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THERMAL PROPERTIES OF GROS MICHEL BANANA GROWN IN GHANA

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ABSTRACT

Thermal properties such as specific heat, thermal conductivity and thermal diffusivity of tropical fruits provide critical information and data for the design and manufacture of equipment and machines for their processing. Literature generally abounds in information on subtropical fruits but not on tropical fruits like banana. Banana was selected because currently it is not widely processed in the dried form in Ghana. The purpose of the study was thus to provide information on the thermal properties of locally grown banana to aid in the design and manufacture of equipment for processing, handling and transportation. The selected variety for the study was dried to moisture contents (MC) ranging from 18.5-50.0% wb. Specific heat was measured by the method of mixtures while the thermal conductivity was measured by the line heat source probe method. Thermal diffusivity was calculated from the experimental results obtained from specific heat, thermal conductivity and bulk density. Bulk density was measured by mass per unit change in volume of the sample. The bulk density was found to be in a range of 1376.2-1130.0 kg m^{-3}. The bulk density decreased with increasing MC. The specific heat ranged from 1574.0-2506.8 $Jkg^{-1}\ {}^{o}C^{-1}$. The thermal conductivity of the banana varied from 0.249- 0.458$Wm^{-1}\ {}^{o}C^{-1}$ whiles the thermal diffusivity ranged from 1.15 $x10^{-7}$-1.62 $x10^{-7}m^2s^{-1}$. Specific heat, thermal conductivity and thermal diffusivity were found to increase with increasing MC. The effects of MC on all parameters studied were highly significant at ($p < 0.05$). Regression equations were established which could be used to reasonably estimate thermal property values at other MC.

Keywords: gros michel banana, thermal conductivity, specific heat, thermal diffusivity, bulk density, moisture content, Ghana.

1. INTRODUCTION

Banana (*Musa acuminata*) is a perennial herbaceous plant which belongs to the genus *Musa*. It is a native crop of Southeast Asia and was first domesticated in Papua New Guinea. Today it is cultivated throughout the tropics (The World of Plants, 1999-2010). Banana and plantain are perennial crops that grow quickly and can be harvested all year round. According to Gowen (1995) as cited by Picq *et al*. (1999), banana is an important tropical dessert food crop which is eaten by many people in the tropics in a raw state when ripe. The development of banana export industry at the end of the 19th century has resulted in a surplus of fruit in producer countries. This is because of the high standards imposed on the appearance of the fruits by importing countries resulting in a high proportion of the fruit being judged not to be of export quality. In recent decades, this surplus has turned to increase due to increasing production from both established and new producer countries. Bananas have wide nutritional and therapeutic values in diet such as low cholesterol, fat and salt levels. The importance of bananas as a food crop in tropical areas cannot be under-estimated. Banana is a climacteric fruit, when harvested at the pre-climacteric matured 'green' stage, the fruit undergoes various physicochemical changes such as composition, colour, texture, aroma and taste, pertaining to changes in metabolic rates and biochemical reactions like respiration, ripening and senescence in the climacteric phase (Areas and Lajolo, 1981; Wills *et al*., 1984; Adisa and Okey, 1987; Garcia and Lajolo, 1988; Golding *et al.* 1999 and Adeyemi and Oladiji, (2009) cited by Mohapatra *et al*., (2010). These changes in the physicochemical properties are due to various complex biochemical reactions. These biochemical reactions which take place within and outside the fruit reduce the shelf life of the banana fruit. According to Nimsung *et al.*, (2007), the banana fruit contains high amount of sugar and moisture and is very perishable during ripening as such there are many discarded fruits. Hence, the need to process the banana fruit into other finished products. Thermal properties of various foods and agricultural products have been studied by researchers such as Kazarian and Hall, (1965); Sherpherd and Bharddway, (1986), Dutta *et al*., (1988) cited by Aviara and Hague, (2001) and Bart-Plange *et al*., (2009). The influence of thermal properties on equipment design and prediction of heat transfer operations during drying, heating, cooking of foods cannot be overemphasized. Information on thermal properties of exotic bananas may be available, however, empirical data on thermal properties of Gros michel banana grown locally in Ghana is lacking. Over the years both measured and calculated values of thermophysical properties of food have been published (Bhumbla *et al*., 1989; de Moura *et al*., 1998). However, most of the available data are for subtropical fruits. Little published information is available about the thermal properties of tropical fruits. Ikegwu and Ekwu (2009) reported that lack of mechanization for the processing of a variety of fruits, which abound in the tropics presently, could be traced to the fact that data on their engineering properties are lacking. Banana was selected in this study due to its intense worldwide acceptability and high nutritional value and also because of its potential of been processed commercially in dried form in the tropics. The objective of the research was to investigate the effects of moisture content variations on specific heat, thermal conductivity and thermal diffusivity of the Gros michel banana grown locally in Ghana.

