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Some moisture dependent thermal properties of Cashew kernel (*Anarcardium occidentale* L.)

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Abstract

Thermal properties of crops are very important in the design of drying, processing and storage equipment. The availability of such relevant information on cashew nutwill aid in the design and manufacture of equipment for postharvest operations. The thermal conductivity, specific heat capacity and thermal diffusivity of cashew kernel were evaluated as a function of moisture content. Specific heat was measured by the method of mixtures while the thermal conductivity was measured by the line heat source probe method. Thermal diffusivity was calculated from the experimental results obtained from specific heat, thermal conductivity and bulk density. The bulk density for nut and kernel decreased from 625.62 to 592.42kg/m^3 and 559.60 to 505.06kg/m^3 respectively with increasing moisture content from 5.0% to 9.0% w.b. Specific heat increased linearly from 1586 to1756J/kgºC with increasing moisutre content. The thermal conductivity ranged from 0.2103 to 0.2296W/mK and thermal diffusivity varied from 2.369×10^{-7} to 2.588×10^{-7}m^2/s. Specific heat, thermal conductivity and thermal diffusivity were found to increase linearly with increasing moisture content from 5.0 to9.0% w.b.

Keywords: cashew, thermal conductivity, thermal diffusivity, moisture content, specific heat.

Abbreviations: ρ_b bulk density, kg/m^3; C_p: specific heat of sample, J/kgK; K:thermal conductivity; W/m K, α :thermal diffusivity m^2/s; Q: mass of water to be added, kg; W_i: initial mass of the sample, kg; M_i: initial moisture content of the sample, % w.b. M_f :final moisture content of the sample, % w.b; C_c:specific heat of calorimeter, J/kgK; C_w:specific heat of water, J/kgK; M_w:mass of water, kg; T_s:initial temperature of sample, K; T_e:equilibrium temperature, K; T_w:initial temperature of water, K; Q_i: heat input, W/m; V:electrical voltage, volts; t_i: initial time, s; t_2:final time, s; T_1:initial temperature, ℃ ; T_2: final temperature, ℃ C_n: cashew nut; C_k: cashew kernel.

Introduction

The cashew tree (*Anarcardium Occidentale* L.) is a native of Brazil and the Lower Amazons. It has been a valuable cash crop in the Americas, the West Indies, Madagascar, India and Malaysia (Frankel, 1991). The tree is now widely distributed throughout the tropics particularly in many parts of Africa and Asia. The five major producing countries are Vietman, India, Nigeria, Côte d'Ivoire and Brazil. Cashew nut is a high value edible nut and it ranks third among the edible tree nuts of the world with a current annual output of 28400 tonnes in Ghana (FAO, 2012). Nuts may be sold raw or as kernels and may be further processed into valued-added products such as fried, roasted, or chocolate-coated kernels and confectioneries (Azam-Ali and Judge, 2001; Ogunsina and Bamgboye, 2007). Following the gradual increasing interest in cashew production in Ghana, there is the need to expand the production base of the crop so as compete with the leading producing and exporting nations in Africa (Ojolo and Ogunsina, 2007). Knowledge of thermal properties of food and agricultural products, are essential for equipment design and prediction of heat transfer operations (Viviana et al., 2007). Thermal properties of various foods and agricultural products have been studied by researchers such as Sherpherd and Bhardwaj(1985) for pigeon pea, Dutta et al. (1988) for gram, Aviara and Hague (2001) for shea nut kernel, Tansakul and Chaisawang(2007) for coconut milk and Nouri Jangi et al. (2011) for barley grains. A study on thermal properties of straw mushroom by Tansakul and Chaisawang (2007) indicated that specific heat, thermal conductivity and thermal diffusivity increased with increase in moisture content. Moisture dependency of engineering properties of some cash and industrial crops have been studied by other researchers (Bart-Plange and Baryeh, 2003 for category B cocoa beans; Yalcin and Ozarslan, 2004 for vetch seed; Kinsley et al. 2005 for pomegranate seed; Yang and Zhao,2001 for radish and alfalfa seeds ; Gharibzahedi et al., 2011 for castor seed; Tarighi et al., 2011 for sunflower seeds . Engineering properties of other biological materials affected by moisture content have been found by other researchers (Aviara and Haque, 2001 for sheanut kernel; Baryeh, 2002 for millet; Erica et al., 2004 for safflower seed; Aydin, 2006 for peanut and kernel; Yalcin, 2006 for cowpea seed; Pliestic et al., 2006 for filbert nut and kernel and Singh and Goswani, 2007 for cumin seed Sayed and Maryam , 2007 for kiwi fruit). Many researchers have worked on cashew nuts (Nathakaranakule and Prachayawarakorn, 1998; Balasubramanian (2001); Kurozawa et al., 2008; Ogunsina and Bamboye, 2007) but very little research work on variation of moisture content with thermal properties of cashew was found. The objective of the study was to determine the effect of moisture on the thermal properties of the cashew kernel.

