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Design Optimization of Hot Air Dryer for Yam Flour Chunk

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ABSTRACT

In this research, an improved method for the design and adaptation of a hot air dryer for yam chunk was conducted. The system consists of the heating element, blower, drying chamber and heating chamber. The heating chamber was directly connected to the drying chamber of 1200 mm by 600 mm which comprise of drying elements and three perforated trays for laying the chunks. The frame for the system was made from angle iron with its body fully lagged to reduce heat loss to the surroundings. Also, tests for load and no-load situations were performed to optimize the condition of its maximum performance. It was observed that the system performed satisfactorily by giving optimum efficiency of 53%. Also, nearness of the trays to the vent did not play any major role in the drying rate of the yam chunks. Hence, it is concluded that drying of yam flower chunk was effectively achieved with a hot air dryer under a time of 6 hours compared to 5-7 days in sun drying and 2 days in most drying methods. This drying duration promoted the nutrient levels and hygiene of the yam chunk by eliminating mucus growth.

Key words: Hot air dryer, yam chunk, system optimization, agriculture, food preservation, efficient drying

INTRODUCTION

History had shown that food preservation have come a long way with drying reported to be one of the oldest methods of conservation (Zomorodian *et al.*, 2006). In rural communities and particularly among the poor people, sun-drying has been one common means of food preservation. Moreover, this method is weather dependent and exposes the food item to microbes and other contaminants (Kingsly *et al.*, 2007). These food substances, after such crude processing, are sold to unsuspecting consumers. Based on this, there is therefore the need to look into ways of improving food product drying with such technology that will be cheap, simple, available and easily applicable to the poor and probably the uneducated. In addition, it is well known that drying have effects on the physical and chemical standards of the dried product as a result of the transformations that takes place. Hence, careful design is required to cater for the heat and mass transfers occurring during the process (Mujumdar and Zhonghua, 2007).

In Nigeria, just like several other developing nations, agriculture is considered a factor for growth and development. The country is blessed with a landmass of 98.3 million hectares of which 72% is considered suitable for agricultural production (Makanjuola *et al.*, 1991). However, the rate of growth in food production is very low, amounting to 2.5% per annum. This poor growth has been attributed to the level of agricultural preservation in the country (Odigboh, 1991). Her poor record of food preservation has led to improper management of agricultural produce and thus impinged on the growth of food production (Karim, 2010). Moreover, efforts have been made towards achieving sustainable growth in a number of ways. These ways are however limited to some set of food stuffs which include; rice, beans, millet, soya beans, fruits and beverages all of which possess moisture content that is as low as 30-40% as compared to 70% of yam, a major staple in Nigeria. Existing dryers include refrigerated dryer for drying fruit and beverages. It removes about 10% of moisture but also posses the danger of refrigerant contamination and its effect on global warming. Another is the solar dehydrator for beverages, vegetables and cereals designed by Mother Earth. This utilizes solar energy for drying. A major shortcoming of this is its inefficiency when used for food items with high moisture content. It lacks facilities to guarantee inflow and outflow of air. Yam tuber contains high moisture content, coupled with additional water from parboiling (for atomizing the water content). This, unlike the other food stuffs, needs a high temperature dryer for effective drying and venting controls that will allow for easy adjustment of drying temperature.

Yam (*Dioscorea* spp.) of predetermined thickness is called chunk. It is produced nationwide and harvested between June and December annually. It is a tuber crop of over 600 species and is highly perishable when fresh, primarily because of its high moisture content (50-80% wet basis) (Degras, 1993; Osunde, 2008). As a result of this, difficulties in preservation are inevitable as existing preservation methods lack temperature control and causes harmful effects on the standard of the dried product (Babajide *et al*., 2006). Therefore, the need for alternative drying method that maintains preservable temperature, eliminate agglomeration and gives quality end product cannot be overemphasized. After successful preservation, powdery yam (yam flour) is a long lasting food item (Akanbi *et al*., 1996; Kingsly *et al*., 2007).

