Influence of Moisture Content and Temperature on Thermal Properties of Cocoa Pods

Jekayinfa, S. O[1]., Olaniran, J. A[1]., Oloyede, C. T[1]., Jaiyeoba, K. F[2]., and Ogunlade, C. A[2].

[1] Department of Agricultural Engineering, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Oyo State, Nigeria.
[2] Department of Agricultural Engineering, Adeleke University, Ede.

ABSTRACT
Knowledge of thermal properties is essential for equipment design, study and prediction of heat transfer operations such as heating, drying and cooling processes. The availability of relevant data on the thermal properties of the crop residue will aid design and manufacture of processing equipment. The objective of this study was to determine the effect of moisture content and temperature on the specific heat capacity, thermal conductivity and thermal diffusivity of cocoa pods. The specific heat capacity of cocoa pods was determined using the method of mixture; thermal conductivity was determined using method of poor conductors and the thermal diffusivity was calculated using the experimental data of thermal conductivity, specific heat capacity and bulk densities of the samples. The specific heat capacity of cocoa pods increased with both moisture content and temperature from 7.37 and 8.78 $kJkg^{-1}K^{-1}$ and 0.064 to 0.083 $kJkg^{-1}K^{-1}$; the results showed that there is a strong linear relationship between the specific heat capacity, moisture content and temperature. Also, the thermal conductivity of cocoa pods increased with both moisture content and temperature, values obtained lies between 0.229 to 0.308 $Jm^{-1}s^{-1}\,^{0}C$. The relationship was found to be linear between thermal conductivity, moisture content and temperature. An increasing trends in the thermal diffusivity of the pods were observed with increase in temperature and moisture content from 0.063 to 0.087m^2s^{-1} which implies that there is a strong linear correlation between temperature, moisture content and thermal diffusivity of the pods.

Keywords: cocoa pods, specific heat capacity, thermal conductivity, thermal diffusivity

Corresponding author: jaolaniran@lautech.edu.ng

INTRODUCTION

Cocoa (*Theobroma cacao* L.), is a major cash crop cultivated in the tropical regions of West Africa, the Caribbean, South America and Asia. In West Africa, where over 70% of the world's cocoa is produced with about 21% coming from Ghana; it is a significant component of the rural economy, as the industry is dominated by large numbers of small-holder peasant farmers who depend on the crop for their livelihood (Acquaah, 1999; Appiah, 2004, Afrane and Ntiamoah, 2011). In postharvest handling of cocoa, residues in the form of cocoa pods are generated and it has been estimated that about 150 kg dry pods per ha are left in the plantation; this has the likelihood of providing a valuable source of potash fertilizer (Lim, 1986; Koopmans and Koopejan, 1997; FAO, 1998). Substantial quality characteristics of cocoa depend on correct processing, which starts already with the harvesting process and ends with the storing of the processed product. Depending on the temperature, pod ripening can take between 4.5 to 7 months from flowering. Pods are harvested when they are fully ripe with a visible orange or yellow shell; beans from unripe pods produce low quality cocoa. Harvesting is carried out at regular intervals of 1.5 to 3 weeks. Pods are cut off the tree with knives without damaging the stem on which further fruits will form; after harvesting. Pods are then opened for the removal of the beans either in the field and or near the fermenting kegs. The beans are collected further processing while the residues (in form of pods) remain nuisance to the farmland and the environment. Considerable quantities of crop residues remain unused; promoting the use of residues for other applications such as power generation will not only put a value on the residues but may also deprive a part of the population (often the poorest section) of their cooking and heating fuel, aid conversion of waste to wealth and above all reduce the volume of waste generated from agricultural processing. Agricultural residues constitute a major part of the total annual production of biomass residues and are an important source of energy both for domestic as well as industrial purposes. Residues are used as fuel, but a large amount is burnt in the field.

