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DETERMINATION OF THERMAL CONDUCTIVITY OF THE ROOTS OF THREE IMPROVED CASSAVA VARIETIES

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ABSTRACT: *Processing of cassava roots into various cassava based products often involves the application of heat and this is still being done traditionally. Improved methods of processing and handling the roots could be developed for these purposes but it requires a good knowledge of the thermal behavior of the roots as their response to heat treatments is dependent on their thermal behaviour. The thermal conductivity of a crop is particularly useful in this regard as it controls the heat flux during heat transfer processes. However, such information on cassava roots is currently scarce. Thermal conductivity (k) of three improved cassava varieties (TME 419, TMS 30572 and TMS 0326) were determined at moisture contents of 50 – 70% (wet basis) using the KD 2 Pro. The value of k ranged from 0.5284 – 0.5662; 0.4804 – 0.5530 and 0.4660 – 0.5800 W/m*^{0}*K for TME 419, TMS 30572 and TMS 0362 respectively. k of the roots also varied sinuously with increase in moisture content and the relationship was described by polynomial models of the third order with* R^2 *values of the plots ranging from 0.7569 – 0.9544. The influence of moisture was not significant (*$p > 0.05$*).*

Keywords: Thermal Conductivity, Root Crop, Cassava Varieties
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INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a root crop belonging to the family of Euphorbiaceae and is the most important root crop grown in the tropics (Enwere, 1998; Anikwe and Onyia, 2005). Cassava plays an important role in agriculture in developing countries because it does well on poor soils (even in areas with low rainfall) and the fact that it is a perennial that can be harvested as and when required. It is highly perishable and has a storage life of less than 48 hours. As a result of this, farmers usually leave cassava roots in the ground after they have matured and harvest them for processing when required. Therefore, on average cassava roots are often harvested about fifteen months after planting even though they are ripe for, and harvesting usually starts 12 months after planting. Apart from in-ground storage, cassava roots are also processed into shelf-stable forms such as chips, High Quality Cassava Flour (HQCF), *Lafun*, tapioca etc. Processing of cassava roots into these aforementioned products often involve heat treatment either by heat addition (drying, dry-aeration to prevent spoilage during storage, sterilization, freezing etc) or heat removal (cooling or tempering), all of which required a good knowledge of the thermal behavior of cassava. Knowledge of thermal properties of food and agricultural products are essential for equipment design and prediction of heat transfer operations involving foods and vegetables (Viviana *et al.*, 2008). Thermal conductivity data is needed for calculating energy demand for 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, drying etc. most of which are often carried out without taking into consideration the actual quantity of heat needed to accomplish a given heat treatment operation. This is as a result of non-availability or inadequacy of such information as thermal conductivity for most local agricultural products (Bart-Plange *et al.*, 2012), cassava inclusive.

Most of the postharvest processing operations performed on cassava roots and its bye-products often involve the application of, or removal of heat. However, most of these operations are still being done manually. For instance, despite the large volume of demand by China for cassava chips from Nigeria, commercial cassava drying/frying equipment are yet to be found in the market. Most of these chips are still being dried in the sun. This may not be unconnected with the serious dearth of data on the thermal properties of cassava that would enhance the design of efficient equipment as revealed by literature search. The work of Njie *et al.* (1998) is about the only reported work on the thermal properties of cassava which was conducted alongside those of yam and Plantain. Whereas, thermal properties have been determined extensively for other crops such as deoum palm fruit (Aremu and Fadele, 2010), sugarbeet (Talib *et al.*, 2003), Peanut (Bitra *et al.* 2010), Sheanut kernel (Aviara and Haque, 2001), cumin seed (Singh and Goswani 2000), borage seed (Yang *et al.*, 2002).

Thermal conductivity is the rate at which heat passes through a specified material expressed as the amount of heat that flows per unit time through a unit area with a temperature gradient of one degree per unit distance. Fourier's law described the steady state heat conduction (Mohsenin, 1980);

$$q = kAdt/dx$$

k, the thermal conductivity represents the proportional factor in the equation, q is heat energy flow per unit time, A is cross sectional area, T is temperature and x is distance in the direction of heat flow. Knowledge of the thermal properties helps the engineer to formulate his drying equations and select materials for the design of dryers, heat exchangers, heaters and other heat equipment. It also helps him to solve various problems on heat transfer operations always encountered in bulk storage or drying of agricultural materials. These also lead to increase in process simulation activity since adequate property data are available (Oyerinde, *et al.*, 2006).