Most studies that have been carried out on the drying process of this nature are for industrial applications such as textile and pharmaceutical industries. According to Zomorodian *et al*. (2006), an alternative and better drying system for high moisture materials is either a dryer with continuous flow of heat or that with continuous movement of products in them. The flow of hot air may be in the same direction, opposite or across with respect to the products. This drying system is more sophisticated with higher capacity and requires several mechanical tools to run. Therefore, this study focused on the use and adaptation of hot air dryer for drying yam chunks. It developed a dryer which made the process of yam chunk drying rapid and hygienic. Furthermore, due to the importance of the flour and its abundant production, it was necessary to investigate the stability of yam flour in storage and this required the knowledge of moisture sorption isotherms (Oyelade *et al*., 2008). This study was undertaken to design and experimentally determine a perfect drying method for its preservation at predetermined thickness.

MATERIALS AND METHODS

Matured white yam (*Dioscorea rotundata*) and *Dioscorea alata* used in this study were sourced from northern and western part of Nigeria. It was parboiled in water of 60°C for between 10-12 h in accordance with the procedure adopted by Falade *et al*. (2007) after it has been peeled and cut to the predetermined thickness of 10 and 15 mm. The resulting product was then blanched to benefit the control of various bacterial problem associated with it according to the procedure from Aborisade and Akomolafe (2007).

A dryer was developed for the purpose of this study. It was made of galvanized steel of about 2 mm thickness and insulated with fibreglass with insulation thickness of 10 mm. In this design optimum consideration was given to the ability of the materials to resist corrosion and possible metallurgical reactions (Coulsion and Richardson, 2000). The dryer consist of the body system, dimension 1200×600×1200 mm. The drying chamber has three grill shelves each 1200×600 mm which allowed the convected heat to pass through the grill and heat the chunk more evenly on both sides. The heating chamber channeled heat towards the drying chamber for atomization of water molecules on yam and blower station. Venting controls was also included. The size of the dryer was 850 g capacity, with its interior painted with dull black paint. Also the frame supports was made of the angle iron square pipe. The fasteners, screw, all purpose electrodes, bolt and nuts were used for joining the parts together. The optimum design of the hot air dryer involved the critical evaluation of the following: flow head of the blower, speed and drying rate, required drying heat, pressure of the heating chamber and the drying area. The heat transfer in the dryer was as a result of conduction and convention. Using the Wakjira *et al.* (2011) thickness determination, a predetermined thickness was obtained. Then the experiment was performed for No-load test. A no-load test refer to the procedures when the dryer is empty (i.e., contains no yam). This was done to check the rate at which temperature changes in the system and also to determine the operating performance. The drying chamber was then stocked with the yam and the tests were conducted. This is referred to as a load test. The conditions of no-load and load test were then assessed and analyzed. Weight loss monitoring was carried out until the 10 and 15 mm yam chunk became dry. The duration for the drying period was between 5 and 6 h for the 10 and 15 mm chunk, respectively.

The drying chamber employed for this study was designed and constructed according to the following design calculations:

Head flow (H_f): The head flow developed by the centrifugal blower distribute the heat to drying chamber and it mainly depends on the whirl velocity at the inlet and the outlet of the impeller expressed as (Basunia and Abe, 2001):

$$H_f = \frac{(U_2 V_{w2} \, U_1 V_{w1})}{g} \tag{1}$$

U_2 = Tangential velocity at impeller outlet
U_1 = Tangential velocity at the impeller inlet
V_{w2} = Outlet velocity of the whirl
V_{w1} = Inlet velocity of whirl
g = Acceleration due to gravity