2. MATERIALS AND METHODS

2.1 Sample preparation

Gros michel *'Asante Kwadu'* of fresh ripe bananas were bought from the local market in Kumasi. The samples were cleaned to remove any foreign matter. The fresh bananas were peeled and cut to sizes of same weight. The samples were dried in an electric (laboratory hot) oven at a temperature of 80^{o}C for 24h in order to determine the moisture content. This method was used by Katekawa and Silva (2007) for the determination of moisture content (MC) of banana. During the drying process, time and weight of samples were recorded at an interval of one hour until there was no change in weight of the samples. 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). The moisture content of the banana was determined using equation (1).

$$M_w = 100\frac{w_w}{w_t} = 100\frac{w_w}{w_w + w_d} \quad (1)$$

In order to obtain the desired moisture contents of 18.5%, 24.5%, 39.7% and 50.0% a drying curve of moisture content against time of the banana from preliminary experiment was required to estimate the drying time to obtain the desired MC. The drying time needed to obtain dried samples of MC levels 18.5%, 24.5%, 39.7%, and 50.0% wet basis were 12hr, 10hr, 8hr and 6hr, respectively as shown in Figure-1.

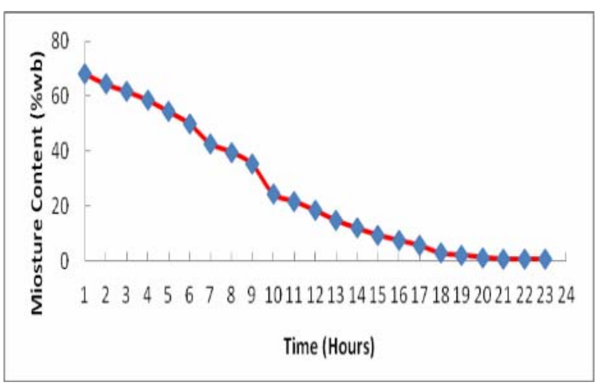

Figure-1. Drying curve of Gros Michel Banana.

After preparation, the samples were completely sealed in polyethylene bags to prevent moisture loss or gain. These were kept in a refrigerator at 5^{o}C overnight to allow moisture to equilibrate and minimize quality change before analysis. Finally, the dried banana samples were checked for their moisture contents again to ensure that they were at the desired levels of moisture contents.

2.2 Determination of Bulk Density

Samples of known weight were gently dropped into a 100ml graduated cylinder filled with water to 50ml. The volume displaced was recorded as the volume of the sample. The bulk density of the banana was determined as the ratio of the mass of sample to the volume occupied by the sample as found in equation (2). Similar methods have been used by Stroshine and Hemann (1995) and Ikegwu and Ekwu (2009).

$$\rho_b = \frac{M_b}{V_b} = \frac{M_b}{V_2 - V_1} \quad (2)$$

Where,
ρ_b = bulk density of banana
V_b = volume of banana (m^3)
M_b = mass of banana (kg)
V_2 = final volume of water in cylinder (m^3)
V_1 = initial volume of water in cylinder (m^3)

The experiment was repeated four times at each moisture content level.

2.3 Determination of specific heat

Several methods have been used in the determination of specific heat as reported in literature, but the most common method used for agricultural and food products is the method of mixtures. This method has been used by researchers such as Mortaza *et al*., (2008) for berberis fruit; Aviara and Haque (2001) for sheanut kernel and Tansakul and Lumyong (2008) for straw mushroom. In the method employed, the following assumptions were made: **(a)** Heat loss as a result of transfer of product from the heated chamber to calorimeter is negligible and **(b)** loss of evaporation during equilibration period is negligible.

