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COMPARATIVE EVALUATION OF THE EFFECT OF OVEN AND SUN DRYING METHODS ON THE PROXIMATE AND FUNCTIONAL PROPERTIES OF PLANTAIN (*Musa parasidiaca*) FLOUR

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ABSTRACT
Drying is the most energy consuming process in all processes on the farm and is essentially important for preservation of agricultural crops for future use. This study investigated the effect of drying methods on the chemical, physical (bulk and tap density), functional (water absorption, oil absorption and hydration capacities) and pasting properties of plantain flour. Plantain was dried at different temperatures (sun-drying, 60˚C, 70˚C, 80˚C) and thickness and the dried plantain chips were made into flour. Statistically significant difference in all the data were determined by Analysis of Variance (ANOVA) while Least Significant Difference (LSD) were used to separate the means. The proximate composition of the plantain flour ranged from 1.54 – 3.27%, 4.75 – 12.80%, 8.88 – 9.45%, 4.60 – 6.95%, 0.98 – 1.67% and 68.95 – 79.33 % for ash, moisture, protein, fat, fibre and carbohydrate respectively. The values for the bulk density tap density and flowability of sun and oven dried plantain flour ranged from (0.46 – 0.56) g/ml, (0.62 – 0.69) g/ml and (18.65 - 25.89) respectively. The water absorption, oil absorption and hydration capacities varied from (19.17 – 44.83), (28.33 – 32.50) and (2.47 – 25.64) % respectively. The peak viscosity (-2.52 - 4.38RVU), trough (-3.862 – 7.063 RVU), breakdown (2.02 – 3.08 RVU), final viscosity (2.38 – 4.49 RVU), setback (1.51 – 2.94 RVU) and peak time (1.65 – 4.15 min) varied with drying methods and thickness. Oven dried plantain flour samples generally have desirable functional and pasting properties.

Keywords: Evaluation, Oven, Sundrying, Functional properties, Plantain flour,

INTRODUCTION
Plantain is an important staple food in Central and West Africa (Stover and Simmonds, 1987) which provides about 25% of calories (Wilson, 1987). Nigeria produces about 2.11 million metric tonnes annually (FAO, 2004). Plantain flour is used traditionally for preparation of gruel which is made by mixing the flour with appropriate quantities of boiling water to form a thick paste (Mepba *et al*., 2007). The processing of plantains into flour is limited as most plantain foods are eaten as boiled, fried or roasted (Tortoe *et al*., 2008).

Drying is the most energy consuming process in all processes on the farm (Onigbogi *et al*., 2012) and is essentially important for preservation of agricultural crops for future use. It preserves crops by removing enough moisture from it to prevent decay and spoilage (Eze and Agbo, 2011). It is one of the most efficient methods used to preserve food products for longer periods and has been established as the most efficient preservation technique for most tropical crops, while water content of most agricultural produce is greater than 50%, that of properly dried food varies from 5-25%, depending on the food (Bhandary *et al*., 1997).

Food crops are dried before storage or, during storage, by forced circulation of air, to prevent spontaneous combustion by inhibiting fermentation (Onigbogi *et al*., 2012). About 35 to 60% postharvest losses in plantain and banana had been reported and attributed to lack of storage facilities and inappropriate technologies for food processing (Olorunda and Adelusola, 1997). One of the main problems facing Nigerian farmers has remained lack of proper method of preserving the agricultural produce which is usually produced in large quantities during harvest. The traditional open sun drying widely practiced by rural farmers has inherent limitations of high crop losses due to inadequate drying, fungi attacks, insects, birds, rodent encroachment and unpredictable weather effects (Ezechukwu, 2010) such as dust, rain and wind. It involves simply laying the product in the sun on mats, roofs or drying floors.

The implication of improper handling and drying is far reaching. It was reported that yearly, millions of dollar worth of gross national products are being lost due to spoilage (Fumen *et al*., 2003). The length of time an agricultural produce can be safely stored depend on its condition during harvest and the type of storage facility being utilized (Onigbogi *et al*., 2012). The functional properties are the characteristics of a substance that affect its behaviour and those of the products to which it is added and it affects the potential application of the substance (Wilcox, 2006). Knowledge of the correlation between the processing method and the functional properties is necessary from industrial point of view as it provides the opportunity to further define the functionality and end uses (Gomand, *et al*., 2010). This research, therefore, evaluated the effectiveness of oven and sun drying techniques on the proximate and functional properties of plantain flour.