Actual head of flow (H_{af}): According to Basunia and Abe (2001) the actual head flow is given as:

$$H_{af} = S_f (H_f) \tag{2}$$

Where:
S_f = Slip factor

Amount of water removed: The amount of water removed per square foot of surface area per hour using a fixed air dryer is given as (Claude, 1982):

$$W_R = 0.192k\left(\frac{1+V}{200}\right)(W_0 - W_{RH}) \tag{3}$$

Where:
W_R = Amount of water removed
k = Constant
V = Velocity of air
W_o = The amount of water in the air when it is saturated at the given air temperature
W_{RH} = The amount of water in the air at given temperature and the percent relative humidity

Drying rate, T_d: Further analysis involved the estimation of the drying rate, T_d which is defined as the rate at which the condensates are removed from material being dried (Yam chunk) per time and is expressed as Mujumdar (2007) and Mohammadi *et al.* (2009):

$$T_d = \frac{W_{TR}}{W_R} \tag{4}$$

T_d = The total drying time
W_{TR} = Total water removed ($ft^{-2}\,h^{-1}$)
W_R = Water removed (ft^{-2})

Drying weight (M_d): The drying weight of a particular product depend largely on its moisture content and is expressed as the ratio of the difference between wet (W_w) and dried (W_d) weight of the product to its drying weight Mohammadi *et al.* (2009). Moreover, the determination of the moisture content is extremely important in a drying process because the time and the temperature requirement depend on it (Mardiah *et al.*, 2010; Aborisade and Akomolafe, 2007; Reza *et al.*, 2006). Therefore, Dowgiallo and Dutkiewicz (1998) proposed the drying weight as the weight of the material outside the drying chamber. This is expressed as:

$$M_d = 0.503P^{0.037} + F_o^{0.127} \tag{5}$$

Where:
P = Drying pressure
F_o = Fourier number

While the drying chamber pressure is calculated using Dowgiallo and Dutkiewicz (1998) model is expressed as:

$$P = \frac{V_a t^2}{A} \times W \tag{6}$$

Where:
V_a = Drying chamber air flow velocity
A = Drying chamber area
t = Drying time
w = Width of the drying chamber

Shrinkage (K) effects: For a proper design process the knowledge of the shrinkage effects in the design of improved drying equipment is inevitable. Shrinkage is simply defined as the changes in a product that causes the deformation of both physical and chemical compositions. Different drying methods have different effect on the quality of a product. This effect may be on the volume, shape and/or entire composition. The shrinkage effect is expressed as (Panyawong and Devahastin, 2007):

$$K = \frac{V_p}{W_a^3} \tag{7}$$

Where as:

$$W_a = \frac{A_p}{L} = \text{Equivalent projected area width} \tag{8}$$

V_p = Volume of the moisture in the material
A_p = Projected area of the drying chamber

Slip factor (SF): The St $K = V_p/W^3_a$ anit relation (Ying and Jin, 1998) is employed to evaluate the slip factor in impeller design. It can used to determine the accuracy of the impeller speed and it is given as:

$$SF = 1 - \left(\left(\frac{0.63\pi}{N} \right) \left(\frac{V_f}{V_2} \right) \cos \beta_2 \right) \tag{9}$$

Where:
N = Number of blade in the impeller
β_2 = Angle between the plate and the tangential direction

RESULTS AND DISCUSSION

After a comprehensive design (Fig. 1) of the hot air drying system through step wise procedures, experiments were performed and the results are presented using Fig. 2-7.

Figure 2 and 3 shows the no-load test for the first and second days of the experiment. This was done to know the relationship between ambient and drying chamber temperature. This also helps to ascertain the temperature of the drying chamber based on the ambient temperature which is affected by weather conditions (sunny or cloudy). From Fig. 2 and 3 it was generally observed that drying chamber temperature increases ambient temperature increases. First and second day drying chamber temperatures were of 61 and 71°C. This is obvious since first day readings were taken between 10 a.m and 3 p.m (low average ambient temperature), while second day readings was taken between 9.30 am and 3.30 pm (high average ambient temperature). This clearly demonstrated that the surrounding temperature has absolute effect on the drying chamber effectiveness.