The heat capacity of the calorimeter was determined experimentally: a known quantity of hot water at a temperature of (85^{o}C) was added to the calorimeter containing a known quantity of water at a lower temperature. The heat capacity of the calorimeter was determined using equation 2 as reported by Mortaza *et al*., (2008).

$$C_{pc} = \frac{M_{cw}C_w\left(T_e - T_i\right) - M_{hw}\left(T_{hw} - T_e\right)}{M_c\left(T_{hw} - T_e\right)} \quad (3)$$

The specific heat of aluminum foil was also determined experimentally. The foil with a known mass

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and high temperature was put into a calorimeter that contains a known quantity of distilled water at a known low temperature (room temperature). The system was assumed to be adiabatic. Therefore, the specific heat capacity of the foil was calculated from equation 4 (Mortaza *et al*., 2008).

$$C_{pf} = \frac{\left(M_c C_c + M_w C_w\right)\left(T_e - T_i\right)}{M_f \left(T_f - T_e\right)} \quad (4)$$

To determine the specific heat of banana, a sample of known weight and temperature was wrapped in aluminium foil and heated in a heating chamber for one hour and the final temperature recorded. The sample was quickly removed and dropped into a calorimeter containing water of known quantity and temperature. The mixture was stirred continuously with a glass rod in order to obtain a uniform mixture. At equilibrium, the final temperature was recorded and the specific heat of sample was calculated using the equation reported by Mortaza *et al*., (2008) as follows:

$$C_{pb} = \frac{\left(m_c c_c + m_w c_w\right)\left(T_e - T_i\right) - M_f C_f}{M_b \left(T_f - T_e\right)} \quad (5)$$

The experiment was replicated four times at each moisture content level.

2.4 Determination of thermal conductivity

The thermal conductivity of banana was determined using the line heat source probe method based on non-steady state heat conduction. This method is convenient, rapid and suitable for small samples. For food and biological materials, this method has frequently been used in recent years for the determination of thermal conductivity (Sweat, 1995; Mortaza *et al*., 2008; Bart-Plange *et al*., 2009). The apparatus consists of an ammeter and voltmeter for the recording of current and voltage respectively. A direct current (DC) power source was used to provide the heat source. Current and voltage of 0.7A and 4.5 ±0.5V respectively were used throughout this experiment. In the set-up was a rheostat to vary resistance in the circuit in order to achieve the desired current for the experiment. The conditioned samples of specific MC were allowed to warm up to room temperature. After weighing, it was put into the sample holder of diameter 2cm, length 7±0.5cm and thickness 0.2cm. A heating coil was placed in the middle of the sample and connected externally to the power source. The temperature meter was inserted into the sample holder and then the switch turned on. Reading of temperature was done after the sample and sample holder had reached a temperature of 30°C. The current and voltage readings were adjusted to 0.7A and 4.5 ±0.5V, respectively and used as heat source for the sample. Temperatures were recorded at regular intervals of 30seconds for 40minutes for each sample. The experiment was replicated four times at each moisture content level and recorded. A graph of temperature difference at the intervals considered T_2-T_1 was plotted against the natural logarithm of the corresponding time ratio $\left(\ln\frac{\theta_2}{\theta_1}\right)$. The slope (S) of the graph was determined from the straight line portion of the graph which is given as $S = \frac{Q}{4\pi K}$. Hence, thermal conductivity was determined as

$$K = \frac{Q}{4\pi S}$$

2.5 Determination of thermal diffusivity

The thermal diffusivity (α) of banana was calculated from experimentally determined values of thermal conductivity (K), specific heat (C_{pb}) and bulk density (ρ_b) of the samples using the equation:

$$\alpha = \frac{K}{\rho_b C_{pb}} \quad (6)$$

2.6 Statistical analysis

The means of four replicates were determined and reported for all the samples studied. The statistical analysis was performed using complete randomized design with single factor analysis of variance (ANOVA) for all data and analyzed with Microsoft Excel at $p < 0.05$.

3. RESULTS AND DISCUSSIONS

3.1 Bulk density

Figure-2 represents the experimental variation of bulk density of banana with moisture content. The bulk density of Gros michel banana at a moisture content range of 18.5-50.0% wb, was found to be in a range of 1376.2 to 1130.0 kg m^{-3}. The bulk density decreased with increasing moisture content. Talla *et al*. (2004) reported same trend in variation in moisture content with bulk density of banana.

