DETERMINATION OF THERMAL PROPERTIES OF RED HORSE COWPEA SEED AS A FUNCTION OF MOISTURE CONTENTS

Yisau Bolanle*, Rasaq Babatunde# & AbdulAzeez Oderinde
Department of Science Laboratory Technology, The Federal Polytechnic, Ilaro, Ogun State Nigeria.
*yisau.bolanle@federalpolyilaro.edu.ng. 08026894514
#rasaq.babatunde@federalpolyilaro.edu.ng.

Abstract

The effects of moisture content on thermal properties of red horse cowpea seeds were investigated on a range of 15% to 35% wet basis at 5% intervals, for five moisture levels. The considered thermal properties were thermal conductivity, thermal diffusivity, and specific heat. Increase in moisture content from 15% to 35%, resulted in increase in the thermal conductivity, thermal diffusivity, and specific heat from 0.41 to 1.32 W m^{-1} $^{o}c^{-1}$, 0.000015 to 0.000039 m^2 s^{-1}, and 0.26 to 2.62 J g^{-1} $^{o}C^{-1}$, respectively. The result obtained proved that the thermal properties of the sample was improved by increasing temperature and moisture contents. Thus, thermal properties were found to be moisture dependent. The data are necessary for design of equipment's and facilities for the drying, preservation and processing of the seeds.

Keywords: Moisture content, specific heat, **t**hermal conductivity, thermal diffusivity.

Introduction

Cowpea, is a food legume of the family *Fabaceae/Papilionaceae* (Oyewale & Bamiyi, 2013). All cultivated cowpeas are grouped under the species *Vigna unguiculata*, which is subdivided into four cultivar groups: *Unguiculata, Biflora, Sesquipedalis and Textilis*. They can be distinguished from one another by different physiological factors such as seed size and color, taste, yield and maturity time (Ries & Frederico, 2001). Hence, the plant is a herbaceous legume which shows considerable adaptation to the warm climate with adequate rainfall, it is cultivated across Southeast Asia, Africa, Southern United States and Latin America. The origin of cowpea is considered as Africa. It is one of the sources of food for millions of people mainly in developing countries with an annual worldwide production of about 4.5 million metric tons (Animasaun, Oyedeji, Mustapha, & Azeez, 2015).

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 (Mahapatra, Melton, & Isang, 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 (Fontana, Varith, Ikediala, Reyes, & Wacker, 1999).

Thermal conductivity is defined as the ratio of heat flux density to temperature gradient in a food material. It is a measure of the ease with which heat flows through a food material and this property can be used to predict or control heat flux in food processing operations such as cooking, freezing, sterilization, drying or pasteurization (Fontana et al., 1999). Thermal diffusivity is the ratio of thermal conductivity to specific heat and is the rate at which heat diffuses within a food material. This property helps in estimating processing time of heating, cooling, freezing and cooking (Fontana et al., 1999). It is also used in calculating temperature change in storage bins because of fluctuations in external and internal temperature (Irtwange and Igbeka, 2003).

Specific heat or heat capacity is the amount of heat required to raise the temperature of a unit mass of a food material by 1°C. It is the ability of a food material to store heat relative to its ability to conduct (loose or gain) heat. Specific heat is an important thermal property used in heat transfer and energy balance calculations (Kaletunç, 2007).

The thermal conductivity has been evaluated as a function of moisture content in various literatures. The result below shown that thermal conductivity of Peanut Pod, kernel, and shell was determined at different moisture levels. It was observed that the thermal conductivity of Peanut pod, kernel and shell increased linearly from 0.12 to 0.16, 0.15 to 0.19, and 0.11 to 0.18 $Wm^{-1}s^{-1}$ respectively with increase in moisture level of 5.2 to 23.7, 5.0 to 30.6, and 3.5 to 28.7 % w.b. respectively. (Bitra, Banu, Ramakrishna, Narender & Womac, 2010).

