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# STUDY ON EFFECT OF MOISTURE CONTENT ON THERMAL PROPERTIES OF BAMBARA GROUNDNUT (*Vignasubterranea L. Verdc.*) SEED

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## Abstract

*Thermal properties of food product are very important in the design of drying, processing and storage equipment. To this end, the specific heat capacity, thermal conductivity, and thermal diffusivity of Bambara groundnut seeds were determined as a function of moisture content. Specific heat capacity was determined by the Differential Scanning Calorimeter. The thermal conductivity was determined by transient heat flow using line heat source method. Thermal diffusivity was determined theoretically from the specific heat and thermal conductivity values. The specific heat capacity varied from 1.113 to 3.076 kJ/kg$^{o}$Kat moisture content range of 7.05 to 23.00% d.b.The thermal conductivity varied from 0.0358 to 0.1864 W/m$^{0}$K at 7.05 to 23.00% d.b. Thermal diffusivity varied from 7.6541x10$^{-5}$ to 9.4981x10$^{-5}$ m$^{2}$/s with increasing moisture content in the range of 7.05 to 23.00% d.b. Thermal conductivity and specific capacity were found to increase linearly with increasing moisture content while thermal diffusivity increase not linearly with increase in moisture content. The values obtained could be used as parameters in the designing and manufacturing of equipment. Specific heat is the property needed in the estimation of the amount of energy required to change the temperature of a product, while thermal conductivity and thermal diffusivity are involved in the determination of the rate of heat transfer for efficient process and equipment design. Thermal properties of agricultural materials and foods need to be known to better understand their nature and to be able to develop new technologies. Knowledge of thermal properties is important for mathematical modeling and simulation of heat and moisture transport. However, the moisture content significantly affects different thermal characteristics. The presented models and equations in this study allow engineers to predict these properties, thus saving time, material and cost.*

***Keywords:****Thermal conductivity, Specific heat, Moisture content, Thermal diffusivity, Bulk density, Temperature, DSC, Line heat source, Bambara groundnut seeds*

## Introduction

Bambara groundnut (Vignasubterranea L. Verdc.) seeds is an easy to cultivate legume seed which is widely grown throughout tropical Africa, Indonesia, Malaysia, India, Sri Lanka, Central and South America and some parts of Northern Australia (Eltayeb et al., 2011). Bambara groundnut originated in West Africa with its name derived from the Bambara tribe who now lives in Mali (Nwanna et al., 2005). Considered as one of the main attributes of Bambara groundnut is its tolerance of poor soils and drought, as well as its ability to yield in conditions in which groundnut fails completely.

Bambara groundnut which is primarily grown for its edible seeds are lower in oil content compared to groundnuts, but higher in protein and carbohydrates. The seeds may be consumed fresh, grilled or it may be soaked and boiled before consumption (Sirivongpaisal, 2008). The varieties of the seeds have four colours which are black, red, brown and cream. Although it is a nutritious crop and underutilized in Nigeria. The crop is essentially grown for human consumption.

Adebowaleet al., 2002 also reported that it is richer than groundnut in essential amino acids such as leucine, isoleucine, lysine, methionine, phenylalanine, threonine and valine. Bambara groundnuts have been fairly well supplied with calcium and iron although poor in phosphorus. It contains thiamine, riboflavin, niacin and carotene but very low in ascorbic acid (Adebowale&Lawal, 2004).

Bambara seeds may be consumed in various forms for food. Fresh seeds may be consumed raw, boiled, grilled or dry seeds made into a powdery form to make cakes (Adebowale and Lawal, 2002). The seed is regarded as a balanced food because when compared to most food legumes, it is rich in iron and the protein contains high lysine and methionine (AduDapaah and Sangwan, 2004).

