VOL. 11, NO. 1, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECTS OF DEGREE OF RIPENESS, MOISTURE CONTENT AND TEMPERATURE ON THERMAL CONDUCTIVITY OF '*APANTU*' VARIETY OF PLANTAIN

J. K. Afriyie[1], A.Bart-Plange[2] and E. Asiedu[2]
[1]Department of Mechanical Engineering, Kumasi Polytechnic, Kumasi, Ghana
[2]Department of Agricultural Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
E-Mail: john.afriyie@kpoly.edu.gh

ABSTRACT

The effects of degree of ripeness, moisture content and temperature on the thermal conductivity of both ripe and unripe *apantu* variety of plantain were investigated. A transient heat transfer technique was used to determine the thermal conductivity at four levels of moisture content as ripening progressed and at four temperature levels. The effective thermal conductivity decreased as ripening progressed from day one to day seven from0.617 to 0.55 W/mK at a temperature of 50^{0}C.With decreasing moisture contents from 55% to 40%, thermal conductivity decreased from 0.755 to 0.564 W/mK for day one, 0.710 to 0.546 W/mK for day three, 0.655 to 0.537 W/mK for day five and from 0.601 to 0.527 W/mK for day seven. For a moisture content of 55%, the thermal conductivity increased from 0.637 to 0.791 W/mK for a temperature range of 40^{0}C to 55^{0}C.From the investigation it was found that thermal conductivity increased with increasing moisture and increased in temperature, however thermal conductivity decreased as the degree of ripening increased.

Keywords: thermal conductivity, ripeness, moisture content, bulk density, temperature, transient heat transfer

1. INTRODUCTION

Thermal conductivity is an important thermal property in modelling, simulation and control of various food processing operations. Plantain (*musa paradisiacal*) is a large perennial herbaceous plant, which belongs to the musacace family and is an important staple food in Africa. It is cultivated in many tropical and sub-tropical zones of Africa, Asia, Central and South America. The plant is seldom grown alone but in combination with certain industrial crops such as cocoa trees and many food crops such as cassava, cocoyam, maize and groundnuts. Ghana is the largest producer of plantain in West Africa and the third in Africa after Uganda and Rwanda (FAO, 2010). The major plantain cultivars grown in Ghana are "*apantu*" (false horn) and "*apem*" (French plantain) and in isolated cases *Asamienu* or *Asamiensa* (true horn). The different types are distinguished by the colour of pseudo stem fruits, skin and pulp as well as the number of bunches (Hemeng *et al.,* 1995). Plantain and banana are very important foodcrops in the humid forest and mid-latitude zone of Sub-Sahara Africa providing more than 25% (percent) of the carbohydrate and 10% (percent) of the calorie intake for approximately 70 million people in the region (Adejoro *et al*., 2010). Plantain can be processed into different food for human consumption and it can be used at any stage of ripeness. As the plantain ripens it becomes sweeter and the colour changes from green to yellow to black (Nwaichi *et al.,* 2014).

In addition to being a staple food for rural and urban consumers, plantain and banana provide an important source of rural income. The crop is mainly produced by smallholders in compound or home gardens as well as in large fields (Swennen, 1990; Ortiz and Vuylsteke, 1994). In the Ghanaian agricultural sector, plantain is ranked third after yam and cassava (FAO, 2010) and contributes about 13.1% to the Agricultural Gross Domestic Product. Estimated annual consumption in Ghana is 85 kg per capita (MOFA-SRID, 2011).

Thermal conductivity of food material is an essential physical property in mathematical modelling and computer simulation of thermal processing (Cevoli *et al.*, 2014). Thermal Conductivity of some agricultural products have been studied by several researchers including Timbers (1975), Moysey *et al.* (1977), Wallapapan and Sweat (1982), Shepherd and Bhadwaj (1986), Van Gelder (1998), Dutta *et al.* (1988), Aviara and Hague, (2001), Kara *et al*. (2011), Bart-Plange *et al.* (2012), Sirisomboon and Posom (2012) and Cevoli *et al.* (2014).

Generally, there are a number of possible ways to measure thermal conductivity, each of them suitable for a limited range of materials, depending on the temperature of the medium. Methods for measuring thermal conductivity can be classified into two broad categories; steady-state and transient-state (non-steady-state) heat transfer methods (Mohsenin, 1980). The transient-state heat transfer method is most suitable for biological materials that are generally heterogeneous and often contain high moisture content. The line source method is widely used for this test (Mohsenin, 1980; Kazarian and Hall, 1965; Dutta *et al.*, 1988; Huang and Liu, 2009; Kumar *et al*., 2014).

