Effect of Moisture Content and Drying Methods on the Thermal Properties of African Walnut Flour

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ABSTRACT

The specific heat, thermal conductivity, thermal diffusivity, and bulk density of African Walnut flour were determined as a function of moisture content. The specific heat and thermal conductivity were measured using Choi and Okos (1986) equation and Sweat (1986) equation, respectively. The thermal diffusivity was calculated from measured specific heat, thermal conductivity, and bulk density. Within the moisture range of 12% to 18% (d.b), The specific heat of big and wmall sized oven eried sample of African Walnut flour increased from 190.49 KJ/Kg°C to 195.75 KJ/Kg°C and 191.90 KJ/Kg°C to 194.20 KJ/Kg°C, respectively while big and small size sun dried sample flour of African Walnut also increased from 191.21 KJ/Kg°C to 193.56 KJ/Kg°C and 192.46 KJ/Kg°C to 196.56 KJ/Kg°C with increase in moisture content from 12% to 18% (d.b) range for the both sample, respectively.

The thermal conductivity of big and small size oven dried processed African Walnut flour increased from 22.07 W/m°C to 24.08 W/m°C and 21.15 W/m°C 23.73 W/m°C with increase in moisture content from 12% to 18%, respectively while big and small size sundried processed African Walnut flour increased from 21.06 W/m°C to 25.09 W/m°C and 22.86 W/m°C to 25.34 W/m°C with corresponding increase in moisture content from 12% to 18%. Thermal diffusivity of big and small sized oven dried processed African Walnut flour decreased from 0.198 (m^2/s) to 0.186 (m^2/s) and 0.186 (m^2/s) to 0.176 (m^2/s) with increase in moisture content from 12% to 18%, respectively while big and small size sundried processed African Walnut flour decreased from 0.196 (m^2/s) to 0.187 (m^2/s) and 0.196 (m^2/s) to 0.165 (m^2/s) with increase in moisture content from 12% to 18%.

Bulk density of big and small size oven dried processed African Walnut flour decreased from 0.78 (Kg/m^3) to 0.58 (Kg/m^3) and 0.63 to 0.54 (Kg/m^3) with increase in moisture content from 12% to 18%, respectively while big and small size sundried processed African Walnut flour decreased from 0.80 (Kg/m^3) to 0.73 (Kg/m^3) and 0.68 (Kg/m^3) to 0.57 (Kg/m^3) with increase in moisture content from 12% to 18%. Thermal properties of African Walnut were determined as a function of moisture content varied significantly with increase in moisture content. Thermal properties are very important in the engineering design calculations involving thermal processing such as pasteurization, sterilization, drying, heating, cooling, refrigeration, freezing, thawing, baking, and frying in food processing, handling, and preservation operations.

(Keywords: specific heat, thermal conductivity, thermal diffusivity, African Walnut flour)

INTRODUCTION

Agricultural and food materials undergo heating or cooling during processing and storage. Heating comes in the form of drying, evaporation, sterilization, pasteurization, and baking, whereas cooling comes in the form of chilling or freezing. The response of a material during the heating and cooling process is dependent on its thermal properties. Therefore, understanding of the engineering properties of agricultural material at any condition are important in order to solve problems associated with designing and selecting the modes of preservation, packaging, processing, storage, marketing, and consumption.

Thermal properties of agricultural materials and foods need to be known to better understand their nature and to be able to develop new technologies (Seyed *et al.,* 2013). Thermal processes such as pasteurization, concentration, drying, heating, cooling, sterilization, thawing, cooking, refrigeration, freezing, and evaporation are frequently used in food processing, transportation, and preservation operations (Melton *et al.,* 2013).

Knowledge of thermal properties of foods is thus crucial not only for equipment design but also for the prediction and control of various changes occurring in foods during heat transfer processes associated with storage and processing (Mahapatra *et al.,* 2013) . Thermal properties data are required both for existing foods and for new products and processes. Besides processing and preservation, thermal properties also affect sensory quality of foods as well as energy savings from processing (Mahapatra *et al., 2013*).