MATERIAL AND METHODS

Materials

Fresh unripe (green) plantains (*Musa parasidiaca*) were purchased from Owena market in Oriade Local Government Area of Osun state, Nigeria.

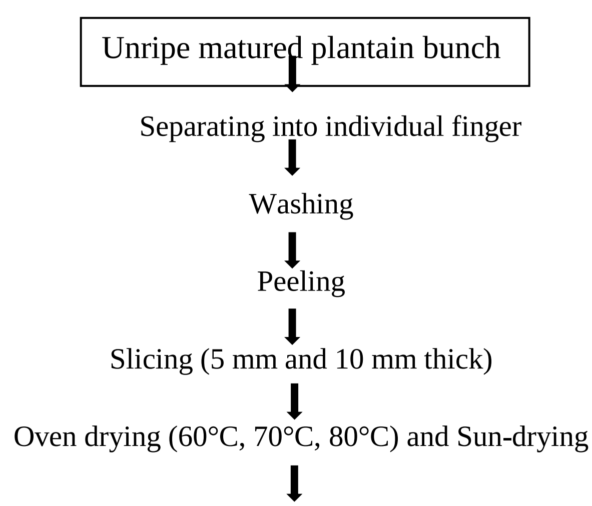
Methods

Drying procedure for plantain chips

The plantains were dried according to the method of Adeniji *et al*. (2006) method. The matured green plantain were sliced longitudinally into chips of about 5 and 10 mm thick and placed on an aluminum foil drying trays. The chips were dried in the oven at 60, 70 and 80 °C, and in the sun to a constant weight. The dried chips were packaged in a high density polyethylene bag at room temperature prior to production of flour.

Production of plantain flour

Plantain flour was produced according the method of Arisa *et al*. (2013) as shown in Figure 1. The dehydrated plantain samples were milled using a laboratory blender (Marlex, Ecella model, Kanchan International Limited, Darman India) and passed through 100 µm screen. The plantain flour were packaged in high density polyethylene bags and kept until required for laboratory analyses.



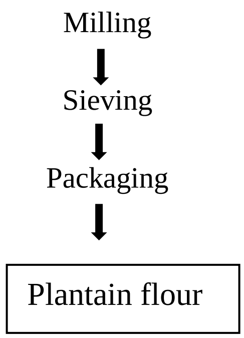


Fig. 1: Flow chart for plantain flour production (Arisa *et al*., 2013)

Laboratory analysis

Determination of Chemical Composition of the Plantain Flour

Proximate analyses were carried out according to the standard methods of the Association of Official Analytical Chemists (AOAC, 2005).

Physical Characteristics of the Plantain Flour

Determination of Bulk and Tapped Densities of the Plantain Flour

Bulk and tapped densities were determined according to the method of Arisa *et al*. (2013). About 10 g of the sample were weighed into a 50 ml graduated measuring cylinder and the loose volume determined. The sample was packed by gently tapping the cylinder on the bench top for fifty times until there was no more decrease in volume. The volume of the compacted sample was recorded. The bulk density and tap densities were calculated as shown in equations 1 and 2 respectively.

$$\text{Bulk density}\left(\frac{g}{ml}\right) = \frac{weight\,of\,sample}{loose\,volume\,of\,sample} \qquad (1)$$

$$\text{Tapped density}\left(\frac{g}{ml}\right) = \frac{weight\,of\,sample}{packed\,volume\,of\,sample} \qquad (2)$$

Determination of Carr (Compressibility) Index of the Plantain Flour

The Carr index was calculated from the values of the bulk and tapped densities as shown in equation 3.

$$\text{Carr Index} = \frac{Tapped\,density - Bulk\,Density}{Tapped\,density} \qquad (3)$$

Functional Properties of the Plantain Flour

Determination of Water absorption and Hydration Capacities of the Plantain Flour

The water absorption and hydration capacities were determined according to the method of Nuwamamnya *et al*. (2011). An aqueous suspension was made by dissolving 1 g of the flour in 10 ml of distilled water. The suspension was agitated for 3 min on a shaker and allowed to stand for 10 min after which it was centrifuged (SORVALL GLC-1 centrifuge Model 06470, USA) for 10 min at 3000 rpm. The free water was decanted from the wet flour and washed. The residue was drained for 10 min and weighed. The water absorption and hydration capacities were calculated as shown in equations 4 and 5 respectively.

