Global Journal of Science Frontier Research
Agriculture and Veterinary Sciences
Volume 12 Issue 7 Version 1.0 Year 2012
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Effect of Moisture, Bulk Density and Temperature on Thermal Conductivity of Ground Cocoa Beans and Ground Sheanut Kernels

By A. Bart-Plange, A. Addo, S. K. Amponsah & J. Ampah
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract - Thermal conductivity is an important engineering parameter in the design of food processing equipment. It predicts or controls the heat flux in food during processing such as cooking, frying, freezing, sterilization, drying or pasteurization. The thermal conductivity of ground cocoa beans and ground sheanut kernels with varying moisture content, bulk density and temperature was studied using the transient heat transfer method. The thermal conductivity increased linearly for ground cocoa beans sample from 0.0243 to 0.0311 W/oCm and for ground sheanut kernels from 0.0165 to 0.0458 W/oCm in the moisture content range of 12.59 to 43.84 % w.b. at a constant bulk density of 295 kg/m3. For bulk density range of 322 to 410 kg/m3, thermal conductivity of ground cocoa beans and ground sheanut kernel increased linearly from 0.0265 to 0.0324 W/oCm and 0.0209 to 0.0252 W/oCm respectively when moisture content was at 16 % w.b Thermal conductivity of ground sheanut kernel and ground cocoa beans increased significantly ($p<0.05$) from 0.0233 to 0.0382 W/oCm and 0.0261 to 0.0397 W/oCm respectively as temperature increased from 35 to 55 oC. Effect of moisture, bulk density and temperature on thermal conductivity of sheanut kernel and cocoa bean were found to be significant ($p>0.05$).

Keywords : Thermal conductivity, sheanut, kernels, cocoa beans, moisture content, bulk density, temperature.

GJSFR-D Classification : FOR Code: 070399

EFFECT OF MOISTURE, BULK DENSITY AND TEMPERATURE ON THERMAL CONDUCTIVITY OF GROUND COCOA BEANS AND GROUND SHEANUT KERNELS

Strictly as per the compliance and regulations of :

Effect of Moisture, Bulk Density and Temperature on Thermal Conductivity of Ground Cocoa Beans and Ground Sheanut Kernels

A. Bart-Plange [α], A. Addo [σ], S. K. Amponsah [ρ] & J. Ampah [ω]

Abstract - Thermal conductivity is an important engineering parameter in the design of food processing equipment. It predicts or controls the heat flux in food during processing such as cooking, frying, freezing, sterilization, drying or pasteurization. The thermal conductivity of ground cocoa beans and ground sheanut kernels with varying moisture content, bulk density and temperature was studied using the transient heat transfer method. The thermal conductivity increased linearly for ground cocoa beans sample from 0.0243 to 0.0311 W/ºCm and for ground sheanut kernels from 0.0165 to 0.0458 W/ºCm in the moisture content range of 12.59 to 43.84 % w.b. at a constant bulk density of 295 kg/m^3. For bulk density range of 322 to 410 kg/m^3, thermal conductivity of ground cocoa beans and ground sheanut kernel increased linearly from 0.0265 to 0.0324 W/ºCm and 0.0209 to 0.0252 W/ºCm respectively when moisture content was at 16 % w.b Thermal conductivity of ground sheanut kernel and ground cocoa beans increased significantly ($p<0.05$) from 0.0233 to 0.0382 W/ºCm and 0.0261 to 0.0397 W/ºCm respectively as temperature increased from 35 to 55 ºC. Effect of moisture, bulk density and temperature on thermal conductivity of sheanut kernel and cocoa bean were found to be significant ($p>0.05$).

Keywords : Thermal conductivity, sheanut, kernels, cocoa beans, moisture content, bulk density, temperature.

I. Introduction

Sheanut and Cocoa are important oil producing crops in Ghana. Sheanut hails from the *Sapotaceae* family. The commonly known varieties include *Vitellariaparadoxa* (*Butryospermum parkii*) and *Vitellarianilotica.* Shea nut is obtained from the shea tree, and is grown mostly throughout West and Central Africa; in the semiarid Sahel from Senegal to Ethiopia (Aremu and Nwannewuihe, 2011). Shea nut contains reasonably high amounts of oleic acids from which the shea butter (fat) is obtained. Shea butter is one of the basic raw materials for most food, cosmetics, soap as well as the pharmaceutical industries (Thioune et al., 2000) and it is sometimes used as a substitute for cocoa butter (Bekure et al., 1997).