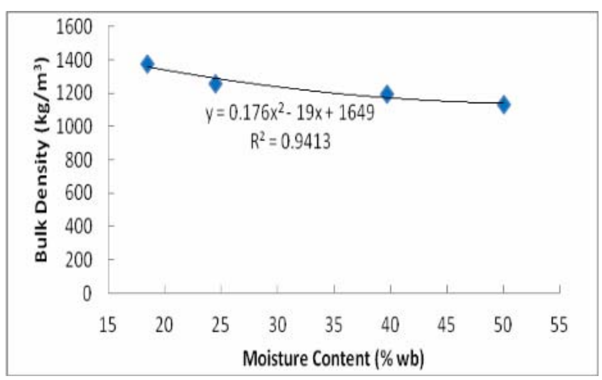

Figure-2. Variation in bulk density of Gros michel banana with moisture content.

The experimental results for bulk density of banana correlate well with what is reported in literature. Dithfield *et al*. (2005) found that the bulk density of banana puree was 1115 kg m^{-3}. At a MC of 4 kg/kg dry basis, the bulk density of banana as reported by Karim and Hawlader (2005) was 980 kg m^{-3}. Ikegwu and Ekwu (2009) indicated that the bulk density of banana at a moisture content of 71%wb was 964kg m^{-3}. Some variations exist between this work and that of other researchers and this may be due to the method employed, stage of maturity of samples used and the control factors employed to obtain the results.

Empirical equation was developed to describe the effect of moisture content on bulk density of the banana. However, the polynomial regression equation gave the best coefficient of determination.

$$\rho_b = 0.176MC^2 - 19MC + 1649 \ (R^2 = 0.941) \quad (7)$$

The statistical analysis (ANOVA) for bulk density with variations in moisture content reveals a highly significant level of treatment effect (moisture content) on bulk density ($p < 0.05$. The least significant difference (LSD) was computed and was found to be 3.09. Comparing the differences of any two mean treatments with the computed LSD showed a significant difference among the means.

3.2 Specific heat (C_{pb})

The mean experimental value for specific heat of Gros michel banana at four replications at MC range of 18.5-50.0 %wb varied from 1574 J kg^{-1} $^oC^{-1}$ to 2506.8 J kg^{-1} $^oC^{-1}$. The specific heat of the banana increased with increasing moisture content (Figure-3).

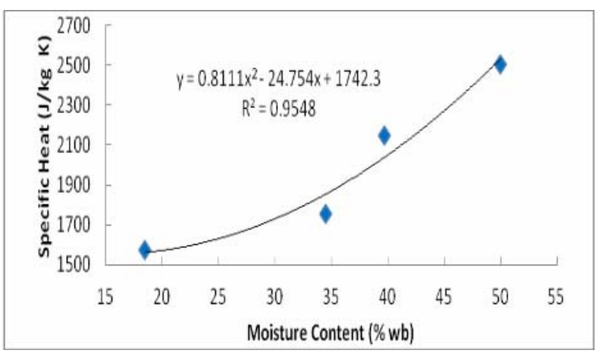

Figure-3. Variation in specific heat of banana at different moisture contents.

Specific heat of food products according to Tansakul and Lumyong (2008) is a function of the moisture content in the product. The trend in specific heat with variation in moisture content correlates well with other research works. Singh and Goswami (2002) reported increase in specific heat of cumin seed with increase in moisture content. Other researchers also reported similar results: Aviara and Haque (2001) for shea-nut kennel; Tansakul and Lumyong (2008) for straw mushroom and Nwabanne (2009) for fermented ground cassava. The experimental values obtained for specific heat of the Gros michel banana was found to be non-linear which deviates from other published works. However, the experimental results obtained agree with other published results. Talla *et al*., (2004) found that the specific heat of banana with average moisture content ranging from 39.3 to 50.6 % db $(kg/kg)^{-1}$ varied from 1028 - 1093J kg^{-1} K^{-1}. Also, the specific heat of banana reported by Ikegwu and Ekwu (2009) was 3.45kJ kg^{-1} $^oC^{-1}$ at a moisture content of 71%wb. The binomial equation was used to express the relationship between specific heat and moisture content using equation 8:

$$C_{pb} = 0.811MC^2 - 24.75MC + 1742 \ (R^2 = 0.954) \quad (8)$$

From the analysis of variance (ANOVA), the effect of moisture content on specific heat was highly significant at ($p < 0.05$). The mean LSD was 33.74. Comparing the difference between any two mean treatments with the computed LSD show no two means were significantly the same. This shows that for any two mean differences of MC there is a significant effect of treatment (moisture content) on specific heat. The coefficient of determination (expressed in %) was 95.4%.

