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Effects of ageing and moisture content on thermal properties of cassava roots using response surface methodology

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Abstract

Cassava farmers often leave the roots in the ground for months after maturity due to its poor storability after harvest coupled with non-availability of acceptable storage alternatives. This practice leads to physiological changes in the roots which may affect their thermal properties. This study therefore investigated the influence of tuber age and moisture content on the thermal properties of cassava roots. Freshly harvested cassava roots were peeled, cut into cylindrical shape of length 5cm and diameter 3.5 cm and then conditioned to moisture contents of 50, 55, 60, 65 and 70% (wet basis). The thermal properties were determined at 12, 15 and 18 Months After Planting (MAP) using the KD 2 Pro that measures the properties simultaneously based on the transient line heat source method. The mean thermal conductivity ranged from 0.4770 to 0.5654, 0.4804 to 0.5530 and 0.4302 to 0.6102 W/mK at these ages respectively. The thermal diffusivity also ranged from 1.588 to 2.426, 1.614 to 0.1972 and 1.610 to 2.020m^2/s while the specific heat capacity ranged from 2.3626 to 3.1495, 2.4900 to 3.7538 and 3.4222 to 3.8830 kJ/kg.K ages 12, 15 and 18 MAP respectively. Second order polynomial models described the relationship between the parameters studied. Analysis of variance showed that age, moisture content and their interactions significantly influenced the thermal diffusivity. Age alone had no influence on the thermal conductivity, but moisture content and its interactions with age. Specific heat was influenced by neither age nor moisture content

Keywords: Response surface, root age, moisture content, thermal conductivity, diffusivity, specific heat

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 (Ngeve, 1995). Farmers therefore prefer to leave cassava roots in the ground after they have matured and harvest them for processing only when needed. As a result of this practice cassava roots are often left in-ground for months after maturity, at times up to 24 months (Ngendahayo and Dixon, 1998) or more. This practice makes the cassava roots to become more fibrous and woody with time and such roots often end up been processed into starch, 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 which may be influenced by the root age as reported by researchers. For instance, Chotineeranat *et al.* (2006) reported that roots exhibited different levels of chemical compositions at different ages thus resulting in the production of flour whose levels of cyanide contents vary with tuber age. Meanwhile, Mohsenin (1980) reported that thermal conductivity of agricultural materials is influenced by their chemical compositions. Also, Ngeve (1995) investigated the cooking properties/quality of some cassava cultivars in Cameroon and reported that all the clones investigated would cook when harvested at the age of 8 months after planting while some that were classified as 'non-cookable' would not cook beyond this age, whereas, the cooking time of the 'cookable' clones increased with increase in tuber age thereby suggesting a the need for a better understanding of the thermal behavior of the crop with time. Therefore, the knowledge of thermal properties of the roots with respect to age is essential for effective and efficient equipment design and prediction of heat transfer operations involving them. 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 information on thermal properties of 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 due to the serious dearth of data on the thermal properties of cassava as revealed from literatures. 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 but their results are yet to be corroborated or refuted. Whereas, thermal properties have been determined extensively for other crops such as sweet potato and yam (Oke *et al.*, 2007; Farinu and Baik, 2007), yam (Oke *et al.* 2008), 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). Therefore, the aim of this research work was to study the influence of tuber age and moisture content on thermal conductivity, thermal diffusivity and specific heat capacity of cassava roots.

Materials and methods

Fresh roots of the TMS 30572 cultivar (a popular improved variety among farmers) were harvested at the ages of 12, 15 and 18 Months After Planting (MAP) from Experimental, Teaching and Research Farm of the Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria, which was established purposely for this research. The cutting stems used for establishing the farm were obtained from the International Institute for Tropical Agriculture (I.I.T.A), Ibadan, Nigeria. The planting was pre-planned such that the harvesting periods would fall within the raining season when the average moisture content of the roots would be above 70% (Njie *et al.*, 1998).