African walnuts (Tetracarpidium conophorum) a member of Juglandaceae family, is one of the finest nuts of the temperate regions. It is the oldest cultivated fruit in the world (Caglarirmak, 2003). It is a perennial woody, climber commonly found in low bush especially in Africa. In Nigeria, it is widely cultivated in the rainforest belt of Nigeria and called Ukpa in Igbo, in Efik and Ibibio is called "*eporo*" and awusa or asala in Yoruba language (Dalziel, 1937). African Walnut is one of the several high nutrient density foods with the presence of oxalates, phytates, tannins, as well as protein, fiber, carbohydrate, and vitamins (Savage et al., 2001). Other minerals though in trace amount are essential for body metabolism (Okwu and Okele, 2003; 2004). African Walnut is a rich source of mineral elements such as calcium, magnesium, sodium, potassium, and phosphorus (James, 2009).

African Walnut when eaten, have a bitter taste usually observed upon drinking water immediately. This is attributed to the presence of chemical substances such as alkaloids (Ayolele, 2003). Its commercial, nutritive, medicinal, and pharmaceutical values cannot be over emphasized. In order to explore all these benefits of this agricultural product (African Walnut), there is need to process it into different food formulations and food products.

Processing of African Walnut involves different thermal treatments. The existing method of carrying out this above processing procedures are task demanding, labor-intensive, time consuming, and very wasteful. Therefore, it is necessary to properly understand some of the thermal properties of this African Walnut that are relevant in the designing and fabrication of its postharvest processing machines and equipment. Thus, the objective of this study was to determine the effect of moisture content on thermal properties of African Walnut flour that are relevant to its processing, storage and handling. The concerned properties were thermal conductivity, thermal diffusivity, bulk density and specific heat.

MATERIAL AND METHODS

Sample Preparation

The African Walnut samples used for this research were collected from a local farm at a stable storage moisture. The seeds of African Walnut were properly cleaned and sorted to select viable seeds. The samples were, milled into flour using disc attrition mill and sieved with American Standard Sieve No with 435 ppm aperture to obtain fine flour.

The African Walnut flour moisture content level were conditioned by adding predetermine amount of distilled water. The flour was kept and allowed the moisture content to be distributed uniformly throughout the African Walnut flour. After the moisture content of the flour equilibrated at room temperature, a Multi-Purpose Oven Dryer was used to condition the flour sample into desired moisture content level (10.5%, 13.2% and 16.87%) dry basis (d.b,) at 105^0C for 24 hours . The conditioned flour was package in an airtight container with proper labelling and then moved to the laboratory where thermal properties were analyzed.

DETERMINATION OF THERMAL PROPERTIES

Bulk Density

The bulk densities of the processed African Walnut flour were determined using the method reported by Kii-Kabari et al., (2012). The centrifuge tube was weighed and recorded; flour sample was then poured into the centrifuge tube, and weighed (untapped). The centrifuge tube was then tapped and filled until a constant volume was achieved.

$$Bulk\ density\ (\%) = \frac{Weight\ of\ tapped\ flour - Weight\ of\ untapped\ flour}{\text{Volume of sample}} X\ 100 \quad \textbf{(1)}$$

Specific Heat Capacity

The specific heat capacity of the processed African Walnut flour sample was determined using the method reported by Choi and Okos (1986). It is the amount of heat energy required to raise the temperature of a body per unit mass and expressed as (j/g°c). The specific heat capacities were obtained using the various mass fractions derived from the proximate composition of the samples and then applying the Choi and Okos (1986) equation as stated below:

$$C_p = 1.547\ M_c + 1.711M_p + 1.92\ M_f + 0.908\ M_a + 4.180\ M_m \quad \textbf{(2)}$$

where C_p = specific heat capacity (kj/kg) and M_c, Mp, M_f , M_a, M_m are mass fraction of carbohydrate, protein, fat, ash and moisture content present in each sample flour, respectively.

Thermal Conductivity

The thermal conductivity of the processed African Walnut sample flour was determined using the method reported by Sweat (1986). The thermal conductivities were obtained by substituting the various proximate composition of the sample in the expression developed by Sweat (1986) as shown below

$$K = 0.25\ M_c + 0.155\ M_p + 0.16\ M_f + 0.135\ M_a + 0.58\ M_m \quad \textbf{(3)}$$

Where k is the thermal conductivity (w/m°c) and M_c, Mp, M_f, M_a, M_m are mass fraction of carbohydrate, protein, fat, ash, moisture content of the sample.

