DETERMINATION OF SOME MECHANICAL AND THERMAL PROPERTIES OF COCONUT (*COCOS NUCIFERA L.*) UNDER VARYING MOISTURE CONTENT

F. U. Asoiro and K. I. Onah
Department of Agricultural and Bioresources Engineering, University of Nigeria, Nsukka, Nigeria
Email: felixasoiro@yahoo.com

ABSTRACT

Some mechanical and thermal properties of coconut (cocos nucifera l.) were determined under varying moisture content ranges (37%, 49% and 55% db). It was discovered that at moisture content of 37%, 49% and 55% d.b mean thermal heat conductivity were 4089×10^{-3}W/m^{0}C, 32132×10^{-3} W/m^{0}C and 1.59×10^{-3} W/m^{o}C respectively. Thermal heat resistivity were 2445.5^{0}C-m/w, 3112.076 ^{0}C-m/w and 627 ^{0}C-m/w respectively. Thermal heat diffusivity for the different moisture content levels were 2.57×10^{-7}m^2/s, 2.508×10^{-7}m^2/s and 2.356×10^{-7}m^2/s respectively. Specific heat capacity were found to be 6.36 J/g^{0}C, 4.997 J/g^{0}C and 26.539 6 J/g^{0}C respectively. The bioyield strength, rupture strength and compressive strength at 37% db were 31175, 57254.2 and 61211.03N/m^2 respectively. At 49% db moisture content, bioyield strength, rupture strength and compressive strength were 24925.22, 46734 and 50598.22N/m^2 respectively while at 55% db, bioyield strength, rupture strength and compressive strength were 22066.59, 35834.63 and 34896.88N/m^2 respectively. It is obvious that thermal conductivities, thermal diffusivities and specific heats of coconut were found to increase with increase in moisture content. Also, as moisture content increased, mechanical strength decreased.

KEYWORDS: Coconut, specific heat capacity, thermal heat conductivity, bio-yield strength, rupture strength, compressive strength

1. INTRODUCTION

Coconut (cocos nucifera) is a native of South America and carried west ward across the Pacific in prehistoric times. Its original home must be sought in some sheltered valley of the Equatorial Andes. All the other members of the Cocoineae (except *Elaeis guinensis*) are American. However, it has been opined that despite the presence of botanically related genera on the plains, plateaus and highlands of continental south America, the home of the coconut is often said to be unknown. Its mode of dispersal is thought to have evolved on the coastal beaches of ant hills and islands of the Indian Ocean and western pacific.

Cocos nucifera trees have a smooth, columnar, light grey-brown trunk, with a mean diameter of 30-40 cm at breast height, and topped with a terminal crown of leaves. Tall selections may attain a height of 24-30 m. Dwarf selections also exist. The trunk is slender and slightly swollen at the base, usually erect but may be leaning or curved. The leaves are pinnate, feather shaped, 4-7m long and 1-1.5 m wide at the broadest part. The leaves stalk 1-2 cm in length and thorn less. The inflorescence consists of female and male axillaries flowers. Flowers are small, light yellow, in clusters that emerge from canoe-shaped sheaths among the leaves. The male flowers are small and more numerous. Female flowers are fewer and occasionally completely absent with larger, spherical structures, about 25 mm in diameter. Fruits (Figure 1) are roughly ovoid, up to 5 cm long and 3 cm wide, composed of a thick, fibrous husk surrounding a somewhat spherical nut with a hard, brittle, hairy shell. The nut is 2-2.5 cm in diameter and 3-4 cm long. Three sunken holes of softer tissue, called (eyes) are at one end of the nut. Inside the shell is a thin, white, fleshy layer (meat). The interior of the nut is hollow but partially filled with a watery liquid known as (coconut milk). The meat is soft and jellylike when immature but becomes firm with maturity. Coconut milk is abundant in unripe fruit but is gradually absorbed as ripening proceeds. The fruits are green at first; turning brownish as they mature while yellow varieties go from yellow to brown.