In designing various machine and equipment required for conversion of agricultural residues to useable products, the knowledge of engineering is needed which include physical, mechanical, thermal, electrical, frictional and optical properties. Jaiyeoba *et al.* (2016) reported the effect of moisture content on some physical and thermal properties of mango seeds while there are no published knowledge and information on the thermal properties of cocoa pods and the effects of moisture content and temperature on the thermal properties. The thermal properties of farm products include thermal conductivity, diffusivity and specific heat capacity which are important properties of a material involving heat transfer. Knowledge of these properties is essential for equipment design and in studying and prediction of heat transfer operations such as heating, drying and cooling processes. The availability of relevant data on the thermal properties of the crop residue will aid design and manufacture of processing equipment thus, the objective of this study includes the determination of specific heat capacity,

thermal conductivity and thermal diffusivity of cocoa pods and the influence of moisture content and temperature on these thermal properties.

METHODOLOGY

Sample Collection and Preparation: fresh samples of cocoa pods were obtained from Oyo state Ministry of Agriculture Oyo State, Nigeria. The residues were manually cleaned and sorted to remove foreign or dissimilar materials. The moisture content of the samples was determined in accordance with ASAE Standard S358.2 (1983). Samples of cocoa pods were conditioned to five different moisture levels through dehydration and rehydration. The moisture content of the sample in percent dry basis was calculated using Equation 1.

$$Ms = \frac{100\,(W_i - W_f)}{W_f} \qquad (1)$$

Where: *Ms* is the moisture content (% dry basis), *Wi* is the initial mass of seeds before oven drying (in grams) and *Wf* is the final mass of seeds after oven drying (in grams).

Thermal Properties: Moisture content and temperature were selected as variables to simulate variations of the thermal properties of cocoa pods. The experiments were conducted at temperature ranges 50, 60, 70, 80 and 90^{0}C and moisture content values 12.45, 24 .37, 34.35, 38.37 and 44.50%.

Specific Heat Capacity: The method of mixture as described by Anyakoha (2007) was used to obtain the specific heat capacity of the cocoa pod samples. A sample of known mass, temperature and moisture content was dropped into the copper calorimeter of a known mass containing water of known mass and temperature. The mixture was gently stirred. At equilibrium, the final temperature of the mixture was noted and recorded. The experiments were performed at temperatures of 50, 60, 70, 80 and 90^{0}C. The specific heat capacity was calculated at different moisture level using the Equation 2.

$$C_s = \frac{M_c.C_c\left(Q_f - Q_1\right) + M_w.C_w\left(Q_f - Q_1\right)}{M_s(Q_2 - Q_f)} \qquad (2)$$

Where: C_s, C_c and C_w are the specific heat capacity of samples, calorimeter, and water respectively (kJkg^{-1}K^{-1}), M_c , M_s, and M_w are the masses of calorimeter sample and water (kg) while Q_1 is the initial temperature of water (K), Q_2 is the initial temperature(K) of the samples and Q_f is the final temperature (k) of the mixture at equilibrium.

Thermal Conductivity: The thermal conductivity of the samples was determined using method of poor conductors as cited by Oluka and Bardey (2000). A carbon steel of a known thickness and area was heated by steam from boiling water in a conical flask. The temperature of the carbon steel (hot) was measured until the temperature was constant (Q_1). The temperature of the samples (cold), Q_2 was measured and the sample was placed on the carbon steel while the thermometer was placed on the sample. The increase in temperature of the sample was recorded at every two minutes for ten minutes. The slope of the graph of temperature against time was used to determine the thermal conductivity using the Equation 3.

$$K_s = \frac{\theta.M_c}{(Q_1 - Q_2)A_s} \qquad (3)$$

Where: K_s is the thermal conductivity of the sample (Jm^{-1}s^{-1} ^{0}C), X is Thickness of the sample (m), ϴ is the quantity of heat supplied (J), M is the mass of carbon steel (g), C is the Specific heat capacity of steel (Jg^{-1} ^{0}c^{-1}), Q_1 is the temperature of carbon steel (hot) ^{0}C, Q_2 is the temperature of sample (cold) ^0C, A is the Area of carbon steel (equal to area of sample) and S is the Slope of graph of temperature against time.