The harvested roots were peeled and cut into a cylindrical shape of length 5 cm and diameter 3.5 cm. This was done in order to accommodate the whole length of the needles of the KD 2 Pro (Decagon Devices Inc. USA) used for determining the thermal properties of the samples as specified by the manufacturer of the equipment, as well as provide for allowance of 0.5 cm between the tip of the needles and the end of the samples (lengthwise) on one hand and 2.0 cm from each of the needles to the circumference of the samples on the other. The KD 2 Pro uses the transient line heat source method to measure the thermal properties.

Table 1: Mean thermal properties of cassava roots at different ages

Parameter	Moisture Content (%)	12 Months	15 Months	18 Months
Thermal Conductivity (W/mK)	50	0.5550	0.5530	0.5530
	55	0.5450	0.5136	0.5920
	60	0.5292	0.4956	0.5358
	65	0.5654	0.5354	0.4302
	70	0.4770	0.4804	0.6102
Thermal Diffusivity (10^{-7} m^2/s)	50	2.426	1.614	1.870
	55	1.680	1.552	1.630
	60	1.980	1.432	2.020
	65	1.856	1.938	1.610
	70	1.588	1.972	1.692
Specific Heat Capacity (kJ/kgK)	50	2.3626	3.3835	3.6970
	55	2.8946	3.7538	3.5622
	60	2.6966	3.3977	3.4222
	65	2.8946	2.7390	3.8830
	70	3.1495	2.4900	3.4827

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 (0.001 precision). 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 properties (thermal conductivity, thermal diffusivity and specific heat capacity) simultaneous by inserting the SH-1 probe of the KD 2 Pro through the centre of the samples. Data generated from the experiments were analyzed using the Design Expert 6.0.8.

Results and discussion

Results of the thermal conductivity, thermal diffusivity (α) and specific heat capacity of the TMS 30572 cassava varieties at ages of 12, 15 and 18 Months After Planting (MAP) and moisture content range of 50 – 70% (w.b) are presented in Table 1. The thermal conductivity ranged from 0.4770 to 0.5550, 0.4804 to 0.5530 and 0.4302 to 0.6102 W/mK at these ages respectively. The thermal diffusivity also ranged from 1.588 x 10^{-7} to 2.426 x 10^{-7}, 1.614 to 1.972 x 10^{-7} and 0.1692 x 10^{-7} to 1.870 x 10^{-7} m^2/s while the specific heat capacity ranged from 2.3626 to 3.1495 kJ/kg.K, 2.4900 to 3.3835 kJ/kg.K and 3.6970 to 4.4827 kJ/kg.K respectively.

