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Determination of Thermal Conductivity and Thermal Diffusivity of Three Varieties of Melon

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Abstract

Most food materials are thermally processed to extend their shelf life and maintain high quality. Hence, knowledge of thermal properties of food materials becomes very important. To this end, the thermal properties of three different *Egusi* melons: *Wuruwuru (Cucumis melo), Bakabaka (Cucumeropsis mannii)*and *Bara (Colocythis citrullus)* were investigated. The investigated properties include the thermal conductivity using Lee's disc method, the thermal diffusivity using diffusivity tube and specific heat capacity using method of mixture. The thermal conductivity of each specie increased linearly as the thickness of the samples increased from range 250µm to 800µm at constant moisture content; with *Bakabaka* recording 0.259W/m°C to 0.382W/m°C*;Wuruwuru,*0.187W/m°C to 0.357W/m°C and *Bara,* 0.226W/m°C to 0.359W/m°C. The thermal diffusivity increased from 8.42×10^{-06} to 1.127×10^{-05} m^2/s for *Wuruwuru* at moisture content range of 6.56 and 60.5% (wb) and 8.630×10^{-06} to 1.050×10^{-05} m^2/s for *Bakabaka* at moisture content range of 6.59 and 51.13% (wb) for *Bakabaka* respectively. The specific heat capacity varied linearly from 2.803 kJ/kgºC to 3.454 kJkgºC with moisture content range of 6.59 to 39.62 % (w.b) for *Wuruwuru* and 3.735 to 4.509 kJ/kg^{0}C with moisture content range of 6.56 to 48.64%wb. The result obtained is useful in processing of melon involving heat transfer, design of storage and processing equipment and formulation of mathematical model for drying of the crop.

Keywords: *Egusi* melon, thermal conductivity, thermal diffusivity, moisture content, specific heat capacity

INTRODUCTION

Egusi melon (*Colocynthis citrullus lanatus*) is a vegetable crop commonly cultivated in West Africa (van der Vossen *et al*., 2004). Because of its creeping nature and ability to use its leaves to provide cover on the soil, farmers use it as weed suppressant in their mixed crop farms

According to Achigan-Dako *et al*. (2008), *Egusi* melons play vital roles in the farming system and in the well-being of West African rural dwellers as weed suppressants and for soil fertilization. Further studies by Achigan-Dako *et al*. (2008) summarized the socio-cultural uses of *Egusi* melons to include the provision of cash income, household food, gift to relatives and seeds. In the Republic of Benin, some farmers also reported the medicinal role of some '*Egusi*' species such as *C. lanatus subsp. Mucosospermus* (sliced young fruit of this specie is said to heal stomach aches while the seed coat in decoction with Eucalyptus (*Eucalyptus camaldulensis dehnh.*) roots is a sedative for epilepsy). The roasted seeds, ground with salt are taken with warm water or porridge to prevent vomiting (Achigan-Dako *et al*. 2008).

Knowledge of the essential thermo-physical properties is of primary importance to the food industry. This information is required to make proper design of food processing equipment such as tanks, pumps, pipes, chillers and evaporators (de Moura *et al.,* 1998). 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). Several researchers including Qashou, et al. (1972), Choi and Okos (1983), Sweat (1974) and Rahman (1993) have emphasized the need for thermal properties of foods in general and seafood in particular. But several researchers including Lentz (1961) and Reidy and Rippen (1971) have reported that these parameters are more often not reported.

Despite the large productivity and nutritional potentials of this crop, there has been a hindrance to the use of melon for large-scale production of oil and protein sources. This is as a result of inadequate processing of this crop. Therefore the objectives of the study were to: determine effect of thicknesses (i.e bulk of the materials) on thermal conductivity of three different species of *Egusi* melon; *Wuruwuru, Bakabaka* and *Bara* using lee's disc method; and determine the effect of moisture content on thermal diffusivity and specific heat capacity of two species of the *Egusi* melons.

MATERIALS AND METHODS

Sample Preparation

The samples of three different *Egusi* Melons (C*itrullus lanatus)* were purchased from the Local market and were *Wuruwuru (Cucumis melo), Bakabaka (Cucumeropsis mannii)* and *Bara (Colocynthis citrullus)*. One part of each sample was used for thermal conductivity and specific and the other part for thermal diffusivity. The moisture content of each sample was determined and later grinded. Four different thicknesses (2.5mm, 4mm and 8mm) of a disk-like shape was moulded from each sample in this way resulting in three replication of each thickness for thermal conductivity. But the grinded melon was used for thermal diffusivity; in this case the moisture of the melon was conditioned into four (4) moisture contents (6.56% to 60.50%) was used from each sample and in this way also resulting in three replications of each moisture content.