Thermal Diffusivity: The thermal diffusivity of the selected samples was calculated using the experimental data of thermal conductivity, specific heat capacity and bulk densities of the samples using Equation 4.

$$\alpha = \frac{K}{(\rho_b \cdot C_p)} \quad (4)$$

Where: α is the thermal diffusivity (m^2s^{-1}), K is the thermal conductivity ($Jm^{-1}s^{-1}\,{}^0C$), ρ_b is the bulk density (g/cm^3) and C_P is the specific Heat Capacity ($Jg^{-1}\,{}^0c^{-1}$).

RESULTS

Thermal Properties

Specific Heat Capacity: The variations in specific heat capacity of Cocoa pod with moisture content and temperature were best explained in Figure 1. The specific heat capacity of Cocoa pod varied from 7.37 to 8.78 $kJkg^{-1}K^{-1}$ with temperature in the range of 50^0C to 90^0C and moisture content in the range of 12.45 to 44.5 % (d.b).

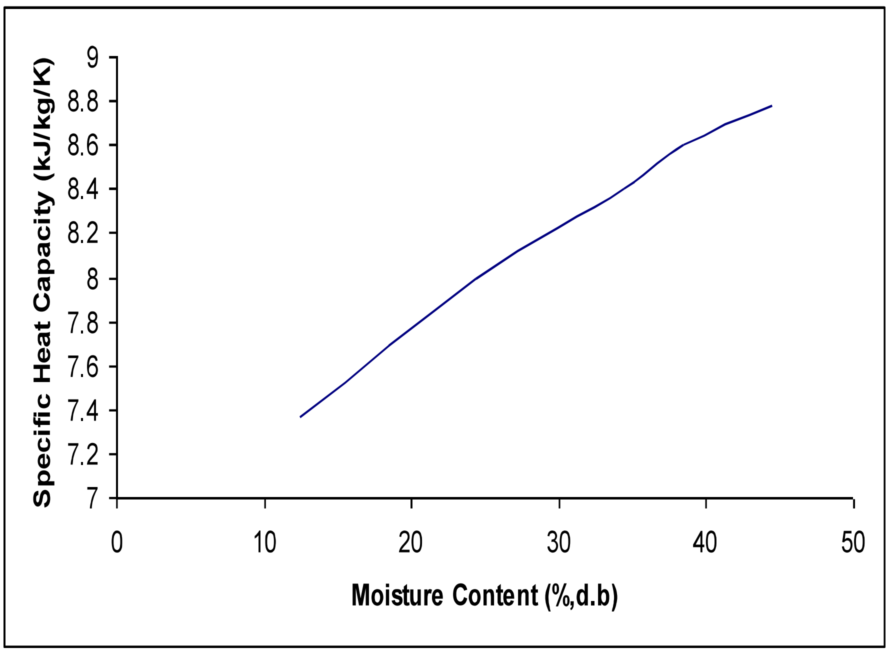

Figure 1: Effect of moisture content on specific heat capacity of cocoa pods

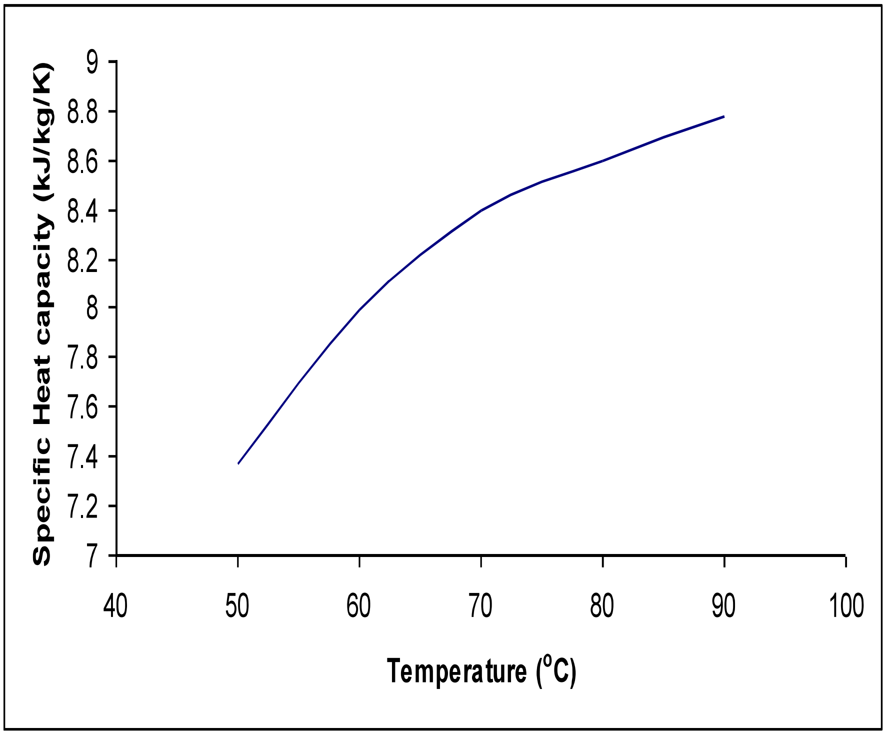

Figure 2: Effect of temperature on specific heat capacity of cocoa pod.

The linear regression obtained for the specific heat capacity (Cp) of the cocoa pods as a function of moisture content (*MC*) and temperature (T) were:

$$Cp = 6.06 + 0.046MC_{(\%,\ d.b)} \qquad r = 0.836$$

$$Cp = 5.301 + 0.039T \qquad r = 0.941$$

Thermal Conductivity: The changes in the thermal conductivity of the pods with moisture content at different temperatures are presented in Figures 3 – 4. It was observed that the thermal conductivities increased with increasing moisture content and temperature.

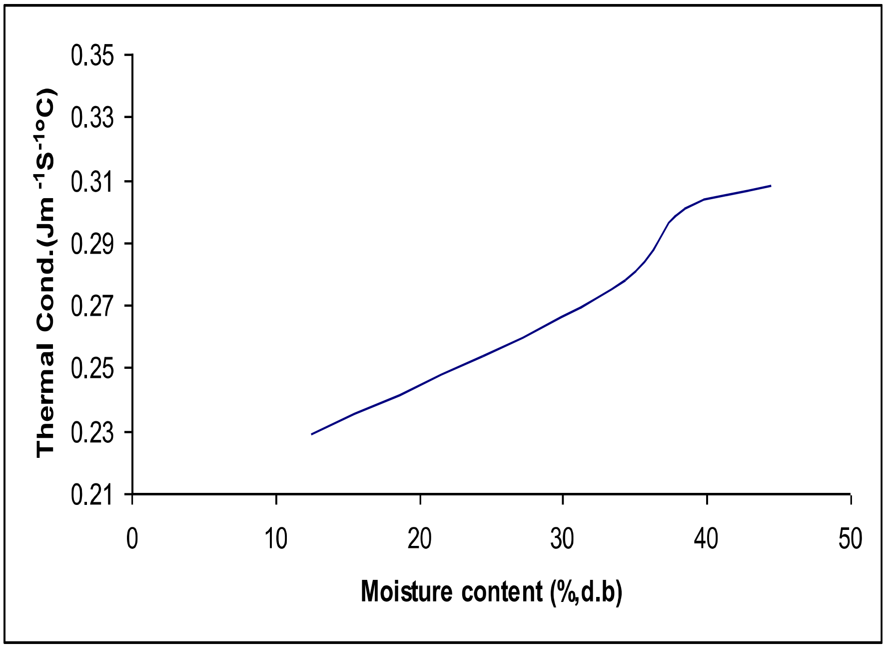

Figure 3: Effect of moisture content on thermal conductivity of cocoa pod.