Published results of thermal conductivity of different crops have shown that it is influenced by a number of factors which include porosity, moisture content, composition of the agricultural material and fibre orientation (Stroshine and Hamann, 1994; Mohsenin, 1980). They reported that k increased with increase in moisture content (Opoku *et al.* 2006; Aremu and Falade, 2010; Aviara *et al.*, 2008; Sweat, 1986). Miles *et al.* (1983) assigned constant values to each component of food materials with water having the highest value of 0.6 for unfrozen food and ice was allocated a constant value of 2.24 for frozen foods. This constant was used to multiply the volume fraction of each component such as carbohydrate, protein, water etc. Hence, food materials with high moisture content may have k in the same range if their percentage of carbohydrate, ash, protein etc components is the same. Therefore the aim of this study was to determine the thermal conductivity of three improved cassava varieties.

MATERIALS AND METHODS

Fresh roots of the TME 419, TMS 30572 and TMS 0326 cassava cultivars were harvested from the Experimental, Teaching and Research Farm of the - Department of Agricultural Engineering, LAUTECH, Ogbomoso, Oyo state, which was established purposely for this research. The planting was pre-planned such that the harvesting period would fall within the raining season when the average moisture content of the roots would be above 70%. The harvesting was done at 15 Months After Planting (MAP). The fresh roots were peeled and cut into a cylindrical shape of length 5cm and diameter 3.5cm to accommodate the whole length of the needles as well as provide for allowance of 0.5cm between the tip of the needles and the end of the samples (lengthwise) and 2.0cm from each of the needles to the circumference of the samples. This was done to ensure accurate results as specified by the manufacturer of the KD 2 Pro used for conducting the experiment. The KD 2 Pro uses the transient line heat source method to measure the thermal properties. The samples were grouped into five batches which contained five samples each, making a total of 25 samples. The initial moisture content of the samples was first determined with the use of an OHAUS MB 35 Halogen moisture analyzer. Thereafter, the samples were placed in a DHG 9101.1SA (UK) oven which had already attained a temperature of 70°C. They were brought out in batches after attaining the desired moisture contents of 50, 55, 60, 65, and 70% (wb) and then placed in the refrigerator for 24hrs for moisture equilibration. The samples were allowed to attain room temperature before measuring their thermal conductivity by inserting the SH-1 probe through the centre of the samples. Data generated from the experiments were analyzed using the Design Expert 6.0.8.

RESULTS AND DISCUSSION

Table 1: Thermal Conductivity of Cassava

MC (%)	TME 419	TMS 30572	TMS 0326
50	0.5662	0.5530	0.4660
55	0.5363	0.5136	0.5390
60	0.5284	0.4956	0.5800
65	0.5440	0.5354	0.4660
70	0.5290	0.4804	0.4880

Mean values of the thermal conductivities obtained for the roots of the three cassava varieties are as presented in Table 1, it was observed that the thermal conductivity (k) of the cassava roots ranged from 0.5284 – 0.5662; 0.4804 – 0.5530 and 0.4660 – 0.5800 W/m^{0}K for TME 419, TMS 30572 and TMS 0362 respectively. These values are higher than those reported by Oke *et al.* (2007) for sweet potato (0.042 – 0.217 W/m^{0}K) at 70% moisture content (wb) and temperature range of -18 to 33^{0}C. On the other hand, a mean value of 0.49W/m^{0}K reported by Farinu and Baik (2007) for the same crop at moisture content of 45 – 70% (wb) and temperature range of 20 – 60^{0}C are closer than those of Oke *et al.* (2007). The difference may be due to the different temperature ranges used. The values obtained in the study being reported here are, however, in perfect agreement with the 0.50 – 0.57 W/m^{0}K reported by Njie *et al.* (1998) for cassava at moisture range of 47 – 70% (wb). Similarly, the values are within the same range of 0.5246 – 0.6052 W/m^{0}K reported for unfrozen sugarbeet by Talib *et al.* (2003). This is an indication that generally the thermal conductivity of cassava roots is high and it wound transmit heat energy better and faster than sweet potato during processing operations involving heat application such as drying or heat removal such as freezing probably due to its relatively low porosity compared to sweet potato. It was also observed that k did not increased with increase in moisture content as reported for most agricultural crops such as cocoa (Bart-Plange *et al.*, 2012); Doum palm fruit (Aremu and Falade,2010), rather, it increased or declined with increase in moisture content within certain range of moisture content depending on the cultivar of cassava involved. The plot of the data in Table 1 is shown in Figures 1 – 3 with R^2 values of each of them. A third order polynomial was fitted to the thermal conductivity data as only this model gave the highest coefficient of determination of all the models fitted. Similarly, a third order polynomial model was reported by Oke *et al.* (2007) for specific heat, thermal conductivity and thermal diffusivity of sweet potato with temperature.