Processing of Bambara groundnuts into these aforementioned products often involves heat treatment either by heat addition (drying, dry aeration to prevent spoilage during storage, sterilization, freezing, etc) or heat removal (cooling or tempering), all of which required a good knowledge of the thermal behaviour of Bambara groundnut. Knowledge of thermal properties of food and agricultural products is essential for equipment design and prediction of heat transfer operations involving foods and vegetables (Viviana et al., 2008).

The thermal properties of agricultural materials are greatly affected by its temperature and moisture content. In general, specific heat is represented by a function of moisture content using linear relations (Yang et al. 2002). In early work, the effect of temperature on specific heat of agricultural materials was generally not considered (Singh &Goswami 2000). The differential scanning calorimetry (DSC) facilitates the measurement of specific heat as a function of moisture content and temperature.

Thermal conductivity, thermal diffusivity and specific heat capacity are three important engineering properties of a material related to heat transfer characteristics. These parameters are essential in studying heating, drying and cooling processes for coriander seeds by YalcinCoskuner and ErsanKarababa (2006).

Specific heat the property needed in the estimation of the amount of energy required to change the temperature of a food by one degree. It can be used to calculate the heat load imposed on the equipment by the loosing or gaining of heat. Thermal diffusivity is an important parameter that quantifies the ability of a food material to store thermal energy during heat transfer processes. Thermal diffusivity is defined as the ratio of thermal conductivity to specific heat and is the rate at which heat diffuses within a food material. It is the rate which thermal energy diffuses by conduction through a material (K. C. Yadav, 2005).

Objectives of the Research

The objective of the study was conducted on the effect of moisture content variation on;

i. Specific heat, thermal conductivity and thermal diffusivity needed in food processing machinery design.
ii. To develop equations for the prediction of thermal properties as a function of moisture contents.

## Materials and Methods

This chapter covers the description of methods applied, materials, instruments used and system adopted to perform the operation involved to achieve the objectives. The experiment was conducted in the Laboratory of Food Process Engineering Department, Vaugh School of Agricultural Engineering & Technology, SHIATS-Allahabad. The study has been divided into two parts one as to measure thermal properties and second as to evaluate the effect of moisture content on Bambara groundnuts seeds.

**Raw materials**

The study was conducted with the good quality of Bambara groundnut seeds as were provided by the International Institute of Tropical Agriculture, (IITA), located at Sabo BakinZuwo, Kano. Broken, dirt, spoiled and other foreign materials were discarded before sample were prepared for the experiment.

### 3.2 Experimental procedures

**Moisture content**

In order to obtain the desired moisture content, the samples were conditioned by soaking the grains with required quantity of water and mixing thoroughly and then sealing them in a polyethylene bags for some hours to allow the moisture to distribute uniformly throughout the sample. All of the physical properties of the grain were assessed at one hour different time interval. For attaining equilibrium, the samples were placed in air tight plastic container until further use (Ndirika et al, 2006).

The amount of distilled water was added based on equation (Solomon and Zewdu, 2008, Bart-Plange and Baryeh, 2003);

$$Q = Wi\frac{(M_f - M_i)}{(100 - M_f)}$$

Q = is the mass of water to be added in kg; $W_i$ = is the initial mass of the sample in kg; $M_i$ = is the initial moisture content of the sample in % db and $M_f$ = is the final moisture content in % db.

**Determination of thermal properties**

Thermal properties such as specific heat, thermal conductivity, thermal diffusivity and bulk density were measured.

**Specific Heat**

Specific heat is the property needed in the estimation of the amount of energy required to change the temperature of a product. These properties indicate the ability of theseed to retain heat when processed and is not dependent on its mass density.

**Specific heat Experimental procedure**

The most popular modern thermal analysis technique is the Differential Scanning Calorimetry (DSC). In the present study, the effect of heating rates was determined by DSC.

Differential scanning calorimetryor DSC is a thermo-analytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature. The sample is maintained at nearly the same temperature throughout the experiment. Generally, the temperature program for a DSC analysis is designed such that the sample holder temperature increases linearly as a function of time.