It is often argued that the ripe *apantu* takes a longer time to get boiled, fried or roasted than the unripe *apantu*. However, not much has been done concerning experimental work on the thermal conductivity of *apantu* in relation to the stage of ripening. Njie *et al*. (1998) did some work on a local plantain variety in Nigeria, but this was not based on ripeness. Due to this lack of knowledge about heat requirement, local food processors end up either over boiling, over frying, or over roasting.

The objective of this study was to determine the thermal conductivity of plantain and its variation with moisture content, temperature and ripeness using the line heat source method.

2. MATERIALS AND METHODS

2.1 Sample Preparation and conditioning

Each sample finger was peeled, cut to 5cm long and a hole was drilled through the centre. The bunch of *apantu* was kept in the laboratory under ambient conditions. The samples were then conditioned to moisture contents of 55%, 50%, 45%, and 40% using the oven drying method. The MC of the sample was determined on percentage wet basis (% wb) using the Association of Official Analytical Chemists (AOAC, 1984) method. This method has been used by researchers such as (Addo *et al*., 2009; Bart-Plange *et al*., 2005; Tansakul and Lumyong, 2008; Mahmoodi and Kianmeehr, 2008) with appreciable success. The moisture content of the plantain was determined using the equation

$$W_2 = W_1 - \frac{W_1(M_1 - M_2)}{100 - M_2} \quad (1)$$

Where
W_1= mass of undried sample (Kg)
W_2 = mass of dried sample (Kg)
M_1 = initial moisture content of undried sample (%)
M_2 = desired moisture content of dried grain (%)

A sample of the plantain was initially dried completely in the oven to determine the initial moisture content M_1. Then, knowing W_1, the 5cm long sample was placed in the oven and reweighed at small intervals of time till the mass was W_2.

2.2 Experimental setup

The setup for the thermal conductivity measurements is shown in Figure-1. The thermal conductivity apparatus is a simple set-up consisting of an aluminium cylinder with a heating wire or a heater stretching between two insulated ends of the cylinder. A thermocouple was fitted through the top end of the cylinder for temperature readings in the sample. Heat was supplied by a constant DC power source. In the set-up, there was an ammeter to take current readings, voltmeter across the heater to take voltage readings, a rheostat to vary resistance in the circuit and a key to close or open the circuit. A current of 1 amp with voltage 3V was used in this experiment.

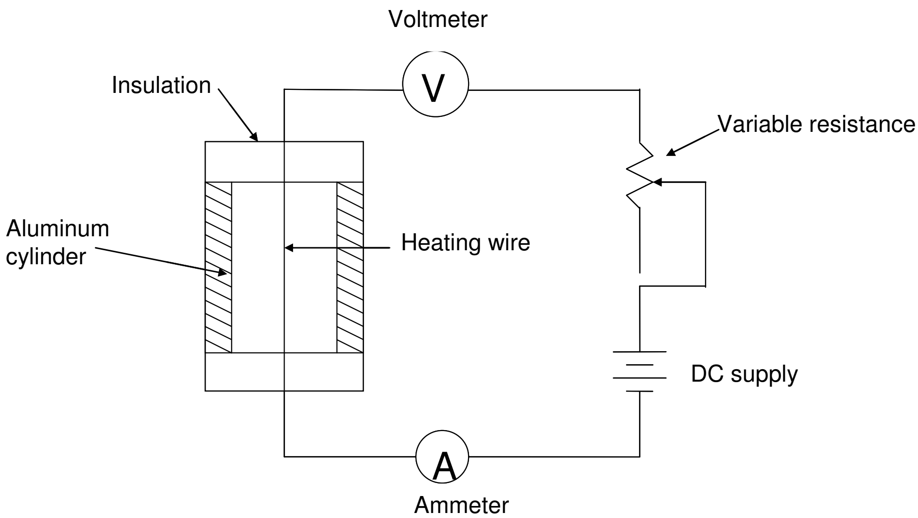

Figure-1. Schematic diagram of thermal conductivity measuring apparatus.

2.3 Procedure for determining temperature and time of sample

The conditioned samples were placed in the aluminium sample cylinder in the setup of the thermal conductivity measuring apparatus. The temperature at the centre of the cylinder was checked by means of a thermocouple. The setup was adjusted to a current of 1.0 A and a voltage of 3 V. Temperature readings were taken at a regular time interval of one minute for thirty minutes. Temperature was then plotted against time on a semi–log paper.

