%, 25% and 30% dry basis). A decreasing trend in bulk density has been reported by Altunas and Demirtola (2007) for some legume seeds and Garnayak *et al.* (2008) for Jatropha grain. A negative linear relationship between bulk density and moisture content was observed by Aydin (2003) and Gupta and Das (1997) for neem nut and sun flower seed respectively. Also, the bulk density decreased slightly with increase of moisture content of other sunflower seed varieties studied by Khazaei *et al.*, (2006). The bulk density of sun flower seeds decreased slightly with increase in moisture content from 269.06-275.57kgm$^{-3.}$ (Jafari *et al.,* 2011). The bulk density of cowpea varieties decreased linearly with increase in moisture contents levels. Values showed that bulk densities decreased from 689.29 to 622.12kg/m^3 and 726.91 to 672.05kg/m^3 for IAR-339-1, IT86D-1010 and Ife beans respectively (Davies and Zibokere 2011).

True density has been determined by some researchers (Joshi *et al.,* 1993; Nelson 1980; Suthar and Das, 1996) using the gas displacement method, while others (Aviara *et al*., 1999, Oje, 1994, Shepherd and Bhardwaj, 1986) employed the water displacement method. True density of three varieties of cowpea decreased with increase in moisture contents from 1010.83 to 979.59kg/m^3, 1054.88 to 1014.54kg/m^3 and 1083.12 to 1037.53kg/m^3 for 339-1. IT86D-1010 and Ife brown respectively (Davies and Zibokere 2011). A negative correlation between true density and moisture content of beniseed was reported by Tunde and Akintunde (2007). Esref and Halil (2007) and Dursun *et al.* (2007) found the true density to have decreased with increase in moisture content for bambara ground nuts, red kidney bean and sugar beet respectively. These seeds thus have lower weight increase in comparison to volume increase as their moisture content increases (Plange *et al.,* 2012). Porosity increased linearly from 30.86 to 40.05% for kernel and 43.19 to 51.02% for cashew nut with increase in moisture content from 5.0% to 9.0% wet basis (Plange *et al*., 2012). However a reverse relationship has found for Okra seed (Sahoo and Srivastava, 2002). An increase in porosity with moisture content was reported for green gram (Nimkar and Chattopadhyay, 2001), chickpea seeds (Komak *et al.*, 2002), faba bean grains (Yalcin and Ozarslan, 2004) and Karajan kernel (Pradhan *et al.*, 2008).

The one thousand seed mass increased from 316.8-326.7g for shelled moringa seeds and 318.0-329.3g for unshelled moringa seeds with an increase in moisture content from 6.8%-15% wet basis (Adejumo and Abayomi, 2012). Also Aviara *et al.* (2005) had reported the 1000 nut mass of balanites aegyptiaca to have increased from 2.39 to 3.33kg for oblong nuts as moisture content increased from 4.72-26.35% (dry basis) and from 2.66 to 3.11kg for the spheriodal variety as moisture content increased from 4.71 - 24.18% dry basis. Singh *et al.* (1996) determined the 1000 seeds weight of cumin seed and reported that it increased linearly from 4.13 to 4.8g, when moisture content changed from 7-22 % dry basis.

The sphericity of IAR-339-1 variety of cowpea decreased from 0.778 to 0.741 between 15 % and 20% moisture content, but latter increased to 0.759 at 30% moisture content. That of IT86D-1010 decreased linearly from 0.749 - 0.723 in the moisture range of 15 - 20%, and subsequently increased at 30% moisture content. For Ife brown the sphericity increased from 0.734 to 0.795 in the moisture range of 15 and 20%, and later decreased to 0.665 at 30% moisture content dry basis (Davies and Zibokere 2011). Garnayak *et al*. (2008) and Pardhan *et al*. (2008) reported similar trends in the sphericity of jatropha seed and karanja kernel.

A specially constructed box with removable front panel was used by Singh and Goswami (1996) to determine the angle of repose of cumin seed. Results showed that the angle of repose increased linearly from 36.5 - 51.3^o with increase in moisture content from 7-22% dry basis. Aviara *et al*. (1999) using a similar method also studied the angle of repose of guna seed and observed that the angle of repose increased from 28.07 - 43.58^o as the moisture content increased from 4.7 - 39.3%.