Results and Discussion

Bulk Density

Figure 1 shows the variation of bulk density of cashew nut and kernel with moisture content. The values of bulk density of cashew nut and cashew kernel decreased linearly from 625.62kgm^{-3} to 592.42kgm^{-3} and 559.60kgm^{-3} to 505.06kgm^{-3} respectively when the moisture content increased from 5.0% to 9.0% w.b. This decrease is mainly due to the fact that moisture gain in the sample was lower than accompanying volumetric expansion of the bulk (Solomon and Zewdu, 2009). Ogunsina and Bamboye, 2007 in a study on the effects of pre-shelling treatment on the physical properties of cashew nut found the bulk density to be 596.67kg/m^3 which falls within the range of values obtained in this study. Balasubramanian (2001) also found the bulk density of raw cashew to decrease linearly with increasing moisture content. The negative linear relationship of bulk density with moisture content was also observed by Kibar et al. (2010) for rice, Seifi and Alimardani (2010) for corn and Gupta and Das (1997) for sunflower seed. Emperial equations were developed to describe the effect of moisture content on bulk density of cashew nuts and kernel.

Specific Heat

The variation of specific heat with moisture content is presented in Fig. 2. The specific heat varied from 1586kJkg^{-1}°C^{-1} to 1756kJkg^{-1}°C^{-1} in the moisture content range of 5.0 to 9.0 %w.b. The specific heat increased linearly with increasing moisture content. The increasing trend in specific heat with in moisture content correlates with work done by other researchers. Nathakaranakule and Prachayawarakorn (1998) also found a similar linear variation with the specific heat of cashew nutsvaried linearly with moisture content. Hsu et al. (1991) reported that the specific heat of pistachios varied from 1.1 to 2.1kJ/kgK at within the moisture content range of 9.5-39% w.b. Chandrasekar and Viswanathan (1999) studied the thermal properties of two varieties of coffee beans in the moisture content range of 9.9-30.05% w.b. and showed that specific heat increased linearly from 0.78 to2.36kJ/kgK with increasing moisture content. However, other studies have reported non-linear relationships of some food and agricultural products (Murata et al., 1995 for rice; Tang et al., 1995 for lentil seeds; Chakraborty and Johnson, 1999 for tobacco)

Thermal Conductivity

The variation of thermal conductivity with moisture content is shown in Fig. 3. The thermal conductivity of cashew kernel varied from 0.2103 to 0.2296 W/m K with increasing moisture content in the range of 5.0-9.0% w.b. Other researchers such as Perusella et al., (2010) for banana, Bart-Plange et al., (2009) for cowpea and maize, Nwabanni (2009) for cassava and Singh and Goswami (2000) for cumin seeds also reported the existence of linear relationship between thermal conductivity and moisture content. Kurozawa et al. (2008) found thermal conductivity to increase from 0.57 to 0.61 W/m °C with temperature in the range of 25 to 45 ºC for cashew apple .

Thermal Diffusivity

Fig. 4 shows the existence of a linear relationship between thermal diffusivity and moisture content. Thermal diffusivity increased linearly from 2.369×10^{-7} to 2.588×10^{-7} m^2/s with increasing moisture content in the range of 5.0% to 9.0% w.b. Hobani and Al-Askar, (2000), found the thermal diffusivity of Khudary and Sufri dates to increase linearly with increasing moisture content. The average thermal diffusivity for Nosrat and Kavir varieties of barley grains was found to be 14.67x10-^{8} and 15.70x10^{-8} m^2/s respectively (Nouri Jangi et al., 2011). Other researchers such as Aviara and Haque (2001), Tansakul and Lumyong (2008), Shyamal et al., (1994) reported a linear relationship between thermal diffusivity and moisture content for sheanut kernel, straw mushroom and wheat respectively.