$$\text{Water absorption Capacity (\%)} = \frac{\text{weight of water bound}}{\text{weight of sample}} \times 100 \qquad (4)$$

$$\text{Hydration Capacity (\%)} = \frac{\text{weight of residue}}{\text{weight of sample}} \times 100 \qquad (5)$$

Pasting characteristics

Pasting characteristics of the plantain flour was determined in triplicate using a Rapid Viscous Analyzer (RVA 4500, Pertson Instruments, AB SE – 12609, Hagersten, Denmark) according to the method of Arisa *et al.* (2013) About 12 % flour suspension was prepared by adding 3 g of dried flour to 25 ml of distilled water in the RVA sample canister. It was placed centrally into the paddle coupling and inserted into the RVA machine. It was heated over a temperature range from 50 to 95 ^{o}C for 3 min and subsequently cooled to 50 ^{o}C over a period of 4 min and kept constant for 1 min.

Statistical Analysis

Data generated in triplicates were analyzed statistically with Statistical Analysis System (SAS) package (Version 8.2 of SAS Institute Inc. 1999). Statistically significant differences ($p < 0.05$) in all data were determined by Analysis of Variance (ANOVA) procedure while Least Significant Difference (LSD) were used to separate the means.

RESULTS

Chemical Composition of the Plantain flour

The results of the effect of drying methods on the proximate composition are shown in Table 1. The ash content ranged between 1.54 and 3.27 % for the sun dried and oven dried (60 ^oC) samples, respectively. The ash content of the oven dried samples were significantly ($p<0.05$) higher than the sun dried samples. The moisture content ranged between 4.75 and 12.80 % in the oven dried (80 ^oC) and sun dried samples, respectively. Oven drying significantly ($p<0.05$) reduced the moisture content of the plantain flour. It was also observed that as the temperature of the oven was increasing, there was corresponding reduction in the moisture content,

The protein content ranged between 8.88% for oven dried samples at 80 ^oC and 9.41% for sundried samples. It was observed that the temperature had no significant ($p > 0.05$) influence on the protein content of the plantain flour. The fat content of the plantain flour ranged between 4.60% for oven-dried samples at 80˚C and 5.77% in the sundried sample. Temperature significantly ($p < 0.05$) increased the fat content of the plantain flour. The crude fibre values of the plantain samples ranged between 0.98% for

oven-dried samples at 80˚C and 1.55% for the sundried samples.

Temperature significantly ($p < 0.05$) reduced the crude fibre content. The carbohydrate content of the plantain flour ranged from 68.95 to 79.35% for sun-dried and oven-dried samples, respectively. Drying temperature had significant ($p < 0.05$) influence on the carbohydrate content of the plantain flour sample. As temperature increased, the carbohydrate content of the plantain flour increased.

Physical characteristics of plantain flour

The results of the effect of drying on the physical properties are presented in Table 2. Bulk density

values as affected by drying method ranged between 0.46 and 0.56 g/ml. The values obtained for the oven dried samples are significantly ($p<0.05$) higher than the sun dried samples. It was also observed that as the temperature of the oven increased, the bulk density of plantain flour increased.

The tapped density values ranged from 0.62 to 0.69 g/ml for sundried samples and oven-dried samples at 80 ^oC, respectively. Oven drying method led to significantly ($p<0.05$) higher tapped density values. It was also observed that the tapped density values were higher than the corresponding bulk density values. The Carr (Compressibility) Index ranged between 18.65 and 25.89 for oven-dried samples at 70 ^oC and sun dried samples, respectively. Oven drying significantly ($p<0.05$) reduced the Carr Index. It was also observed that as the temperature of the oven increases, the Carr Index was reducing,

Table 1: Effect of drying temperatures and methods on the proximate composition of Plantain flour (%)

Drying Temperature (°C)	Ash	Moisture	Protein	Fat	Fibre	Carbohydrate
Sun	1.54c	12.80a	9.41a	5.77c	1.55b	68.95d
60	3.27a	7.93b	9.45a	6.95a	0.99c	71.43c
70	3.26a	6.65c	8.91b	6.85b	1.67a	72.68b
80	1.69b	4.75d	8.88b	4.60d	0.98c	79.33a

Mean values with the same letters along the same column are not significantly ($p > 0.05$) different

Table 2: Effect of drying temperature on the physical characteristics of plantain flour

DryingTemperature (°C)	Drying method	Bulk density (g/ml)	Tap density (g/ml)	Flowability (%)
Sun	Sun	0.46c	0.62c	25.89a
60	Oven (60 °C)	0.51b	0.65b	20.85b
70	Oven (70 °C)	0.56a	0.69a	18.65b
80	Oven (80 °C)	0.55a	0.69a	19.70b

Mean values with the same letters along the same column are not significantly ($p > 0.05$) different

Functional properties of plantain flour.