Thermal Conductivity

Shown below is the schematic of the experimental set up of lee's disc apparatus. Assuming that the heat transferred between an object and its surrounding depends on the exposed surface of the object and temperature difference between the object and the surroundings. Let e Joules of energy be emitted from each exposed unit surface area (m^2) per second per °C above the initial temperature and assume that this is the same for disc A, B, C and specimen. Assume also that the temperature of the specimen is the mean temperature of disc A and B. then the total heat emitted from the apparatus is;

$$H = e\left[Q_A T_A + Q_S \frac{(T_A+T_B)}{2} + Q_B T_B + Q_C T_C\right] J/_S \qquad 1$$

where Q_A, Q_B, Q_C, Q_S are the exposed surface area (m^2) of A, B,C, S respectively. Area Q_A and Q_C include the flat end section of the disc. T_A, T_B, T_C is temperature of the disc A, B, C at the steady state above the initial temperature. The temperature is then applied by the heating element;

$$H = IV\ (Js^{-1}) \qquad 2$$

Where I and V are current and voltage respectively, from equations 1 and 2;

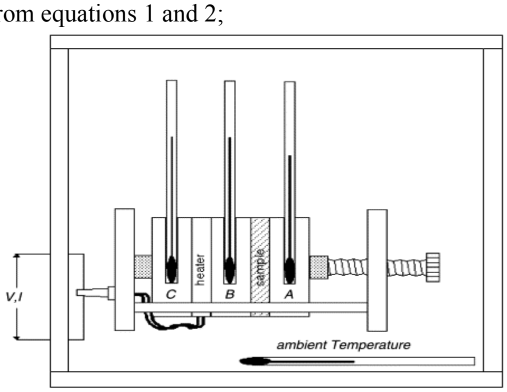

Figure 1: Schematic diagram of the experimental setup

Then the thermal conductivity

$$k = \frac{ed}{2\pi r^2 (T_B - T_A)}\left[Q_s\left(\frac{T_A+T_B}{2}\right) + 2Q_A T_A\right]$$

(Telford *et al*, 1984) 3

Thermal Diffusivity

Thermal diffusivity is always associated with heating time. A transient method is more appropriate since the method is based on one dimensional linear heat transfer conditions and requires only time-temperature rise, the Fourier's equation of one dimensional radial condition heat transfer in a cylindrical sample is :

$$\frac{A}{\alpha} = \frac{d^2T}{dr^2} + \frac{1}{r}\frac{dT}{dr}$$

(Magee and Bransburg, 1995) 4

Where

A is a constant rate of temperature rise at all points in the test cylinder. The solution of equation (10) above after substituting boundary conditions at r= 0, (dT/dr)=0 and r=R, T= T_R, for the center of the cylinder, r= 0 and T= T_0 is:

$$T_R \quad T_0 = \frac{AR^2}{4\alpha} \text{ or } \alpha = \frac{AR^2}{4(T_r - T_0)}$$

(Magee and Bransburg, 1995) 5

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, 2000 and Nouri Jangi *et al*., 2011). For the determination of specific heat in this study, the method of mixtures was used. Grounded melon samples moulded into disk-like shape of known mass, temperature and moisture content was dropped into a copper calorimeter containing water of known 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. The equilibrium (final) temperature was noted and the specific heat determined using equation (12) as used by Aviara and Haque (2001).

$$C_p = \frac{(M_c C_c + M_W C_W)(T_e - T_W)}{M_S (T_S - T_e)} \qquad 6$$

RESULTS AND DISCUSSION

Thermal Conductivity

The results of the thermal conductivity and thermal resistivity obtained for each species of *Egusi* melon at the respective thickness are as summarized in table 1. It was noted that *Bakabaka (Cucumeropsis mannii)* has its highest thermal conductivity of 0.382W/m°C at 800µm and lowest at 250µm. According to table 1, it can be deduced that thermal conductivity increases with particle size and thickness or bulk density. The thermal resistivity of *Bakabaka (Cucumeropsis mannii)* is highest at 250µm and lowest at