Materials and methods

Materials

The materials were used for the experiment include cashew nut samples, distilled water, digital electronic balance, calorimeter, DC power source, ammeter, voltmeter and a thermocouple.

Sample Preparation

The cashew nuts used in the study were purchased from a local market at Wenchi in the Brong Ahafo region of Ghana in December 2009. The cashew samples were processed at a local cashew processing company and manually cleaned to remove chaff. The moisture content of the samples were determined using a standard oven method at 105°C for 24 hours (Dursun et al., 2006). In order Samples were conditioned by adding calculated amounts of distilled water to attain the desired moisture levels using equation (1) (Solomon and Zewdu, 2009, Ibrahim et al., 2006).

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad (1)$$

The samples were sealed in separate polythene bags and kept in a refrigerator at 5°C for five days to ensure uniform moisture distribute throughout the sample. Before starting a test, the required quantity of seeds were taken out of the refrigerator and stored at room temperature for about two hours (Nimkar and Chattopadhyay, 2001).The moisture content of cashew nut and /kernel was investigated at four moisture levels of 5.0, 6.5, 8.0, and 9.0% w.b. These values are within the range of moisture contents encountered for cashew nut and kernel during postharvest operations.

Bulk Density Determination

The bulk density of nuts and kernels was determined by pouring samples into a cylindrical container of known volume while striking excess samples off the brim without compacting the nuts and kernel (Zewdu and Solomon, 2007). The bulk density was then determined by dividing the mass of samples with the volume of the cylinder. All experiments were replicated four times at each moisture content

Determination of Thermal Properties

All experiments in this study were repeated four times at four levels of moisture content (5.0-9.0%), four levels of bulk density (505.06, 535.25, 539.84, 559.60 kgm^{-3}) and four temperature levels (35,45,55,65℃) for the cashew and kernel.

Determination of Specific Heat

The method of mixtures has been the most common technique reported in the literature for measuring the specific heat of agricultural and food materials (Singh and Goswani,

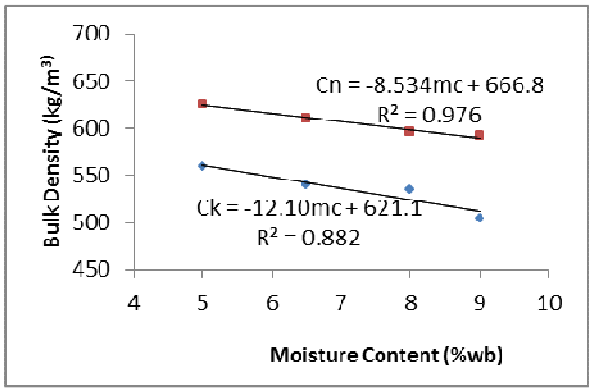

Fig1. Effects of moisture content on bulk density of cashew nut and kernel.

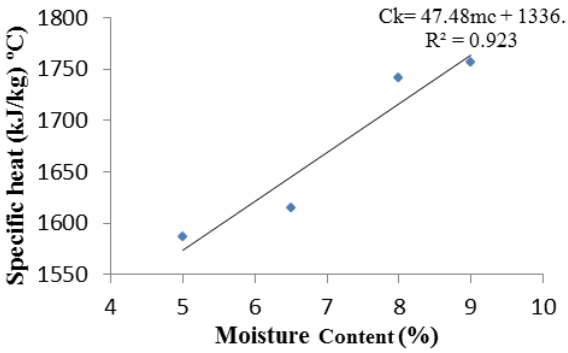

Fig 2. Moisture content variation on specific heat of cashew kernel.

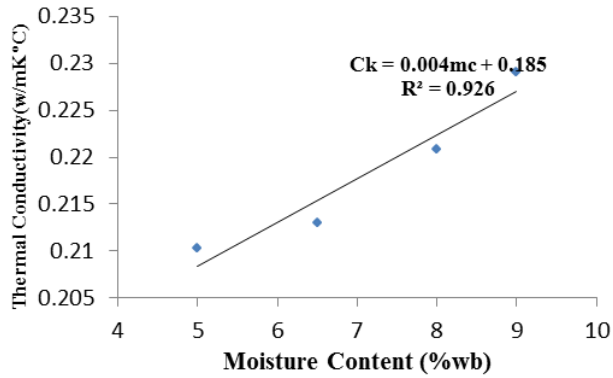

Fig3. Variations of moisture content on thermal conductivity of cashew kernel.