Differential scanning calorimeter technique was used to determine the specific heat capacity of Bambara groundnut powder by thermal analyser (DSC 204 Phoenix, Thermische Analyse, NETZSCH, Germany). The DSC measures specific heat capacity by heating a sample and measuring the temperature difference between the sample and a reference.

As described by K.K. Singh and T.K. Goswami (2000). Sample was crushed and a portion of the powder obtained was filled in the aluminium crucible (6 mm diameter and 1.5 mm deep) which was covered with an aluminium lid.

The sample was brought to the initial temperature by cooling with liquid nitrogen. It was allowed to equilibrate isothermally and then scanned dynamically at the rate of $5^0$C per min over the selected temperature range of 10 to $50^0$C.

Finally, the weighed five milligram sample of Bambara groundnut powder was taken to run the experiment for specific heat after activating the nitrogen gas and oxygen gas in the system. The DSC provided thermogram which is used to evaluate the specific heat of the sample.

**Thermal conductivity**

Thermal conductivity determine the ability to which an agricultural product conducts heat is necessary to predict or control the flow of heat in this product during processing operations, such as steady and transient.

**Thermal Conductivity Experimental procedure**

Thermal conductivity values of Bambara groundnut seeds have been determined by transient heat flow method. The transient heat flow is considered in an infinitive homogeneous medium heated by a line-heat source.

The Bambara groundnut seed was milled using a hand miller. The milled samples were kept in polythene bags and stored in a cool and dry place to avoid any moisture addition. The samples were divided into parts, and these parts were conditioned to achieve the various desired moisture content.

Conditioned samples were placed in the sample cylinder in the set-up of the thermal conductivity measuring apparatus. The thermocouple (thermometer) was used to determine the temperature of the sample in the cylinder. This was positioned some distance away from the heating wire in the cylinder. The switch was closed when the temperature became stable. Current and voltage readings were adjusted to 1 amperes and 3 volts respectively. Temperature readings were taken at sixty seconds time interval after a constant heat flow was attained.

Thermal conductivity was determined from equation be used by Tansakul and Lumyong (2008), Kara et al. (2011) and Afriyieet al. (2016).

$$k = \frac{Q}{4\pi(T_2 - T_1)} \ln(\frac{t_2}{t_1})$$

The heat flow per metre was obtained from the relation

$$Q = \frac{VI}{L}$$

Where;
V = Voltage across the ends
I = Current used
L = Length of sample tube
k = Thermal conductivity of the medium (W/m$^0$K)
T1 = Initial temperature (°C)
T2 = Final temperature (°C)
t1 = Initial time (mint)
t2 = Final time (mint)

The thermal conductivity apparatus as shown in figure 1 is a simple setup consisting of

(i) Aluminium cylinder.
(ii) Heating wire or a heater stretching between two insulated ends of the cylinder.
(iii) Thermocouple was fitted for temperature readings in the sample.
(iv) Voltmeter connected across the heater for voltage readings.
(v) Ammeter for recording the current which was supplied from a DC source.
(vi) Rheostat for varying the resistance in the circuit.
(vii) Switch to open or close the circuit for the current to flow through the heating wire for heat supply.

This set up was made for determination of thermal conductivity of Bambara groundnut seeds.