The thermal conductivity of persimmon fruit was determined at different moisture levels. The transient-state line heat source method was used in the evaluation of the thermal conductivity of the persimmon fruit, it was evaluated that the thermal conductivity of the sample was given to increase from 0.14 to 1.3819 $Wm^{-1}s^{-1}$ with an increase in moisture level of 37.33, 56.49, 70.47, and 88.42 % (w.b.). (Akbari & Chayjan, 2017).

The thermal diffusivity of peanut pod, kernel, and shell was determined at different moisture levels ranging from 5.2 to 23.7, 5.0 to 30.6, and 3.5 to 28.7% (d.b.) respectively. The thermal diffusivity of peanut pods and kernels was determined using the formula method, in which the thermal conductivity, specific heat capacity, and bulk density were determined firstly and these calculated values were used to determine it. It was found that the thermal diffusivity decrease from 2.8 X 10^{-7} to 2.3 X 10^{-7} and 1.1 X 10^{-7} to 1.0 X 10^{-7} m^2 s^{-1}, respectively, with an increase in moisture content. But, the diffusivity of shells increased from 5.9 X 10^{-7} to 6.7 X 10^{-7} m^2 s^{-1}. The thermal diffusivity of shells was the highest, followed by pods and kernels. (Bitra et al., 2010).

The thermal diffusivity of locust beans was evaluated for moisture levels ranging from 5.9–28.2 % (d.b.). The thermal diffusivity of the locust beans was seen to increase from 2.93 X 10^{-8} to 3.79 X 10^{-8} m^2 s^{-1} with increasing moisture levels. (Olajide & Isaac, 2014).

Moshen, Mohamad, Barat, & Saeid, (2013), used method of mixture, which is the most accurate method as reported in different literatures, to investigate the Specific heat capacity of soybean pod at different moisture level of 14.5, 21.5, 25.5, and 30.5 % (w.b.). Thus, increase in specific heat capacity of the sample was reported from (1.856 to 4.39) jg^{-1} ^{o}C with increase in moisture contents.

The specific heat capacity for peanut pods, kernels and shells were investigated as a function of moisture content. The method of mixture was employed using a built in Vacuum flask calorimeter to determine the specific heat capacity of the Peanut Pod, kernel, and shell. It was also recorded that the specific heat of the pod, kernel, and shell increased linearly from 2.1 to 3.3, 1.9 to 2.8, and 2.7 to 4.1 $Jg^{-1\circ}$C respectively, at moisture levels of 5.2 to 23.7, 5.0 to 30.6, and 3.5 to 28.7 %(w.b.) respectively. (Bitra et al., 2010).

Then, specific heat capacity of Persimmon fruit was determined using formula method, in which the thermal conductivity and thermal diffusivity were initially determined and the specific heat was then calculated at different moisture levels. It was also reported that the specific heat capacity of the persimmon fruit increased non-linearly from (3.50 to 6.01) $jg^{-1\circ}$C with increased moisture levels of 37.77, 56.49, 70.47 and 88.42 % (w.b.) (Akbari et al., 2017).

Materials and Methods

Sample Collection and Preparation

Horse red cowpea was purchased at the local market in Ilaro, Ogun State, Nigeria. The initial moisture content of the red horse cowpea was determined by using the standard oven-drying method at 105±1^{o}C. Five different levels of moisture contents determined by adding a calculated quantity of distilled water to the samples (eqn 1). The prepared samples were sealed in different polythene bags and then placed in the refrigerator at 5^{o}C for 48hrs in other for the moisture to diffuse uniformly in the samples. Before each test the required sample was taken out of the refrigerator and allowed to be at equilibrium with ambient temperature for 24 hrs. Evaluation of the effect of moisture content on the thermal properties of red horse cowpea was carried out at five moisture levels (15%, 20%, 25%, 30% and 35%) and all of which were measured on a wet basis (w.b.).

$$Q = \frac{A(b-a)}{100-b} \qquad (1)$$

Where Q = Quantity of water added (Kg)
A =Initial mass of sample (Kg)
b = Final moisture level (% w.b)
a = Initial moisture level (% w.b)

Thermal Properties Measurement

The method of mixture was employed using a built in Vacuum flask calorimeter to determine the specific heat capacity of the samples in this study. Specific heat capacity of the calorimeter used was determined by adding a known mass of hot water to the calorimeter after which its specific heat was calculated, the result obtained from this calculation was applied to determine the specific heat of the test samples. The specific heat capacity of the sample determined was observed to increase from 1.856 to 4.39jg^{-1}°C with increase in moisture levels.(Moshen et al., 2013).