Thermal Diffusivity

The thermal diffusivity of the processed African Walnut sample flour was determined using the method reported by Nwanekezi and Ukagu (1999). The thermal diffusivity (α) is the thermal conductivity divided by bulk density and specific heat capacity at constant pressure and the Si unit is m^2/s. The thermal diffusivity of the samples was calculated using the equation.

$$\alpha = \frac{\mathbf{k}}{\rho Cp} \quad \textbf{(4)}$$

Where K = thermal conductivity, $\rho =$ bulk density and Cp = specific heat capacity.

DATA ANALYSIS

All the thermal properties were determined at three different moisture content level and the mean values calculated for three replications at each moisture content level. Data were analyzed using the Statistical Analysis, Least Significant Difference (LSD) among means was calculated at 5% significant level ($p < 0.05$) interval.

Table 1: Effect of Moisture Content on Thermal Properties of African Walnut Flour.

VARIATIONS		OVEN-DRIED SAMPLE				SUN-DRIED SAMPLE			
MOISTURE CONTENT (%)	Varieties	Bulk Density (Kg/m^3)	Specific heat Capacity (KJ/Kg°C)	Thermal Conductivity (W/m°C)	Thermal Diffusivity (m^2/s)	Bulk Density (Kg/m^3)	Specific heat Capacity (KJ/Kg°C)	Thermal Conductivity (W/m°C)	Thermal Diffusivity (m^2/s)
12	Big	0.78	190.49	22.07	0.198	0.80	191.21	21.06	0.196
	Small	0.63	191.90	21.15	0.186	0.68	192.46	22.86	0.196
15	Small	0.58	192.74	22.65	0.179	0.64	194.23	24.72	0.178
	Big	0.58	195.75	24.08	0.186	0.73	193.56	25.09	0.187
18	Big	0.58	195.75	24.08	0.186	0.73	193.56	25.09	0.187
	Small	0.54	194.20	23.73	0.176	0.57	196.56	25.34	0.165

Effect of Moisture Content on the Specific Heat of African Walnut Flour

The specific heat of the flour sample presented in the Table 1 and Figure 1, showed that specific heat of big and small size oven dried samples of African Walnut flour increased from 190.49 KJ/Kg°C to 195.75 KJ/Kg°C and 191.90 KJ/Kg°C to 194.20 KJ/Kg°C, respectively, while big and small size sun dried samples of African Walnut flour also increased from 191.21KJ/Kg°C to 193.56 KJ/Kg°C and 192.46 KJ/Kg°C to 196.56 KJ/Kg°C with increase in moisture content from 12% to 18% (d.b.) range for the both sample, respectively.

The observed increase in moisture content of the sample had significant effect on the specific heat values ($p < 0.05$) and this similar with *Akbari and Chayjan (2017)* reported on the Moisture content modelling of thermal properties of persimmon. The relationship between the specific heat of the flour sample as it effected by the moisture content and temperature was expressed through the linear regression equation in the Table 2 as SH= 0.8767 (MC) + 179.94 R^2 = 0.9996 and SH= 0.3833(MC) + 187.2 R^2 = 0.9764 for big and small size oven dried sample while the linear regression equation for big and small size sun dried sample are SH = 5.8233 (MC) + 176.79 R^2 = 0.9934 and SH = 489.9ln (MC) - 1192. R^2 = 0.807, respectively.

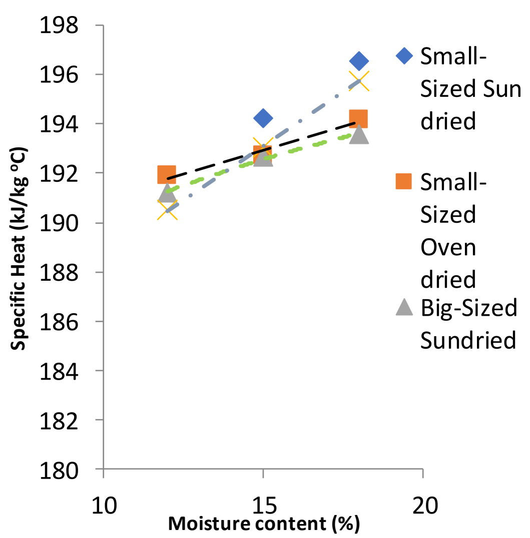

Figure 1: Effect of Moisture Content on Specific Heat of African Walnut Flour.

