INTERNATIONAL JOURNAL OF CURRENT
Agricultural Sciences
Available Online at http://www.journalijcas.com
Vol. 6, Issue, 8, pp. 98-102, August , 2016
Research Article
ISSN: 2277-1026

DETERMINATION OF THERMAL PROPERTIES OF SIX YAM CULTIVARS GROWN IN THE BENUE RIVER BASIN, NIGERIA

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A R T I C L E I N F O

Received 15 th, May, 2016,
Received in revised form 11 th,
June, 2016, Accepted 16th, July, 2016,
Published online 28th, August, 2016

Keywords:

Thermal properties, yam cultivars, measurements

A B S T R A C T

Thermal conductivity (k), specific heat capacity (Cp) and thermal diffusivity (d) are important properties in modelling, simulation and control of various food processing unit operations. This study, investigates these properties for tubers of six yam cultivars grown in the Lower Benue River Basin, Nigeria. The measurements were done for the head, middle and tail sections of yam in 10 replicates. The yams were first characterized in terms of moisture contents and density. Thermal conductivity was measured using a line heat source probe at the storage moisture contents and temperatures near 30 C. The results for specific heat ranged from 1.1157 to 5.3282 Jkg^{-1} C^{-1} and it is neither significantly affected by the tuber section nor the cultivar so a mean ± standard deviation of 3.5181 ± 0.7516 Jkg^{-1} C^{-1} value was returned for yam. Both thermal conductivity and thermal diffusivity were not affected by yam tuber section but were affected by cultivar. Consequently conductivity relates as follows: Amula ≤ Agbo (Pan ave) ≡ Agbo (Kor) < Gbangu ≤ Pepa ≤ Hemba kwase which in terms of numerical values are 0.2258 ≤ 0.2363 ≡ 0.2662 < 0.3058 ≤ 0.3230 ≤ 0.3485 W/(m C). A similar relationship for thermal diffusivity is Hemba kwase < Amula < Agbo-kor ≡ Agbo-pan ave ≤ Gbangu < Pepa which in terms of numerical values reads: 4.257E-05 < 6.339E-05 < 6.560E-05 ≡ 6.602E-05 < 9.770E-05. Thermal conductivity and thermal diffusivity of D. alata cultivars are not significantly different from each other

INTRODUCTION

Yam, *Dioscorea* spp., is the second most important tropical tuber crop in Nigeria after cassava (FAO,).It is rich in carbohydrates and also contain other nutrients. Besides their importance as a food source, yams play a significant role in the socio-cultural lives of some producing regions such as the celebrated New Yam Festival in West Africa. West and Central Africa account for about 94% of world production, Nigeria being the major producer (FAO, 2011; Osunde, 2008). For example, in 2011, global yam production was about 50 million metric tons (MT) with 96% of this coming from Nigeria (FAO, 2011). Although more than six hundred species of the tuber exist, only a few are important as staple food in the tropics. These include white yam *(D. rotundata*), yellow yam (*D.Cayenensis*), water yam (*D. alata*), trifoliateyam (D. *dumetorum*), aerial yam (*D. bulbifera*) and Chinese yam (*D. esculenta*).

In the tropics, little or nothing has been done on postharvest properties and handling of tuber crops especially on yam which is economically important and used as staple food in various forms. The under utilization of tuber crops which abound in the country and the low level of mechanization of their processing could be traced to the fact that there is a dearth of data on their thermo-physical properties. In fact, there are no known records of thermal properties of yam at the head, middle and tail regions. Thus, their processing cannot be made adaptable to the rapidly increasing range of new technologies serving the processing industries.

Yam is important because of its excellent eating quality; they are preferred food at social gatherings. People consume yams, sweet in flavour, as a cooked vegetable fried or roasted. In West Africa yam is often pounded into a thick paste after boiling (pounded yam) and is eaten with soup (See figure 1). Presently, whole roasted yam has become a popular street or fast food in urban areas throughout the West African yam belt. Yams are also processed into yam chips and flour that is used in the preparation of a paste. Boiled yam is traditionally consumed with palm oil, but is also commonly served with a sauce such as pepper sauce. In big cities and border towns in West Africa, fried yam and pepper sauce is a popular street food and has a similar position as French fries and ketchup in Western cuisine.

