Abstract—Thermal properties of crops are very important in the design of drying, processing and storage equipment. To this end, the thermal conductivity, specific heat capacity and thermal diffusivity of three egusi melon species Bakabaka (Cucumeropsismannii), Bara (Colocynthis citrullus) and Waruwaru (Cucumis melo) were determined as a function of moisture content. The thermal conductivities were determined by the Lees’ Disc method. Thermal diffusivity was determined experimentally by the use of a cylindrical tube and a thermally controlled water bath while Specific Heat Capacity was determined by the method of mixtures. The thermal conductivity of Cucumeropsis mannii varied from 0.33 to 0.49 Wm⁻¹K⁻¹ at 3.28 – 23.12% w.b; for Colocynthis citrullus from 0.33 to 0.51 Wm⁻¹K⁻¹ at 2.45 – 20.69% w.b and for Cucumis melo from 0.39 to 0.56 Wm⁻¹K⁻¹ at 1.87 – 22.06% w.b. all increase with moisture content; thermal diffusivity increased linearly from 0.09 × 10⁻² to 0.12 × 10⁻² m²s⁻¹ with increasing moisture content in the range of 6.57 to 60.8% w.b for Cucumis melo and decreased linearly from 0.13 × 10⁻² to 0.10 × 10⁻² m²s⁻¹ with increasing moisture content in the range of 5.79 to 53.65% for Colocynthis citrullus. The Specific Heat Capacity varied from 1.39 KJkg⁻¹K⁻¹ to 3.42 KJkg⁻¹K⁻¹ at moisture content range of 5.79 to 41.80 % w.b and from 1.51 KJkg⁻¹K⁻¹ to 2.45 KJkg⁻¹K⁻¹ at 6.59 to 39.62% for Colocynthis citrullus and Cucumis melo respectively. Thermal conductivity and specific capacity were found to increase linearly with increasing moisture content while thermal diffusivity increased in moisture content for Cucumis melo but decreased with increasing moisture for Colocynthis citrullus. The values obtained could be used as parameters in the designing and manufacturing of equipment for packaging egusi melon for safe storage and longer shelf life.

Keywords—Egusi species, Lees’ disc apparatus, specific capacity, thermal conductivity, thermal diffusivity.

I. INTRODUCTION

The origin of melon is Africa and Asia [9] and areas where it is widely cultivated include the Caribbean, Indonesia and Africa. In Nigeria, the existence of melon dates back to the 17th century. Egusi melon is a popular fruit in Nigeria because of the edible seeds which are commonly used in the preparation of local soup or stew and snacks such as fried melon seed ball known as Robo in South Western Nigeria.

Recent statistics shows that 100,000 and 488,000 metric tons of melon were produced in Nigeria in 1992 and 1997 respectively [14]. In the East, the seeds are sometimes boiled and eaten as snacks too. The seeds are rich in oil (30–50 percent) which is comparable to other oil plants [32] and the oil contains a high level of saturated fatty acids [1]. Egusi melon is also an important component of the traditional cropping system usually inter-planted with such staple crops as cassava, maize, sorghum, etc. [31].

Egusi melon (Citrullus lanatus) Bara (Colocynthis citrullus) and Serewe are most common in Nigeria. Survey and evaluation trials conducted by Lanre and Adeniran [1] showed definite geographical distribution and differences in the performance of the two types. The Colocynthis citrullus has the widest distribution. The geographical distribution was attributed to consumers’ preference rather than physiological adaptation of the crop. The cross-ability between egusi melon and water melon had been exploited by National Institute for Horticultural Research and Training (NIHORT) to produce new cultivars with edible seeds [26]. Studies by researchers indicated that egusi melon pods have an almost spheroidal external shape and an ellipsoidal seed cavity [34], [29], [8], [2]. To transform these produce into internationally acceptable and marketable products, their shelf life needs to be improved and high quality maintained. Since only a few agricultural crops such as fresh fruits and vegetables go from field to the table without any thermal processing, therefore thermal processing becomes unavoidable. Thermal processing (include treatments such as pasteurization, concentration, drying, cooling, etc.) is frequently used in food processing, transportation, storing and cooking to improve the shelf life and good quality of the material. To achieve these, there is therefore need to determine the thermal properties of the produce.