Thermal Conductivity Determination of Red Horse Cowpea

The coefficient of thermal conductivity of the red horse cowpea was determined using the line heat source method. Before the experiment, the initial temperature of the samples at desired moisture content and ambient temperature were both measured. During the heating process, the temperature of the samples was read and recorded at a selected interval of time (30 seconds).

$$k = \frac{VI\ln(\frac{t_2}{t_1})}{4\pi l\,(T_2 - T_1)} \qquad (2)$$

Where K = Thermal conductivity

V = Voltage (V)

I = Current (A)

t = Time (s)

T = Temperature (˚C)

Determination of Bulk Density

The bulk density was determined using a regular container having a specific volume. The container was filled with some seeds to the brim. The mass of the seed inside the container was found together with the volume of the container. This is referred to as bulk mass (M_b) and bulk volume (V_b) respectively. The ratio of the bulk mass to the bulk volume was evaluated to give the bulk density as;

$$\beta = \frac{Mb}{Vb}$$

Thermal Diffusivity Determination of Red Horse Cowpea

The thermal diffusivity (ρ) of the red horse cowpea was obtained from the experimental results of thermal conductivity (K), specific heat capacity (Cs) and bulk density (β) using the equation (3) below;

$$\rho = \frac{k}{\beta c_s} \qquad (3)$$

Specific Heat Determination of Calorimeter

The specific heat of the calorimeter, Cc, was determined prior to the determination of the specific heat of the test samples. A calculated amount of hot distilled water was added to the calorimeter and the rate of heat loss was monitored with the passage of time. The initial temperature of calorimeter, Ti and ambient temperature were measured by thermocouple. A measured mass of hot distilled water, Mwh, at a temperature (maintained at 75oC), was then poured into the vacuum flask, the lid closed, and the container agitated at 2 min intervals to equilibrate the temperature. The water temperature was measured with thermocouple with a temperature indicator at various time intervals for 240 min. The temperature history of calorimeter and hot water mixture was plotted on temperature – time graph. Thus, equilibrium temperature was observed at about 60 min of elapsed time. The heat capacity of the calorimeter was obtained by the equation (4):

$$C_c = \frac{Mw_h C_h (T_h - (T_e + T)}{M_c((T_e + T) - T_c)} \qquad (4)$$

Where C_c = Specific heat capacity of flask (Jg^{-1}°C^{-1})
M_{wh} = Mass of hot water (g)
M_c = Mass of calorimeter (g)

C_h =Specific heat capacity of hot water ($Jg^{-1}{}^\circ C^{-1}$)
T_h =Temperature of hot water (˚C)
T_e = Equilibrium Temperature (˚C)
T = Temperature correction (˚C)
T_i = Initial Temperature (˚C)

Specific Heat Determination of Red Horse Cowpea

The initial temperature of calorimeter, T_c , the initial temperature of sample, T_s , and the ambient temperature were measured and recorded. A known mass of red horse cowpea seeds, W_s at specific moisture content was placed in the calorimeter. A known mass of hot distilled water, W_h , at a temperature T_h, which was maintained at 80˚C for all the experiments, was poured into calorimeter with the lid closed, and the container agitated at 2min intervals to maintain equilibrium temperature. A higher temperature of water than the one used during determination of specific heat of calorimeter was used to compensate additional weight of red horse cowpea in calorimeter. The time required to achieve equilibrium temperature by the calorimeter, sample, and hot water mixture was assumed equivalent to 60 min as considered earlier. Hence, the temperature was measured with thermocouple and temperature indicator at different time intervals over 120 mins. The specific heat of sample, C_s , was determined using the equation (5) below:

$$C_s = \frac{\{Mw_h C_h (T_h - (T_e + T)\} - \{M_c C_c ((T_e + T) - T_c)\}}{M_s((T_e + T) - T_s)} \tag{5}$$

Where:

C_s= Specific heat capacity of the sample ($Jg^{-1}{}^\circ C^{-1}$)

M_s = Mass of sample (g)

T_s= Temperature of sample (˚C)

3.0 Results and Discussion

The data recorded in table 1 below are the results of thermal conductivity, thermal diffusivity and specific heat of the sample as a function of moisture contents, obtained from the study. The results of each parameter increased down the table.