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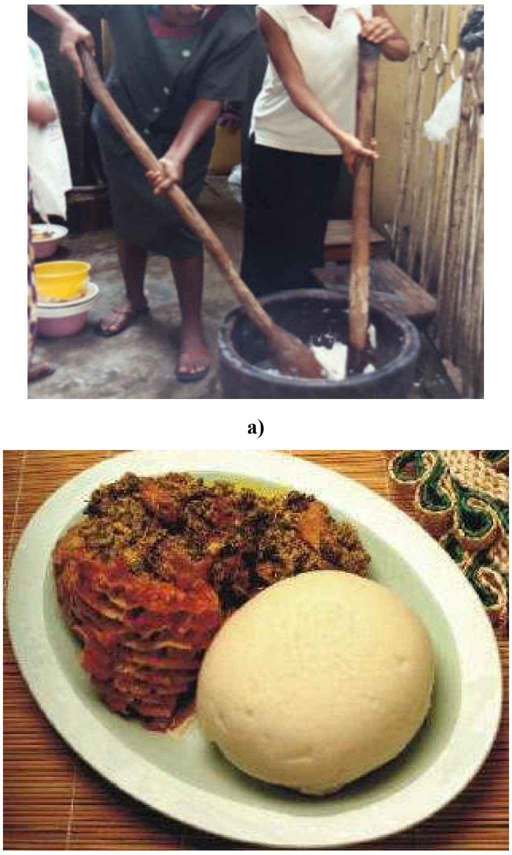
Yam balls (styled after meat balls) have also gained some popularity in contemporary West African cuisine. (Linus, 2003). Among the Akan of Ghana, boiled yam can be mashed with palm oil into *eto* in a similar manner to the plantain dish *matoke*, and is served with eggs. Another method of presentation is to leave the raw yam pieces to dry in the sun. When dried, the pieces turn dark brown color. These are then milled to create a brown powder known in Nigeria as *elubo*. The powder can be mixed with boiling water to create a thick starchy paste known as *amala*, which is used in local soups and sauces. (FAO,1989). All these require the knowledge of thermal properties of yam which are scarce. Hence, this research is concerned with the study thermal properties of six cultivars of yam as affected by sections (head, middle and tail).which will fill a gap in this chasm of knowledge.



a)

b)

Figure 1 a) Preparation of pounded yam b) Pounded yam meal served with meat and vegetable soup

MATERIALS AND METHODS

MATERIALS

Whole intact yam tubers of six cultivars belonging to two varieties, *Dioscorea alata* and *Dioscorea rotundata* were bought in various sizes from North Bank local market in Makurdi, Benue state, Nigeria. The tubers were *Agbo (Pan Ave)* and *Agbo-kor* both cultivars belonging to *D.alata* variety while the other four: *Amula, Gbangu, Hemba kwase,* and *Pepa* of *D.rotundata* variety were used for this study. The tubers were characterized in terms of tuber size, regularity in shape, moisture content and density.

Experimental Design

The experiment is basically a two-factor design, precisely 6 x 3 experiments. There are six yam cultivars namely *Agbo (Pan Ave), Agbo-kor, Amula, Gbangu, Hemba kwase,* and *Pepa* which forms six levels of one factor while the three yam sections of the tuber (Head, Middle and Tail) are the levels of the second factor. See figure 2. Ten replications of each experiment were carried out to ensure highly robust statistics. This made a total of 180 readings all together.

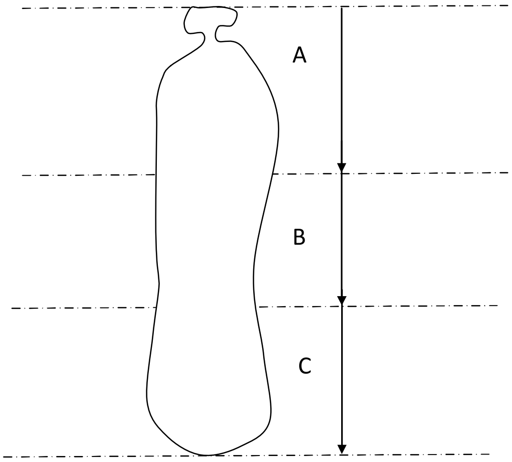


Fig 3 Schematic drawing of yam sections: A) Head, B) Middle and C Tail

METHODS

The yam was prepared by scrubbing to remove adhering soil, washed, peeled and cut into three parts (Head, middle and tail).The head section was cut into slabs measuring 4 x 2 cm. This was applicable to other sections (middle and tail) for all the six cultivars.

Moisture content determination

The mean initial moisture content (MC) of the samples was determined using convection oven dry method. Accordingly the yam samples of about 40 g piece was placed in a container of known weight and dried in the oven at 105 ^{0}C for about 78 hours to a constant weight. The moisture content on dry basis was found by applying equation 14 (AOAC, 1984).

$$Mc\ (\%\ db) = \left(\frac{Mi - Mf}{Mf}\right) \times 100 \qquad \text{--------------------} (1)$$

Where Mc is the Moisture content, Mi is the initial mass of Sample and container (g), Mf is the final mass of sample and container (g). This was replicated five times and the average value taken as the initial moisture content of sample.