Van Gelder[44] used a thermistor based method to measure the thermal conductivity and thermal diffusivity of moist potato and lean beef at high temperatures. Timbers [43] calculated the thermal conductivity of rapeseed from its thermal diffusivity measured with the Dickerson apparatus.
Moysey et al., [23], Wallapahan & Sweat [45], Shepherd & Bhadwaj [36] and Dutta et al., [12] used the line heat source thermal conductivity probe to measure the thermal conductivity of rapeseed, defatted soy flour, pigeon pea and grain respectively, while Ojha et al., [30] and Farrall et al., [13] determined the thermal conductivity of non-fat dry milk, wheat flour and powdered milk, using the steady state method. Timbers [43] and Drusas et al., [10] measured thermal diffusivity using the Dickerson apparatus, while Kazarian and Hall [20], Shepherd and Bhardwaj [36], and Dutta et al., [12] determined it from the measured values of Specific Heat Capacity, thermal conductivity and bulk density. Among the published methods for Specific Heat Capacity measurement, differential scanning calorimetry (DSC) has so far been the most accurate and rapid method. Tang et al., [40] reviewed the literature on thermoeasurement of specific heat capacity for agricultural products, and provided analyses on the key factors that can affect the specific heat capacity measurement using the DSC method. Yang et al., [46] described DSC procedures for measuring the specific heat capacity of borage seeds, and developed a model to correlate the Specific Heat Capacity with temperature and moisture content. The aim of this study is to determine the thermal properties of three species of egusi melon with respect to their thermal conductivity, thermal diffusivity and specific capacity in relation to the various moisture contents.

II. MATERIALS & METHODS

The egusi melon species Bakabaka (Cucumeropsis mannii), Bara (Colocynthis citrullus) and Wuruwuru (Cucumis melo) used in this research were purchased from Oja-oba in Akure, Ondo State, Nigeria. It was carried out at the Department of Agricultural Engineering, Processing Laboratory Obakekere of the Federal University of Technology, Akure, Ondo State.

Plate 1: Egusi Species (a) Bakabaka (Cucumeropsis mannii) (b) Bara (Colocynthis citrullus) (c) Wuruwuru (Cucumis melo)

A. Sample Preparation

The melon samples were manually cleaned to remove foreign materials from the whole seeds. The moisture contents of the samples were determined using a standard oven method at 105°C for 24 hours [11].

Samples were conditioned by adding calculated amounts of distilled water to attain the desired moisture levels using equation 1 [39], [17].

\[ Q = \frac{W_i(M_f-M_i)}{100-M_f} \]

The samples were sealed in separate polythene bag and kept in a refrigerator at 5°C for five days to ensure uniform moisture distribution 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 [27] in a desiccator (to prevent moisture reabsorption). The moisture content of melon samples was investigated each at five moisture levels between 3.28 and 23.12%; 2.45 and 20.69%; and 1.87 and 22.06% w.b for Cucumeropsis mannii, Colocynthis citrullus and Cucumis melo respectively.

B. Method of Moulding

The sample was weighed in an electronic weighing balance to determine the quantity of the powder. The powder was then placed inside the moulding device. The device was placed under a hydraulic machine in which a load meter is attached to determine and maintain a constant load for all samples. Thereafter, the samples were weighed and stored in a polythene material kept in a desiccator to prevent moisture absorption.

i. Thermal Conductivity

The apparatus used is made of a polished wood and it consists of disc A, B and C, heater and the space for sample to be inserted to determine its thermal conductivity and the corresponding voltage, V and current, I supplied for powering the heater which lead to the determination of temperature effect on the thermal and electrical conductivity. Each of the discs contains a hole into which the thermometer is inserted. The apparatus is arranged in this order; disc C followed by heater followed by disc B, then the sample and lastly disc A which is connected to the external circuit that contains a rheostat, voltmeter and ammeter. The thermal conductivity is determined mathematically by the equation 2.

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

Wm⁻¹°C⁻¹ 2

ii. Thermal diffusivity

The following method was used for the determination of thermal diffusivity of food grains [18]. The apparatus consists of a thermal diffusivity tube and an insulated and well-stirred water bath of 25 litre capacity.
The cylinder was filled with the milled melons and the entire assembly was placed with end caps and thermocouples in a water bath. Heat at constant rate applied to the water bath with the help of 1000 W immersion heater. The water in the bath was stirred with the help of a stirrer at suitable speed, driven by a motor of 40 W, 4000 rpm and coupled to a speed regulator. The thermal diffusivity was determined by using the following formula:

\[ \alpha = \frac{R^2 A}{4(\tau_R - \tau_c)} \]  

iii. Specific heat capacity

The method of mixtures has been the most common technique reported in literature for measuring the Specific Heat Capacity of agricultural and food materials [38], [3], [35], [28], [5].