800µm.This result shows that its thermal resistivity is probably decreases with particle size or thickness. *Wuruwuru (Cucumis melo)* has its highest thermal conductivity of 0.357W/m°C at 800µm and lowest of 0.187W/m°C at 250µm. It could be deduced that its thermal conductivity increases with particle size. *Wuruwuru (Cucumis melo)'s* thermal resistivity is highest at 250µm and lowest at 800µm.This shows that its thermal resistivity decreases of particle size. *Bara (Colocynthis citrullus)* has highest thermal conductivity at 800µm and lowest at 250µm particle sizes. *Bara (Colocynthis citrullus)* also showed high thermal resistivity at 250µm and low at 800µm. This result also indicated the same behaviour with thermal conductivity and thermal resistivity of the other species respectively.

Table 1: Thermal conductivity of melon samples analyzed at different thickness with constant moisture content for each specie

Thickness (µm)	**Bakabaka (Cucumeropsis mannii) Thermal Conductivity [W/m°C]**	**Wuruwuru (Cucumis melo) Thermal Conductivity [W/m°C]**	**Bara (Colocynthis citrullus) Thermal Conductivity [W/m°C]**
250	0.259369	0.187269	0.226683
400	0.274002	0.278064	0.276811
600	0.314837	0.360087	0.298693
800	0.382282	0.375289	0.359831

The bar chart below compared the result of temperature variations with time at each thickness of the samples. In *Bakabaka (Cucumeropsis mannii)* samples for all the thicknesses considered, temperature increases with time. However, the increment was rapid at the beginning but attain steady level at about 105 minutes except at thickness 800µm that attain equilibrium at 90 minutes, this suggests the time at which the samples attain its steady temperature. Also for *Wuruwuru (Cucumis melo)* melon samples, temperature increases with time for all the particles sizes analyzed. *Wuruwuru (Cucumis melo)* melon particles showed anomalous relationship with time. Thicknesses of 250µm and 800µm attained a steady temperature in 90 minutes, 400µm attained steady temperature in 105 minutes and 600µm in 120 minutes as shown Figures 2 - 5.