Determination of density of yam (ρy)

10 g of yam sample was weighed and put into 100 ml measuring cylinder containing 50 ml water (as floatation liquid). Applying the simple floatation principle of Nwanekazi & Ukagu (1999). The bulk density of yam was determined as ratio of mass of

sample to the volume occupied by the sample as found in equation (15).

$$\rho y = \frac{My}{Vy} = \frac{My}{V2 - V1} \qquad (2)$$

Where ρy = bulk density of yam, kg/m^3 My = mass of yam, kg, Vy = volume of yam (ml), V_1 = initial volume of water in cylinder (ml), V_2 = final volume of water in the cylinder (ml) The experiment was replicated five times.

Determination of Specific Heat Capacity of yam (c_p)

The method of mixture which has been reported as the most common technique (Mohsenin, 1980) was used for measuring the specific heat of biomaterials was used for the tubers. The specific heat of the sample was determined by using a calibrated copper calorimeter placed inside a flask. The calorimeter was calibrated by pouring a measured quantity of cold water, M_{cw}, into it. The temperature of the cold water was allowed to stabilize at T_c, and a measured quantity of hot water, M_{hw}, at a known temperature T_h, was added. The equilibrium temperature T_e of the mixture of hot and cold water was recorded. The respective quantity of the hot and cold water was adjusted until a final temperature of the mixture that is close to the room temperature is obtained. The equation for the heat capacity C_c of the calorimeter was obtained from the energy balance using equation 16 (Aviara and Haque, 2001, and Aremu and Nwannewuihe, 2011)

$$C_c = \left[\frac{M_{hw} C_w (T_h - T_e)}{T_e - T_c}\right] - M_{cw} C_w \qquad \text{-------------------} (3)$$

Where, Cc is specific heat of the calorimeter (KJ/kg ^{o}C), M_{cw}, is the mass of cold water (g), C_w is the specific heat of water (KJ/kg ^{o}C), M_{hw} is the mass of hot water (g), T_h is the temperature of hot water (^{o}C), T_e is the equilibrium temperature while T_c is the temperature of cold water (^{o}C). The calibration was repeated five times while adjusting the quantities of hot and cold water.

The specific heats of the samples was obtained by adding some yam slab of known weight, temperature and moisture content into the calorimeter containing hot water of known mass and temperature. The mixture was stirred at interval with the aid of a copper stirrer. The temperature was recorded at an interval of 30 seconds using a k-type thermocouple. The equilibrium temperature was noted and the specific heat calculated by adopting equation (5). The experiment was repeated ten times for uniform moisture content and the average values of the specific heat reported. Fig 4 shows Schematic of the apparatus used for measuring the Specific Heat of yam. In this method, the following assumptions were made:

(a) Heat loss from calorimeter to the surrounding environment is negligible
(b) Heat loss by evaporation during equilibrium period is negligible.
(c) The rate of water absorption by the sample is negligible