2.4 Degree of ripeness

The colour of plantain for various experimental days, indicating the degree of ripeness at which the thermal conductivities were determined, is shown in Figure-2.

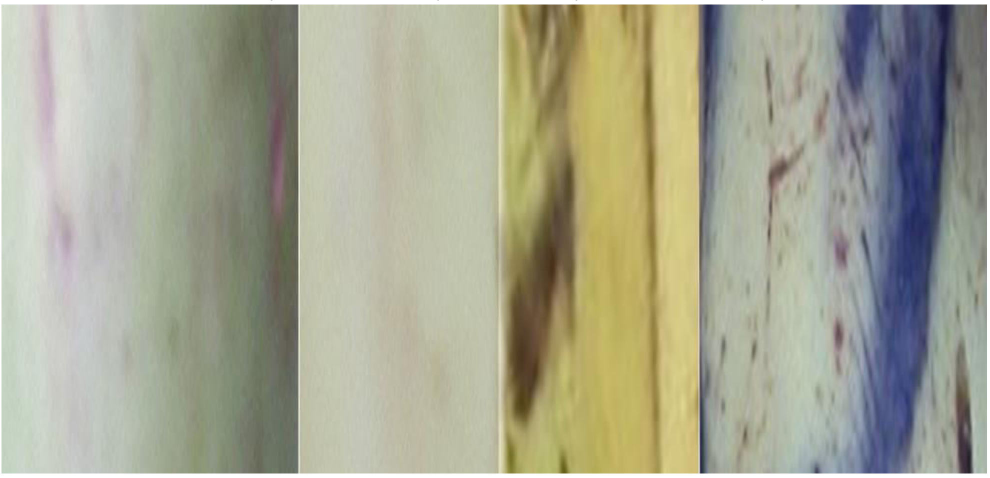

Figure-2. Colour of plantain for the various experimental days.

2.5 Thermal conductivity

Thermal conductivity was determined using the following relation given by Hooper and Lepper (1950):

$$k = \frac{Q}{4\pi(T_2 - T_1)} \ln \theta_2 / \theta_1 \quad (2)$$

Where times θ_2 and θ_1 correspond to temperatures T_2andT_1 respectively on a curve of Temperature rise against time for specific moisture content.
Equation (2) can be rearranged as

$$(T_2 - T_1) = \frac{Q}{4\pi k} \ln \theta_2 / \theta_1 \quad (3)$$

Thus the slope *S* of the straight line portion of the temperature against time on a semi-log graph is given as

$$S = \frac{Q}{4\pi k} \quad (4)$$

The heat input *Q*, expressed in W/m is obtained from

$$Q = VI/L \quad (5)$$

where *V* is the voltage in V, *I* is the current in A and *L* is the length of heater wire in m. Using the value of *Q* together with *S* from the graph, the values of *k* for various trials are then calculated from equation (4) as

$$k = \frac{Q}{4\pi} \frac{1}{S} \quad (6)$$

Similar procedure has been used by Kazarian and Hall (1965), Sweat (1974), Morita and Singh (1979), Tavman and Tavman (1998), Shrivastava and Datta (1999), Tansakul and Chaisawang (2006) Tansakul and Lumyong (2008) and Kara *et al*. (2011) to determine thermal conductivities of various agricultural materials.

2.6 Statistical analysis

Four replicates were determined and reported for all results obtained. Statistical analysis was performed using completely randomized design with single factor analysis of variance (ANOVA) for all data and analyzed with Minitab Version 15. Statistical significance was carried out using Tukey and Fisher's approach at $p<0.05$.

3. RESULTS AND DISCUSSIONS

The following procedure was used to determine the thermal conductivity value from the graph of temperature against time at moisture content of 45% (day 1) as shown in Figure-3.