3.3 Thermal conductivity (K_b)

Figure-4, the thermal conductivity of the gros michel variety of banana of moisture content ranging from 18.5-50.0 %wb varied from 0.249 W m^{-1} $^oC^{-1}$ to 0.458 W m^{-1} $^oC^{-1}$.

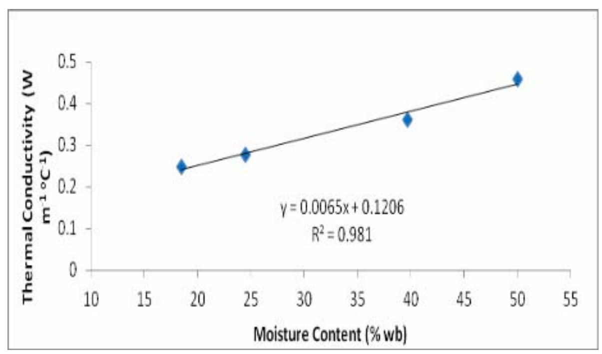

Figure-4. Variation in thermal conductivity of banana with moisture content.

The thermal conductivity of the banana was seen to increase linearly with increasing moisture content. The magnitude of the coefficient of determination confirms a stronger effect of moisture content on thermal conductivity. Equation (9) was used to express the relationship existing between thermal conductivity and moisture content.

$$K = 0.006MC + 0.120 \ (R^2 = 0.981) \quad (9)$$

Other researchers such as Shrivastava and Dutta, (1999); Muir and Varavanichai, (1972); Dutta *et al*., (1988); Bart-Plange *et al*., (2009) and Nwabanni (2009) reported the existence of linear relationship between thermal conductivity with moisture content for other agricultural products. The experimental values obtained for the thermal conductivity of banana correlate well with what has been published in literature. At a moisture content of 63-65%wb, Perusella *et al.* (2010) found that the thermal conductivity of banana using the line heat probe method varied from 0.3- 0.55W/m °C. Other researchers have worked on the thermal conductivity of banana. Sweat (1974), in an experiment to determine the thermal conductivity of selected fruits and vegetables reported 0.481W/m K at moisture content of 75.5%wb for banana. Dithfield *et al*., 2005, found the thermal conductivity of banana puree to be 0.695 W/m K. The analysis of variance (ANOVA) indicated a significant difference ($p<0.05$) of thermal conductivity of Gros Michel banana at various moisture content. The LSD of the means was computed and it was found to be 0.0091 and the coefficient of determination was 98.1%.

3.4 Thermal diffusivity (α)

From Figure-5, it is observed that increasing moisture content had a corresponding increase in thermal diffusivity of the banana studied. The thermal diffusivity in the MC range of 18.5-50.0 %wb varied from 1.15×10^{-7} to $1.62 \times 10^{-7} m^2 s^{-1}$.

Figure-5 shows the existence of linear increasing trend of thermal diffusivity with moisture content. Coefficient of determination of the banana was 86.9%. The linear equation between thermal diffusivity and moisture content is shown equation (10)

$$\alpha = 0.013MC + 0.903 \quad (R^2 = 0.869) \qquad (10)$$

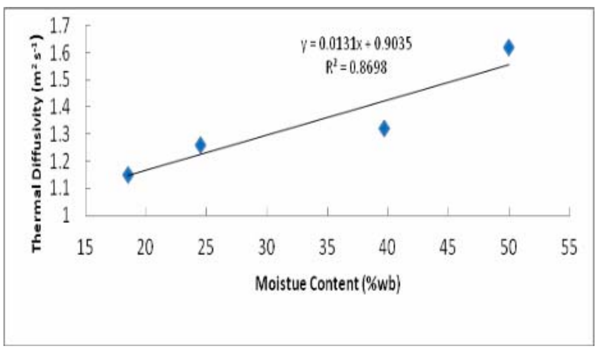

Figure-5. Variation in thermal diffusivity of Gros Michel banana with moisture contents.