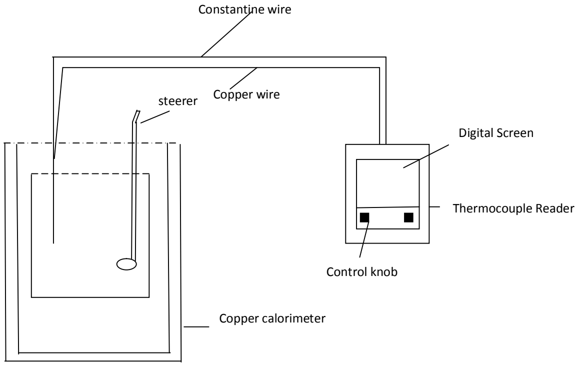


Fig 4 Schematic of the apparatus used for measuring the Specific Heat of yam

Determination of thermal conductivity of yam

Thermal conductivity of yam was determined using the line heat source probe method based on non – steady heat conduction. This method which is considered by Mortaza *et al.* (2008) to be convenient, rapid and suitable for small sample of food and biological materials was used. The apparatus consist of Ammeter and voltmeter for the recording of current and voltage respectively. Direct current (DC) power source was used to supply heat. Current and voltage of 0.7A and 4.5 ± 0.5V respectively was used throughout the experiment. In the setup is a rheostat to vary resistance in the circuit in order to achieve the desired current for the experiment. Samples of specific moisture content were allowed to warm up to a room temperature. After weighing, it was put into a sample holder. A high resistance heating wire was placed in the middle of the sample and connected externally to the power source. A 5-in-1 multi-meter was calibrated in accordance with Tong *et al.* (1993) and was used to measure the temperature read of the thermocouple. The thermocouple wire was inserted into the middle of the sample in the holder and then the switch turned on. Reading of temperature was taken after the sample and the sample holder had reached a temperature of 30^{0}C. The current and voltage readings were adjusted to 0.7 A and 4.5 ± 0.5 V and used as heat source for the sample. Temperatures were recorded at regular intervals of 30 seconds for 40 minutes for each sample. The experiment was replicated 10 times and average value recorded. A graph of temperature difference at the intervals considered (T_1-T_2) was plotted against the natural logarithm of the corresponding time ratio (ln (θ_2/θ_1)).

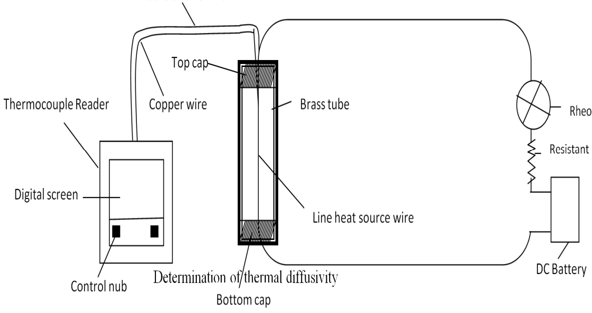


Fig 2 Schematic of the apparatus used for measuring thermal conductivity of yam

The slope (s) of the graph was determined from the straight line potion of the simple graph which is $S = \frac{Q}{4\pi\ k}$ hence thermal conductivity evaluated using equation (9). Fig 2 shows Schematic of the apparatus used for measuring thermal conductivity of yam.

Determination of thermal diffusivity

The thermal diffusivity of yam was evaluated using experimentally determined values of thermal conductivity (K), specific heat (Cy) and bulk density (ρy) of the yam sample using equation (4)

$$\alpha = \frac{K}{\rho y\ Cy} \qquad \text{--} \ (4)$$

RESULTS AND DISCUSSIONS

The characterization of the yam tubers in terms of moisture content and density are as displayed in Table 1. The data obtained for other properties in 10 replicates was subjected to statistical analysis through complete randomize design with double factor analysis of variance (ANOVA) for all data collected and analyzed with Microsoft Excel at $P < 0.05$ as shown in Table 2. From Table 2, the section of the yam does not significantly affect any of the three thermal properties of the six yam cultivars while thermal conductivity and thermal diffusivity are affected. In the case of specific heat it is not affected by cultivar either but it may be affected by some other property.

Table 1 Characterization of six yam cultivars grown in the Lower Benue River Basin in terms of Moisture content and density

S/No	Cultivar	Moisture Content, % wet basis	Density, kg/m^3
1	*Agbo (pan ave)*	71	1116
2	*Agbo (Kor)*	73	1098
3	*Amula*	68	1109
4	*Gbangu*	62	1183
5	*Himbua Kwase*	67	1133
6	*Pepa*	59	1192

Therefore, the specific heat of yam can be given by pooling the 180 readings which gives a range of 1.1157 to 5.3282 Jkg^{-1} C^{-1} with a mean ± standard deviation of 3.5181 ± 0.7516 Jkg^{-1} C^{-1}. This value of specific heat compare well with that reported by Cresel *et al.* (2011) and for potatoes (Wang and Brennan. J992; Califano, and Calvelo, 1991; ASHRAE, 1989 and Califano and Calvelo,. 1991)

The values of thermal conductivity and thermal diffusivity which are both not significantly affected by section are lumped for each cultivar to form 30 replications. Then the mean thermal conductivity and thermal diffusivity ± standard errors are separated using Duncan's multiple range tests and the results as shown in Table 3 for each of the six yam cultivars used in this study. Thermal conductivity generally ranged from 0.2258 for *Amula* to 0.3485 W/(m C^{-}) for *Hemba kwase.* In specific terms thermal conductivity of the six cultivars rank as follows: *Amula* ≤ *Agbo - Pan ave* ≡ *Agbo - Kor* < *Gbangu* ≤ *Pepa* ≤ *Hemba kwase* which in terms of numerical values are 0.2258 ≤ 0.2363 ≡ 0.2662 < 0.3058 ≤ 0.3230 ≤ 0.3485 W/(m C). When it is considered that *Agbo - Pan ave* and *Agbo - Kor* are both *Dioscorea alata* species and which thermal conductivity are not significantly different from each other at $\alpha = 0.05$, it can be concluded that the thermal conductivity of water yam is the same without regard to cultivar. This statement is in agreement with the value obtained by Oke et al., (2008) for another water yam cultivar called *Ubi.* The other four yam cultivars belong to *Dioscorea rotudata* species and are more varied than that of *D. alata.*