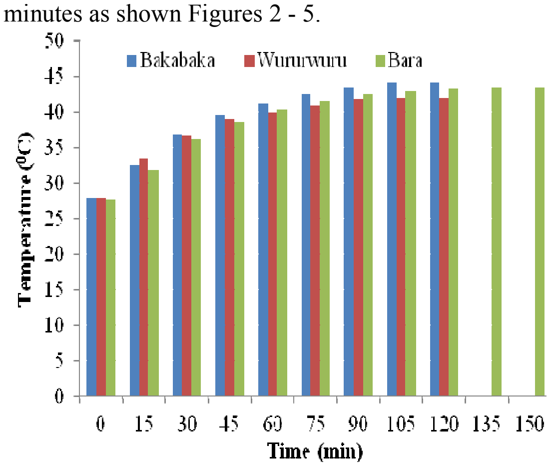

Figure 2: Bar Chart of temperature time Variation at thickness 250µm

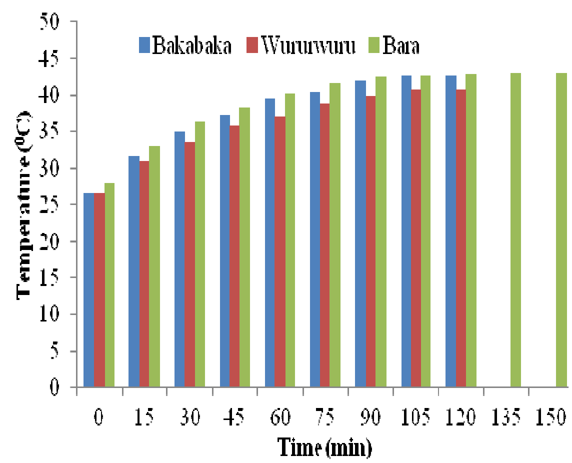

Figure 3: Bar Chart of temperature time Variation at thickness 400µm

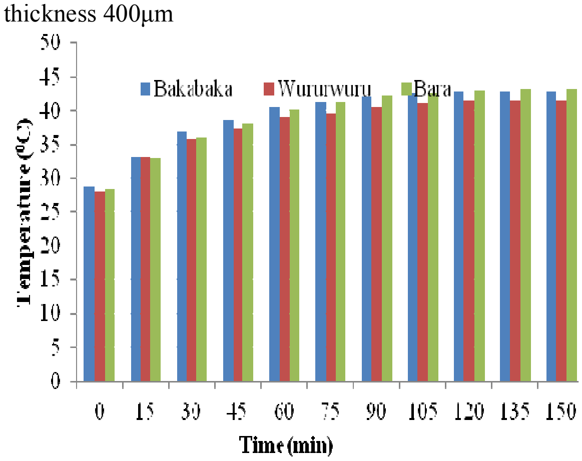

Figure 4: Bar Chart of temperature time Variation at thickness 600µm

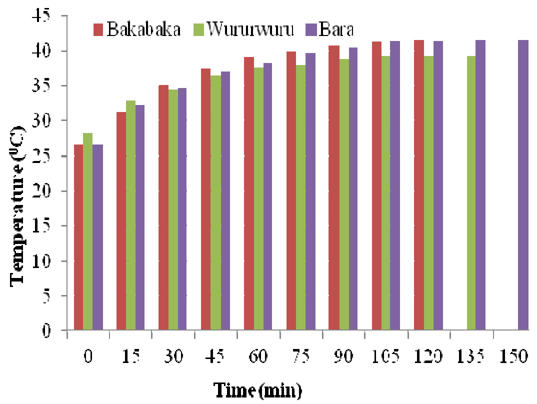

Figure 5: Bar Chart of temperature time Variation at thickness 800µm

Composite Plots

The variation of thermal conductivities with thickness sizes in both profiles and bar charts are shown in Figures 6 respectively. The results indicated that *Wuruwuru (Cucumis melo)* has the lowest thermal conductivities i.e. less than 0.2W/m°C while other melon samples; *Bakabaka (Cucumeropsis mannii)*, and *Bara (Colocynthis citrullus)* have high thermal conductivity ranging from 2.2W/m°C to 2.7W/m°C for all the particle sizes. It was observed that thermal conductivity is lowest at 250µm and highest at 800µm for all the melon samples. This could be attributed to variation in response of the melon samples to heat conductivity at smaller thickness sizes and at larger thickness sizes.

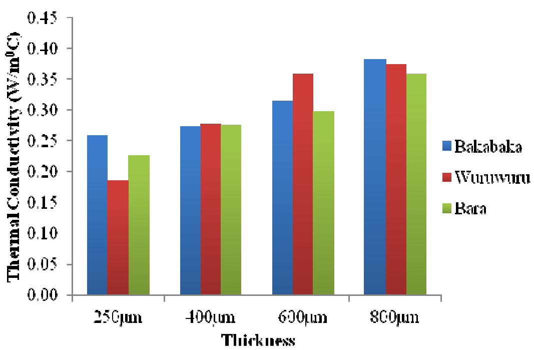

Figure 6: Bar Chart of Variation of Thermal Conductivities with Particle Size

Studies by other researchers also found thermal conductivity to be increasing by temperature and as the thickness (equivalent of bulk density) Taiwo *et al.,* (1996) 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 ºC 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.

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 increased heat conduction ability of the sample.

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.

THERMAL DIFFUSIVITY

Effect of Moisture Content On Thermal Diffusivity Of Melon Species (*citrullus lanatus*)

The thermal diffusivity values of melon species; namely *Wuruwuru,* and *Bakabaka* obtained at four moisture levels in the moisture and temperature ranges of 6.59 to 51.13% (wb) and 300K to 358K for *Wuruwuru* and 6.56 to 60.5% (wb) under the same temperature ranges for *Bakabaka*, respectively; was found to increase from 8.42×10^{-06} to 1.127×10^{-05} m^2/s for *Wuruwuru* and 8.630×10^{-06} to 1.050×10^{-05} m^2/s for *Bakabaka*.

The variation of thermal diffusivity with moisture content is shown in Figure 7, from this, a third order polynomial relationship between thermal diffusivity and moisture content in the above moisture range was observed, which is the perfect expression that describes the behaviour of the graph. This was in agreement with Aviara and Haque (2001), who observed that the thermal diffusivity of sheanut kernel increased with moisture content; and dissimilarity to Aremu and Fadele (2010), whose obtained values for doum palm fruit showed inverse relationship with moisture content, this may be due to the form in which the sample was tested.