Singh and Goswani (1999) using the differential scanning calorimeter measured the specific heat of cumin seed and found that it increased from 1330-3690J/kJK with increase in moisture content from 1.8% to 25% dry basis. Little information however appears to exist on the relationships existing between physical properties and specific heat of neem nut kernel and its moisture content. The objective of this study was to determine some physical properties and specific heat capacity of the neem kernels relevant to the design and manufacture of agricultural processing machines and investigate their relationship with moisture content.

2. Materials and methods

2.1 Study area and sample preparation

The Neem (*Azadirachta indica A. juss*) kernels used for this study were obtained from University of Maiduguri campus, Maiduguri, Nigeria. Matured and ripped fallen fruits were collected from different trees. The fruits were de-pulped manually and then exposed to the sunshine in a thin layer to dry out for a few days. The white hard shells were then decorticated using a stone by breaking them gently. The loose shells were removed by winnowing to get the kernels. Some samples were collected and used for initial moisture content determination. This was carried out by oven drying at 105 degree for 24 h. The drying condition was decided based on preliminary studies and in reference to ASAE standard S352.3 9 (ASAE, 1994). Different samples at three moisture levels of the desired moisture content were prepared by soaking the kernels in water and each moisture group was collected after 30 min, 1 h, 30 min and 2 h, 30 min respectively. This was followed by spreading out in thin layer to dry in natural air for five hours. The samples were then poured in to separate polyethylene bags and the bags sealed tightly and stored in a refrigerator. Before starting a test, the required quantity of the seed was taken out of the refrigerator and allowed to equilibrate at room temperature for about 2 h (Singh and Goswami, 1996; Coskun *et al.*, 2006).

2.2 Determination of Physical Properties

The physical properties determined in this study at different moisture contents were size, shape, surface area, 1000 kernel mass, true and bulk densities, porosity, angle of repose and static coefficient of friction.

The moisture content of Neem (*Azadirachta indica A. Juss)* seed kernels was determined using the method of Aviara *et a*l. (1999). Samples soaked in water for different time duration were oven dried at 105°C for 24 h. The moisture content was calculated from the relation used by Aviara *et al.* (2005b) given in Equation (1).

$$M_{wb} = \frac{W_i - W_f}{W_i} 100 \qquad (1)$$

where: M_{wb}= %, wet basis moisture content, W_i= initial weight (g), W_f= final weight (g).

The resultant moisture content from Equation (1) was converted to dry basis moisture content by using Equation (2).

$$M_{db} = \left[\left(\frac{M_{wb}}{1 - M_{wb}}\right)\right] \qquad (2)$$

where: $M_{d.b}$= dry moisture content

A vernier caliper was used to measure the axial dimensions (length, width and thickness) of the 100 randomly selected kernels, at each of the moisture contents. The average diameter of kernels was calculated by using the arithmetic mean (A) and geometric mean (G) of the axial dimensions. The arithmetic mean diameter and geometric mean diameter of the kernels were calculated by using Equations (3) and (4) respectively (Mohsenin 1970)

$$A = \frac{L+W+T}{3} \quad (3)$$

$$G = (LWT)^{\frac{1}{3}} \quad (4)$$

where: L is the length along the longest axis (m), W is the width in the dimension along the longest axis perpendicular to L (m) and T is the thickness in the dimension along the longest axis perpendicular to both L and W (m).

One thousand kernel weight was determined using an electronic weight balance reading to 0.001g. Sets of 1000 kernels were collected randomly, and weighed on the balance and the mass was recorded at different moisture contents.

Roundness and sphericity were determined by tracing the shadowgraphs of the kernels on a graph sheet, at each of the moisture levels. The shadowgraphs were then fitted with smallest inscribing and largest circumscribing circles, respectively. For roundness the projected area and smallest circumscribing area were determined using the method of counting the squares. Thirty trials were carried out at each moisture level and the mean areas were determined.

Roundness was calculated from the relation:

$$R = \left(\frac{A_p}{A_c}\right)100 \quad (5)$$

where:

R = roundness, %, A_p = projected area (cm^2), A_c=area of smallest circumscribing circle (cm^2)

Sphericity was calculated from the relation:

$$S = \left(\frac{D_i}{D_c}\right)100 \quad (6)$$

where: S = sphericity, %, D_i= diameter of inscribed circle (cm) and D_c= diameter of circumscribed circle (cm).