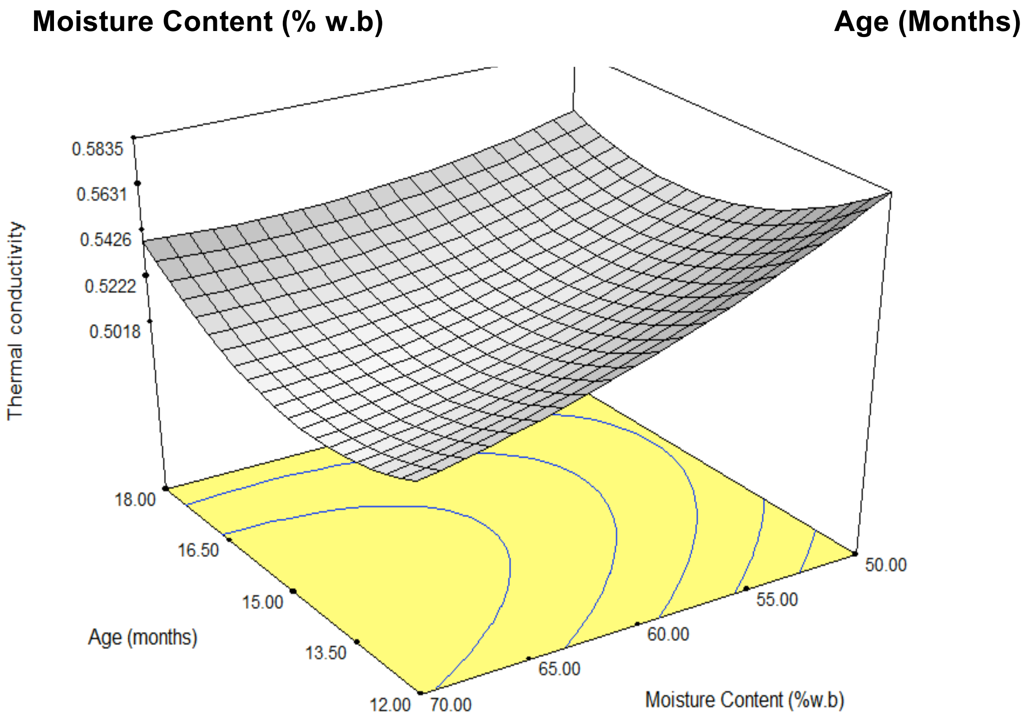

Figure 1: Thermal Conductivity of Cassava with Age and Moisture Content.

Thermal Conductivity

It was observed from Table 1 that the thermal conductivity (k) of the roots decreased with increase in moisture content at 12MAP from 0.5550 to 0.4770 W/m.K. A similar trend was observed at 15 MAP (Table 1) while a reversed trend was obtained at 18 MAP with thermal conductivity increasing from 0.5530 to 0.6102W/m.K. Njie *et al.* (1998) also observed a non-linear (quadratic) negative relationship between k and moisture content of cassava. Generally, the 18 MAP samples had better thermal conductivity. These values are higher than the 0.126 - 0.209 W/mK and 0.49 ± 0.038 W/mK reported by Oke *et al*. (2007) and, Farinu and Baik (2007) respectively for unfrozen samples of similarly high moisture content sweet potato tubers and 0.177-0.182 W/m.K reported for yam (Oke *et al*., 2008). This means that cassava roots are better heat conductors and heat energy transfer during drying, cooling, and related operations would be faster than those of these other crops. However, the k values obtained in this study were within the same range (0.50 – 0.57 W/mK for moisture content between 47-70%) reported by Njie *et al.* (1998). The relationship between thermal conductivity, age and moisture content is as shown in Figure 1. The response surface plot shows a non-linear (quadratic) relationship between k and moisture content such that at low moisture content of 50% (w.b), thermal conductivity of the samples decreased from 0.5800 W/m.K at 12MAP to 0.5600 W/m.K at 18MAP whereas the thermal conductivity increased non-linearly with increase in age (from 0.5100 W/m.K at 12MAP to 0.5400 W/m.K at 18MAP) at high moisture content (70%w.b) indicating that the heat conduction ability of cassava roots improves with increase in age in the presence of adequate moisture while younger roots would conduct heat better at low moisture contents. The influence of age on the thermal conductivity of this variety of cassava was, however, not significant ($P > 0.05$), but the influence of moisture as well as the interactions between age and moisture content have significant effects on the thermal conductivity of the roots ($P < 0.05$). The second order model equation fitted for this relationship is presented in Equation 1 (R^2 of 0.9539).

$$k = 0.52 - 8.649\text{x}10^{-4}A - 0.022M + 0.023A^2 + 7.970\text{x}10^{-3}M^2 + 0.013AM \qquad (1)$$

Where,

k = Thermal Conductivity of TMS 30572 (W/m.K)
A = Age (months)
M = Moisture Content (% w.b)