The results of the effect of drying on the functional characteristics of the plantain flour are presented in Table 3. The water absorption capacity values of the flour ranged between 19.17 and 34.67% for the oven dried samples and sundried samples, respectively. It was observed that oven-dried samples at 60 °C had significantly ($p<0.05$) higher values than other samples and that as the temperature of the oven increased, the water absorption capacity was reducing.

The oil absorption capacity values ranged between 30.83 and 32.50% for sundried samples and oven dried samples, respectively. It was observed that there was no statistical difference ($p>0.05$) in the values. The hydration capacity values ranged between 2.47 and 25.64% for oven dried samples (60 °C) and sundried samples, respectively. Oven drying significantly ($p<0.05$) reduced the hydration capacity values.

Pasting characteristics of plantain flour

The results of the effect of drying temperatures on the pasting characteristics of the plantain flour samples are presented in Tables 4. The peak viscosity ranged between -2.52 and 4.38 RVU for sun-dried and oven-dried samples, respectively. The values recorded for the oven dried samples

Table 3: Effect of drying temperature on the functional characteristics of plantain flour

Drying Temperature (°C)	Drying method	Water absorption capacity (%)	Oil absorption capacity (%)	Hydration capacity (%)
Sun	Sun	34.67a	32.50a	25.64a
60	Oven (60 °C)	44.83a	30.00a	2.47c
70	Oven (70 °C)	20.00b	28.33a	13.20b
80	Oven (80 °C)	19.17b	30.83a	13.71b

Mean values with the same letters in the same column are not significantly ($p > 0.05$) different.

Table 4: Effect of drying temperature on the pasting characteristics of plantain flour

Drying Temperature (°C)	Drying method	Peak (RVU)	Trough (RVU)	Breakdown (RVU)	Setback (RVU)	Final (RVU)	Peak time (min)
Sun	Sun	-2.52c	-3.86c	3.06a	1.51b	2.38c	1.64c
60	Oven (60 °C)	4.51b	6.92a	3.08a	3.04a	8.36b	3.53b
70	Oven (70 °C)	9.08a	7.06a	2.02b	3.51a	10.45a	3.38b
80	Oven (80 °C)	4.38b	1.56b	2.55b	2.94a	4.48c	4.14a

Mean values with the same letters in the same column are not significantly ($p > 0.05$) different

were significantly ($p<0.05$) higher than those of sundried samples. The trough values ranged from -3.86 to 7.06 RVU in the sundried samples and oven dried (80 °C) samples, respectively. Increased trough values were noticed with increased drying temperatures.

The breakdown values of the plantain flour ranged between 2.02 and 3.08 RVU. The highest values were obtained in the samples oven dried at 60˚C. Temperature significantly ($p < 0.05$) reduced the breakdown value in all samples. The final viscosity values ranged between 2.38 and 4.49 RVU in the sundried and oven dried samples, respectively. Temperature significantly ($p < 0.05$) increased the final viscosity of the samples. Setback values ranged between 1.51 RVU for samples sundried and 2.94 RVU for samples oven dried at 80˚C. Oven drying significantly ($p<0.05$) increased the setback values of the flour samples. Peak time values ranged between 1.65 to 4.15 min with sundried samples having the lowest value and oven-dried samples at 80˚C having the highest value. The values of the oven dried flour samples were significantly ($p < 0.05$) higher than those of the sundried samples.

DISCUSSION

From the results of proximate composition presented in Table 1, the ash content is an indicator of the total mineral content of the flour. The increased ash content might be due to higher temperature of the oven. It was also observed that as the temperature of the oven increased, there was corresponding decrease in the mineral content. The result conforms to the report of earlier researchers (Oluwalana and Oluwamikomi, 2011). The reduction in the moisture content might be due to the fact that drying took place faster in the oven than the open sun drying method. The moisture content has a direct influence on the shelf life of any product. The lower the moisture content, the longer the shelf life and the keeping quality. This result agrees with earlier report of Arisa *et al*. (2013). The increased fat content has a direct correlation with the moisture content. The lower level of fat in the plantain flour samples suggested longer shelf life in terms of the onset of rancidity. The increase in carbohydrate content might be due to low level of moisture with increased temperature. This result agrees with the findings of Oluwalana and Oluwamukomi (2011) who observed that as the temperature of plantain flour blanched under three temperature regimes increased, their carbohydrate content also increased.