Paper foil was used to determine the surface area of 30 randomly selected kernels. The kernels were carefully wrapped in the foil and the boundaries were cut out. The foil was then unwrapped from the kernel, placed on graph paper and traced with a very sharp pencil. The surface area was measured by counting the squares within the traced marks (Oje and Ugbor, 1991).

The bulk density was determined by filling an empty 500ml graduated cylinder with kernels and weighing (Mohsenin 1970). The weight of the kernels was obtained by subtracting the weight of the cylinder from the weight of the cylinder and content. To achieve the uniformity in bulk density, the graduated cylinder was tapped 10 times for the kernels to consolidate. The volume occupied was then noted. The process was replicated four times and the bulk density for each replication was calculated using equation (7).

$$P_b = \left(\frac{W_s}{V_s}\right) \tag{7}$$

where: P_b=Bulk density (kg/m^3), W_s=Mass of seeds alone (kg) and V_s=Volume of seeds (m^3)

True density of the kernels was determined using the water displacement method. Sample of the kernel at specified moisture level was collected, weighed on an electronic balance, coated with epoxy resin around the ring to prevent absorption of water during the test, and submerged in 50ml cylinder containing water. The volume of water displaced was noted and taken as the volume for the kernel. The masses and volumes were recorded and true density calculated using Equation (8). The test was replicated thirty times at specified moisture content and the average values of true density were noted.

$$P_t = M/V \tag{8}$$

where: P_t = True density (kgm^{-3}), M = mass of individual kernel (kg) and V= volume of individual seed (m^{-3})

The porosity (ε) of the seeds was determined from the values of bulk and true densities using Equation (9) due to Mohsenin (1970)

$$\varepsilon = \left(1 - \frac{P_b}{P_t}\right)100 \tag{9}$$

where: ε =Porosity (%), P_b= Bulk density (kgm^{-3}) and P_t = Particles density (kgm^{-3}).

Angle of repose was determined using an apparatus consisting of plywood box 150 mm long, 150 mm wide and 150 mm deep and two plates; one being fixed and the other was adjustable. The box was filled with kernel sample and then the adjustable plate was inclined gradually allowing the seeds to flow and assume a natural slope, the angle with the horizontal of which was taken as the angle of repose (Tabatabaeefar, 2003; Heidabeigi *et al*., 2005).

Static coefficient of friction was evaluated on plywood with wood grain parallel to direction of movement. The inclined plane method was used as described by Suthar and Das (1996) and Dutta *et al*. (1998). This involved the placing of an open ended box (150mm×150mm×150mm) on an adjustable tilting surface which was formed with structural surface. The box was filled with the kernels and the structural surface with the box and its content on top was gradually raised using a screw device until the box started to slide down. The angle of tilt was read from a graduated scale and the tangent of the angle was taken as the static coefficient of friction. This was carried out at different moisture content.

2.3 Determination of Specific heat

The specific heat of the kernels was determined using a copper calorimeter placed inside a flask by the method of mixture as described by Ogujimi *et al*. (2002). A sample of known weight and temperature was poured into the calorimeters containing water of known weight and temperature. The mixture was stirred with a copper stirrer until equilibrium was attained. The final temperature was noted and the specific heat capacity of sample was calculated using Equation 10.

$$C_s = \frac{(M_c C_c + M_w C_w)(T_w - T_c)}{M_s(T_e - T_s)} \tag{10}$$

where: C_c = specific heat of calorimeter ($Jkg^{-1}\ {}^oC^{-1}$), C_s = specific heat capacity of the seed samples ($Jkg^{-1}\ {}^oC^{-1}$), C_w = specific heat of water ($J/kg\ {}^oC$), M_c = mass of calorimeter (kg), M_s = mass of sample (kg), M_w = mass of water (kg), T_e = equilibrium temperature of seed (${}^oC$), T_s = initial temperature of sample (${}^oC$) and T_w = initial temperature of water (${}^oC$).

3. Results and Discussion

3.1 Seed moisture content

The initial moisture content of Neem kernels was found to be 5.82% (dry basis). The three other moisture levels obtained after conditioning the seeds were 26.4%, 35.9% and 44.9% (dry basis) respectively.