Cocoa (*Theobroma Cacao*) is an ancient crop of the lowland tropical forest, which originated from the Southern and Central America (Lefeber et al., 2011). In West Africa, cocoa is one of the most important cash crops. Globally, Ghana's cocoa bean production is ranked second in the world after her western neighbour Côte d'Ivoire (FAOSTAT, 2005). Ghana is recognized as the world leader in premium quality cocoa beans production. Cocoa serves as the major source of revenue for the provision of socio-economic infrastructure in the country. In terms of employment, the industry employs about 60% of the national agricultural labour force in the country (Appiah, 2004 cited in Ntiamoah and Afrane, 2008). For these farmers, cocoa contributes about 70 -100% of their annual household incomes (COCOBOD, 2004 cited in Ntiamoah and Afrane, 2008). Cocoa seeds are the source of commercial cocoa beans and cocoa products include cocoa liquor, cocoa butter, cocoa cake and cocoa powder as well as chocolate. Cocoa powder is essentially used as flavour in biscuits, ice cream and cakes and is consumed by most beverage industries. Besides the traditional uses in chocolate manufacture and confectionery, cocoa butter, like shea butter, is also used in the manufacture of cosmetics. It is also a folk remedy for burns, cough, dry lips, fever, malaria, rheumatism and wounds. Studies show that the cocoa bean contains flavonoids with antioxidant properties that can reduce blood clot and the risk of stroke and cardiovascular attacks (ICCO, 2011).

The thermal conductivity of materials can be influenced by a number of factors such as the moisture content of the material, porosity and fibre orientation of the material (Stroshine and Hamann, 1994; Mohsenin, 1990). Thermal conductivity of food and biological materials increase with increase in moisture content and density (Opoku et al., 2006 for hay; Muramatsu et al. 2006 for brown rice, Aviara et al., 2008 for guna seeds and Perusella et al., 2010 for banana). Thermal conductivity data is needed for calculating energy demand for the design of equipment and optimization of thermal processing of foods (Polley et al., 1980). It controls the heat flux in food during processing such as cooking, frying, freezing, sterilization, drying or pasteurization. In the determination of thermal conductivity of food materials, the commonly employed methods arethe transient and the steady-state methods (Mohsenin, 1980). Besides processing and preservation,

Author α σ ρ ω : Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
E-Mail : abartp@yahoo.com

thermal conductivity and other properties such as specific heat and thermal diffusivity also affect sensory quality of foods as well as energy saving during processing (Opoku et al., 2006).It is not uncommon to see farmers dry their produce without taking into consideration the quantity of heat needed to accomplish the drying process which in turn affects the market value of the end product. This is because such information on thermal conductivity of local agricultural products is either unavailable or inadequate.

The objective of this study therefore, was to determine the thermal conductivity of ground sheanut kernel and ground cocoa beans and investigate their dependence on moisture content, bulk density and temperature using the transient heat method.

II. Materials and Methods

a) Sample Preparation

The samples were cleaned by removing foreign materials and damaged kernels or beans. Sheanut kernel and cocoa beans had all the quality checks performed and ready for local and export market. Both samples were conditioned to four moisture content levels of 12.59, 22.41, 31.55 and 43.84% wet basis. The samples were sealed in separate polythene bags and kept in a refrigerator at 5°C for five days to ensure uniform moisture distribution. The amount of distilled water added was calculated using equation (1) (Balasubramanian, 2001).

$$M_w = \frac{M_i(m_f - m_i)}{100 - m_f} \qquad (1)$$

where:

M_w is the mass of distilled water (g),
M_i is the initial mass of sample (g),
m_f is the final moisture content of sample (%w.b.) and
m_i is the initial moisture content of sample (%w.b.).

For bulk density variation sampleswere milled in a laboratory hammer mill to a particle size of two millimetres using a set of screen. Varying bulk densities of 322, 346, 381 and 410 kg/m^3 were obtained by compressing in a cylinder with known weights at a constant moisture content using standard procedures (AOAC, 2002).

b) Experimental Setup

The setup for the thermal conductivity measurements is shown in Figure 1. The thermal conductivity apparatus is a set-up consisting of an aluminium cylinder with a heating coil stretching between two insulated ends of the cylinder. A thermocouple was fitted through the top end of the cylinder for temperature readings in the sample. Heat source (Q) was supplied by a constant direct current power source with current and voltage of 1A and 3V respectively throughout the experiment. In the set-up, there was an ammeter to take current readings, voltmeter to take voltage readings and a rheostat to vary resistance in the circuit in order to achieve the desired current.