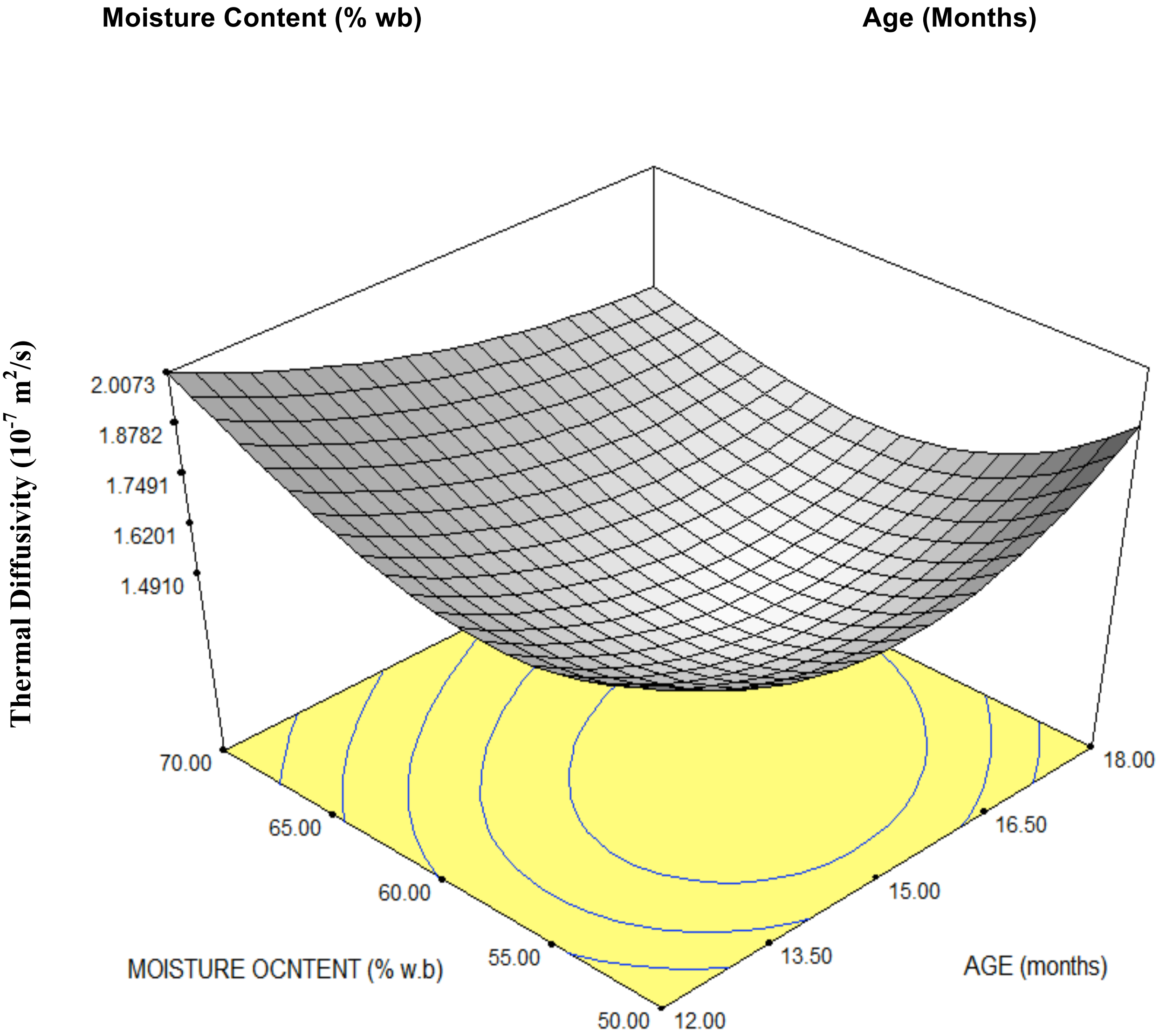

Figure 2: Thermal Diffusivity of Cassava with Age and Moisture Content

Thermal Diffusivity

The thermal diffusivity (α) of the samples at 12MAP and 18MAP decreased with decrease in moisture content whereas the thermal diffusivity of the 15 MAP samples initially decreased with increase in moisture content from 1.614 x 10^{-7} m^2/s at 50% moisture content to 1.432 x 10^{-7} m^2/s at 60% (wb), beyond which the α increased rapidly to 1.972 x 10^{-7} m^2/s when the moisture content was increased to 70% (Table 1). This was as a result of opposing effects of k and density of cassava. The low α suggests that cassava roots would conserve and take more time to loss heat whereas it would conduct heat at a faster rate due its high k values. Again, the values of α obtained in this study were higher than the 1.2 x 10^{-7} m^2/s and (6.688 – 8.823) x 10^{-8} m^2/s reported for sweet potato by Farinu and Baik (2007) and Oke *et al.* (2007) respectively as well as the (2.365 – 11.86) x 10^{-8} m^2/s reported for yam by Oke *et al.* (2008), with slight difference in the (1.52 – 1.66) x 10^{-7} m^2/s reported for cassava by Njie *et al.* (1998). This indicated that cassava root would transmit heat faster than yam and sweet potato. A second order polynomial model was also fitted for α (Equation 2) which produced a response surface with a high R^2 value (0.9340). It can be observed from the response surface (Figure 2) that at low moisture content, thermal diffusivity of the samples increased non-linearly with increase in age whereas