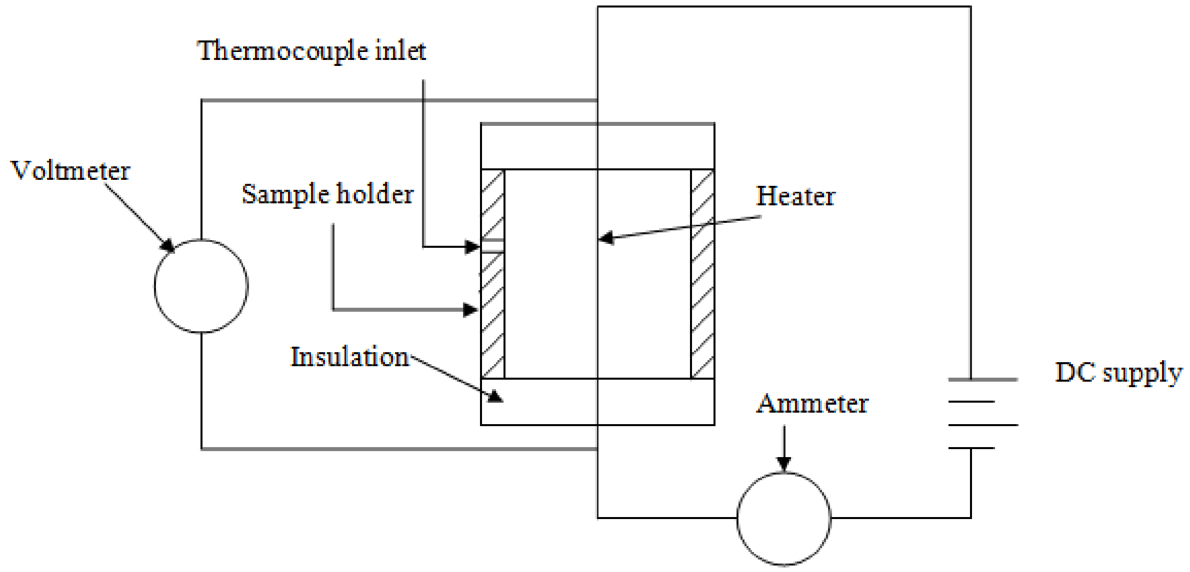


Figure 1: Schematic diagram of the thermal conductivity measuring apparatus.

**Thermal Diffusivity**

Thermal diffusivity is an important parameter that quantifies the ability of a food material to store thermal energy during heat transfer processes. Thermal diffusivity is defined as the ratio of thermal conductivity to specific heat and is the rate at which heat diffuses within a food material.

**Thermal Diffusivity Experimental procedure**

Thermal diffusivity of samples was calculated using the experimental value of specific heat, thermal conductivity and bulk density from equation below as described by Tansakul and Chaisawang (2006);

$$\alpha = \frac{k}{\rho C_p}$$

Where;

$\alpha$ = Thermal diffusivity in $m^2/s$

k = Thermal conductivity $W/m^0K$

$\rho$ = Bulk density in $kg/m^3$,

$C_p$ = specific heat capacity in $J/kg^oK$.

**Bulk Density**

Bulk Density is necessary to determine thermal diffusivity of Bambara groundnuts seeds. The bulk density was calculated by dividing the mass of samples filling the cylinder with the volume of the cylinder. The bulk density ware calculated from the relationship Zewdu and Solomon, 2009:

$$\text{Bulk Density} \left(\frac{\text{Kg}}{\text{m3}}\right) = \frac{\text{Weight of the seeds (Kg)}}{\text{Volume of Container (m3)}}$$

Other parameters were determined using DSC and transient heat flow method for specific heat and thermal conductivity respectively.

### Results and discussion

This chapter deals with the results obtained from the different experiment of the present investigation, such as thermal properties and it is effect of moisture and temperature on some parameters. The observation recorded through various experiments have been made to develop a graph plots to describe the effects of the process parameters on responses. The findings have been explained suitably with logical reasons whenever possible. The findings also have been in discussed in the light of theories and with the literature support to the possible extent.

The results obtained were subjected to t-test analysis, plot test and analysis of regression using sigma software (version 13, USA).

All the above experiments were replicated five times, unless stated otherwise and the average values reported.

### Thermal properties

For determining the thermal parameters, Differential Scanning Calorimeter (DSC), transient heat flow method for thermal conductivity set up was used and bulk density was determined by dividing the mass of samples filling the cylinder with the volume of the cylinder. This data is useful in the heat load imposed on the equipment by the loosing or gaining of heat, estimating process time of heating, cooling, freezing and cooking

### Specific heat

Specific heat of Bambara groundnut seeds are presented in table 1.1. Pyris manager software was installed in the system for evaluating the data.