Table 1: Moisture contents of red horse cowpea seed and the corresponding values of thermal conductivity, thermal diffusivity and specific heat of the sample.

Moisture Level/%(w.b.)	Thermal conductivity ($Wm^{-1}\ oc^{-1}$)	Thermal diffusivity ($m^2\ s^{-2}$)	Specific heat of the sample ($Jg^{-1}{}^\circ C^{-1}$)
15	0.41	0.000015	0.26
20	0.43	0.000017	0.65
25	0.70	0.000021	0.80
30	0.83	0.000026	1.30
35	1.32	0.000039	2.62

Thermal Conductivity

As the moisture content increased from 15% to 35% (w.b.) the thermal conductivity of samples also increased from 0.26 to 2.62 W $m^{-1}\ {}^oc^{-1}$ (Figure 1). Added water resulted in a higher thermal conductivity of moisture rich cowpea flour. Thermal conductivity of rice flour increased with the increase in moisture content. (Mahapatra, Lan, & Harris, 2011)

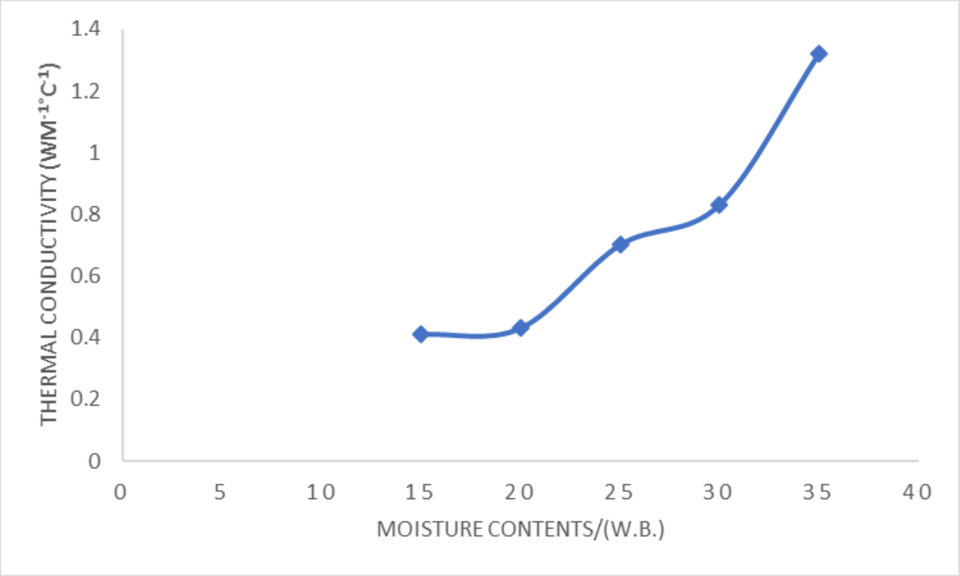

Fig. 1 Thermal conductivity of red horse cowpea as a function of moisture content.

Thermal Diffusivity

Thermal diffusivity of sample increased from 0.000015 to 0.000039 m^2 s^{-1} with increased in moisture content from 15% to 35% (w.b.) (Figure 2). Similar pattern was observed for corn and wheat flour (Božiková, 2003). As moisture content increased, the pores and capillaries of the seeds which was initially filled with air was gradually displaced by absorbed water. Heat was released by water adsorption in the cowpea flour and as a result the thermal diffusivity increased (Kostaropoulos and Saravacos, 1997).