ARPN Journal of Engineering and Applied Sciences

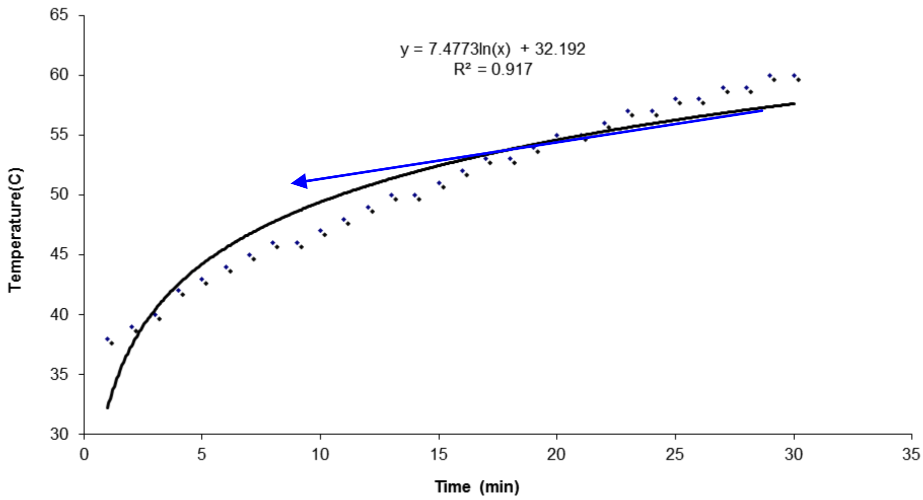

Figure-3. Temperature rise against time for moisture content of 45%, day 1.

The slope S for the line portion of the semi-log graph was obtained as

$S = 7.4773$

Various values were measured from the experiment as

$V = 2.9\text{V}$, $I = 1.0$ A, and $L = 0.05\text{m}$

So that $Q = VI/L = 58$W/m. Substituting for S and Q in equation 6 gave a k value of 0.617W/mK. This same procedure was used to determine thermal conductivity (k) values for all the ripening stages.

3.1 Thermal conductivity as a function of ripening of the plantain

Figure-4 is a graph of thermal conductivity values against colour change during ripening.

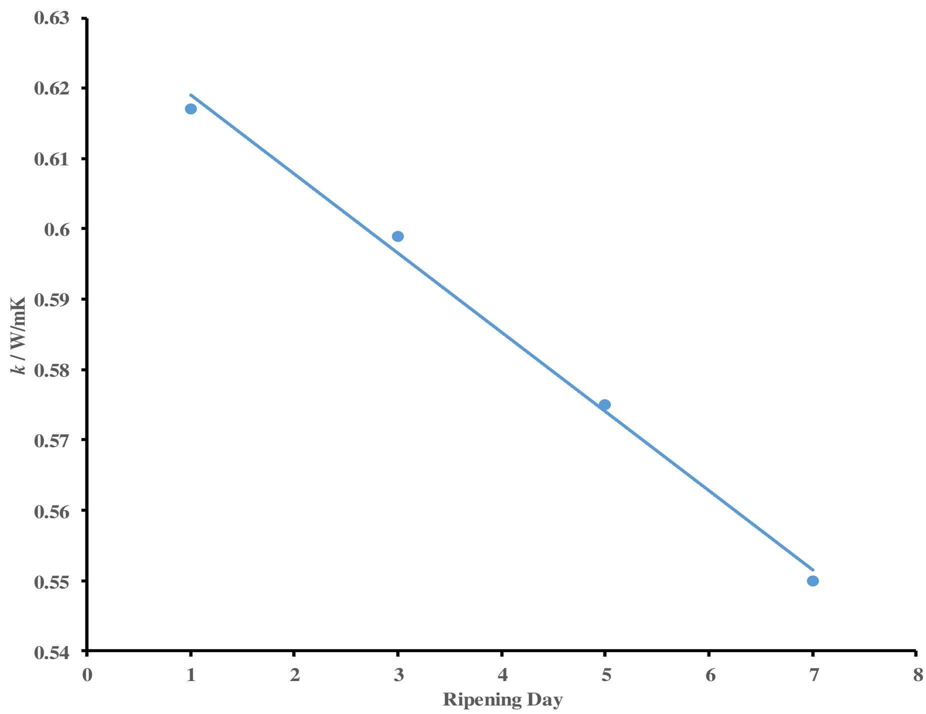

Figure-4. A graph of thermal conductivity against ripening at 50°C.