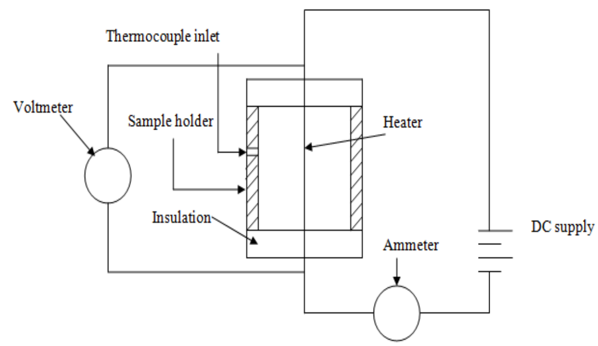

Figure 1 : Schematic diagram of the thermal conductivity measuring apparatus

The conditioned samples were placed in the aluminium sample cylinder in the set-up. The sample temperature at the centre of the cylinder was checked by means of a thermocouple, the current was adjusted to one ampere and a voltage of three volts was used. Temperature readings were taken at regular time interval of one minute for 40minutes for each sample experimented. Thermal conductivity was determined at five sample temperatures of 35, 40, 45, 50 and 55°C.

c) Thermal Conductivity Determination

Thermal conductivity (k) was determined using equation (2) (Tabil, 1999).

$$k = \frac{Q}{4\pi(t_2 - t_1)} \ln\frac{\theta_2}{\theta_1} \qquad (2)$$

where:

Q = VI (V is the supplied voltage, I is input current, heat source per meter of the line source)

k = thermal conductivity of the medium (W/°Cm)
t_1 is initial temperature (°C)
t_2 is final temperature (°C)
θ_1 is initial time (min)
θ_2 is initial time (min)

The thermal conductivity values of the ground sheanut kernel and ground cocoa beans were determined by calculating the slopes of the graphs of temperature changes against time ratio on a semi-logarithm graph. The experiment was replicated four times at each moisture content, bulk density and temperature level and thermal conductivity was recorded in each case.

d) Statistical Analysis

The experimental design used was the completely randomized design (CRD) with single factor analysis of variance (ANOVA) for all data and analyzed with Minitab Version 15.Statistical significance was carried out using Tukey and Fisher's approach at $p<0.05$.

III. Results And Discussion

a) *Effect of Moisture Content*

Figure 2 shows the linear variation of thermal conductivity of ground sheanut kernel and ground cocoa beans with moisture content at constant bulk density (295 kg/m^3). Thermal conductivity of ground sheanut kernel and ground cocoa beans increased significantly ($p<0.05$) from 0.0165 to 0.0458 W/°Cm and 0.0243 to 0.0311 W/°Cm respectively with increasing moisture content from12.59 to 43.84 %w.b.

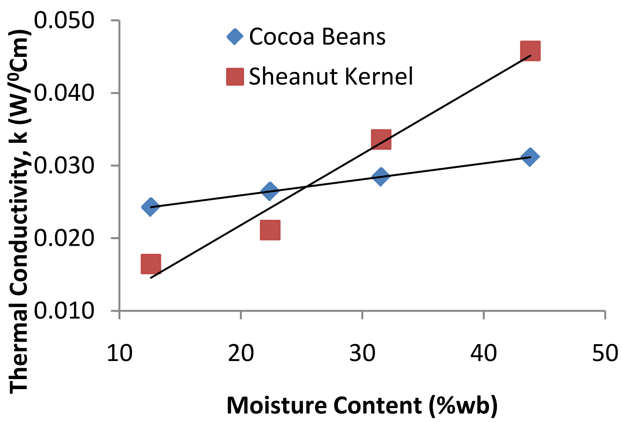

Figure 2 : Thermal conductivity as a function of moisture content

Similar trend was observed in the thermal conductivity of soybean (Deshpande et al., 1996), cumin seed (Singh and Goswami, 2000), sheanut kernel (Aviara and Haque, 2001), borage seed (Yang et al., 2002), millet grains (Subramanian and Viswanathan, 2003), rough rice (Yang et al., 2003), brown rice (Muramatsu et al., 2006), maize and cowpea (Bart-Plange et al., 2009) and guna seed (Aviara et al., 2008).

The increase in thermal conductivity with moisture content can be attributed to the fact that an increase in moisture content of the sample increases the amount of water molecules available to fill the pores within the sample thus increasing the ability of the sample to conduct more heat.