Table 2 presents the values of the physical characteristics of the plantain flour after drying. Bulk density is the ratio of the mass per unit volume of the flour (Etudaiye *et al*., 2009) and is affected by the weight of the flour. It is very important in determining the packaging requirement and material handling indicating a lesser packaging requirement with increase in bulk density and concentration of material (Adebowale *et al*., 2008). The results obtained is a confirmation of the earlier report by Torgul and Pehlivan (2004) that bulk density of flour from fruits increased as a results of heat treatment of the flour prior to drying. The increase in tapped density values in the oven dried samples is an indication of improvement in the potential to flow and rearrange under compression and it provides information about flowability of the flour (Singh *et al*., 2011). The reduction in the Carr index values due to increased temperature is an indication that the voids in the oven dried samples are easily filled during compression than those of sundried samples (Abiodun *et al*., 2010). Carr Index is an indication of the flowability of the flour with a value between 5 and 10 indicating excellent flow (Jelcic *et al*., 2007). This also implies that oven dried samples would have better flowability than their corresponding sundried samples, hence will flow freely in chutes and silos without clogging (Olu-Owolabi *et al*., 2010).

The results of the functional characteristics as affected by drying are presented in Table 3. The increased water absorption capacity at 60 ^{o}C is an indication that the flour at this temperature is capable of absorbing water than the other samples within a short time (Itiola and Odeku, 2005). This may be attributed to amylose leaching (Etudaiye *et al*., 2009) while the low water absorption capacity values at elevated temperature may be attributed to the formation of covalent bonds between hydroxyl groups (Jiang *et al*., 2012). The high water absorption capacity values also have direct correlation with the gelatinization temperature (Falade and Okafor, 2013). The oil absorption is the likelihood of the flour being useful in food preparations that involve oil mixing such as bakery products. This result conforms to the earlier report by Oluwalana and Oluwamukomi (2011). Hydration capacity is the rate and the extent of water retention and a measure of swelling power which determines the weight measure of swollen starch granules and their occluded water (Daramola and Osanyinlusi, 2006). Food eating quality is often connected with retention of water in the swollen starch granules.

Table 4 presents the results of the effect of drying on the pasting characteristics. Peak viscosity indicates the water binding capacities of the flour samples (Daramola and Osanyinlusi, 2006). It is a measure of ability of the flour to form paste during cooking and it provides an indication of the viscous load likely to be encountered during reconstitution (Igbian and Adegoke, 2007). Trough value is the maximum viscosity value in the constant temperature phase of the RVA and it measures the ability to withstand breakdown during cooling (Otutu, 2015).

. Breakdown viscosity value is an index of the stability of the starch and is also a measure of the ease with which the swollen granules can be disintegrated (Okafor and Egwu, 2013). Cohesiveness of paste is attributed to the extent of breakdown of starch molecules during heating and stirring. Setback viscosity indicates the extent of stability of the cooked paste against retrogradation and could be used to predict the storage stability of a product prepared from the flour (Zaidul *et al*., 2007). From this study, it could be inferred that oven drying reduced the retrogradation tendency of the flour samples (Fasasi, 2008). Peak time provides an indication of the shortest cooking time required. This has cost implication because the longer the cooking time, the more the energy needed (Daramola and Osanyinlusi, 2006).

CONCLUSION

The results from this study showed that selection of drying methods for producing food materials, especially flour, can influence their functional characteristics. The traditional open sun-drying method widely practiced by rural farmers have inherent limitations or high crop losses due to inadequate drying, fungi attacks, insects, birds, rodent encroachment and unpredictable weather effects. Possibility of these inadequacies can be avoided by using a good and suitable drying method, and in this study, the two drying methods have shown different level of functional properties which promotes the uses of oven drying instead of the traditional sun drying methods. Thus, oven-drying could be used to replace the traditional sun-drying method for the production of plantain flour (elubo). -

REFERENCES

Adeniji, T.A, Sanni, L.O., Barimalaa, I.S. and Hart, A.D. (2006). Determination of micronutrients and colour variability among new plantain and banana hybrids flours. *World J. Chem*. 1(1): 23-27.