For the determination of Specific Heat Capacity in this study, the method of mixtures was used. Moulded melon samples of known mass, temperature and moisture content were 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. A digital thermometer was used to monitor the temperature of the mixture. The equilibrium temperature was noted and the Specific Heat Capacity was determined using equation 4 as used by [3].

\[ C_p = \frac{M_2 C_1 + M_3 C_2 (\Delta T_2 - \theta)}{M_1 (\Delta T_1 + \theta)} \]  

III. RESULTS AND DISCUSSION

i. Effect of moisture content on the thermal conductivity of Colocynthis citrullus L samples

The variation of thermal conductivity with moisture content is shown in Figure 1. The thermal conductivity of ground melon Cucumeropsis mannii varied from 0.33 to 0.49 Wm\(^{-1}\) °C\(^{-1}\) with increasing moisture content in the range of 3.28 – 23.12% w.b; for Colocynthis citrullus from 0.33 to 0.51 Wm\(^{-1}\) °C\(^{-1}\) with increasing moisture content in the range of 2.45 – 20.69% w.b as shown in Figure 2 and for Cucumis melo from 0.39 to 0.56 Wm\(^{-1}\) °C\(^{-1}\) with increasing moisture content in the range of 1.87 – 22.06% w.b as shown in Figure 3.

The linear relationship and increase of thermal conductivity with moisture content of all the Colocynthis citrullus L samples agreed with other researchers such as Perusella et al., [33] for banana, Bart-Plange et al., [4] for cowpea and maize and Singh and Goswami [38] for cumin seeds also reported the existence of linear relationship between thermal conductivity and moisture content. Kurozawa et al., [21] found thermal conductivity to increase from 0.57 to 0.61 Wm\(^{-1}\) °C\(^{-1}\) with temperature in the range of 25 to 45 °C for cashew apple.

The thermal conductivity of the three samples all increased steadily with increase in moisture content (Figure 5). Cucumis melo increases greatest and the least was Cucumeropsis mannii. At moisture content 22.0%, the thermal conductivity was greatest for all the samples (Cucumeropsis mannii at 0.49, Colocynthis citrullus at 0.51 and Cucumis melo at 0.56 Wm\(^{-1}\) °C\(^{-1}\)) and least at 2.5% moisture content (Cucumeropsis mannii at 0.33 Wm\(^{-1}\) °C\(^{-1}\), Colocynthis citrullus at 0.33 Wm\(^{-1}\) °C\(^{-1}\) and Cucumis melo at 0.39 Wm\(^{-1}\) °C\(^{-1}\)). This is because at the initial temperature level, thermal energy intake by the sample was very low. However, at a higher temperature level the thermal energy increased as a result of large amount of moisture present in it and cellular structure of the product, also because water has a higher thermal conductivity compared to dry agricultural materials and thus contributes to high thermal conductivity in them. This property could be useful when heat treating the produce prior to further processing.

![Figure 1: Variation of Moisture Content with Thermal Conductivity of Cucumeropsis Mannii](image-url)
ii. Effect of moisture content on the thermal diffusivity of *Colocynthis citrullus* l samples

Figure 5 shows the existence of a linear relationship between thermal diffusivity and moisture content. Thermal diffusivity increased linearly from $0.09 \times 10^{-5}$ to $0.12 \times 10^{-5}$ m$^2$s$^{-1}$ with increase in the moisture content in the range of 6.57 to 60.8% w.b for *Cucumis melo*. The *Colocynthis citrullus* sample showed different behaviour from that of *Cucumis melo* sample. In general, values for thermal diffusivity of *Colocynthis citrullus* decreased linearly from $0.13 \times 10^{-5}$ to $0.10 \times 10^{-5}$ m$^2$s$^{-1}$ with increasing moisture content in the range of 5.79 to 53.65% as shown in Figure 6. Hobani and Al-Askar, [15], 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 [28]. Other researchers such as Aviara and Haque[3], Tansakul and Lumyong[42], Shyamal et al., [37] reported a linear relationship between thermal diffusivity and moisture content for sheanut kernel, straw mushroom and wheat respectively. This is in support with the behaviour exhibited by *Cucumis melo*. The values for thermal diffusivity of borage seeds decreased with increasing moisture content. *Colocynthis citrullus* also showed this decrease with increase in moisture content.
iii. Effect of moisture content on the specific heat capacity of colocynthis citrullus L samples