It can be observed from Figure-4 that, thermal conductivity (*k*) decreased with ripening. This is due to the conversion of starch to simple sugars - themost predominant one being sucrose, duringripening. Starch constitutes most (80-98%) of the carbohydrate fraction in unripe plantain. When plantains were stored by Thompson and Burden (1995) at 22˚C, the starch content decreased from 97% to 51% in 14 days, while the sucrose content increased commensurately from 2% to 23%. Sucrose has a lower *k* than starch. Halliday *et al.* (1995) gave the intrinsic k of sucrose at 20˚C as 0.29W/mK.On the other hand, the intrinsic *k* of starch at 18.5˚C was 0.388W/mK according to Sakiyama *et al.* (1993). Apart from having a lower *k*, sucrose has a better water-binding capacity than starch (Richardson and Jones, 1987). Thus as the sucrose-content increases, the quantity of free water in plantain decreases so that the pores are filled with air. This may lead to a decrease in *k* since water also has a higher *k* than air.

3.2 Thermal conductivity as a function of moisture content

Figure-5 is the graph of thermal conductivity values against varying moisture content for various ripening days. It can be observed that, the thermal conductivity values decreased with decreasing moisture contents from 55% to 40%for the various experimental days as also indicated by Singhand Goswami, 2000, where thermal conductivity increased from 0.046 to 0.223 W/m K with the increase in moisture content from 1.8% to 20.5% dry basis in cumin seed. Kazarian and Hall (1965) determined the thermal conductivity of soft wheat and yellow dent corn and observed that *k* increased with increase in moisture content. The first day has higher thermal conductivity values which decreased from 0.755 to 0.564W/mK, followed by the third day with thermal conductivity values decreasing from 0.710 to 0.546W/mK, the fifth day with values from 0.655 to 0.537W/mK and the seventh day with values between 0.601 and 0.527 W/mK.

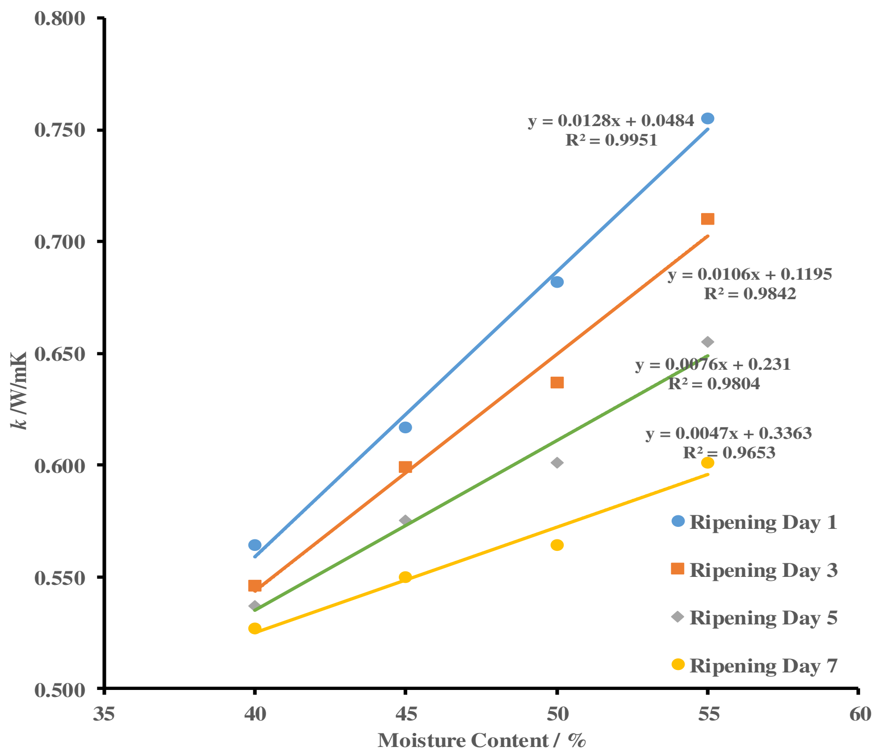

Figure-5. A graph of thermal conductivity against moisture content.

The possible reason for this trend in values is that the density of the sample decreased with decreasing moisture content, meaning porosity was increasing. At high porosity the pores are now filled with air, which has lower thermal conductivity than the moisture. Generally, an increase in porosity leads to a decrease in *k* of food material (Szczesniak, 1983; Sweat, 1986; Maroulis *et al.*, 1990).

3.3 Thermal conductivity as a function of temperature

Figure-6 shows thermal conductivity values against temperature for the moisture content of 55%.