Table 1.1: Specific Heat

| Moisture Content (%, d.b.) | Observations | Specific Heat kJ/kg$^0$K |
|---|---|---|
| 7.05 | 5 | 1.113±2.015 |
| 11.09 | 5 | 1.508±5.973 |
| 15.24 | 5 | 1.951±2.613 |
| 19.00 | 5 | 2.526±1.028 |
| 23.00 | 5 | 3.076±2.967 |

### Thermal conductivity

Thermal conductivity of Bambara groundnut seeds are presented in table 1.2.

Table 1.2: Thermal Conductivity

| Moisture Content (%, d.b.) | Observations | Thermal Conductivity W/m$^0$K |
|---|---|---|
| 7.05 | 5 | 0.0358±0.215 |
| 11.09 | 5 | 0.0726±0.399 |
| 15.24 | 5 | 0.1102±0.243 |
| 19.00 | 5 | 0.1538±0.559 |
| 23.00 | 5 | 0.1864±0.137 |

Thermal conductivity values are comparable with the thermal conductivity of some other grain seed of the same nature.

**Thermal diffusivity**

Thermal diffusivity is described in table 1.3.

Table 1.3: Thermal diffusivity

| **Moisture Content (%, d.b.)** | **Observations** | **Thermal Diffusivity x $10^{-5}m^2/s$** |
|---|---|---|
| 7.05 | 5 | 7.6541±0.010 |
| 11.09 | 5 | 7.8645±0.032 |
| 15.24 | 5 | 8.3147±0.001 |
| 19.00 | 5 | 8.7397±0.068 |
| 23.00 | 5 | 9.4981±0.036 |

**Effect of moisture content on thermal properties of Bambara groundnut seeds**

Thermal properties such as specific heat, thermal conductivity and thermal diffusivity were measured and determined by the methods described earlier. Thermal properties were measured and determined at different moisture content of the seed. The replications were made for each property measurement.

**Effect of moisture content on the specific heat**

Specific heat capacity is needed in estimating the amount of heat energy required to change the temperature of locust bean seeds by $1^0$C. The specific heat capacity of Bambara groundnutseeds increased linearly from 1.113 to 3.076 kJ/kg$^o$K with increase in seed moisture content from 7.05 to 23.00% d.b. and was statistically significant ($p<0.05$) as shown in figure 2.Increased specific heat with increasing moisture content is due to the high specific heat of water compared to the dry material and the water occupying the air-filled pores faster at lower moisture contents. Therefore, the results of specific heat capacity will be useful in determining heat energy required for optimization of the processing stages to reduce the boiling duration to the barest minimum. This is also important in the design of dehullers.

The equation showing the relationship existing between specific heat capacity and moisture content is presented as;