AOAC (2005). Association of Official Analytical Chemists. Official methods of analysis, 17th Edition, Horowitz Vol. 1 Marylan ch 45, 112 - 120

Arisa, N.U., Adelekan, A.O., Alamu, A.E. and Ogunfowora, E.J. (2013). The Effect of Pretreatment of Plantain (*Musa parasidiaca*) Flour on the Pasting Characteristics of biscuit; *International Journal of Food and Nutrition Science* 2(1): 10-23.

Bhandary, U., Sharma, J.N. and Zafar, R. (1997). Effects of protection action of Ethanolic Ginger (*zingiber officinales*) extract in cholestered fed rabbits. J. Ethnopharm, 61(2). 167-175.

Eze, J.I. and Agbo, K.E. (2011). Comparative Studies of Sun and Solar Drying of Peeled and Unpeeled Ginger. *American Journal of Scientific and Industrial Research*, 2(2): 136-143.

Ezechukwu, V.O. (2010). Solar Drying Technology: An Overview Paper presented at FUTO Alternative Energy Conference, Federal University of Technology Owerri. 16th-20th May.

FAO (2004). Statistics Series No 95. Food and Agriculture Organization of the United Nations, Rome.

Fumen, G.A., Yiljee, Y.D. and Ajisegiri, E.S.A. (2003). Survey of ginger processing and drying method in Nigeria: a case of southern Kaduna State: In proceeding of Fourth Institution of Agricultural Engineers, Damaturu, Nigeria, September 8th-12th.

Gomand, S.V., Lamberts, L., Visser, R.G.F. and Declour, J.A. (2010). Physicochemical properties of potato and cassava starches and their mutants in relation to their structural properties. *Food Hydrocolloids* 24: 424 - 433

Ingbian, E.K. and Adegoke, G.O. (2007). Proximate compositions, pasting and rheological properties of mumu- A roasted maize meal. *International Journal of Food Science and Technology* 42: 762-767.

Mepba, H.D., Eboh, L. and Nwaojigwa, S.U. (2007). Chemical Composition, Functional and Baking Properties of Wheat-Plantain Composite Flours, 7(1): 4-5.

Okafor, C.I. and Egwu, E.E. (2013). Comparative Study of Pasting Properties of High Fibre Plantain based Flour Intended for Diabetic Food. *World Academy of Science, Engineering and Technology* Vol.79, p 193-197.

Olorunda, A.O. and Adelusola, M.A. (1997). Screening of plantain n / banana cultivars for import, storage and processing characteristics. Paper presented at the International Symposium on Genetic Improvement of Bananas for Resistance to Disease and Pests 7—9th September, (IRAD, Montpellier, France).

Oluwalana, I.B. and Oluwamukomi, M.O. (2011). Proximate composition, rheological and sensory qualities of plantain (*Musa parasidiaca)* flour blanched under three temperature regimes. *Afr. J. of Food Sci*. Vol. 5(14): 769 – 774.

Onigbogi, I.O., Sobowale, S.S. and Ezekoma, O.S. (2012). Design, construction and Evaluation of Small Scale Solar Dryer. *Journal of Engineering and Applied Science*, 4: 8-15.

Satimehin, A.A., Alakali, J.S. and Alabi, O.T. (2010). Thin-Layer Drying Characteristics of Plantain (*Musa parasidiaca*) Chips. *Journal of Tropical Agriculture, Food, Environment and Extension.* 9(1): 31-38.

Stover, R.H. and Simmonds, N.W. (1987). Banana 3rd edition. Wiley New York USA. 97-103.

Torgul, I.T. and Pehlivan, D. (2004). Modeling of thin layer drying kinetics of some fruits under open air sun drying process. *Journal of Food Engineering* 65: 413-425.

Tortoe, C.T., Paa-Nil, T.J. and Apollonius, I.N. (2008). Effects of Osmo-Dehydration, Blanching and Semi-Ripening on the Viscoelastic, Water Activity and Colorimetry Properties of Flour from Three Cultivars of Plantain (*Musa AAB*). CSIR – Food Research Institute, Accra Ghana.

Wilcox, B.F. (2006). Fundamentals of Food Chemistry. Vol. 1. Paraclete Publishers, Yola, Adamawa State, Nigeria.

Wilson, C.F. (1987). Status of Bananas and Plantains in West Africa in Bananas and Plantain Breeding Strategies Proceedings of International Workshop on Plantain and Banana. Australian Council for International Research.