The relationship between the thermal conductivity of ground sheanut kernel (k_{sk}) and ground cocoa beans (k_{cb}) and moisture content (M) can be expressed using equations (3) and (4) respectively.

$$k_{sk} = 0.097M + 0.002, \quad R^2 = 0.974 \quad (3)$$

$$k_{cb} = 0.022M + 0.021, \quad R^2 = 1 \quad (4)$$

Equations (3) and (4) depict that thermal conductivity of ground sheanut kernel and ground cocoa beans have a linear relationship with moisture content. This agrees with what was reported by Aviara and Haque, (2001) on sheanut kernel. Studies by other researchers also found thermal conductivity to increase with increasing moisture content (Sweat, 1974; Rao and Rizvi, 1986; Mohsenin, 1990; Tansakul and Lumyong, 2008; Meghwal and Goswami, 2011).

b) *Effect of Bulk Density*

The variation of thermal conductivity of ground sheanut kernel and ground cocoa beans with bulk density at constant moisture content (16 %w.b.) is shown in Figure 3.

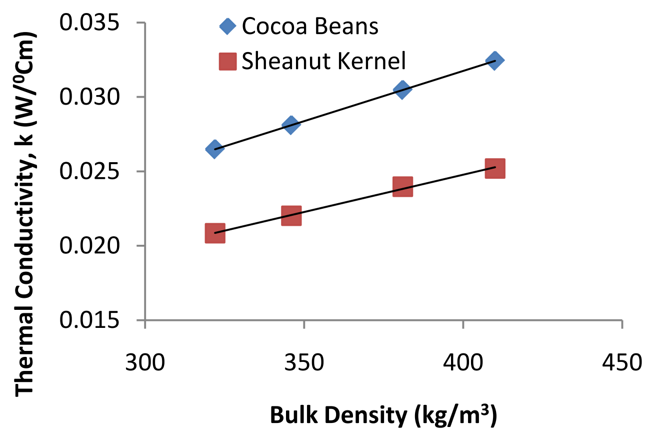

Figure 3 : Thermal conductivity as a function of bulk density.

The thermal conductivity of ground sheanut kernel and cocoa beans increased linearly and significantly ($p<0.05$) from 0.0209 to 0.0252 W/°Cm and 0.0265 to 0.0324 W/°Cm respectively as bulk density increased from 322 to 410 kg/m^3. This trend was similarly observed by other researchers including Taiwo et al (1996) for cowpea, Aviara and Haque (2001) for sheanut kernel, Bart-Plange et al. (2009) for maize and cowpea and Meghwal and Goswami (2011) for black pepper. Moreover, it was observed that the thermal conductivity of ground sheanut kernel was generally lower than ground cocoa beans with increase in bulk density.The increase in thermal conductivity with bulk density can best be explained by making reference to the conduction ability of the sample particles in relation to the pores between them. Increasing the bulk density means increasing the number of particles in a constant volume thus decreasing the pore volume which leads to increasedheat conduction ability of the sample.

The linear relationship between the thermal conductivity of ground sheanut kernel (k_{sk}) and ground cocoa beans (k_{cb}) and bulk density (ρ) may be expressed using equations (5) and (6) respectively.

$$k_{sk} = 5\times10^{-5}\rho + 0.004, \quad R^2 = 0.997 \quad (5)$$

$$k_{cb} = 7\times10^{-5}\rho + 0.004, \quad R^2 = 1 \quad (6)$$

c) *Effect of Temperature*

Figure 4 describes the variation of thermal conductivity with increasing temperature at constant moisture content and bulk density. At constant moisture content of 20.5 %w.b. and constant bulk density of 420 kg/m^3, the thermal conductivity of ground sheanut kernel and ground cocoa beans increased significantly ($p<0.05$) from 0.0233 to 0.0382 W/°Cm and 0.0261 to 0.0397 W/°Cm respectively as temperature increased from 35 to 55 °C.