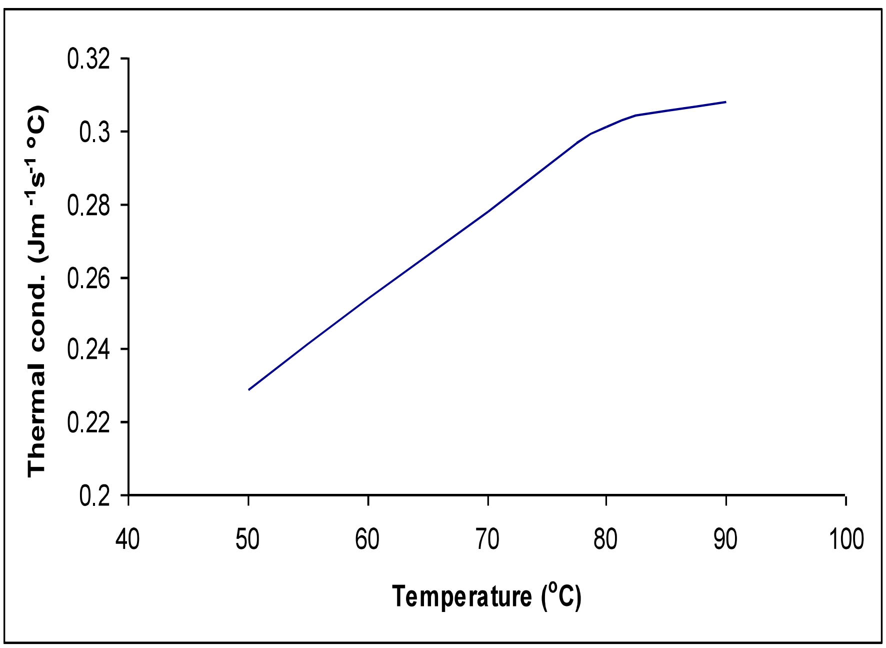

Figure 4: Effect of temperature on thermal conductivity of cocoa pod.

The relationship existing between thermal conductivity (K) of the pods with moisture content *(MC)* and temperature (T) can be expressed mathematically using the following regression equations:

$K = 0.194 + 0.002MC_{(\%,\ d.b)}$ r = 0.988

$K = 0.213 + 0.005T$ r = 0.945

Thermal Diffusivity: The influence of moisture content and temperature on the thermal diffusivity of cocoa pod is presented in Figures 5 and 6.

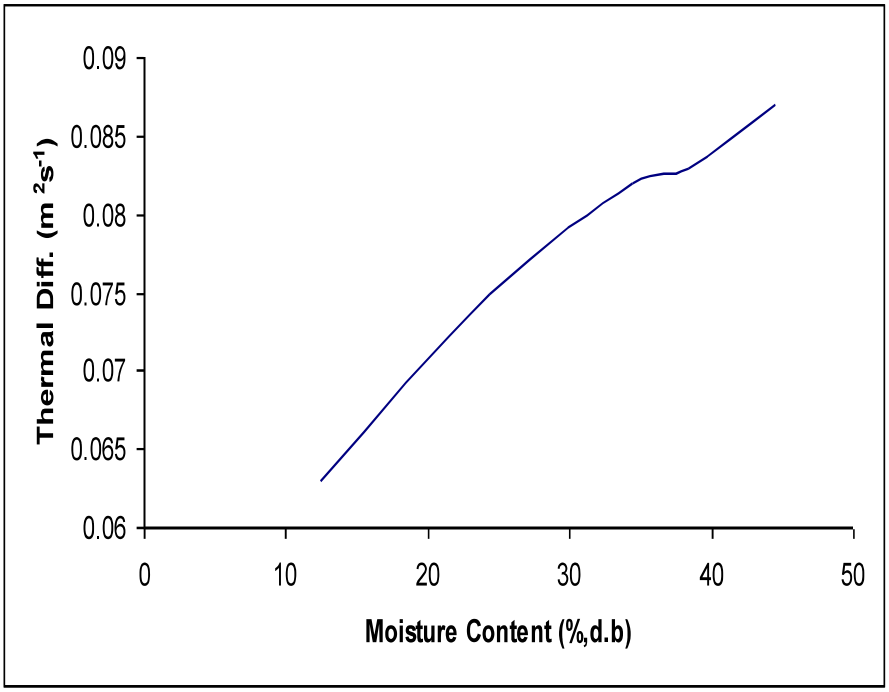

Figure 5: Effect of moisture content on thermal diffusivity cocoa pod.