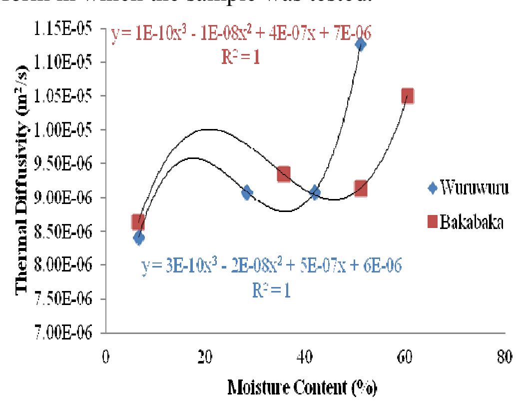

Figure 7: Variations of moisture content on thermal conductivity of the two melon species (*Wuruwuru* and *Bakabaka*).

$$\alpha_{bak} = (1.33x10^{-10})x^3 - (1.33x10^{-8})x^2 + 3.78x + 6.68x10^{-6} \quad R^2 = 1 \qquad 13$$
$$\alpha_{wur} = (2.52x10^{-10})x^3 - (2.02x10^{-8})x^2 + 4.76x + 6.08x10^{-6} \quad R^2 = 1 \qquad 14$$

Aviara and Haque (2001), Taiwo *et al.,* (1996) and Bitra *et al.,* (2010) all tested their materials in granular form for their various samples and were able to establish a linear relationship between thermal diffusivity and moisture content in comparison with the expression obtained above which was polynomial of the third-order.

Specific Heat Capacity

Figure 8 presents the variation of specific heat with moisture content for two melon varieties namely *Wuruwuru (Cucumis melo),* and *Bakabaka (Cucumeropsis mannii)*. The specific heat varied from 2.803kJ/kg°C to 3.454kJkg°C in the moisture content range of 6.59 to 39.62 %(w.b) for *Wuruwuru* and 3.735 to 4.509kJ/kg^{0}C in the moisture content range of 6.56 to 48.64%(wb). The specific heat increased linearly with increasing moisture content and the linear relationship was establish as shown in equation(14 and 15) for both species.

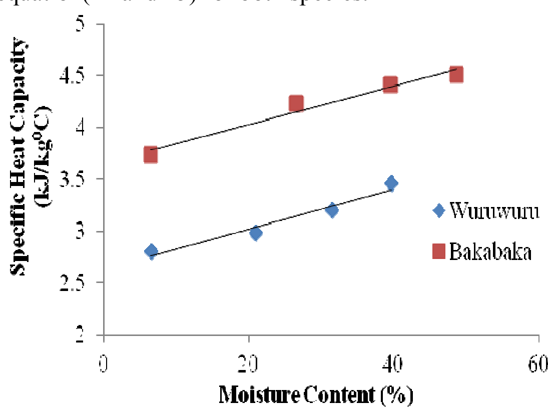

Figure 8: Variations of moisture content on specific heat capacity of the two melon species (*Wuruwuru* and *Bakabaka* variety).

$$c_{wur} = 0.019x + 2.634 \quad R^2 = 0.959 \qquad 14$$
$$c_{bak} = 0.018x + 3.659 \quad R^2 = 0.966 \qquad 15$$

Where c_{wur} is the specific heat of *Wuruwuru* species and c_{bak} specific heat of *Bakabaka* species

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 nuts varied 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).

CONCLUSION

The thermal conductivity, diffusivity and specific heat capacity of three different *Egusi* elon were investigated. Thermal conductivity increases with thickness from 0.259W/m^{0}C to 0.382W/m^{0}C, 0.226W/m^{0}C to 0.375W/m^{0}C and 0.226W/m^{0}C to 0.359W/m^{0}C at 250µm to 800µm for all the melon species (*Bakabaka, Wuruwuru* and *Bara*). It was observed that lowest thermal conductivity was recorded at the lowest thickness size and highest thermal conductivity was recorded at the highest thickness size. Averagely, the specific heat and thermal diffusivity of the *Wuruwuru* and *Bakabaka* 2.803 to 3.454kJ/kg^{0}C at moisture range of 6.59 to 39.62 %(wb) and 3.735 to 4.509kJ/kg^{0}C at moisture range of 6.56 to 48.64%(wb) and thermal diffusivity increased from 8.42x10^{-06} to 1.1271x10^{-05}m^2/s for *Wuruwuru (Cucumis melo)* at moisture range of 6.59 to 51.13% (wb) and 8.63x10^{-06} to 1.05x10^{-05}m^2/s at moisture range of 6.56 to 60.5% (wb). The result of this research work is useful in designing processing procedure and equipment of the crop investigated and also formulation of models for drying the crop.