3.2 Axial dimensions

The results of the neem (*Azadirachta indica A. Juss)* kernel sizes measured at different moisture contents are presented in Table 1. The three axial dimensions increased with moisture content that ranged between 5.82 to 44.9% (db). The major axis increased from 1.04 to 1.23cm, while the intermediate axis and the minor axis increased from 0.42 to 0.6cm and 0.32 to 0.45cm respectively. The arithmetic and the geometric mean of the three principal axes of the kernels also increased with increase in moisture content. The arithmetic mean diameter had the higher value than the geometric mean diameter. These could be of important consideration in the theoretical determination of the kernel volume at different moisture contents. Similar trends of such increase were reported by Tavakkoh *et al.* (2009) for soybean grains and Al-Mahasneh and Rababah (2007) for green wheat.

3.3 One thousand kernel weight

The one thousand kernel weight increased from 0.0987kg to 0.1755kg in the moisture range of 5.82-44.9% (dry basis). This trend with moisture content was due to increase in weight gained at higher moisture content (Figure 1). Similar increasing trend has been reported by Sahoo and Srivastava (2002) for okra seed.

Table1: Axial dimensions of Neem kernels at different moisture contents

Moisture contents (%) d.b	Major diameter L (cm)	Intermediate diameter T (cm)	Minor diameter W (cm)	Arithmetic mean diameter (a+b+c)/3 (cm)	Geometric mean diameter $(abc)^{1/3}$ (cm)
5.82	0.9 – 1.04	0.35 – 0.42	0.25 -0.32	0.62	0.53
26.4	0.95– 1.15	0.45 – 0.46	0.25– 0.36	0.65	0.57
35.9	1.0 – 1.2	0.5 – 0.55	0.35– 0.41	0.73	0.66
44.9	1.15-1.23	0.55-0.6	0.40-0.45	0.78	0.72

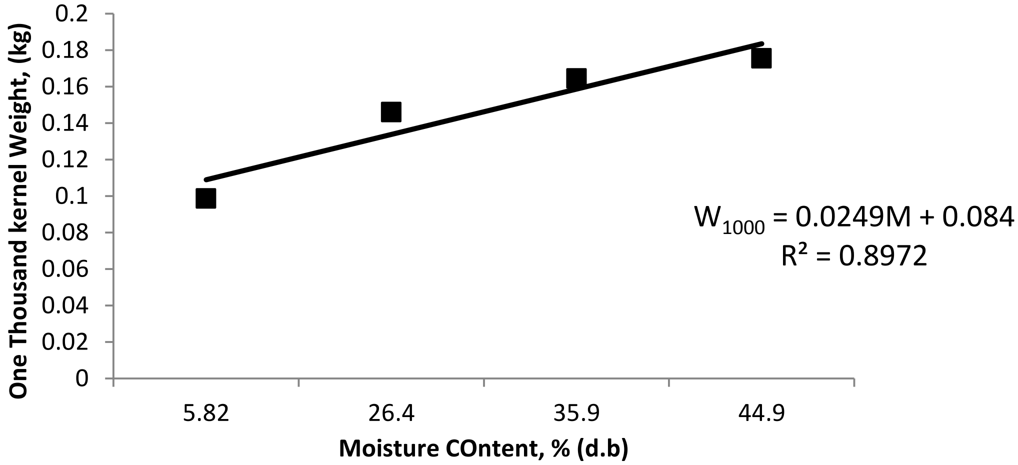

Figure 1: Effect of moisture content on one thousand Seed Weight of Neem kernels

3.4 Bulk density

The bulk density of neem (*Azadirachta Indica A. Juss)* kernels was found to decrease from 591.4-497.4kg/m^3 with an increase in moisture content (Table 2). This was due to the fact that an increase in mass owing to moisture in the sample was lower than accompanying volumetric expansion of the bulk (Pradhan et al. 2008). On the other hand, a decreasing trend in bulk density has been reported by Altunas & Demirtola (2007) for some legumes seed and Garnayak *et al.* (2008) for jatropha.

Table 2: Bulk density of Neem (*Azadirachta Indica A. Juss*) seeds at different moisture contents

Moisture content(%) d.b	5.82	26.4	35.9	44.9
Bulk density (kg/m^3)	591.4	540.0	513.0	497.4

3.5 True density

The true density of the Neem kernels increased from 632 to 733 kg/m^3 as moisture content increased from 5.82 to 44.9% (dry basis) (Figure 3). An increase in true density as the seed moisture content increases was also found by Gupta and Das (1998) for sunflower seeds, and Chandrasekar and Visvanathan (1999) for coffee. The true density of agricultural products have been reported to play significant role in the design of silos and other storage structures, and in maturity and quality evaluation of agricultural products which are essential to grain marketing (Irtwange and Igbeka, 2002).