$$\text{Specific Heat} = 0.1241MC + 0.1722 \qquad (R^2 = 0.9944)$$

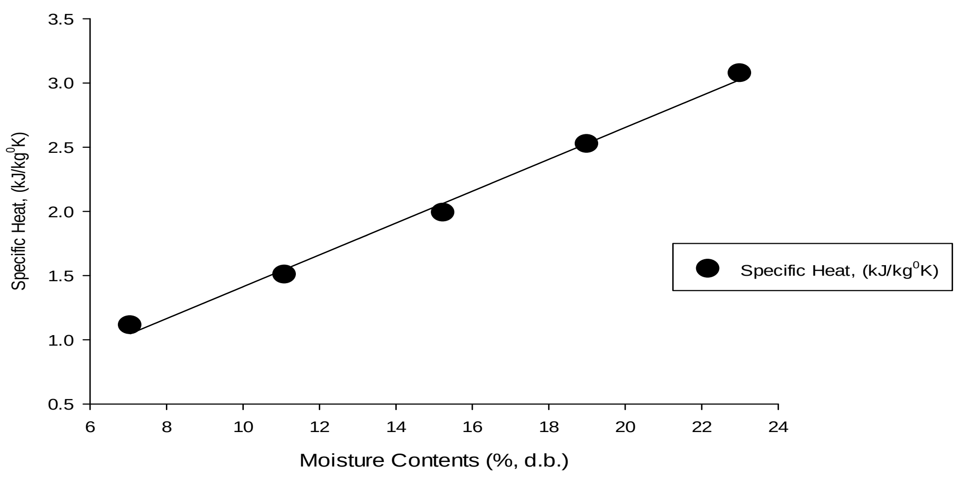


Figure 2.

Similar trend was reported by Singh and Goswani (2000) for Cumin seed, millet flours (Subramanian and Viswanathan, (2003), okra and bitter grourd (Yadav K. C. et. al., 2005), Razavi and Taghizadeh (2007), for Pistachio nuts ground guna seed (Aviara et al., 2008), cowpea flour (Mahapatra et al., 2013) and cryo-ground fenugreek powder (Barnwal et al., 2014).

**Effect of moisture content on the Thermal conductivity**

This is the possibility of transmission of heat within seeds in a bulk. The thermal conductivity of the Bambara groundnut seeds was found to be increased linearly from 0.0358 to 0.1864 W/m⁰K as the moisture content increased from 7.05 to 23.00% (d.b.) and is presented in Figure 3. The mean thermal conductivity values measured at five moisture content levels were significantly different ($p<0.05$). This means that for every unit increase in ground flaxseed moisture content, there will be a corresponding unit increase in its thermal conductivity. The increased thermal conductivity of Bambara groundnut seeds with increasing moisture content might be due to heat transfer rate in the seed is better when wet than when they are dried.

The relationship of thermal conductivity and moisture content is expressed in equation below;

$$\text{Thermal Conductivity} = 0.0096MC + 0.0330 \qquad R^2 = 0.9977$$

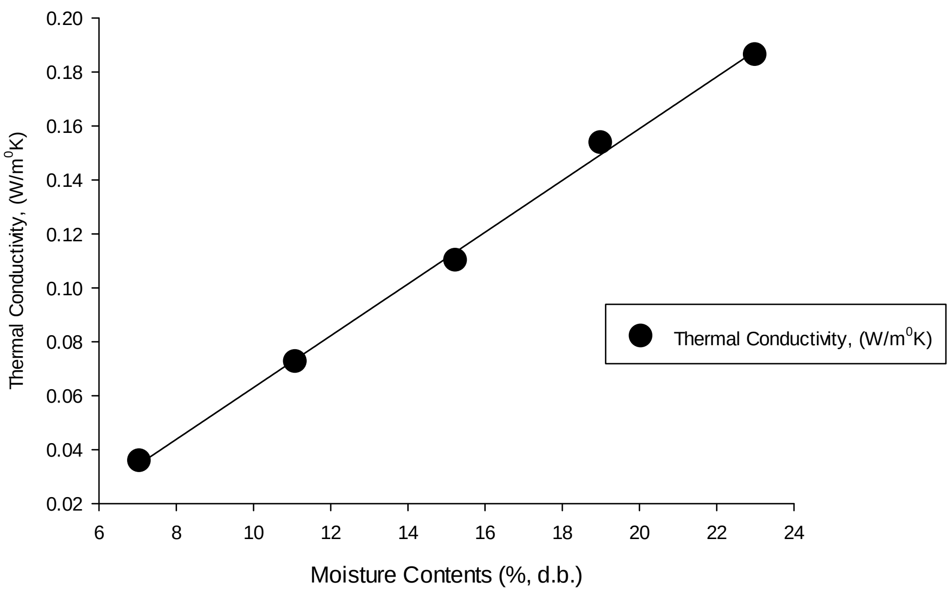


Figure 3.