However, tensile, shear resistance and compressive strength test could further be carried out as this can help to improve processing of the crop.

REFERENCES

Achigan-Dako G. E., Vodouhe S. R. and Sangare A. 2008. Caracterisation morphologique des cultivars locaux de Lagenaria siceraria (Cucurbitaceae) collectes au Benin et au Togo. *Belgium J Bot,* 141: 21-38

Aremu A. K. and Fadele O. K. 2010. Moisture dependent thermal properties of doum palm fruit. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS), I (2), 199-204.

Aviara N. A. and Haque M. A. 2001. Moisture dependence of thermal properties of sheanut kernel. J Food Eng. 47: 109-113.

Bart-Plange A., Asare V. and Addo A. 2009. Thermal conductivity of maize and cowpea. J Eng and Tech. 2-3: 6-11.

Bitra V. S., Banu S., Ramkrishna P., Narender G. and Womac A. R. 2010. Moisture dependent thermal properties of peanut pods, kernels and shell. Journal of Food Engineering, 106, 503-512.

Choi Y., and Okos M. R. 1983. The thermal properties of tomato juice concentrates. Transactions of ASAE, 26(1), 305–311.

De Moura S. C. S. R.; Germer S. P. M.; Jardim D. C. P. and Sadahira M. S. 1998. Thermophysical properties of tropical fruit juices. *Brazilian J. Food Technol.*, 1, 70.

Hsu M. H., Mannapperuma J. D. and Singh R. P. 1991. Physical and thermal properties of pistachios. J Agric Eng Res 49: 311-321.

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.

Lentz C. P. 1961. Thermal conductivity of meats, fats, gelatin gels, and ice. *Food Technology*. 15:243-247.

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.

Magee T. R. and Bransburg T. 1995. Measurement of thermal diffusivity of potato, malt bread and wheat flour. Journal of Food Engineering, 25, 223-232.

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.

Mohsenin, N. N. 1990. Thermal properties of foods and agricultural materials. New York: Gordon and Breach.

Murata S., Tagawa A., Ishibashi S. 1995. The effect of moisture content and temperature on specific heat of cereal grains measured by DSC. J Jap Soc Agric Mach 46(6):547-554.

Nathakaranakule A. and Prachayawarakorn S. 1998. Determination of physical properties of cashew nuts. J Kasetsart 32(2) p. 171-186

Nouri Jangi A., Mortazavi1 S. A., Tavakoli M., Ghanbari H., Tavakolipour A., Haghayegh G. H. 2011. Comparison of mechanical and thermal properties between two varieties of barley (*Hordeum vulgare* L.) grains. Aust J Agric Eng 2(5):132-139.

Qashou, M.S., Vachon, R.I., and Touloukian, Y.S. 1972. Thermal conductivity of foods. *ASHRAE Transactions*. Feb 29.

Rahman, M.S. 1993. Specific heat of selected fresh seafood. *Journal of Food Science*. 58(3):522-524.

Reidy, G.A., and Rippen, A.L. 1971. Methods for determining thermal conductivity in foods. *Transactions of the ASAE*. 15(2):248-251.

Singh S. S. and Goswani T. K. 2000. Thermal properties of cumin seed. J Food Eng45: 181-187.

Stroshine, R., Hamann, D. D. 1994. Physical Properties of Agricultural Materials and Food Products. 1994. Course manual, Purdue University, USA.

Sweat V. E. and Haugh C. G. 1974. A thermal conductivity probe for small food samples. *Transactions of the ASAE*. 17(1):56.

Taiwo K. A., Akanbi C. T., and Ajibola O. O. 1996. Thermal properties of ground and hydrated cowpea. J. Food Eng. 29: 249-256.

Van der Vossen H. A. M., Denton O. A. and El Tahir I. M. 2004. *Citrullus lanatus.In:* Grubben G.J.H. & Denton O.A. *Plant Resources of Tropical Africa 2. Vegetables*. Wageningen, The Netherlands: CTA; Leiden, The Netherlands: Backhuys Publishers, 185-191.