For thermal diffusivity the values ranged from 4.257E-05 for *Hemba kwase* to 9.770E-05 m^2/s for *Pepa* yam cultivar. Similar to conductivity, thermal diffusivity relationship is as follows: Hemba kwase < Amula < Agbo-kor ≡ Agbo-pan ave ≤ Gbangu < Pepa which in terms of numerical values reads: 4.257E-05 < 6.339E-05 < 6.560E-05 ≡ 6.602E-05 < 9.770E-05

This means that heat energy in yam tubers spread at different rates and some can be as much as over twice the value of others.

Table 2 Summary of ANOVA of three thermal properties of six yam cultivars

Property	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
THERMAL CONDUCTIVITY	Cultivar	0.37632	5	0.06272	16.4613	3.15E-15	2.146811*
	Section	0.003723	2	0.001861	0.488532	0.614299	3.043722
	Interaction	0.043018	12	0.003585	0.940857	0.507381	1.803691
	Within	0.720118	189	0.00381			
	Total	1.143178	209				
SPECIFIC HEAT	Cultivar	5.646011	5	1.129202	1.986608	0.083291	2.26996
	Section	1.46776	2	0.73388	1.291117	0.277777	3.051819
	Interaction	1.915662	10	0.191566	0.337023	0.96983	1.889561
	Within	92.08194	162	0.568407			
	Total	101.1114	179				
THERMAL DIFFUSIVITY	Cultivar	2.49E-08	5	4.98E-09	5.8922	4.95E-05	2.26996*
	Section	3.34E-09	2	1.67E-09	1.975493	0.14202	3.051819
	Interaction	6.89E-09	10	6.89E-10	0.814505	0.615052	1.889561
	Within	1.37E-07	162	8.46E-10			
	Total	1.72E-07	179				

*Significant at $\alpha = 0.05$ according to Microsoft Excel

Table 3 Mean* thermal conductivity and thermal diffusivity of six cultivars of Lower Benue River Basin grown yam with 30 replications

		Thermal property	
S/No	***Cultivar***	**Thermal Conductivity W/(m C)**	**Thermal Diffusivity (m^2s^{-1})**
1	*Agbo-kor*	0. 2662^{b} ± .0118	6.560E-05^{ab} ± 4.166E-06
2	*Agbo (pan aver)*	0. 2363^{ab} ± .0145	6.602E-05^{ab} ± 7.087E-06
3	*Amula*	0. 2258^{a} ± .0137	6.339E-05^{a} ± 4.442E-06
4	*Gbangu*	0. 3058^{c} ± .0112	7.976E-05^{bc} ± 3.508E-06
5	*Hemba kwase*	0. 3485^{d} ± .0068	4.257E-05^{cd} ± 3.066E-06
6	*Pepa*	0. 3230^{cd} ± .0066	9.770E-05^{d} ± 8.089E-06

* Same Superscript on the means on the same row shows no significant difference according Duncan's multiple range tests.

Similar to thermal conductivity the thermal diffusivity of *D. alata* cultivars are not significantly different from each other and that of *Amula*.

The properties were correlated and the result shown in Table 4. There is no high correlation coefficient between any of the properties. Even specific heat that Mohsenin (1980) indicated that it can be predicted with moisture content has very low values. The one that is fairest in terms of correlation coefficient is the thermal diffusivity which has high values of correlation coefficient with density and thermal conductivity. This is understandable and can be linked to the fact that thermal diffusivity is derived from these two properties. Thermal diffusivity is negatively correlated with moisture content. That means that yam tubers with high moisture content should have lower thermal diffusivity values. However, this is not the case as can be seen by comparing Table 1 and Table 4 where *Hemba kwase* which has the lowest diffusivity of 4.257×10^{-5} is not the one with the highest moisture content. It can be suggested that these properties may correlate with the chemical composition of the tubers like carbohydrates as proposed by Mohsenin (1980).

Table 4 Correlation coefficients of some properties of yam (*Dioscorea spp*)

	MC, % (wb)	***Density, kg/m3***	***Thermal conductivity***	***Thermal diffusivity***	***Specific heat***
MC, % (wb)	1				
Density, kg/m3	-0.95932	1			
Thermal conductivity	-0.59274	0.634954	1		
Thermal diffusivity	-0.84961	0.851411	0.858955	1	
Specific heat	0.353291	-0.16451	0.428943	0.132173	1

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