Figure 4-5 show the load test results for 10 and 15 mm yam chunks, respectively. However, Figure 4 shows that although the initial weights (300 g) of the trays were the same at the beginning of the experiment, the final weight of tray 1 (100 g) deviates from those of trays 2 and 3 (120 g). During this period, the chamber temperature rose from 50 to 71°C. In addition, Fig. 5 shows that the trays' initial and final weights were the same implying no major difference in phenomenal change. The temperature moved from 49 to 70°C. Comparing Fig. 4 and 5 reveal that yam chunks in tray 1 shows the highest drying sequence. This was due to the fact that, it was closest to the vent, thereby increasing the rate of evaporation across the surface area. Thus, the rate of escape of the condensate was directly proportional to proximity to the vent. This explains the differences in the weight lost by the yam chunks in the trays. Immediate moisture contents of the yam chunks were determined at the end of each experiment to be 14.49±0.01% (wet basis). The yam chunk moisture content in both cases was found to reduce to 22% from the initial 70 to 80%.

Fig. 1: Schematic diagram of the dryer employed for the experiment

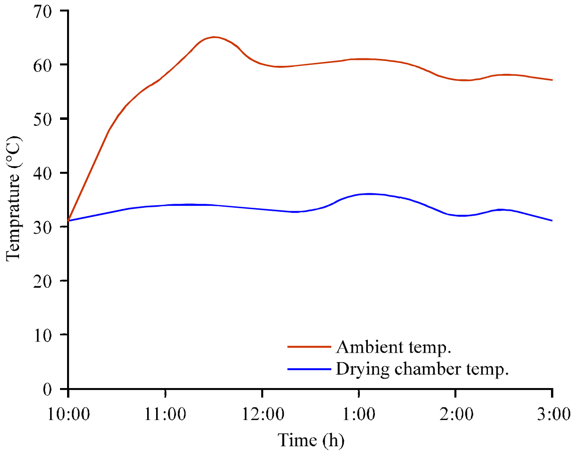

Fig. 2: No load for *Dioscorea alata* (10 mm thick) temperature against time

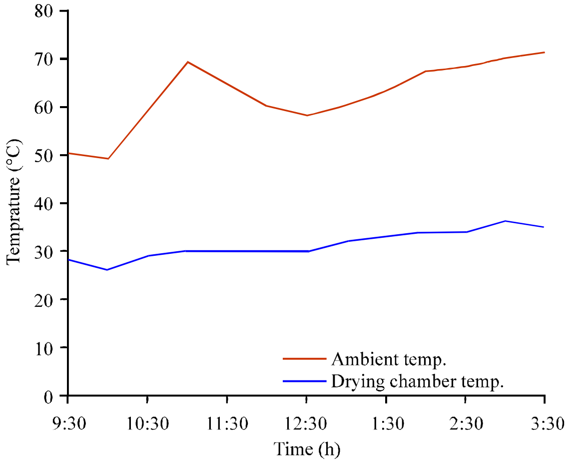

Fig. 3: No load, for *Dioscorea rotundata* (15 mm thick) temperature against time