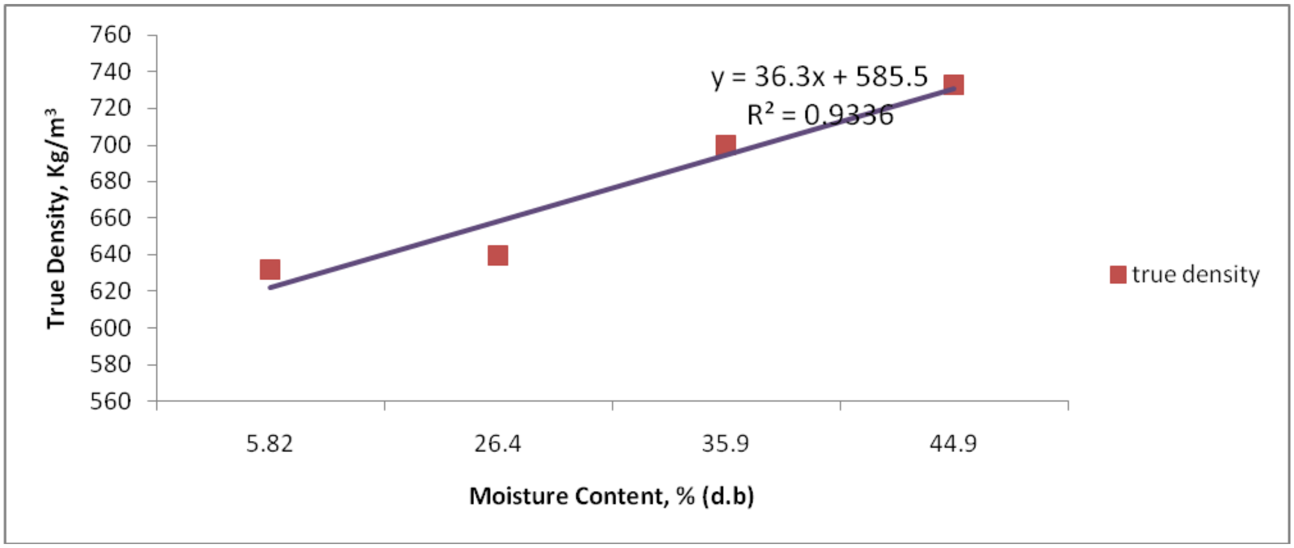

Figure 3: Effect of Moisture Content on True Density of Neem kernels

3.6 Roundness and Sphericity

Table 3 shows the effect of moisture contents on the roundness and sphericity of Neem kernel. The Table revealed that the roundness of the kernel increased from 22 to 36%, and the sphericity increased from 41.3 to 47.5%. Coskum *et al*. (2006) also showed that sphericity of sweet corn seed increased with moisture content.

Table 3: Roundness and Sphericity of Neem seeds at different moisture contents

Moisture content(%) d.b.	5.82	26.4	35.9	44.9
Roundness (%)	22.0	27.0	31.2	36.0
Sphericity (%)	41.3	44.2	46.0	47.5

3.7 Porosity

The porosity of Neem kernels increased from 6.42 to 32.14% with the increase in moisture content from 5.82 to 44.9% (Figure 4). This could have contributed to the expansion and swelling of the seeds that might have resulted in the more voids spaces between the seeds and increased in bulk volume. This is also exhibited in the reduction of bulk density with increase in moisture content. An increase in porosity with moisture content was reported for green gram (Nimkar and Chattopadhyay 2001).