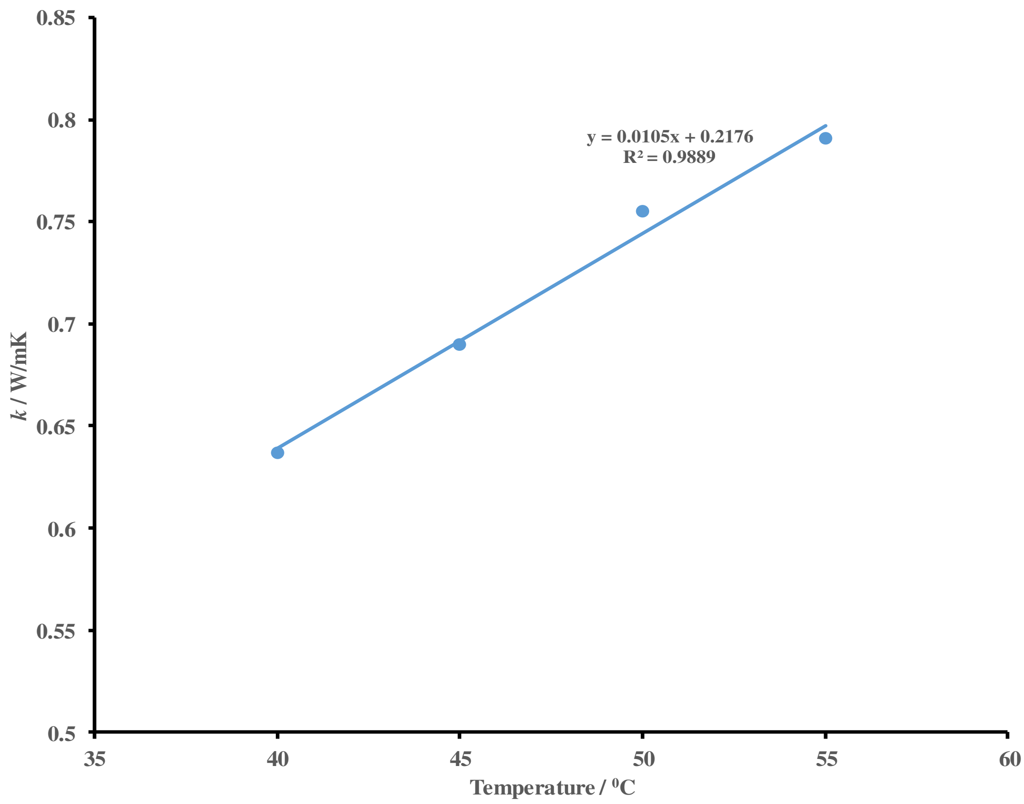

Figure-6. Thermal conductivity against temperature at moisture content of 55 %.

From temperatures 40^{0}C to 55^{0}C, the thermal conductivity increased from 0.637 to 0.791 W/mK. This is attributable to the fact that as the temperature increases the individual sample particles are energized, causing a faster transfer of heat to neighbouring particles.

The results follow the same trend as that of other researchers. Bart-Plange *et al.* (2004) observed in their experiments on *mamaba*and *asetenapa* varieties of maize and cowpea respectively that *k* increased with an increase in moisture content, bulk density and temperature. Bart-Plange *et al*. (2012) also observed that *k* increased with increasing moisture content, bulk density and temperature for ground cocoa bean and shea kernel. Njie *et al*. (1998) also observed that *k* increased when moisture content was high, in their comparison of *k* for yam, plantain and cassava. For Other materials, Ojha *et al.*, (1967) observed that moisture content, bulk density and temperature level were all significant factors affecting *k* of organic powders. Farrall *et al.* (1970) found that the value of *k* increased when the moisture content of powdered milk increased.

4. CONCLUSIONS

After the investigation on the thermal conductivity of ripe and unripe 'apantu' variety of plantain, the following were revealed:

- Thermal conductivity decreased with decreasing moisture. With decreasing moisture content from55%, to40%, thermal conductivity decreased from 0.755 to 0.564W/mK for day one, 0.710 to 0.546W/mK for day three,0.655 to 0.537W/mK for day five and from 0.601 to 0.527 W/mK for day seven

- Thermal conductivity increased with increase in temperature. At temperatures from 40^{0}C to 55^{0}C, thermal conductivity ranged from 0.637 to 0.791W/mK at a moisture content of 55%.

- Thermal conductivity decreased with ripening (green, ripe, over ripe). The effective thermal conductivity decreased from 0.617 to 0.55 W/mK as ripening progressed from day one to day seven with the temperature at 50^{0}C and the moisture content at 55%

It is then concluded that the unripe *apantu* conducts heat faster than the ripe one; meaning a given mass of the unripe *apantu* heat up faster than the same mass of the ripe *apantu*. Also in terms of cooling for export, the unripe *apantu*will cool faster after harvest.