it exhibited a reverse trend at high moisture content (70% (w.b) where it decreased from 2.051 x 10^{-7} m^2/s at 12MAP to 1.692 x 10^{-7} m^2/s at 18MAP. In addition, α increased non-linearly with increase in moisture content at age 12MAP while it decreased with increase in moisture content when it became older (18MAP) up to 60% (w.b) beyond which it started to increase up to 70% (w.b). It is noteworthy from Table 1 that the 15 MAP samples had the least diffusivity at low moisture content (50%) and it gave the highest at high moisture content (70%), indicated that 15Months old cassava roots would store heat instead of dissipating it when the moisture is low and vice versa whereas it would transmit or dissipate heat better at low moisture content at younger age (12MAP) but stores heat better when the moisture content is high, at this same age. This information is useful in the management of cassava and its products in storage as well as processing operations which may involve heat application to cassava roots harvested at different stages after planting as often experienced in real life due to delayed harvest resulting from the in-ground storage practice by farmers. Results of the analysis of variance shows that the influence of age, moisture content and the interaction betweent both variables had significant effect on thermal diffusivity.

$$\alpha = 0.15 - 7.34 \times 10^{-3}A + 4.133 \times 10^{-3}M + 0.014A^2 + 0.017M^2 - 9.520 \times 10^{-3}AM \quad (2)$$

Where,

α = Thermal diffusivity (mm^2/s)
A = Age (months)
M = Moisture content (% wet basis)