Similar result was reported for Cumin seed by Singh and Goswani (2000), sheanut kernel (Aviara and Haque, 2001), borage seeds (Yang et al., 2002), rough rice (Yang et al., 2003), wheat flour Božiková (2003), okra and bitter grourd (Yadav K. C. et. al., 2005),guna seed (Aviaraet al., 2008), pumpkin seed (Kocabiyikaet al., 2009), rice flour (Mahapatra et al., 2011) and cowpea flour (Mahapatra et al., 2013).

**Effect of moisture content on the Thermal diffusivity**

The thermal diffusivity of Bambara groundnut seed increased from $7.6541 \times 10^{-5}$ to $9.4981 \times 10^{-5}$ $m^2/s$ as the moisture content increased from 7.05 to 23.00% (w.b.). Though the moisture effect was not statistically significant ($p<0.05$) as shown in Figure 4. The reason behind the increase of thermal diffusivity may be attributed to its dependence on bulk density which also affects the porosity of the seed thereby making it possible for the seeds to transmit heat and have the ability to store it. It simply means that Bambara groundnut seeds have high ability to gain and retain heat as moisture content increases. Thermal diffusivity is necessary in the design of steamers and dehullers for processing machinery.

The relationship between thermal diffusivity and moisture content was expressed in equation below;

$$\text{Thermal Diffusivity} = 0.0714M + 7.7187 \qquad R^2 = 0.9357$$

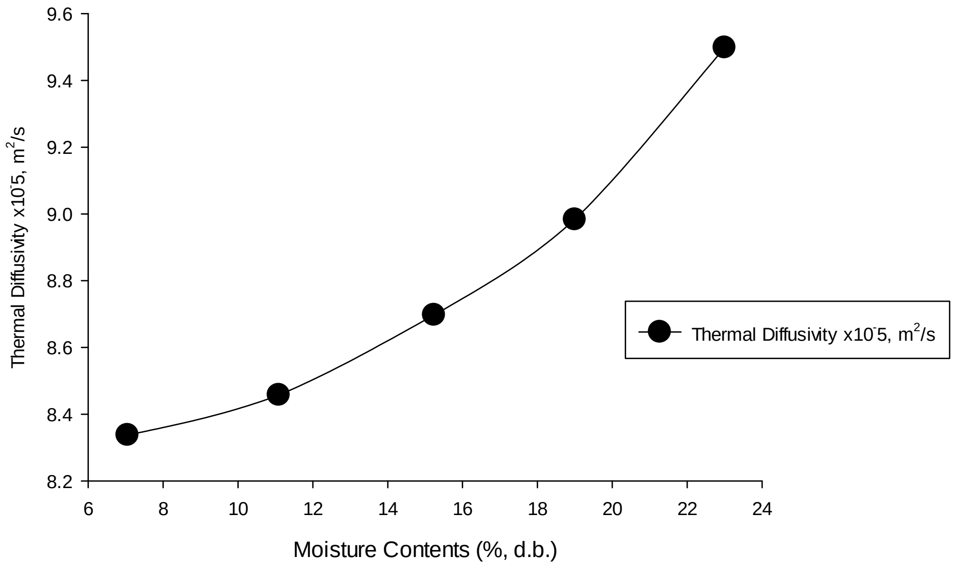


Figure 4.

Similar pattern was observed for Sheanut kernels by Aviara and Haque (2001), for corn and wheat flour (Božiková, 2003), okra and bitter grourd (Yadav K. C. et. al., 2005), for cowpea flour (Mahapatra et al. 2013), millet flour (Subramanian and Viswanathan, 2003), for Roselle seeds (Bamgboye and Adejumo, 2010) and cryo-ground fenugreek powder (Barnwal et al., 2014).

**CONCLUSIONS**

In this study, the effect of moisture content on specific heat, thermal conductivity and thermal diffusivity of Bambara groundnut seeds was investigated. The thermal properties of Bambara groundnut seeds determined as a function of moisture content varied significantly with increased moisture content. Thermal properties are frequently 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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