Aviara and Haque (2001), Tansakul and Lumyong (2008), Shyamal *et al*., (1994) reported a linear relationship between thermal diffusivity and moisture content. On the contrary, Singh and Goswami, (2008) reported non-linear relationship between thermal diffusivity and moisture content of cumin seed. Other research works on thermal diffusivity of banana indicate that there is correlation between obtained experimented values in this study and what is reported in literature. Singh and Heldman (1993) found that thermal diffusivity of banana at moisture content of 76%wb and temperature 5°C and 65°C were 1.181×10^{-7} and $1.421\times10^{-7} m^2 s^{-1}$. Research by Fontana *et al*., (2001) indicated that the thermal diffusivity of banana at 17°C was 1.0×10^{-7}. At moisture content of 71%wb, Ikegwu and Ekwu (2009) found that the thermal diffusivity of banana was $1.5\times10^{-7} m^2 s^{-1}$. Also, research work by Mariani *et al*., (2008) on nanicão variety of banana at minimum and maximum apparent thermal diffusivity ranged from 2.49×10^{-9} to $1.88 \times10^{-7} m^2 s^{-1}$. The statistical analyses (ANOVA) show a significant difference ($p < 0.05$) with mean LSD of Gros Michel banana was 0.0463.

4. CONCLUSIONS

The study conducted revealed the following results on thermal properties of Gros Michel banana at moisture contents ranging from 18.5 - 50.0 %wb:

a) The bulk density of decreased with increasing moisture content and varied from 1376.2 to 1130.0 kg m^{-3} ;
b) The specific heat of varied from 1574 to 2506.8 J kg^{-1} °C and increased with increasing moisture content;
c) The effect of moisture content on thermal conductivity was in the range of 0.249 - 0.458 W m^{-1} $^oC^{-1}$. As moisture content of the banana increased, thermal conductivity increased as well; and
d) The thermal diffusivity of the varied from 1.5×10^{-7} to $1.62 \times 10^{-7} m^2s^{-1}$.

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.

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

Adeyemi O. S. and Oladiji A. T. 2009. Compositional changes in banana (Musa spp.) Fruits during ripening. African Journal of Biotechnology. 8(5): 858-859.

Adisa V. A. and Okey E. N. 1987. Carbohydrate and protein composition of banana pulp and peel as influenced by ripening and mold contamination. Food Chemistry. 25: 85-91.

Areas J. A. G. and Lajolo F. M. 1981. Starch transformation during banana ripening: I – the phosphorylase and phosphatase behavior in Musa acuminata. J. Food Biochem. 5: 19-37.

Aurore G., Parfait B. and Fahrasmane L. 2009. Banana raw materials for making processed food products. Trends in Food Science and Technology. 20: 78-91.

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., 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.

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

Bhumbla V. K., Singh A. K. and Singh Y. 1989. Prediction of thermal conductivity of fruit juices by a thermal resistance model. Journal of food Science. 54: 1007.

de Moura S. C. S. R., Germer S. P. M., Jardim D. C. P. and Sadahira M. S. 1998. Thermophysical properties of tropical fruits juices. Brazilian Journal of Food Technology. 1: 70.

Ditchfield C., Tadini C.C., Singh R.K. and Toledo R.T. 2005. Experimental Determination of Heat Transfer Coefficient in Banana Puree. Eurotherm Seminar 77- Heat and Mass Transfer in Food Processing, June 20-22, Parma, Italy.

Dutta, S. K., NemaV. K. and Bardwarj, R. K. 1988. Physical properties of gram. Journal of Agricultural Engineering Research. 39: 259-268.

Fontana A.J., Wacker B., Campbell C.S. and Campbell G.S. 2001. Simultaneous Thermal Conductivity, Thermal Resistivity and Thermal Diffusivity Measurement of Selected Foods and Soils. ASAE Meeting Paper No. 01-6101, Written for Presentation at the 2001 ASAE Annual International Meeting held from July 30-August 1, 2001 at St. Joseph, Michigan, USA.

Garcia E. and Lajolo F. M. 1988. Starch transformation during banana ripening: The amylase and glucosidase behavior. Journal of Food Science. 53: 1181-1188.