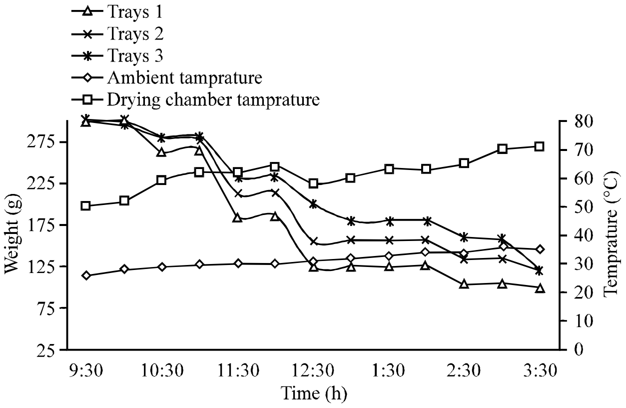

Fig. 4: Load test (10 mm thick): Temperature, weight against time

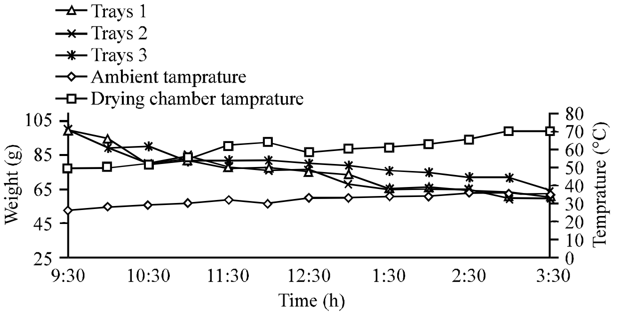

Fig. 5: Load test (15 mm): Temperature and weight against time

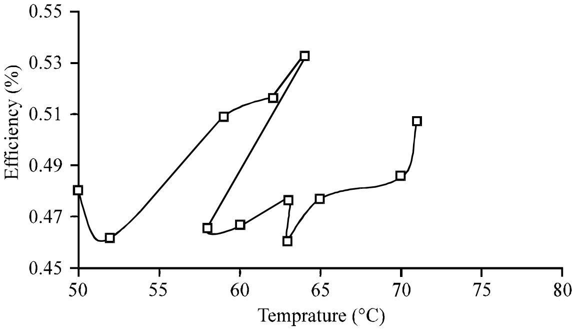

Fig. 6: System performance efficiency

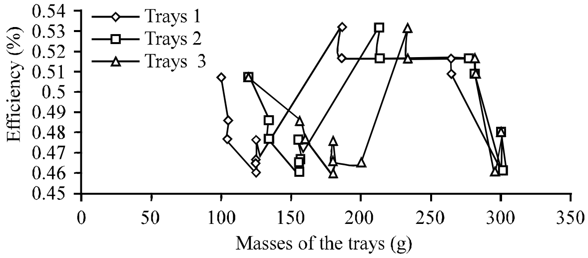

Fig. 7: Inter-relationship between system efficiency and the masses of the trays

This preservable moisture content level is found to be in conformance with the levels obtained in literature (AACC, 2000).

Comparing the drying times achieved in this study with those obtained using direct sun-drying, solar and refrigerator dryers shows that the hot-air dryer developed in this work performed better. Drying via direct exposure to the sun was achieved between 5 to 7 days while those with other dryers (Rozis, 1997) were within two days respectively. More so, in the design a prior knowledge of the effect of deformation were taken into consideration this made the speed of the hot air impingement on the products (Yam tuber) to be maintained at its minimum level to allow uniform drying of the product.

Furthermore, Fig. 6 to 7 presents the system performance. It was observed that the highest efficiency of 53% was obtained when the temperature was 64°C. The system efficiency fluctuated throughout the experiment.

Figure 7 shows the efficiencies obtained for the system with the masses of the yam chunk in the trays. The characteristic trends observed for the system were similar for the trays across the whole period. However, the Fig. 7 demonstrates that the efficiencies of drying peaked and dropped at the same temperature point for the trays.

Observing Fig. 6 and 7, it is clear that the slopes can be divided into two regimes based on the temperature variation. These regimes are pre-64°C (i.e., between 52 and 64°C) and post 64°C (i.e., between 64 and 71°C). The amount of moisture content lost as a measure of weight loss difference at each of the temperature regimes and at the peak efficiency point were the result of Fig. 8. Also, the temperature rate of drying (g $°C^{-1}$) as it affects the weight loss were the results of Fig. 9. Based on Fig. 8 and 9, what was observed were two clearly different trends between the pre and post 64°C regimes. Comparing these figures with those of Fig. 4 and 5, it can be inferred that proximity of the tray to the vent had no clear effect on the extent of drying. Rather, it can be concluded that