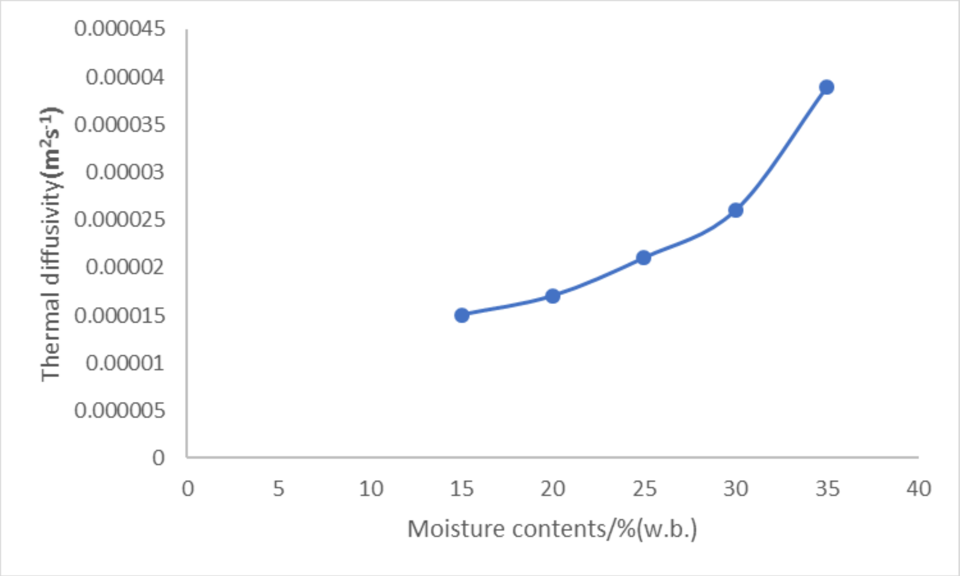

Fig. 2 Thermal diffusivity of red horse cowpea as a function of moisture content.

Specific Heat of the Sample

For specific heat, increase in the moisture content led to an increase in the specific heat (Figure 3). As the moisture content increased from 15% to 35% (w. b.) the specific heat also increased from 0.26 to 2.62 J g^{-1} $^{o}C^{-1}$. The increasing trend in specific heat with moisture content correlates with work done by Nathakaranakule and Prachayawarakorn (1998) who reported similar linear variation with the specific heat of cashew nuts varied linearly with moisture content.

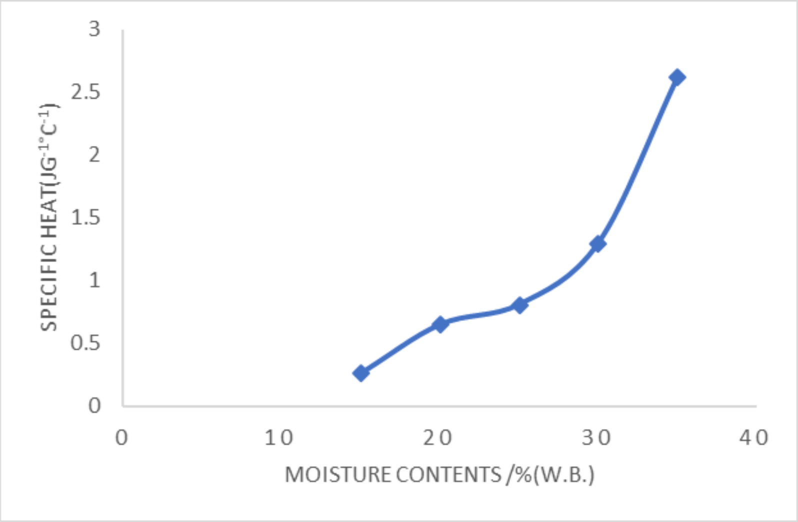

Fig. 3 Specific heat of red horse cowpea as a function of moisture content.

Conclusion

The effect of moisture content on thermal conductivity, thermal diffusivity, and specific heat of red horse cowpea was investigated. Thermal conductivity, thermal diffusivity and specific heat increased with an increase in moisture content. It can be concluded from the results obtained, that moisture content has a significant effect on the thermal properties of red horse cowpea seeds, in this study.

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