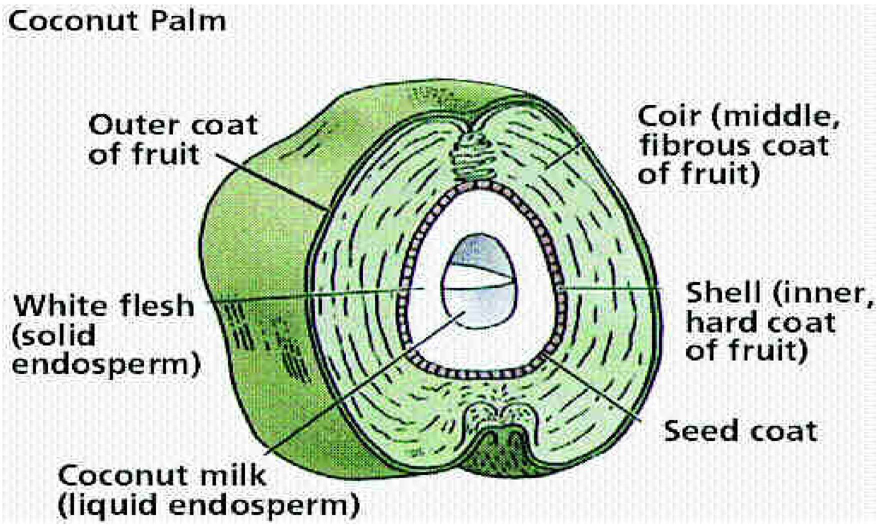

Figure 1. A longitudinal disection of coconut fruit

The composition of coconut varies with the varieties and maturity. The major constituents are coir, mesocarp, copra, and water with composition of 35%, 12%, 28% and 25% respectively. Percentage composition of the shell and husk are shown in Tables 1 and 2.

Table 1. Composition of coconut shell

Content	Percentage (%)
Water	8.0
Ash	0.6
Extractives	4.2
Lignin	29.4
Cellulose	26.6
Pentasans	27.7
Uronic anhydrides	3.5
Exthoxyl(zienel)	5.6
Nitrogen	0.11

Table 2. Percentage composition of coconut husk

	Fiber		
	Old Nut (%)	Young Nut (%)	Very Young Nut (%)
Water soluble substances	26	29	38. 50
Pectin, others soluble in boiling water	14. 25	14. 85	15. 25
Hemicelluloses	8.5	8.15	9. 00
Lignin	29. 33	31. 64	20. 13
	23. 87	19. 26	14. 39

Coconut has vast social, economic, cultural and medicinal values and it is widely consumed in the entire country and beyond. It is served as a highly priced special delicacy to entertain guests and visitors during burials, marriages, festival and ceremonies among the Igbos in some south eastern part of Nigeria. It has different names by the various countries and ethnic groups across the world. It is known as coconut in English. The Igbos in Nigeria refer to it as aki-oyibo/oba. It is known as klapperboom by the Dutch. In French it is known as coco, noix de coco, cocotier, cocoyer, coq au lait. The German refer to it as kokospalme, kokosnusspalme. In Indonesian it is known as kelapa. For the Italians it is called cocco while the Spanish know it as cocotero. Despite the huge economic and agricultural potential of this nut, very little information is available in literature on the mechanical properties of the fruit.

Coconut fruits can be processed into other food units. Part of the post harvest operation in the processing of coconut fruit involves cracking of the shell and subsequently heat treatment. In other to design, fabricate and develop systems, devices and controls for value addition, drying, transportation, conveying, storage, processing etc. knowledge of thermal and and mechanical properties of coconut at varying moisture content is required.

The moisture content of agricultural materials greatly affects various mechanical and thermal properties. Therefore, mechanical and thermal properties data at different moisture contents can be directly used to design/select planting, harvesting, processing, handling and storage equipment, like cleaners, graders, dryers, mills, conveyors, etc.(Kachru *et al*., 1994). Aviara *et al*. (1999) noted that the moisture dependent characteristics of thermal properties have effect on the adjustment and performance of agricultural product processing machines. They further noted that the optimum performance of machines could be achieved at a specific range of moisture contents. It has been reported that the knowledge of thermal properties and their dependence on the moisture content are useful for the design and development of methods and equipment (Oje, 1993; Visvanathan *et al*., 1996). Moisture content also has a great influence in threshing, separation, cleaning and grading operations.