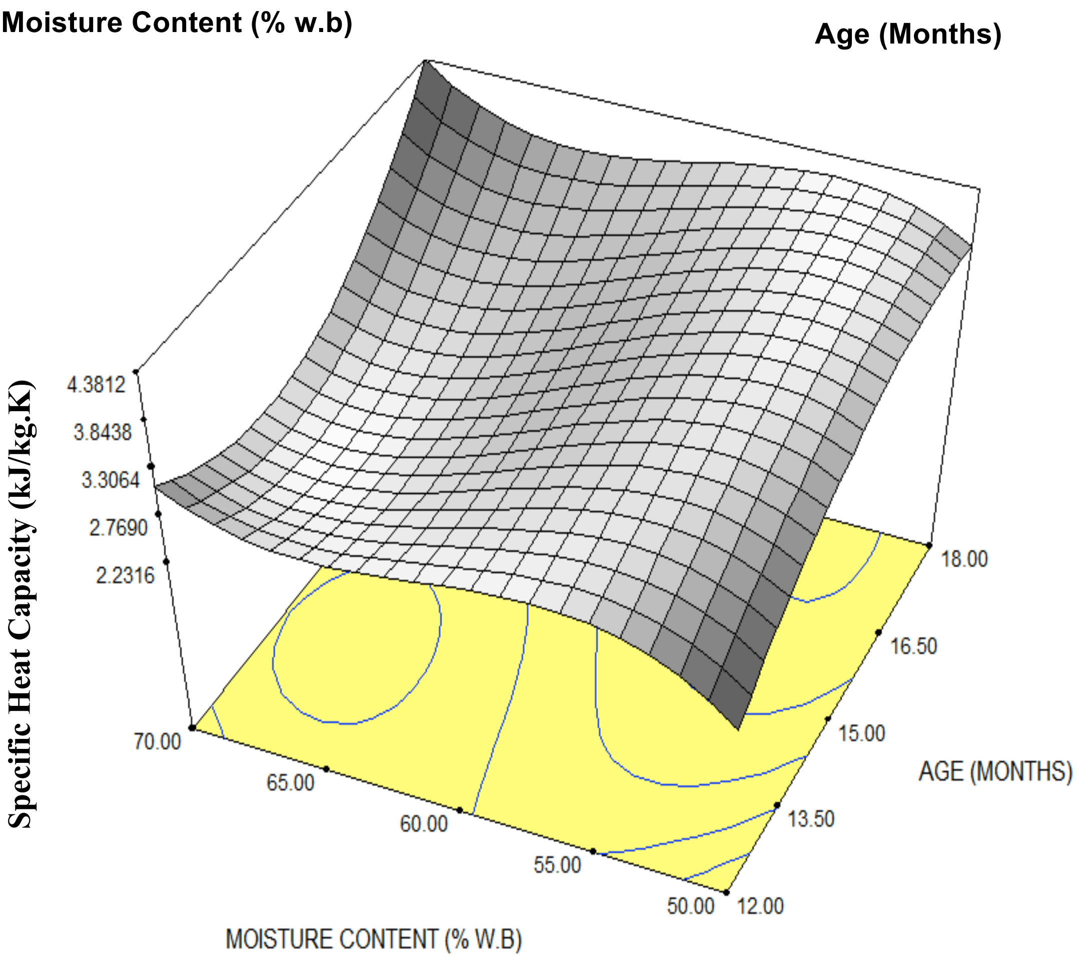

Figure 3: Specific Heat Capacity of Cassava with Age and Moisture Content

Specific Heat Capacity

Specific heat capacity (C_p) of the roots at 12MAP increased from 2.3626 kJ/kgK at 50% moisture content to 3.1495kJ/kgK) at 70% (wb). It followed a reverse trend at 15MAP where a reduction in specific heat capacity from 3.3835 to 2.4900 kJ/kgK was observed with increase in moisture content from 50 to 70% (Table 1). It was also observed that the specific heat capacity of the roots was generally highest at 15 MAP especially at moisture contents between 50 and 60% beyond which the 15 MAP samples had the least (18 MAP samples had the highest between 65 and 70% moisture range) - a reverse of the trend obtained for thermal diffusivity at 12 MAP. The specific heat values were observed to be high, meaning that the heat energy required to raise or lower the temperature of cassava roots by 1°C is thousands of Joule. These values were also higher than those reported for sweet potato and yam but fell within the same range reported by Njie *et al.* (1998) for cassava. The response surface obtained (R^2 = 0.9342) after fitting a second order polynomial model to the data is presented in Figure 3, along with the model equation (Equation 3). The figure shows that at low moisture content of 50% (wb), specific heat capacity increased non-linearly (quadratic relationship) from 2.3626 kJ/kgK at 12 MAP to 3.6970 kJ/kgK at 18 MAP and at 70% (w.b) it decreased initially from 3.1495 kJ/kgK at 12 MAP to 2.4900 kJ/kgK at 15MAP, and improved sharply to 4.3812 kJ/kgK towards 18 MAP. This is suggesting that the relationship between specific heat of cassava root and moisture content may be positive or negative depending on the age of the root being considered. Results of the Analysis of Variance showed that the the influence of age, moisture content and the interaction between both variables had no significant effect on specific heat of the roots ($P > 0.05$).

$$C_p = 2.81 + 0.039A - 0.041M + 0.15A^2 + 0.54M^2 + 0.064AM \qquad (3)$$

Where;
C_p = Specific Heat Capacity of TMS 30572 ($MJ/m^3.K$)
A = Age (months)
M = Moisture content (% wet basis)

Conclusions

The relationships between the thermal properties studied are described by second order polynomial models. The 18 MAP samples generally had better thermal conductivity. The influence of moisture as well as the interactions between age and moisture content have significant effects on the thermal conductivity of the roots ($P < 0.05$) but not age alone. The roots exhibited low thermal diffusivity which was significantly influenced by tuber age, moisture content and the interactions of both. The specific heat capacity of the roots was, however, high especially at 15MAP. Hence, the high specific heat capacity of the roots suggested that high heat energy would be required to change the temperature of the roots by 1°C but the rate at which the heat would be conducted is expected to be fast due to its high thermal conductivity. The heat is however, expected to be conserved as a result of the low thermal diffusivity values obtained.

Acknowledgement

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References

Anikwe, M .A. and Onyia V. N. (2005). Eco-physiology and Cultivation Practices of Arable Crops, New generation Publishers; Enugu, Nigeria. Pp. 195-184.

Aremu, A. K. and Fadele, O. K. (2010). Moisture Dependence Thermal Properties of Doum Palm Fruit (*Hyphaene Thebaica*), *Journal of Emerging Trends in Engineering and Applied Sciences*, 1(2): 199 – 204.

