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 (Colocynthis 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 8.42x10⁻⁶ to 1.127x10⁻⁵ m²/s for Wuruwuru at moisture content range of 6.56 and 60.5% (wb) and 8.63x10⁻⁶ to 1.05x10⁻⁵ m²/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/kg°C to 3.45 kJ/kg°C with moisture content range of 6.59 to 39.62 % (wb) for Wuruwuru and 3.735 to 4.509 kJ/kg°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 Achigian-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 Achigian-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. Mucoospermus (sliced young fruit of this specie is said to heal stomach aches while the seed coat in decoction with Eucalyptus (Eucalyptus camaldulensis dehn.) roots is a sedative for epilepsy). The roasted seeds, ground with salt are taken with warm water or porridge to prevent vomiting (Achigian-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, 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, 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, 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, 1998).
MATERIALS AND METHODS
Sample Preparation
The samples of three different Egusi Melons (Citrus lanatus) were purchased from the Local market and were Waruwaru (Cucumis melo), Bakabaka (Cucumeropsis manni) 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 $J$ 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:

$$H = J \left[ Q_A T_A + Q_B T_B + Q_C T_C \right]$$

where $Q_A$, $Q_B$, $Q_C$ 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;

$$H = IV \left( J^2 s^{-2} \right)$$

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

Then the thermal conductivity

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

(Telford et al, 1984)

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:

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

(Magee and Bransburg, 1995)

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 $r= 0$, ($dT/dr|_{r=0}$) = 0 and $r=R$, $T = T_R$, for the center of the cylinder, $r= 0$ and $T = T_0$ is:

$$T_R - T_0 = \frac{4A R^2}{\pi \alpha}$$

(Magee and Bransburg, 1995)

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 Goswami, 2000 and Nouri Janggi 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).

$$C_p = \frac{(M_1 C_1 + M_2 C_2)/(T_2 - T_1)}{M_2 (T_2 - T_3)}$$

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 manni) has its highest thermal conductivity of 0.382 W/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 manni) 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.

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

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

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.

*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.
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.

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 8.42x10⁻⁹ to 1.127x10⁻⁸m²/s for *Wuruwuru* and 8.630x10⁻⁹ to 1.050x10⁻⁸m²/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.

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.
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 Wurwuru (Cucumis melo), and Bakabaka (Cucumeropsis mannii). The specific heat varied from 2.803kJ/kg°C to 3.454kJ/kg°C in the moisture content range of 6.59 to 39.62 % (w.b) for Wurwuru and 3.735 to 4.509kJ/kg°C in the moisture content range of 6.56 to 48.64% (w.b). 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.

![Graph](image)

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

\[
\begin{align*}
\text{c}_{\text{Wurwuru}} &= 0.018x + 2.634 \quad R^2 = 0.966 \\
\text{c}_{\text{Bakabaka}} &= 0.013x + 3.659 \quad R^2 = 0.966
\end{align*}
\]

Where \(c_{\text{Wurwuru}}\) is the specific heat of Wurwuru species and \(c_{\text{Bakabaka}}\) 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. Hsa et al., (1991) reported that the specific heat of pistachios varied from 1.1 to 2.1kJ/kg°C 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°C to 0.382W/m°C, 0.226W/m°C to 0.375W/m°C and 0.226W/m°C to 0.359W/m°C at 250µm to 800µm for all the melon species (Bakabaka, Wurwuru 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 Wurwuru and Bakabaka 2.803 to 3.454kJ/kg°C at moisture range of 6.59 to 39.62 % (wb) and 3.735 to 4.509kJ/kg°C at moisture range of 6.56 to 48.64% (wb) and thermal diffusivity increased from 8.42x10^{-6} to 1.1271x10^{-5} m²/s for Wurwuru (Cucumis melo) at moisture range of 6.59 to 51.13% (wb) and 8.63x10^{-6} to 1.05x10^{-5} m²/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**