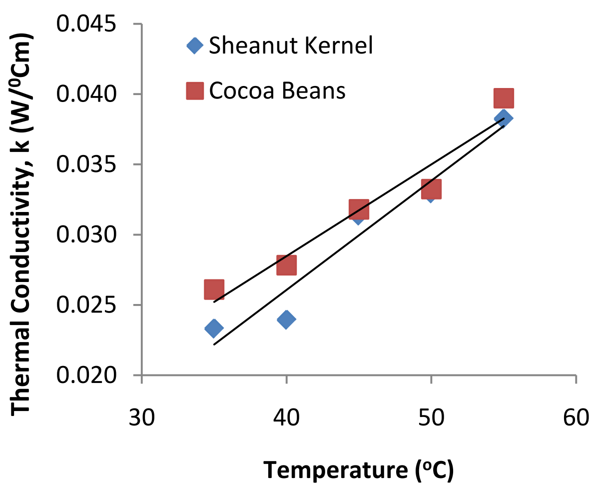

Figure 4: Thermal conductivity as a function of temperature

The linear relationship between the thermal conductivity of ground sheanut kernel (k_{sk}) and ground cocoa beans (k_{cb}) and temperature (°C) can be expressed using equations (7) and (8) respectively.

$$K_{sk} = 0.0008x - 0.005 \quad R^2 = 0.9446 \quad (7)$$

$$K_{cb} = 0.0007x + 0.0024 \quad R^2 = 0.9434 \quad (8)$$

Aviara and Haque (2001) and Bart-Plange et al. (2009) observed an increase in thermal conductivity with temperature for sheanut kernel and maize and cowpea respectively. 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 °C for cashew apple. Mahmoodi and Hosein (2008) also found thermal conductivity of pomegranates to increase linearly from 0.6106 to 0.6372 W/m°C with increase in temperature from 26.5 to 45°C.

IV. Conclusion

Investigations on the thermal conductivity of ground sheanut kernel and ground cocoa beans revealed the following:

1. Thermal conductivity of ground sheanut kernel and ground cocoa beans increased significantly ($p<0.05$) from 0.0165 to 0.0458 W/°Cm and 0.0243 to 0.0311 W/°Cm respectively with increasing moisture content from 12.59 to 43.84 %w.b. at constant bulk density. A linear relationship was found to exist between thermal conductivity and moisture content.
2. Thermal conductivity of ground sheanut kernel and cocoa beans increased significantly ($p<0.05$) from 0.0209 to 0.0252 W/°Cm and 0.0265 to 0.0324 W/°Cm respectively as bulk density increased from 322 to 410 kg/m^3 at constant moisture content. A linear regression best describes the relationship between thermal conductivity and bulk density.
3. At constant moisture content of 20.5 %w.b. and constant bulk density of 420 kg/m^3, the thermal conductivity of ground sheanut kernel and ground cocoa beans increased significantly ($p<0.05$) from 0.0233 to 0.0382 W/°Cm and 0.0261 to 0.0397 W/°Cm respectively as temperature increased from 35 - 55 °C.

References Références Referencias

1. AOAC. (2002). Official Methods of Analysis, 17th Ed. Association of Official Analytical Chemists, Gaithersburg, Maryland, USA.
2. Appiah, M. R. (2004). Impact of cocoa research innovations on poverty alleviation in Ghana. Ghana Academy of Arts and Sciences Publication cited in Ntiamoah, A. and Afrane, G. (2008). Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach, Journal of Cleaner Production. 16(16): 1735-1740.
3. Aremu, A. K. and Nwannewuihe, H. U. (2011).Specific heat of ground fresh sheanut kernel (*Butyrospernum paradoxum*) as affected by particle size, moisture content and temperature. Journal of Emerging Trends in Engineering and Applied Sciences, (JETEAS) 2 (1): 177-183.
4. Aviara, N. A. and Haque, M. A., (2001). Moisture dependence of thermal properties of sheanut kernel. J. Food Eng., 47, 109-113.
5. Aviara, N. A., Haque, M. A. and Ogunjimi, L. A. O. (2008). Thermal properties of Guna Seed. Institute of Agrophysics, Polish Academy of Sciences Vol. 22: 291-297.
6. Balasubramanian, D. (2001). Physical Properties of Raw Cashew Nut. Journal of Agricultural Engineering Research. Vol. 78(3): 291 – 297.
7. Bart-Plange, A., Asare, V. and Addo, A. (2009). Thermal conductivity of maize and cowpea. Journal of Engineering and Technology. 2(3): 6-11.
8. Bekure, Z., Donlan, M., Gordon, Y. and Thomson, J. (1997). "Local to Global. The International market for Shea butter." Presented to United Nations Development Fund for Women.
9. COCOBOD (2004). Socio-economic study. Final report [MASDAR]. Ghana Cocoa Board cited in