Figures 1 – 3 show that generally, thermal conductivities of the samples of two of the three cassava varieties (TME 419 and TMS 30572) followed the same trend and the plots of the two are almost having the same shape such that their thermal conductivities initially reduced as the moisture content of the samples increased from 50% to 55% and they both had the lowest thermal conductivity at 70% moisture content and the highest at 50% moisture content (wb). Samples of the TMS 0326 cassava cultivar on the other hand followed a reverse trend by exhibiting best heat conduction around this same moisture content and the lowest at 50% moisture content.

Specifically, the thermal conductivity of the TME 419 cultivar was better than the other two cultivars except at moisture contents between

52.5 and 62% (wet basis), but it had the highest thermal conductivity at 50% and the lowest at 70% (wb). Unlike other reported results of thermal conductivity for some other agricultural crops such as Doum palm fruit (Aremu and Fadele, 2010); Shea nut kernel (Aviara and Haque, 2001); Pea nut kernel, pod and shell (Bitra *et al*., 2010), a non-linear relationship exists between k of TME 419 and moisture content as shown in Figure 1. A similar trend was also observed for the diffusivity of Doum by Aremu and Fadele (2010) and Oke, *et al.* (2007). The conductivity of TME 419 reduced from 0.5662 W/m^{0}K at moisture content of 50% to 0.5363 W/m^{0}K 55%, thereafter it increased gently to a peak point before attaining the least conductivity value of 0.5290 at 70%.

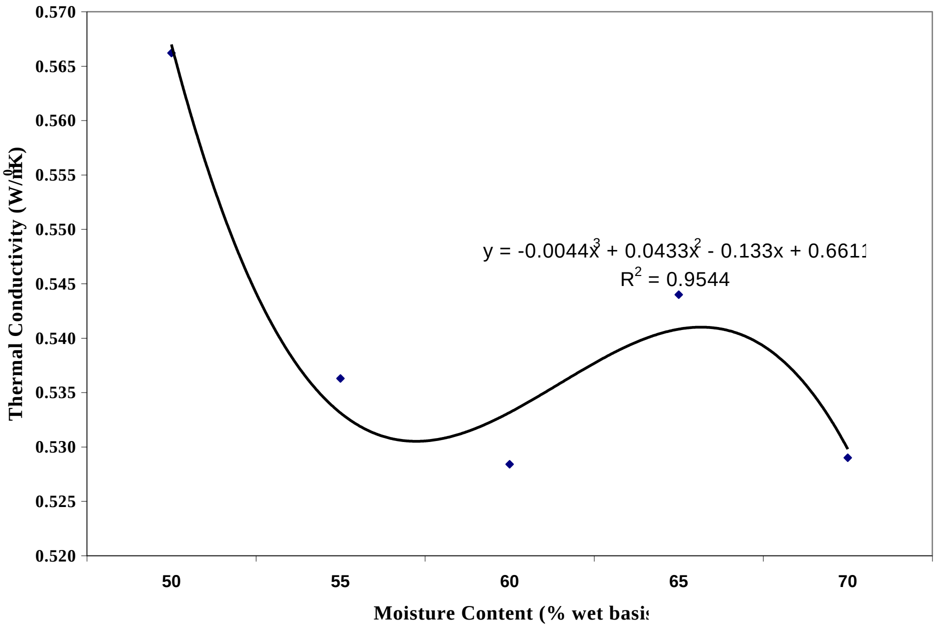

Figure 1: Thermal Conductivity of TME 419 with Moisture Content.