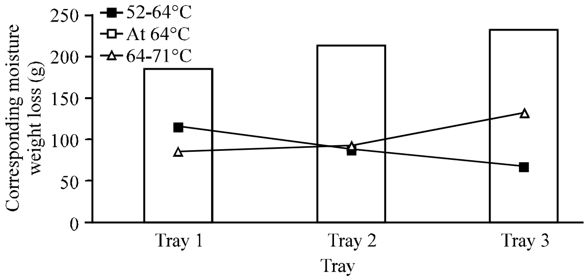

Fig. 8: Relationship between the loss in moisture content and temperature

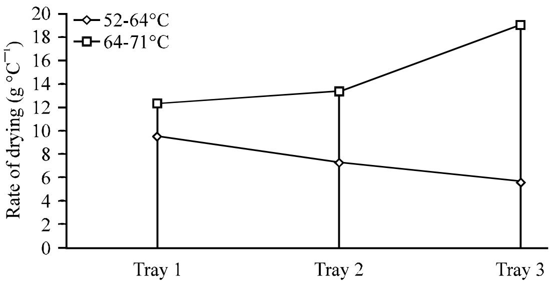

Fig. 9: Plot showing the weight lost by increasing temperature across the period of the experiment

irrespective of the position of the trays in the chamber drying equal levels of drying were achieved at the end of the experiment.

CONCLUSION

This study focused on the drying of yam chunks over a period of 6 h in a dehydrator. Several indices that characterized the drying of the yam chunks were highlighted. The results revealed that maximum temperatures of 61°C for no-load and 71°C for load tests were obtained. In addition, the 10 and 15 mm yam chunk was able to attain preservable moisture content level within 6 h. Furthermore, proximity of the trays to the vent did not play any role in the drying rate of the yam chunks. However, rate of mass loss to temperature change increased before the system attained optimum efficiency at a temperature of 64°C and decreased thereafter. Also, an optimum system efficiency of 53.13% was obtained. The results from the work in terms of moisture content level reduction enhanced the nutrient level in the yam chunk. This supports the study conducted by Leng *et al.* (2011). The reduction in the time of drying from 5-7 days (sun-drying) to 6 h led to the elimination of mucus growth which imparts a brown colour on the yam chunk. The yam chunk is also found to be more hygienically dried when compared to sun-drying.

REFERENCES

AACC, 2000. Approved Methods of the AACC. 10th Edn., The Association, St Paul, MN., USA.

Aborisade, A.T. and O.M. Akomolafe, 2007. Effect of heat treatment of plantain (*Musa paradisiaca*) fruits on peel characteristics and control of decay by *Fusarium verticillioides*. Asian J. Plant Sci., 6: 523-527.

Akanbi, C.T., P.O. Gureje and I.A. Adeyemi, 1996. Effect of heat-moisture pre-treatment on physical characteristics of dehydrated yam. J. Food Eng., 28: 45-54.

Babajide, J.M., O.B. Oyewole, F.O. Henshaw, S.O. Babajide and F.O. Olasantan, 2006. Effect of local preservative on quality of traditional dry-yam slices Gbodo and its products. World J. Agric. Sci., 2: 267-273.

Basunia, M.A. and T. Abe, 2001. Design and construction of a simple three shelf solar rough dryer agricultural mechanisation. Asia Afr. Latin. Am., 32: 54-66.

Claude C., 1982. Farm Machinery. 10th Edn. R.B. and Sons Company, New York Donnelley.

Coulsion, J.M. and J.F. Richardson, 2000. Unit Operations of Chemical Engineering. Vol. 1, 5th Edn., Chemical Engineering Pergamon and ELBS, McGraw Hill, New York.

Degras, L., 1993. The Yam: A Tropical Root Crop. Macmillan Press Ltd., London.

Dowgiallo, A. and D. Dutkiewicz, 1998. Drying parameters of plant-fish feeding concentrates in drum driers. Int. Agrophys., 13: 337-341.