Data on the thermal and mechanical properties of various nuts under varying moisture content are widely available, but relatively few data are available for coconut. Therefore, the present study was conducted to quantify the changes in mechanical and thermal properties of coconut as a result of changes in moisture contents levels (37 %, 49 % and 55 % dry basis).

2. MATERIALS AND METHODS

2.1 Sample Source

About 40 matured coconut heads were harvested from a coconut tree at Ogbodu-Aba in Udenu Local Government Area of Enugu State, Nigeria. Samples were weighed in a weighing balance, soaking in distilled water, kept in a polythene bag for five days for moisture to redistribute across the nuts, oven dried to required moisture content and conditioned in a refrigerator. Thereafter the thermal properties were analyzed at the National Centre for Energy Research and Development, University of Nigeria, Nsukka (NCERD) while the mechanical properties were determined at the Civil Engineering Laboratory of the same university.

2.2 Determination of Moisture Content of Coconut

The moisture content of the coconut seed were determined by AOAC method. An empty dish was dried in an oven at 105^{o}C for 72 hours and transferred to a desiccator to cool and weighed. About 1 sample of the coconut was weighed in the dish and placed in the oven, dried for 72 hours at 105^{o}C. After drying, the dish partially covered with lid and transferred to the desiccator to cool and reweighed. The loss in weight expressed as a percentage of the initial weight, was taken as the moisture content of the sample. The moisture content was calculated using equation 1.

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

Where, MC_{wb} is moisture content (%) wet basis; W_i is initial weight of sample (g) and W_f is final oven-dried weight of sample (g)

2.3 Mechanical Properties

Some mechanical properties of coconut such as, compressive strength, deformation at rupture and bio-yield strength were evaluated using 4 samples of the nut. Four samples of the nut were also tested for each of the diameter. This was done by means of a UK- made Universal Testing Machine.

2.3.1 Determination of Bio-yield Strength of Coconut

The bio-yield force is the force at which the sample begins to fail. This is the force at which the material yields. Further application of force beyond the bio-yield force ruptures the sample.

2.3.2 Determination of Compressive Strength of Coconut

Compressive strength was calculated as the rupture force divided by the deformation. Compressive strength, H (N/mm) is the ratio of rupture force and deformation at rupture point. It was calculated using equation 2

$$H = \frac{F_R}{R_{DR}} \tag{2}$$

2.3.3 Determination of Deformation at Rupture of Coconut

Deformation at rupture point, R_{DR} (mm) is the deformation at loading direction. It is measured in (mm).

2.4 Thermal Properties

2.4.1 Determination of Heat Capacity of Coconut

The method of mixtures has been the most common technique reported in the literature for measuring the heat capacity of agricultural and food materials due to its simplicity and accuracy. (Singh and Goswani 2000; Aviara and Haque 2001; NouriJangi et al. 2011; Deshpande et al. 1996.). This method was used for the determination of heat capacity of coconut at varied moisture levels. It involves the use of a lagged calorimeter, a digital thermometer to measure change in temperature with other heat determinant apparatus. The lagged calorimeter was calibrated using various temperatures ranging from 30^{o}C - 75^{o}C. The calibration of calorimeter is necessary to minimize experimental error. The calorimeter was calibrated by pouring a certain quantity of cold water into it. The temperature of the cold water was allowed to stabilize at a given temperature before a measured quantity of hot water was added to it. The equilibrium temperature of the mixture of hot and cold water was recorded. The respective quantities of hot and cold water were adjusted until a final temperature of the mixture that was close to the room temperature was obtained. The energy balance equation for the calibration of the calorimeter is given in equation 3 (Aviara and Haque 2001; Deshpande et al 1996; Razavi and Taghizadeh, 2007).

$$C_c = \frac{\left[M_{cw}C_w(T_h - T_e - M_{cw}C_w)\right]}{T_e - T_c} \tag{3}$$

Where, C_c is heat capacity of calorimeter (KJ/^{o}C); M_{cw} is mass of cold water (Kg); T_h is temperature of hot water (^{o}C); T_e is equilibrium temperature (^{o}C); C_w is specific heat of water (KJ/Kg^{o}C) and T_c is temperature of cold water (^{o}C)

The calibration was replicated five times and the quantities of hot and cold water adjusted to achieve final temperatures. The average value of the specific heat of calorimeter was noted.