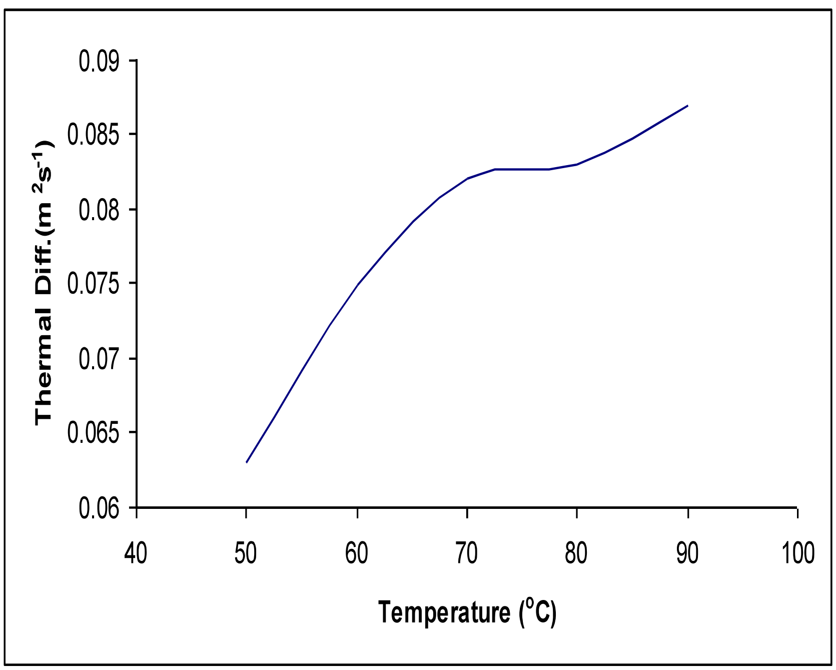

Figure 6: Effect of temperature on thermal diffusivity of cocoa pod.

The relationship existing between thermal diffusivity of cocoa pods with moisture content and temperature can be expressed mathematically using the linear regression equations obtained:

$\alpha = 0.055 + 0.007MC_{(\%,\ d.b)}$ r = 0.987

$\alpha = 0.0388 + 0.006T$ r = 0.931

r = degree of correlation coefficient

DISCUSION

Specific Heat capacity: It was observed that the specific heat capacity of cocoa pods increases with an increase in the moisture content and temperature; similar trend was observed in the specific heat capacity of agricultural residues like dairy cattle manure (Nayyeri *et al*, 2009), mushroom (Tansakul and Lumyong, 2008), Shea-nut kernel (Aviara and Haque, 2001) and Guna seed (Aviara *et al,* 2008). An increasing trend in the specific heat capacity of the cocoa pods was observed with increase in both moisture content and temperatures (Figures 1 and 2)

Thermal Conductivity: The thermal conductivity of Cocoa pod samples varied from 0.229 to 0.308 $Jm^{-1}S^{-1}\,^0C$ as the moisture content and temperature increased. Similar trend was observed in the investigations of Oluka and Bardey (2000) in which the thermal conductivity of pigeon pea flour paste varied from 0.566 to 0.800 $Jm^{-1}S^{-1}\,^0C$. Aviara and Haque (2008) investigation also showed that the thermal conductivity of whole and ground seed kernel of guna seed increased from 0.0711 to 0.1282 and from 0.087 to 0.1260 $Wm^{-1}S^{-1}$, as the moisture content and temperature increased.