The variation of specific heat capacity with moisture content is presented in Figures 7 & 8. The specific heat capacity varied from 1.39 KJ.kg\(^{-1}\)\(\cdot\)C\(^{-1}\) to 3.42 KJ.kg\(^{-1}\)\(\cdot\)C\(^{-1}\) in the moisture content range of 5.79 to 41.80 %w.b and from 1.51 KJ.kg\(^{-1}\)\(\cdot\)C\(^{-1}\) to 2.45 KJ.kg\(^{-1}\)\(\cdot\)C\(^{-1}\) in the moisture content range of 6.59 to 39.62% for Colocynthis citrullus and Cucumis melo respectively. The specific heat capacity increased linearly with increasing moisture content. The increasing trend in Specific Heat Capacity within moisture content correlated with work done by other researchers. Nathakaranakule and Prachayawarakorn[25] also found a similar linear variation with the specific heat capacity of cashew nuts varied linearly with moisture content. Hsu et al.[16] reported that the specific heat capacity of pistachios varied from 1.1 to 2.1kJ/kgK at within the moisture content range of 9.5-39% w.b. Chandrasekar and Viswana than[7] 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 capacity increased linearly from 0.78 to 2.36kJ/kgK with increasing moisture content. However, other studies have reported non-linear relationships of some food and agricultural products, (Murata et al., [24] for rice; Tang et al., [41] for lentil seeds; Chakraborty and Johnson, [6] for tobacco).

IV. CONCLUSIONS

a. The thermal conductivity of Colocynthis citrullus L increased from 0.33 to 0.49 W m\(^{-1}\)\(\cdot\)K\(^{-1}\) at moisture contents from 3.28 to 23.12% w.b for Cucumeropsis mannii; from 0.33 to 0.51 W m\(^{-1}\)\(\cdot\)K\(^{-1}\) at moisture contents from 2.45 to 20.69% w.b for Colocynthis citrullus and 0.39 to 0.56 W m\(^{-1}\)\(\cdot\)K\(^{-1}\) at moisture contents from 1.87 to 22.06% w.b. For Cucumis melo, moisture content had significant effect on the thermal conductivity of Colocynthis citrullus L seeds.
b. The specific heat capacity of melon (Colocynthis citrullus) seeds varied from 1.39 to 3.42 KJ.kg\(^{-1}\).C\(^{-1}\) at 5.79 – 41.8% w.b. While at moisture content range 6.59 – 39.62% w.b and the specific heat capacity varied from 1.51 to 2.45 KJ.kg\(^{-1}\).C\(^{-1}\) for Cucumis melo.

c. The thermal diffusivity of Colocynthis citrullus seeds ranged from 0.13×10\(^{-5}\) to 0.10×10\(^{-5}\) m\(^2\)s\(^{-1}\) at moisture contents from 5.79 to 53.65% w.b. And Cucumis melo seeds ranged from 0.09×10\(^{-5}\) to 0.12×10\(^{-5}\) m\(^2\)s\(^{-1}\) at moisture content 6.57 to 60.8% w.b.

REFERENCES


**Nomenclatures**

\( \alpha \) = Thermal diffusivity, \( m^2s^{-1} \)

\( R \) = Radius of the tube, m

\( M.C \) = Moisture Content (%)

\( k \) = Thermal Conductivity (Wm\(^{-1}\)C\(^{-1}\))

\( A \) = constant slope of temperature versus time curve, \( ^\circ \text{C/s} \)

\( T_R - T_c \) = constant temperature difference at any time between temperature at the surface \( (T_R) \) and temperature at the centre \( (T_c) \) of thermal diffusivity tube in \( ^\circ \text{C} \)

\( Cp \) = Specific Capacity, KJ.kg\(^{-1}\)ºC\(^{-1}\)

\( M_2 \) = Mass of calorimeter cup, g

\( M_1 \) = Mass of sample, g

\( M_3 \) = Mass of water, g

\( C_1 \) = Specific Capacity of a copper calorimeter

\( C_2 \) = Specific Heat Capacity of water, KJ.kg\(^{-1}\)ºC\(^{-1}\)

\( \Delta t_1 \) = Temperature change of the sample, \( ^\circ \text{C} \)

\( \Delta t_2 \) = Temperature change of the calorimeter cup and water, \( ^\circ \text{C} \)

\( \theta \) = Temperature correction, \( ^\circ \text{C} \)

\( Q_A, Q_B, Q_C, Q_S \) 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.

\( T_A, T_B, T_C \) are temperature of the disc A, B, C at the steady state above the initial temperature