The thermal conductivity of the TMS 30572 samples also exhibited a sinuous trend like that of TME 419 but with much lower k values, steeper gradient and sharper graph inflexions (Figure 2). This similarity was also noted in the physical properties of the two cassava cultivars by Oriola and Raji (2013) and it was attributed to the possibility that they were both cloned from the same parent(s) since they were cloned by the same research institute (International Institute for Tropical Agriculture, IITA). The observed trend is an indication that the TMS 30572 samples conducted heat less rapidly than those of the TME 419 but with considerable variations in k with each increase in moisture content than those of TME 419. For instance, the TMS 30572 samples exhibited the best heat conduction at low moisture content of 50% as it exhibited a conductivity of 0.5530 W/m^{0}K. This, however, reduced shapely to 0.5136 W/m^{0}K when the moisture level of the sample was increased to 55%, it increased sharply thereafter to a maximum level of 0.5200 W/m^{0}K before declining to the lowest value of 0.4804 W/m^{0}K. The low values of k observed for the TMS 30572 cultivar may be an indication that the percentage of carbohydrate in the composition of this cassava variety is lower than that of the TME 419 as explained by Njie *et al* (1998).

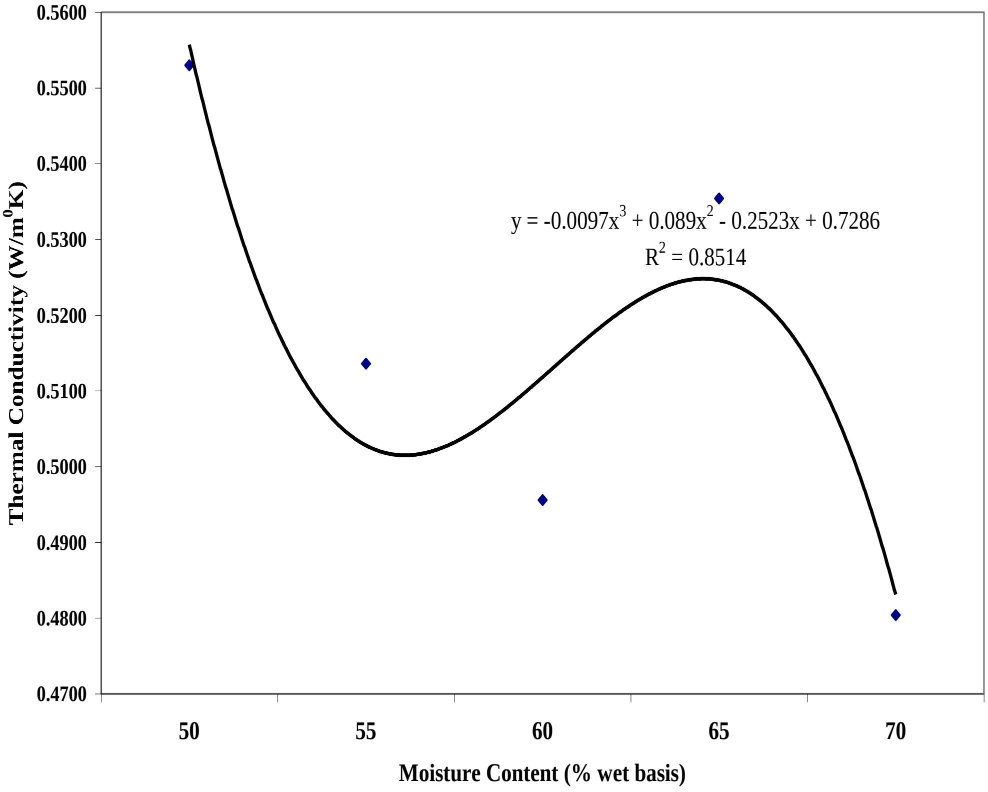

Figure 2: Thermal Conductivity of TMS 30572 with Moisture Content.