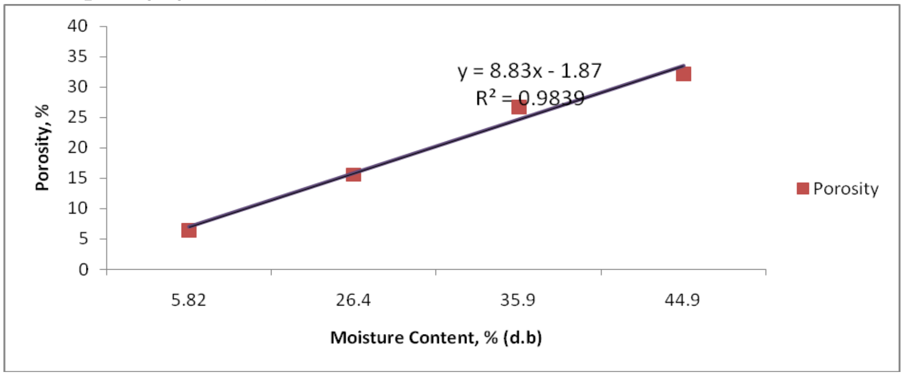

Figure 4: Effect of Moisture Content on Porosity of Neem kernels

3.8 Surface area

Table 4 shows that the surface area of neem (*Azadirachta indica A. Juss)* kernels increased from 13.0 to 24 cm^2 as the moisture content increased from 5.82 to 44.9%. Similar trends of increase have been reported by Sacilik *et al.* (2003) and Baryeh (2002) for Hemp seed and Millet respectively.

Table 4: surface area of Neem (*Azadirachta Indica A. Juss) seed*s at different moisture contents

Moisture content(%) d.b	5.82	26.4	35.9	44.9
Surface area in cm^2	13	17.1	21	24

3.9 Angle of repose

The angle of repose increased from 22.12 to 29.8^o in the moisture range of 5.82 to 44.9% (dry basis) (Figure 5). Seed might tend to stick together due to the plasticity effect over the surface of the seed resulting in better stability and less flow ability increasing the angle of repose (Irtwange and Igbeka, 2002). The angle of repose is of paramount importance in designing hopper openings, side wall slopes of storage bins and bulk transportation of seeds using chutes (Elaskar *et al*., 2001, Irtwange and Igbeka 2002).Therefore, moisture content of seeds should be taken in to account while designing such equipments and structures. Singh and Goswami (1996), Nimkar and Chattopadhyay (2001), Baryeh (2002), Amin *et al*. (2004) and Altunas et al (2005) reported a linear increase in angle of repose with increase in the moisture content for cumin seed, green gram, millet, lentil and fenugreek respectively.

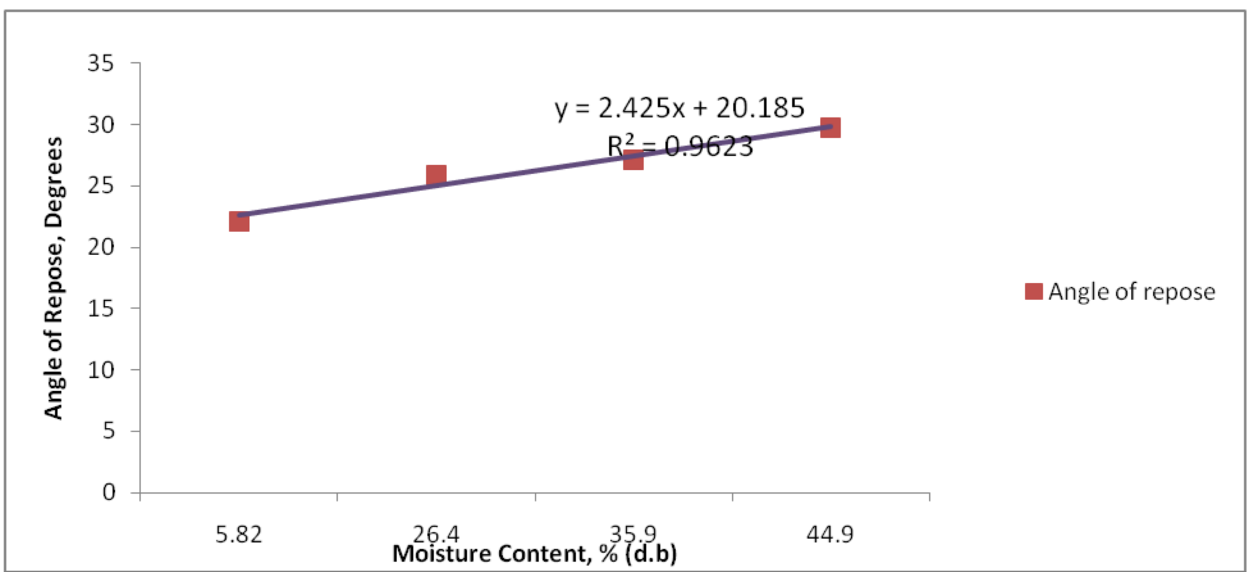

Figure 5: Effect of moisture content on angle of repose of Neem kernels

3.10 Static coefficient of friction.

The static coefficient of friction increased with increase in moisture content on the surface of the plywood from 0.45 to 0.61(Table 5). The design and dimension of hoppers, bulk storage and handling structures, should ensure non-arching (avoid stoppage of flow of bulk solid) phenomenon. The coefficient of mobility represents the freedom of motion of a substance and is inversely related to coefficient of friction (tangent of angle of internal friction) (Irtwange and Igbeka, 2002). Dutta *et al*. (1988), Joshi *et al*. (1993), Carmon (1996), and Ogut (1998), reported that as the moisture content increased so the coefficient of static friction increased.