Effect of Moisture Content on the Thermal Conductivity of African Walnut Flour

The thermal conductivity of the of the African Walnut flour sample presented in Figure 2 showed that the thermal conductivity of big and small size oven dried processed African Walnut flour increased from 22.07 W/m°C to 24.08 W/m°C and 21.15 W/m°C 23.73 W/m°C with increase in moisture content from 12% to 18%, respectively while big and small size sun dried processed African Walnut flour increased from 21.06 W/m°C to 25.09 W/m°C and 22.86 W/m°C to 25.34 W/m°C with corresponding increase in moisture content from 12% to 18%. It implies that thermal conductivity measured in three moisture content level were significantly different ($p < 0.05$). This means that at every unit increase in ground African Walnut flour moisture content, there will be corresponding unit increase in its thermal conductivity.

This increase in thermal conductivity of African Walnut flour with increase in moisture content is due to heat transfer rate in the flour is better when the sample is wet than when it is dried *(Jibril et al., 2016).* The relationship of thermal conductivity of African Walnut flour and its moisture content is expressed in the equations below, TC = 9.966ln (MC) - 3.656 R^2 = 0.9979 and TC = 5.0173ln (MC) + 9.7112 R^2 = 0.9594 for big sun dried and big oven dried, respectively, while TC=6.1981ln (MC) + 7.6062 R^2 = 0.9511, TC = 5.0173ln (MC) + 9.7112 R^2 = 0.9594 for both small sun and oven dried, respectively. This is very similar with what *Aviara and Haque (2008)* on thermal properties of Guna seed and *Mahapatra et al., (2013)* on thermal properties of Cowpea flour.

Effect of Moisture Content on the Thermal Diffusivity of African Walnut

The thermal diffusivity of African Walnut flour is presented in Figure 3, showed that the thermal diffusivity of big and small size oven dried processed African Walnut flour decreased from 0.198 m^2/s to 0.186 m^2/s and 0.186 m^2/s to 0.176 m^2/s with increase in moisture content from 12% to 18%, respectively, while big and small size sun dried processed African Walnut flour decreased from 0.196 m^2/s to 0.187 m^2/s and 0.196 m^2/s to 0.165 m^2/s with increase in moisture content from 12% to 18%.

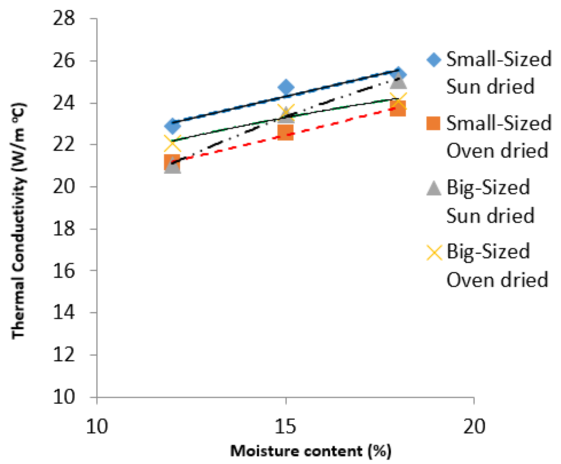

Figure 2: Effect of Moisture Content on Thermal Conductivity of African Walnut Flour.

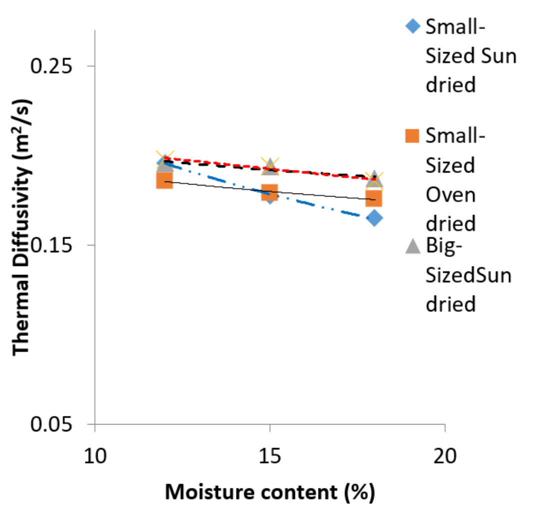

Figure 3: Effect of Moisture Content on Thermal Diffusivity of African Walnut Flour.