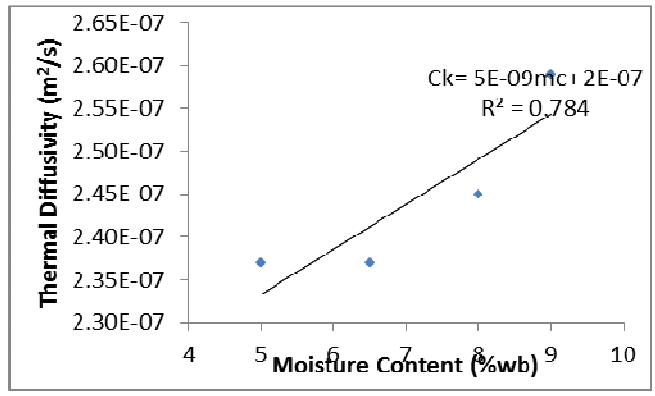

Fig 4. Variations of moisture content on thermal diffusivity of cashew kernel

2000; Aviara and Haque, 2001; Razavi and Masoud, 2007; Nouri Jangi et al.,2011). For the determination of specific heat in this study, the method of mixtures was used. cashew kernel samples of known mass, temperature and moisture content were dropped into a copper calorimeter containing water of know mass and temperature. The calorimeter was well insulated so as to prevent heat loss to the room in which the experiment was performed. The mixture was stirred continuously using a glass rod stirrer. A digital thermometer was used to monitor the temperature of the mixture. The equilibrium (final) temperature was noted and the specific heat determined using equation (2) as used by Aviara and Haque (2001).

$$C_p = \frac{(McCc + MwCw)(Te - Tw)}{Ms(Ts - Te)} \qquad (2)$$

Determination of Thermal Conductivity

The thermal conductivity of the cashew kernel samples were determined using the line heat source method (Sweat and Haugh, 1974). During the experiment, the samples at desired moisture contents were t placed in a cylinder at a particular bulk density. The plastic cylinder was sealed at the top and bottom with wooden plugs. A constant D.C. power source of 3V and a current of 1A were supplied to the Nichrome wire stretching between two ends of the plastic cylinder as the heat input source.The probe was inserted through the centre of the sample mass to take the temperature readings (Kurozawa et al., 2008). During the heating process, the temperature of the sample was recorded as a function of elapsed time at the interval of 30 seconds with the help of a digital time recorder. Recorded temperature values were then plotted against the natural logarithm of elapsed time and subsequently thermal conductivity was calculated by using equations 3 and 4.

$$K = \frac{Q\,In(t_2 / t_1)}{4\pi(T_2 - T_1)} \qquad (3)$$

$$Q_i = V\,I / L \qquad (4)$$

Determination of Thermal Diffusivity

The thermal diffusivity of the cashew kernel was calculated from experimental values of thermal conductivity, specific heat and bulk density using equation (5).

$$\alpha = \frac{K}{\rho_b C_p} \quad (5)$$

Conclusions

For the moisture content between 5.0% w.b. and 9.0% w.b. all the thermal properties of the studied were found to be moisture dependent. Bulk density for nut and kernel decreased from 625.62kg/m^3 to 592.42kg/m^3 and 559.60 to 505.06kg/m^3 respectively as moisture content increased from 5.0% to 9.0% w.b. The specific heat of the cashew kernel increased from 1586J/kgK to 1756J/kgK with increase in temperature from 35ºC to 65ºC and moisture content from 5.0% to 9.0% w.b..
Thermal conductivity increased from 0.2103W/mK to 0.2296W/mK with increased linearly with moisture content from 5.0% w.b. to 9.0% w.b. Thermal diffusivity values increased from 2.369 $\times 10^{-7}$ to 2.588 $\times$ 10^{-7} with increase linearly with increasing moisture content from 5.0 to 9.0% w.b.

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