The heat capacity of coconut was determined by dropping a sample of known weight, temperature (within a range of 25 – 30^{o}C) and a given moisture content into the calorimeter containing water with known weight and temperature. The mixture was stirred continuously using a copper stirrer. The temperature was recorded at an interval of 60s using aK-type thermocouple digital thermometer. At equilibrium, the final or equilibrium temperature was noted and the specific heat of the coconut was calculated using equation 3 (Aviara and Haque, 2001).

$$C_s = \left\{ \frac{(C_c + M_h C_w)\left[T_h - (T_e + tr^1)\right]}{M_s\left[(T_e + tr^1) - T_s\right]} \right\} \quad (4)$$

Where, C_s is specific heat of coconut (KJ/Kg^{o}C); C_c is heat capacity of calorimeter (KJ/^{o}C); M_h is mass of hot water (Kg); C_w is specific heat of water (KJ/Kg^{o}C); T_h is temperature of hot water (^{o}C); T_e is equilibrium temperature (^{o}C); M_s is mass of seed (Kg); T_s is temperature of coconut (^{o}C); tr^1 account for the heat of hydration and heat of exchange with the surroundings; and r^1 is the rate of temperature rise of the mixture after equilibrium was reached.

At each moisture level, the experiment was replicated four times and the average values of the specific heat reported.

2.4.2 Determination of Thermal Conductivity of Coconut

The thermal conductivity was determined employing the method described by Aviara and Haque, (2001) and Mohsenin, (1980) using a guarded hot-plate apparatus with steady-state heat flow method. Figure 2 shows the transfer of heat through surfaces with different temperature.

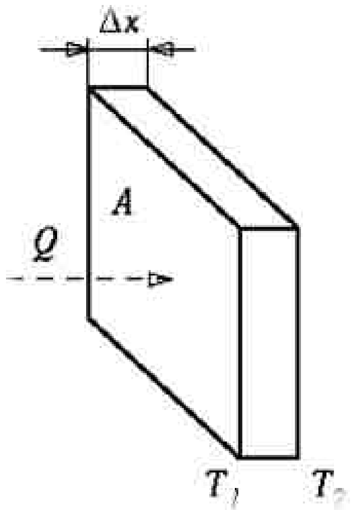

Figure 2. Heat transfer process through surfaces with different temperature
Source: Mohsenin, 1980.

The thermal conductivity method used for the work consisted of an upper (hot) plate and a lower (cold) plate, all made of mild steel. The upper plate was 90 mm in diameter and 30 mm thick. It was surrounded by a guard ring of 120 mm diameter and 13 mm thickness. The gap between them was filled with fiber glass at both the top of the plate and the sides to a thickness of 10 mm. The lower plate had a diameter of 90mm and a thickness of 9 mm. It was surrounded by a wooden guard ring of 125 mm diameter and 14 mm thickness, from which it will be separated by fiber glass to a thickness of 14 mm. The upper plate was heated electrically and this was controlled using a variable voltage regulator. Measurements of current and voltage were made using a multi-meter. The temperature of the plates was measured with 0.2-mm K-type thermocouples and digital thermometer at the heat source and heat sink respectively. The heat flux of the thermal conductivity apparatus was obtained using samples of known thermal conductivity, which was also used to calibrate the equipment. The thermal conductivity of coconut was computed from the temperature changes and heat flux obtained for known thermal conductivity using a sample at specified moisture content which was cut into a regular shape. The heat source was adjusted to maintain a temperature range of 61 – 64^{o}C. At the equilibrium condition or steady state condition, the temperature difference was recorded and used in calculating the thermal conductivity of the sample from equation 5.

$$K = \frac{Q(X_2 - X_1)}{A(T_2 - T_1)} \tag{5}$$

Where, K is thermal conductivity (W/m^{o}C); Q is rate of heat transfer (W/s); X_2 is longer distance (m); X_1 is shorter distance (m); A is area (m^2); T_1 is inside hotter temperature (^{o}C) and T_2 is outside cooler temperature (^{o}C).