Table 5: Static coefficient of friction of Neem (*Azadirachta Indica A.Juss*) kernels on four structural surfaces at different moisture contents

Surfaces	Moisture contents (%)			
	5.82	26.4	35.9	44.9
Plywood with grain parallel to the direction of movement	41	47	52	61
Fiber glass	19	20	27	24
Hessian bay material	28	31	35	38
Galvanized steel sheet	25	27	29	33

3.11 Specific heat

The specific heat of Neem kernels at four moisture levels in the range of 5.82 to 44.9% (dry basis) and temperature of (100^{o}C) between the initial temperature of the seed and final temperature of water and the seed mixture was found to lie between 2738.1 and 4345.4 J/Kg^{o}C (Figure 6). It was observed that the specific heat increased linearly with increase in moisture content. Similar trend was observed for sheanut kernel, guna seed and kernel and cumin seed (Aviara and Haque, 2001, Aviara *et al*., 2008).

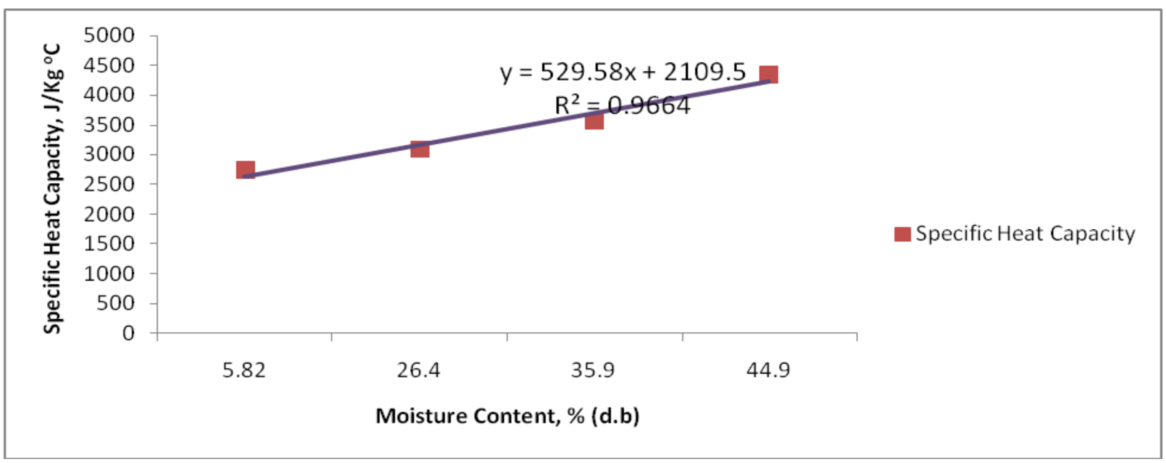

Figure 6: Effect of moisture content on specific heat capacity of Neem kernels

4. Conclusion.

The investigations carried out in this study revealed the following:

The major, intermediate and minor dimension of the kernels all increased from 1.04 to 1.23cm, 0.42 to 0.6cm and 0.32 to 0.45cm respectively. One thousand kernel weight increased from 0.0987 to 0.1755kg as the moisture content increased from 5.82 to 44.9%. True density and porosity of the kernels increased in moisture content from 632 to 733kgm^{-3} and 6.42 to 32.14%, while the bulk density decreased from 302.0 to 294kg/m^3 in the same moisture range. Surface area of the kernels increased from 13 to 24cm^2 with increase in moisture content from 5.82 to 44.9%. Roundness and sphericity of the kernels increased from 22 to 36% and 41.3 to 47.5% respectively with increase in moisture content. Angle of repose increased from 22.12 to 29.8^o. Specific heat increased with increase in moisture content and temperature in the range of 5.82 to 49.7% and 303-341.4k and lies between 1547-6102.8J/kg.

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