The thermal conductivity of samples of the TMS 0326 cassava cultivar was distinctly different from the other two cassava cultivars as it was found to be lowest at low moisture content of 50% and peaked at 55%

moisture content by rising steeply to 0.5390 W/m^{0}K from the initial 0.4660 W/m^{0}K (Figure 3).

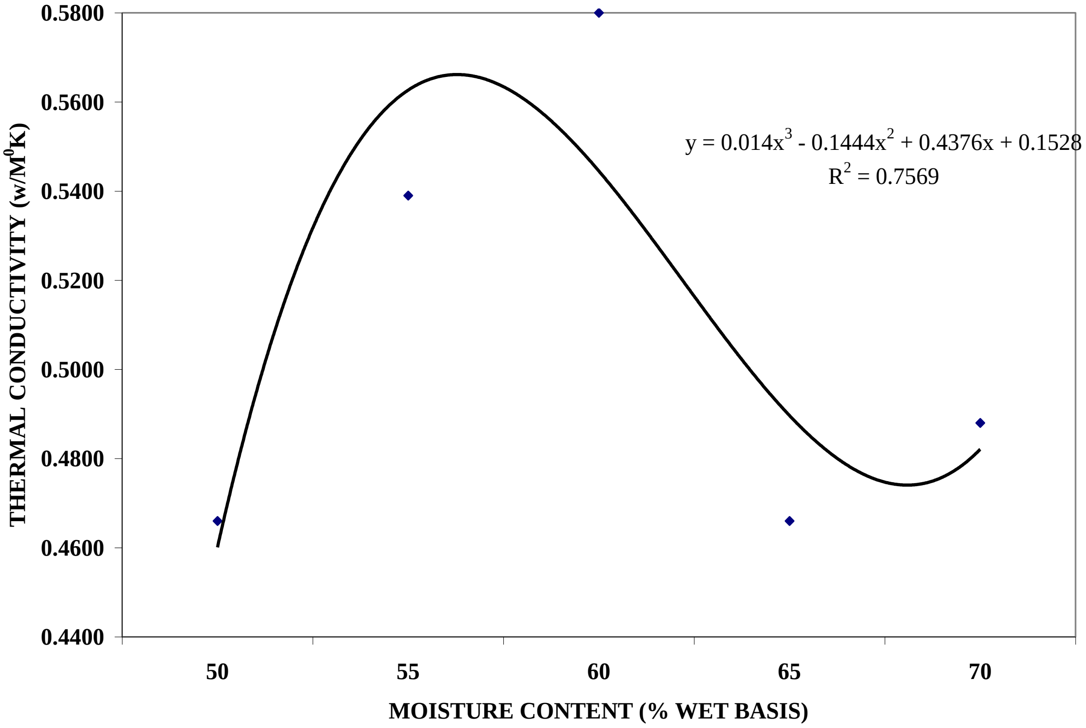

Figure 3: Thermal Conductivity of TMS 0326 with Moisture Content.

A striking difference is the fact that this variety of cassava showed a better ability to conduct heat better at the same moisture content at which the TMS 30572 and the TME 419 cultivars had the least ability to allow the passage of heat i.e. They stored more heat while TME 0326 samples lost more heat when conditioned to the same moisture level. This information may found usefulness in designing of drying equipment, drying process and storage of cassava chips and other cassava by products. The values obtained in this study, were in good agreement with range of 0.5246 -0.6052 W/m^{0}K reported by Tabil *et al.* (2003) for unfrozen sugarbeet roots and 0.648 for potato (Chen, 1990). Results of the analysis of variance (ANOVA) showed that the influence of moisture content on thermal conductivities of the samples of the three cassava varieties was not statistically significant.

CONCLUSIONS

The thermal conductivity of three improved cassava varieties (TME 419, TMS 30572 and TMS 0326) were studied at 15 months after planting and at moisture content between 50 to 70% (wb) using the KD 2 Pro that uses the transient line heat source method. The thermal conductivity of TME 419, TMS 30572 and TMS 0326 cassava varieties ranged from 0.5284 – 0.5662; 0.4804 – 0.5530 and 0.4660 – 0.5800W/m^{0}K respectively and a non-linear relationship was observed between thermal conductivity and moisture content under the study conditions. The relationship was described by a 3rd order polynomial. The influence of moisture content on thermal conductivity was not significant for all the three cassava varieties studied.

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