The experiment was replicated four times for each of the moisture levels and the average calculated as the thermal conductivity.

2.4.3 Determination of Thermal Diffusivity of Coconut

Two methods could be used for the determination of thermal diffusivity of coconut. They are: The mathematical method and experimental method**.** Mathematical method involves direct calculation of thermal diffusivity using thermal conductivity, specific heat and density data. This is the simplest method and has been used by many researchers for thermal diffusivity estimation of peanut, kernel, shell. (Bitra et al., 2010). This method was used for the determination of thermal diffusivity of coconut as it gave a more robust result. This was computed using equation 6 as reported by Fadele, (2010).

$$\beta = \frac{K}{D_b C_s} \tag{6}$$

Where, β is thermal diffusivity (m^2/s); K is thermal heat conductivity (W/m^{o}C); D_b is bulk density (Kg/m^3) and C_s is specific heat (KJ/Kg^{o}C).

This was computed for the three moisture content levels.

2.4.4 Determination of Thermal Resistivity of Coconut

Thermal resistivity was computed using equation 7

$$R_T = S\left[\frac{Q}{4\pi}\right]^{-1} \tag{7}$$

$$Q = I^2 r \tag{8}$$

Where, Q is the heat input per unit length, I is current (Amp), r is the resistance of the nichrome wire per unit length (Ω/cm) and S indicates the slope of the straight line portion of the temperature θ versus log (time) plot

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties

Some mechanical properties of coconut under varying moisture content is presented in Table 3.

Table 3. Some mechanical properties of coconut (cocos nucifera) with varying moisture content

Property	**Moisture Content (%) d.b**		
	37%	**49%**	**55%**
Bio-yield force (N)	1300	1000	877.5
Bio-yield strength (N/m^2)	31175	24925.22	22066.56
Rupture force (N)	2387.5	1875	1425
Rupture strength (N/m^2)	57254.2	46734	35834.63
Compressive force (N)	2552.5	2030	1387.5
Compressive strength (N/m^2)	61211.03	50598.2	34896.88
Diameter (m)	115.25	0.113	0.11
Length (m)	27.75	0.0027	0.0027

The bio-yield force was highest at 37%db of moisture content with a value of 1300N and lowest at 55% with a value of 877.5N. It has a value of 1000N at 49% db of moisture content. The rupture strength of coconut is 57254.2N/m^2, 46734N/m^2 and 35834.63 N/m^2 at moisture content levels of 37, 49 and 55%db respectively. The compressive strength of coconut is highest at 37%db (61211.03N/m^2) and lowest at 55%db (34896.88N/m^2). From Table 3, it is clear that mechanical property values of coconut decreased with increase in moisture content.

3.2 Thermal Properties

Some thermal property values of coconut (*cocos nucifera*) is shown in Table 4.

Table 4. Some thermal properties of coconut (*cocos nucifera*) with varying moisture content

Property	**Moisture Content (%) d.b**		
	37%	**49%**	**55%**
Thermal conductivity (W/m^{o}C)	4.089×10^{-3}	3.2132×10^{-3}	1.59
Thermal resistivity (^{o}C-m/W)	2445.5	3112.076	627.2
Thermal diffusivity (m^2/s)	2.57×10^{-7}	2.508×10^{-7}	2.356×10^{-7}
Thermal heat capacity (J/g^{o}C)	6.36	4.997	26.537