Aviara, N. A. and Haque, M. A. (2001). Moisture Dependence of Thermal Properties of Sheanut Kernel, *Journal of Food Engineering*, 47: 109 – 113.

Bart-Plange, A., Ahmad, A., Francis, K. and Abubakar, K. P. (2012). Some Moisture Dependent Thermal Properties of Cashew Kernel (*Anarcardium occidentale* L.). *Australian Journal of Agricultural Engineering*, 3(2): 65 – 69.

Bitra, V. S. P., Banu, S., Ramfrishna, P., Narender, G. and Womac, A. R. (2010). Moisture Dependent Thermal Properties of Peanut Pods, Kernels and Shell. *Journal of Food Engineering*, Elsevier Science Direct, 106: 503 - 512.

Chotineeranat, P., Suwansichon, T., Chompreeda, P., Piyachomkwan, K., Vichukit, V., Sriroth, K. and Haruthaithanasan, V. (2006). Effects of Root Ages on the Quality of Low Cyanide Cassava Flour from Kasetsart 50, *Kasetsart Journal (National Science)*, 40: 694 – 701.

Enwere, N. J. (1998). Foods of Plant Origin. Afro-Orbis Publishers, Nsukka, Nigeria, 1st Edition, pp. 137-249.

Farinu, A. and Baik, O. (2007). Thermal Properties of Sweet Potato with its Moisture Content and Temperature, *International Journal of Food Properties*, 10(4): 703 – 729.

Mohsenin, N. N. (1980). Thermal Properties of Foods and Agricultural Materials. Gordon and Breach, Science Publishers, Inc., New York, pp 83 – 87.

Ngendahayo, M. and Dixon, A. G. O. (1998). Effects of Varying Stages of Harvest on Tuber Yield, Dry Matter, Starch and Harvest Index of Cassava in Two Ecological Zones in Nigeria. In: Root Crops in the 21st Century. Akoroda, M. O and J. M. Ngeve (Eds). Proceedings of the 7th Triennial Symposium on Tropical Root Crops-AB, Cotonou, Benin. Pp. 661 – 667.

Ngeve, J. M. (1995). Effects of Location and Age at Harvest on Yield and Culinary Qualities of Cassava (*Manihot Esculenta* Crantz). In: Root Crops and Poverty Alleviation. 6th Triennial Symposium of the ISTC-AB. (Akoroda, M. O. and Ekanayake, I. J Eds.). Lilongwe, Malawi. Pp 242 – 248.

Njie, D. N., Rumsey, T. R. and Singh, R. P. (1998). Thermal Properties of Cassava, Yam, and Plantain, *Journal of Food Engineering*, 37: 63 – 76.

Oke, M. O., Awonorin, S. O., Oyelade, O. J., Ogunlakin, G. O. and Sobukola, P.O. (2008). Some Thermo-physical Properties of Yam Cuts of Two Geometries. *Agricultural Engineering International: the CIGR Ejournal*, Manuscript FP 07 027. Vol. X: 1-9.

Oke, M. O., Awonorin, S. O., Sanni, L. O., Akanbi, C. T. and Abioye, A. O. (2007). Determination of Some Selected Engineering Properties of Sweet Potato Cuts as Function of Temperature, *Journal of Food Technology*, 5: 66 – 70.

Polley, S. I., Synder, O. P. and Kotnour, F. (1980). A Compilation of Thermal Properties of Foods, *Food Technology*, 34(11): 76 – 78.

Singh, S. S. and Goswani, T. K. (2000). Thermal Properties of Cumin Seeds. *Journal of Food Engineering*, 45: 181 – 187.

Tabil, L. G. Eliason, M. V. and Qi, H. (2003). Thermal Properties of Sugarbeet Roots, *Journal of Sugarbeet Research*, 40(4): 209 – 228.

Yang, W., Sokhansanj, S, Tang, J. and Winter, P. (2002). Determination of Thermal Conductivity, Specific Heat and Thermal Diffusivity of Borage Seeds, *Biosystems Engineering*, 82 (2): 169 – 176.