Golding J. B., Shearer D., McGlasson W. B. and Wyllie S. G. 1999. Relationships between respiration, ethylene, and aroma production in ripening banana. Journal of Agricultural and Food Chemistry. 47: 1646-1651.

Gowen S. 1995. Bananas and plantains. Chapman and Hall http://www.turbana.com/index.htm

Ikegwu O. J. and Ekwu F. C. 2009. Thermal and physical properties of some tropical fruits and their juices in Nigeria. Journal of Food Technology. 7(2): 38-42.

Karamura D. and Pickersgill B. 1994. A classification of the clones of East Africa highland banana (Musa) found in Uganda. Plant Genetic Resources Newsletter. 119: 1-9.

Karim M. A. and Hawlader M. N. A. 2005. Drying characteristics of banana: Theoretical modeling and experimental validation. Journal of Food Engineering. 70: 35-45.

Katekawa M. E. and Silva M. A. 2007. On the influence of glass transition on shrinkage in convective drying of fruits: a case study of banana drying, Drying Technology. 25(10): 1659.

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.

Mariani V.C., Barbosa de Lima A. G. and Coelho L.S. 2008. Apparent thermal diffusivity estimation of the banana during drying using inverse method. Journal of Food Engineering. 85(4): 569-579.

Mohapatra D., Mishra S., Singh B. C. and Jayas S. D. 2010. Post harvest processing of banana: Opportunity and Challenges. Food Bioprocess Technology, India.

Mortaza A. Mohammad H. K. and Seyed R. H. 2008. Specific heat and thermal conductivity of berberis fruit (*Berberis vulgaris*). American Journal of Agricultural and Biological Sciences. 3(1): 330-336.

Muir, W. E. and Viravanichai, S. 1972. Specific heat of wheat. Journal of Agric. Eng. Res. 17: 338-342.

Nimsung P., Thongngam M. and Naivikul O. 2007. Composition and thermal properties of green banana flour and starch, Kasetsart J. (Nat. Sci.). 41(5): 324-330.

Nwabanne J.T. 2009. Drying characteristics and engineering properties of fermented ground cassava. African Journal of Biotechnology. 8(5): 873-876.

Perusulla C. A., Viviana C. and Mends L.A. 2010. Development of a linear heat source probe and determination of banana thermal conductivity. Journal of Food Engineering. 12(6).

Picq C., Foure E. and Frison E. A. 1999. Bananas and food security. Proceeding of an international symposium held in Douala- Cameroon, 10- 14 November, 1998. International Network for the improvement of banana and plantain, Montepillier, France.

Shepherd H. and Bhardway R. K., 1986. Moisture-dependent physical properties of pigeon pea. J. agric. Engng Res. 35: 227-234.

Shrivastava M. and Dutta A. K. 1999. Determination of specific heat and thermal conductivity of mushrooms (*Pleurotus forida*). Journal of Food Engineering. 39: 225-260.

Shyamal D. K., Chakraverty A. and Benerjee H. D. 1994. Thermal properties of raw, parboiled and debrnned parboiled wheat and wheat bulgur. Journal of Food Engineering. 49: 195-201.

Singh R. P. and Heldman D. R. 1993. Introduction to food engineering. Academic, San Diego.

Singh K. K. and Goswami T. K. 2002. Thermal properties of cumin seed. Journal of Food Engineering. 45: 181-187.

Stroshine, R. and Hamann, D. 1995. Physical Properties of Agricultural Materials and Food Products. Course Manual, Purdue University, Indiana.

Sweat V. E. 1974. Experimental values of thermal conductivity of selected fruits and vegetables. J. Food Sci. 39: 1080.

Sweat V. E. 1995. Thermal properties of foods. In: M. A. Rao & S. S. H. Rizvi (Eds.), Engineering properties of foods (2nd ed., pp. 126). New York, USA: Marcel Dekker.

Talla A., Puiggali J. R., Jounaa W. and Jannot Y. 2004. Shrinkage and density evolution during drying of tropical fruits: Application to banana. Journal of Food Engineering. 64: 103-109.

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

The World of Plants. 1999-2010. Botanical-online. http://www.botanical-online.com/platanos1angles.htm

Wills R. B. H., Lim J. S. K. and Greenfield H. 1984. Changes in chemical composition of 'cavendish' banana (*Musa acuminata*) during ripening. Journal of Food Biochemistry. 8: 69-76.