The thermal conductivity values of coconut increased with increase in moisture content. The thermal diffusivity decreased with increase in moisture content from 37% to 55% db. The thermal conductivity of coconut was 4.089×10^{-3}W/m^{o}C at 37%, 3.2132×10^{-3}W/m^{o}C at 49% and 1.59×10^{-3}W/m^{o}C at 55% db of moisture content. The thermal diffusivity of coconut at 37%, 49% and 55% db were 2.57×10^{-7} m^2/s, 2.508×10^{-7} m^2/s and 2.356×10^{-7} m^2/s respectively. The thermal resistivity of coconut was 2445.5^{o}C-m/W at 37% db, 3112.076 ^{o}C-m/W at 49% db and 627.2 ^{o}C-m/W at 55% db. The thermal heat capacity values decreased from 6.36 J/g^{o}C to 4.997 J/g^{o}C as moisture content increased from 37% to 49% db. It then increased from 4.997 to 26.537 J/g^{o}C as moisture content rose from 49% to 55%db.

4. CONCLUSIONS AND RECOMMENDATIONS

Moisture content greatly affects the thermal properties of coconut fruit. The thermal conductivity decreased as moisture content rose from 37% db to 49% db and later increased as moisture content rose again to 55% db. Similar trend was observed with values for thermal heat capacity. However, thermal resistivity showed a reversed trend. As moisture content increased from 37% to 49%, thermal resistivity values increased from 2445.5 ^{o}C-m/W to 3112.08 ^{o}C-m/W and later decreased to the value of 627.2 ^{o}C-m/W Thermal diffusivity decreased as moisture content increased from 37 to 55%db. As moisture content increased, mechanical strength decreased

It is recommended that other mechanical properties should be tested for any further future work. Mechanical and thermal properties of more than one variety of coconut, under varying moisture content should be investigated and results compared. This work was restricted to only 37 to 55% levels of moisture. More levels of moisture content should be investigated and its behavior ascertained.

REFERENCES

Aviara, N. A., and M. A. Haque. 2001. Moisture dependence of thermal properties of shea nut kernel. *J. Food Eng.* 47(2): 109-113.

Aviara, N.A ., M. I Gwandzang and M. A. Haque. 1999. Physical properties of guna seeds. *Journal of Agricultural Engineering Research,* 73, 105-111.

Bitra, V. S. P., S. Banu, P. Ramakrishna, G. Narender, and A. R. Womak. 2010. Moisture-dependent thermal properties of peanut pods, kernels, and shells. *Biosystems Eng.* 106(4): 503-512.

Desphande, S. D., S. Bal, and T. P. Ojha. 1996. Bulk thermal conductivity and diffusivity of soybean. *J. Food Proc. and Preserv.* 20(3): 177-189.

Fadele, O.K. 2010. Determination of Some Engineering Properties of Doum Palm Fruit (*Hyphaenethebaica*).Unpublished MSc. Thesis. University of Ibadan.

Kachru, R. P., R. K Gupta, and A. Alam. 1994. *Physico–Chemical Constituents and Engineering Properties of Food Crops*. Jodhpur, India: Scientific Publishers.

Mohsenin N.N., 1980**.** Thermal Properties of Food and Agricultural Materials. Gordon and Breach Press, New York, USA.

NouriJangi A, Mortazavi1 SA, Tavakoli M, Ghanbari H, Tavakolipour A, Haghayegh GH. 2011. Comparison of mechanical and thermal properties between two varieties of barley (*Hordeumvulgare* L.) grains. Aust. J. Agric. Eng. 2(5):132-139.

Oje, K. 1993. Locust bean pods and seeds. Some Physical Properties relevance to dehulling and seed processing. *Journal of Food Science and Technology*. 30(4): 233-255.

Razavi, SMA and Taghizadeh, M. 2007. The specific heat of pistachio nuts as affected by moisture content, temperature, and variety. J Food Eng. 79:158–167.

Singh S.S and Goswani T.K. 2000. Thermal properties of cumin seed. J Food Eng.45: 181-187.

Visvanathan, R., P. T. Palanisamy., L. Gothandapani and V .V. Sreenarayanan. 1996. Physical properties of neem nut. *Journal of Agricultural Engineering Research*, 63, 19-36.