The observed different in moisture and thermal diffusivity were significant in moisture content and insignificant with respect to drying method at ($p<0.05$). This is attributed to the fact that thermal diffusivity of the flour sample depends on bulk density. This means that African Walnut flour has the ability to gain and retain heat as the moisture content decreases. The relationship between the thermal diffusivity and moisture content was best described in the following equations below TD= -0.077ln (MC) + 0.3861 R^2 = 0.9988 and TD = -0.025ln (MC) + 0.2475 R^2 = 0.9717 for small sun dried and small oven dried, respectively, while TD = -0.0015 MC + 0.2148 R^2 = 0.9067 and TD = -0.0015 MC + 0.2148 R^2 = 0.9067 for both big sun and oven dried samples, respectively.

Effect of Moisture Content on the Bulk Density of African Walnut Flour

The bulk density of African Walnut flour is presented in Figure 4, showed that the bulk density of big and small size oven dried processed African Walnut flour decreased from 0.78 Kg/m^3 to 0.58 Kg/m^3 and 0.63 Kg/m^3 to 0.54 Kg/m^3 with increase in moisture content from 12% to 18%, respectively while big and small size sundried processed African Walnut flour decreased from 0.80 Kg/m^3 to 0.73 Kg/m^3 and 0.68 Kg/m^3 to 0.57 Kg/m^3 with increase in moisture content from 12% to 18%. The observed different in moisture and bulk density were significant in moisture content but not significant across the drying method at ($p<0.05$). This is attributed to the fact that bulk density of the flour sample depends on thermal diffusivity.

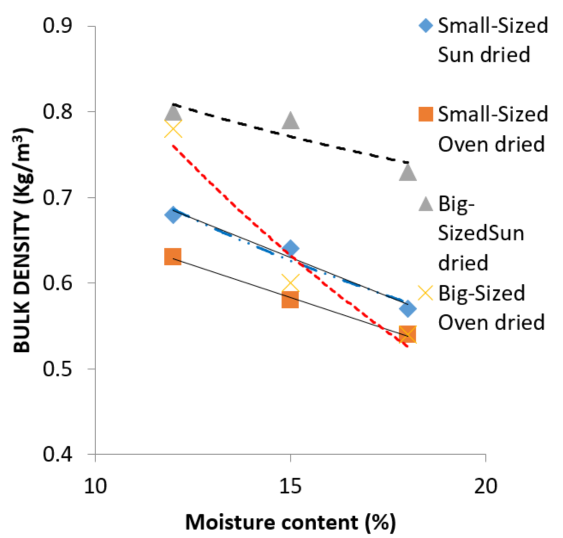

Figure 4: Effect of Moisture Content on Bulky Density of African Walnut Flour.

Bulk density is known have implication in the packing and transportation of food materials, the sample with higher bulk density are known to exhibit better packing factor and transportation advantages than those with low bulk density, based on this fact as the moisture content decreases the packing factor and transportation advantages increases *(Arinola and Jeje, 2017).*

The relationship between the bulk density and moisture content was best described in the following equations below BD = -0.0183 MC + 0.905 R^2 = 0.9758 and BD = -0.015 MC + 0.8083 R^2 = 0.9959 for small sun dried and small oven dried, respectively, while BD = 0.9715 + -0.015 MC R^2 = 0.8508, BD -0.04 MC + 1.24 R^2 = 0.9231 for both big sun and oven dried, respectively.

CONCLUSION

In this study, the effect of moisture content on specific heat, thermal conductivity, thermal diffusivity, and bulk density of African Walnut flour was investigated. Thermal properties of African Walnut determined as a function of moisture content varied significantly with increase moisture content. Thermal properties are frequent important in the engineering design calculations involving thermal processing such as pasteurization, sterilization, drying, heating, cooling, refrigeration, freezing, thawing, baking, and frying in food processing, handling and preservation operations.

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SUGGESTED CITATION

Ezeagba, A.C., I.S. Oluka, and E.P. Ide. 2019. "Effect of Moisture Content and Drying Methods on the Thermal Properties of African Walnut Flour". *Pacific Journal of Science and Technology*. 20(2):217-223.

Pacific Journal of Science and Technology