Thermal Diffusivity: it was observed that the thermal diffusivity of the pods increased linearly from 0.063 to 0.087 with increase in moisture content and temperature. Similar trend was reported for the thermal diffusivity of dairy Cattle manure Nayyeri *et al* (2009), and borage seeds Yang *et al* (2002).

CONCLUSION

The specific heat capacity of cocoa pods increased with both moisture content and temperature from 7.37 and 8.78$kJkg^{-1}K^{-1}$ and 0.064 to 0.083 $kJkg^{-1}K^{-1}$; the results showed that there is a strong linear relationship between the specific heat capacity, moisture content and temperature. Also, the thermal conductivity of cocoa pods increased with both moisture content and temperature, values obtained lies between 0.229 to 0.308$Jm^{-1}s^{-1 0}C$. The relationship was found to be linear between thermal conductivity, moisture content and temperature. An increasing trend in the thermal diffusivity of the pods were observed with increase in temperature and moisture content from 0.063 to 0.087m^2s^{-1} which implies that there is a strong linear correlation between temperature, moisture content and thermal diffusivity of the pods.

REFERENCES

Acquaah, B. (1999): Cocoa Development in West Africa (The Early Period with particular reference to Ghana), Ghana Universities Press, Accra, Ghana

Afrane George and Ntiamoah Augustine (2011). Use of Pesticides in the Cocoa Industry and Their Impact on the Environment and the Food Chain, Pesticides in the Modern World - Risks and Benefits, Dr. Margarita Stoytcheva (Ed.), ISBN: 978-953-307-458-0, InTech, Available from: http://www.intechopen.com/books/pesticides-in-the-modern-world-risks-and-benefits/use-of-pesticides-in-the-cocoa-industry-and-their-impact-on-the-environment-and-the-food-chain

Anyakoha, T. (2007): Heat transfer through materials in New School Physics. *Africana first Publisher Onitsha. 63-80. Third edition.*

Appiah, M. R. (2004): Impact of Cocoa Research Innovations on Poverty Alleviation in Ghana. Ghana Academy of Arts and Sciences Publication. pp1, 17-19.

Aviara, N. A and Haque, M. A. (2001): Moisture Dependence of Thermal properties of Sheanut kernel. *Journal of food Engineering 47, 109-113.*

Aviara, N. A., Haque, M. A and Ogunjinmi, L. A. O. (2008): Thermal properties of guna seed. *Int. Agrophysics 22, 291-297.*

FAO, 1998, Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy, FAO Regional Wood Energy Development Programme in Asia, Report No. 36, Bangkok.

Jaiyeoba, K. F., Jekayinfa, S. O., Ogunlade, C. A., Oke, A. M. and Apata, M. M. (2016). Physical and thermal properties of mango (*mangiferaindica)* seeds. *Science Focus* Vol. 21 (1) 2016 pp. 126 – 132

Koopmans, A and Koppejan, J. 1997. Agricultural and forest residues - generation, utilization and availability. Paper presented at the Regional Consultation on Modern Applications of Biomass Energy, 6-10 January 1997, Kuala Lumpur, Malaysia.

Lim, K.O. (1986), The energy potential and current utilization of agriculture and logging wastes in Malaysia, Renewable Energy Review Journal, Vol. 8, No. 2, December 1986, RERIC-AIT, Bangkok.

Nayyeri, M. A., Kianmehr, M. H., Arabhosseni, A and Hassan-Beygi, S. R (2009): Thermal properties of Diary Cattle Manure *Int. Agrophysics. 23, 359-366.*

Oluka, S. I., and Bardey, I. A (2000): Thermal properties of Pigeon Pea. *Journal of Agric. Engineering and Technology. 8, 37-43.*

Tansukul, A. and Lumyong, R. (2008): Thermal properties of Mushroom. *Journal of food Eng. (87), 91-98.*

Yang, W., Sokahansaj, S., Tang, J. and Winter P (2002): Determination of Thermal Conductivity, Specific heat Capacity and Thermal diffusivity of borage seeds. *Biosystem Engineering.* 82 (2) 169-176.