Values obtained from this study could be used to generate mathematical models to predict the effective thermal conductivity as a function of moisture content, temperature and stage of ripening.

REFERENCES

Addo A., Bart-Plange A. and Boakye D. M. 2009. Drying characteristics of cap and stem of mushroom. Journal of Science and Technology. 29(2): 88-95.

Adejoro M. A., Odubanjo A. O. and Fagbola B. O. 2010. Research focus on banana and plantain (Musa spp.): Nigerian Perspectives. Acta horticulturae. (879): 859.

AOAC. 1984. Official Methods of Analysis (13th Ed.) Washington, DC: Association of Official Analytical Chemists.

Aviara, N.A. and Haque, M.A. (2001). Moisture dependence of thermal properties of sheanut kernel.J. Food Eng. 47: 109- 113.

Bart-Plange, V. Asare and Addo A. 2004. Proceedings of the 2nd West Africa Society of Agricultural Engineers (Hunger without frontiers), International Conference on Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Ghana.

Bart-Plange A., Addo A., Amponsah S. K. and Ampah J. 2012. Effect of Moisture, Bulk Density and Temperature on Thermal Conductivity of Ground Cocoa Beans and Ground Sheanut Kernels. Global Journal of Science Frontier Research (GJSFR). Volume 12 Issue 8 Version 1.0 July. ISSN No.: 2249-4626.

Bart-Plange A., Asare V. and Addo A. 2009. Thermal conductivity of maize and cowpea. Journal of Engineering and Technology. 2(3): 6-11.

Bart-Plange A., Dzisi. K.A. and Darko J.O. 2005. Effects of moisture content on selected physical properties of two varieties of cowpea. Agricultural and Food Science Journal of Ghana. 4: 329-340.

Cevoli C., Fabri A., Marai S. V., Ferrari E., Guarnieri A. 2014. Estimation of thermal conductivity of short pastry biscuit at different baking stages. Journal of Agricultural Engineering. XLV:232: 64-69.

Dutta S.K., Nema V.K. and Bhardwaj R.K. 1988. Thermal Properties of Gram. Journal of Agricultural Engineering Research. 39, 269-275.

FAO (1995). Roots, Tubers, Plantains and Bananas in Human Nutrition. Food and Agriculture Organisation, Rome, Italy.

FAO. 2010. (Food and Agriculture Organization). Food and agriculture indicators ESSA.

Farrall A.W., Chen A.C., Wang P.Y., Dhanak A.K., Hendrick T. and Heldman D.R. 1970. Thermal conductivity of dry milk in a packed Bed.Transactions of the ASAE. 13, 391-394.

Halliday P. J., Parker R., Smith A.C. and Steer D.C. 1995. The thermal conductivity of maize grits and potato granules. Journal of food engineering. 26(3): 273-288.

Hemeng O. B., Oduro K. A., Ofori I. and Banful B. 1995. Plantain production in Ghana. (Final report of farming systems survey. Prepared for National Agricultural Research Project (NARP), (CSIR), Accra, Ghana.

Huang L. and Liu L. 2009. Simultaneous determination of thermal conductivity and thermal diffusivity of food and agricultural materials using a transient plane-source method. Journal of Food Engineering. 95(1): 179-185.

Kara M., Ozturk I., Bastaban S. andKalkan F. 2011. Thermal conductivity of safflower (*Carthamus tinctorius* L.) seeds. Spanish Journal of Agricultural Research. 9(3): 687-692.

Kazarian E. A. and Hall C. W. 1965. The thermal properties of grain. Transactions of the ASAE. 8(1): 33-37, 40.

Kumar S. M., Durga P. B. and Basavaraj M. 2014. Effect of moisture content and temperature on thermal conductivity of *Psidium guajava* L. by line heat source method (transient analysis). International Journal of Heat and Mass Transfer. 78: 354-359.

Mahmoodi M. and Kianmeehr M.H. 2008. Determination and comparison of thermal conductivity of Iranian pomegranate varieties. 18th National Congress on Food Technology, Hashad I. R. Iran, from 15-16 October.

Maroulis Z.B., Drouzas A.E. and Saravacos G.D. 1990. Modeling of Thermal Conductivity of Granular Starches. Journal of Food Engineering. 11: 255-271.