Falade, K.O., T.O. Olurin, E.A. Ike and O.C. Aworh, 2007. Effect of pretreatment and temperature on air-drying of *Dioscorea alata* and *Dioscorea rotundata* slices. J. Food Eng., 80: 1002-1010.

Karim, O.R., 2010. Air-oven drying of pre-treated fruit slices: A promising solution to post-harvest losses. Pak. J. Nutr., 9: 547-551.

Kingsly, A.R.P., R. Singh, R.K. Goyal and D.B. Singh, 2007. Thin-layer drying behaviour of organically produced tomato. Am. J. Food Technol., 2: 71-78.

Leng M.S., I. Gouado and R. Ndjouenkeu, 2011. Blanching and drying behaviour of *Dioscorea schimperiana* and impact on cellular exchanges and on calcium, ascorbic acid and β carotene contents. Am. J. Food Technol., 6: 362-373.

Makanjuola, G.A., T.O. Abimbola and U.G.N. Anazodo, 1991. Agricultural mechanization policies and strategies in Nigeria. Proceedings of a Workshop on Agriculture Mechanical and Strategies in Africa: Case Studies from Commonwealth African Countries, Aug. 13-17, I.A.R./A.B.U., Zaria, Nigeria, pp: 99-120.

Mardiah, A., N. Huda and R. Ahmad, 2010. Study of physico chmical properties, microstructure and sensory characteristic of fish flakes. J. Fish. Acquatic Sci., 5: 469-482.

Mohammadi, A., S. Rafiee, A. Keyhani and Z. Emon-Djomeh, 2009. Moisture content for modeling of sliced Kiwifruits during drying. Pak. J. Nutr., 86: 78-82.

Mujumdar A.S and W. Zhonghua, 2007. Thermal drying technologies: New developments and future r and d potential. Proceedings of the 5th Asia Pacific Drying conference, August 13-15, 2007, World Scientific Publishing Co. Pte. Ltd., Hong Kong.

Mujumdar, A.S., 2007. Handbook of Industrial Drying. CRC Press, Boca Raton, FL. USA., Pages: 1240.

Odigboh, E.U., 1991. Continuing controversies on Tillage Mechanization in Nigeria. J. Agric. Sci. Technol., 1: 41-49.

Osunde, Z.D., 2008. Minimizing postharvest losses in Yam (*Dioscorea* sp.): Treatments and techniques. Int. J. Food Sci. Technol., 12: 2-14.

Oyelade, O.J, T.Y. Tunde Akintunde and J.C. Igbeka, 2008. Predictive equilibrium moisture content equations for yam (*Dioscorea rotundata*, Poir) flour and hysteresis phenomena under practical storage conditions. J. Food Eng., 87: 229-235.

Panyawong, S. and S. Devahastin, 2007. Determination of deformation of a food product undergoing different drying methods and conditions via evolution of a shape factor. J. Food Eng., 78: 151-161.

Reza, M.S., K.M. Azimuddin, M.N. Islam and M. Kamal, 2006. Influence of ice storage on raw materials for the production of high quality dried fish products. J. Biological Sci., 6: 130-134.

Rozis, J.F., 1997. Drying Foodstuffs-Techniques, Processes, Equipment Technical Guidebook. Backhuys Publishers, Leiden, ISBN-10: 9073348757, Pages: 311.

Wakjira, M., D. Adugna and G. Bercela, 2011. Determining sliced thickness of banana (*Musa* spp.) for enclosed solar drying using solar cabinet under Ethiopia condition. Am. J. Food Technol., 61: 568-580.

Ying, Y. and J. Jin, 1998. Design and performance evaluation of a small-scale conduction Type grain dryer. Agric. Mech. Asia Afr. Lat. Am., 29: 55-58.

Zomorodian, A., D. Zare and A. Ghasemkhani, 2006. Optimization and evaluation of a semi-continuous solar dryer for cereals (Rice, etc). Desalination, 209: 129-135.