Ntiamoah, A. and Afrane, G. (2008). Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approah, Journal of Cleaner Production. 16(16): 1735-1740.
10. Deshpande, S. D., Bal, S., and Ojha, T. P. (1996). Bulk thermal conductivity and diffusivity of soy bean. J. Food Process Preservation. 20: 177 189.
11. FAOSTAT (2005). Faostat database. Food and Agriculture Organisation.[Accessed 10 October, 2011]. Available online: www.fao.org/es/ess/top/commodity. html?lang=en&item=125&year=2005.
12. ICCO, International Cocoa Organisation. (2011). Also available at www.icco.org. [Accessed September 1 2011].
13. Kurozawa, L. W., Park, K. J. and Azonbel, P. M. (2008). Thermal conductivity and thermal diffusivity of papaya (Carica papaya,L.) and Cashew apple (Anacardium occidentale L.). Braz. J Food Tech.11:78-85.
14. Lefeber, T., Gobert, W., Vrancken, G. Camu, N. and Vuyst, L. D. (2011). Dynamics and species diversity of communities of lactic acid bacteria and acetic acid bacteria during spontaneous cocoa bean fermentation in vessel. Food microbiology. 28: 457-464.
15. Mahmood, M. and Hosein, K. M. (2008). Determination and Comparison of Thermal Conductivity of Iranian Pomegranate Varieties. 18th National Congress on food technology, Mashhyad, IR, Iran, 15-16 October , 2008.
16. Meghwal, M. and Goswami, T. K. (2011). Thermal properties of black pepper and its volatile oil. International Journal of Advanced Biotechnology and Research. 2(3): 334-344.
17. Mohsenin, N. N. (1980). Thermal Properties of Foods and Agricultural Materials. pp 83–121, Gordon and Breach, New York.
18. Mohsenin, N. N. (1990). Thermal properties of foods and agricultural materials. New York: Gordon and Breach.
19. Muramatsu, Y., Tagawa, A., Kasai, T., Takeya, K., and Fukushima, M. (2006). Prediction of thermal conductivity of kernels and packed bed of brown rice. Journal of the Japanese Society of Agricultural Machinery, 64(1): 70–76.
20. Opoku, A., Tabil, L. G., Crerar, B. and Shaw, M. D. 2006. Thermal conductivity and thermal diffusivity of timothy hay. Canadian Biosystem Engineering. 48: 3.1-3.7
21. Perusulla, C. A., Viviana, C., Mends, L. A. (2010). Development of a linear heat source probe and determination of banana thermal conductivity. International Journal of Food Engineering 6(5)
22. Polley, S. I., Synder, O. P. and Kotnour, F. (1980). A compilation of thermal properties of foods. Food Technology. 34(11): 76–78.
23. Rao, M. A. and Rizvi, S. S. H. (1986). Engineering properties of foods. New York: Marcel Dekker.
24. Singh, K. K. and Goswami, T. K. (2000). Thermal properties of cumin seed. J. Food Eng. 45: 181-187.
25. Stroshine, R., Hamann, D. D. (1994). Physical Properties of Agricultural Materials and Food Products. 1994. Course manual, Purdue University, USA.
26. Subramanian, S. and Viswanathan, R. (2003). Thermal properties of minor millet grains and flours. Biosys. Eng. 84: 289-296.
27. Sweat, V. E. (1974). Experimental values of thermal conductivity of selected fruits and vegetables. J. Food Sci. 39: 1080-1091.
28. Tabil, L. G., (1999). Specific heat of agricultural and food materials. Research report, Department of Agricultural and Bio-resource Engineering, University of Saskatchewan, Canada. p 7.
29. Taiwo, K. A., Akanbi, C. T., and Ajibola O. O. (1996). Thermal properties of ground and hydrated cowpea. J. Food Eng. 29: 249-256.
30. Tansakul, A. and Lumyong, R. (2008). Thermal Properties of Straw Mushroom. Journal of Food Engineering. 87:91-98.
31. Thioune, O., Ahodikpe, D., Dieng, M., Diop, A. B., Ngom, S. and Lo, I. (2000). Inflammatory ointment from shea butter and hydro alcoholic extract of Khaya sengalensis barks (cailcederat) Dakar Med. 45(2): 113-6.
32. Yang, W., Sokhansanj, S., Tang, J. and Winter, P. (2002). Determination of thermal conductivity, specific heat and thermal diffusivity of borage seeds. Biosys. Eng. 82: 169-176.
33. Yang, W., Siebenmorgen, T. J., Thielen, T. P. H and Cnossen, A. G. (2003). Effect of glass transition on thermal conductivity of rough rice. Biosystems Engineering. 84(2): 193-200.