MOFA-SRID. 2011. Agriculture in Ghana. Facts and figures. 2010. Ministry of food and agriculture, statistics, research and information directorate. p. 53.

Mohsenin N. N. 1980. Thermal Properties of Agricultural Materials. Gordon and Breach Science Publishers, New York, USA.

Morita T. and Singh R. P. 1979. Physical and thermal properties of short-grain rough rice. Transactions of the ASAE [American Society of Agricultural Engineers] (USA).

Moysey E.B., Shaw J.T. and Lampman W.P. 1977. The effects of temperature and moisture on the thermal properties of rapeseed. Transactions of the ASAE, 20,461-464.

Njie D.N, Rumesy T.R. and Singh R.P. 1998. Thermal properties of cassava, and plantain, J. Food Eng. 57: 63-76.

Nwaichi E. O., Peters D. E. and Onome E. 2014. Evaluation of the effect of processing on the observed profile of Ripe and Unripe Plantain. Scientia. 1(1): 15-18.

Ojha T.P., Farall A.W., Dhanak A.M. and Stine C.M. 1967. A method of determining heat transfer through powdered food products. Transaction of the ASAE. 10, 543-544.

Ortiz R. and Vuylsteke D. 1996. Improving plantain and banana-based system. In: R. Ortiz and M.O. Akoroda (eds.), Plantain and Banana Production and Research in West and Central Africa. Proceedings of a Regional Workshop, Nigeria, 23-27 September, 1995. IITA, Ibadan, Nigeria.

Ortiz R., Vuylsteke D. 1994. Genetics of apical dominance in plantain (Musa spp., AAB Group) and improvement of suckering behavior. Journal of the American Society for Horticultural Science. 119(5): 1050-1053.

Richardson R. and Jones J.M. 1987. The effects of salt concentration and pH upon water-binding, water-holding and protein extractability of turkey meat. International Journal of Food Science and Technology. 22(6): 683-692.

Shepherd H. and Bhardwaj R. K. 1986. Moisture-dependent physical properties of pigeon pea. Journal of Agricultural Engineering Research. 35(4): 227-234.

Shrivastava M. and Datta A.K. 1999. Determination of specific heat and thermal conductivity of mushrooms (*Pleurotus florida*). J Food Eng. 39, 255-260.

Singh K.K. and Goswami T.K. 2000. Thermal properties of cumin seed. Journal of Food Engineering. 45, 181-187.

Sirisomboon P. and Posom. J. 2012. Thermal properties of *Jatropha curcas* L. kernels, Biosystems Engineering. 113(4): 402-409.

Sweat V. E. 1986. Thermal properties of foods. In M. A. Rao, and S. S. H. Rizvi (Eds.), Engineering properties of foods. pp. 87-99. New York: Marcel Dekker.

Sweat V. E. 1974. Experimental values of thermal conductivity of selected fruits and vegetables. Journal of Food Science. 39(6): 1080-1083.

Swennen R. 1990. Plantain cultivation under West African Conditions (A Reference Manual). IITA, Ibanan, Nigeria. pp. 1-2.

Szczesniak A. S. 1983. Physical properties of foods: what they are and their relation to other food properties. - In: Peleg, M. and Bagley, E. B. (Eds) Physical properties of foods. AVI Publishing Co., Westport, CT. pp. 7-16.

Tansakul A. and Chaisawang P. 2006. Thermo physical properties of coconut milk. Journal of Food Engineering. 73, 276-280.

Tansakul A. and Lumyong R. 2008. Thermal properties of straw mushroom. Journal of Food Engineering. 87: 91-98.

Tavman S. and Tavman I.H. 1998. Measurement of effective thermal conductivity of wheat as a function of moisture content. Int Commun Heat Mass. 25(5): 733-741.

Thompson A. K. and Burden O.J. 1995. Harvesting and fruit care.In Banana and Plantain, Chapman and Hall, London. pp. 424-426.

Timbers G. E. 1975. Properties of Rapeseed: Thermal Conductivity and Specific Heat Capacity. Canadian Agricultural Engineering. 17, 81-84.

Van Gelder M.R. 1998. A Thermistor based method for measurement of thermal conductivity and thermal diffusivity of moist food materials at high temperatures. PhD Thesis, Virginia Polytechnic Institute and State University, Virginia.

Wallapapan K. and Sweat V.E. 1982. Thermal. Thermal conductivity of defatted Soy flour. Transaction of the ASAE. 27(6): 1610-161.