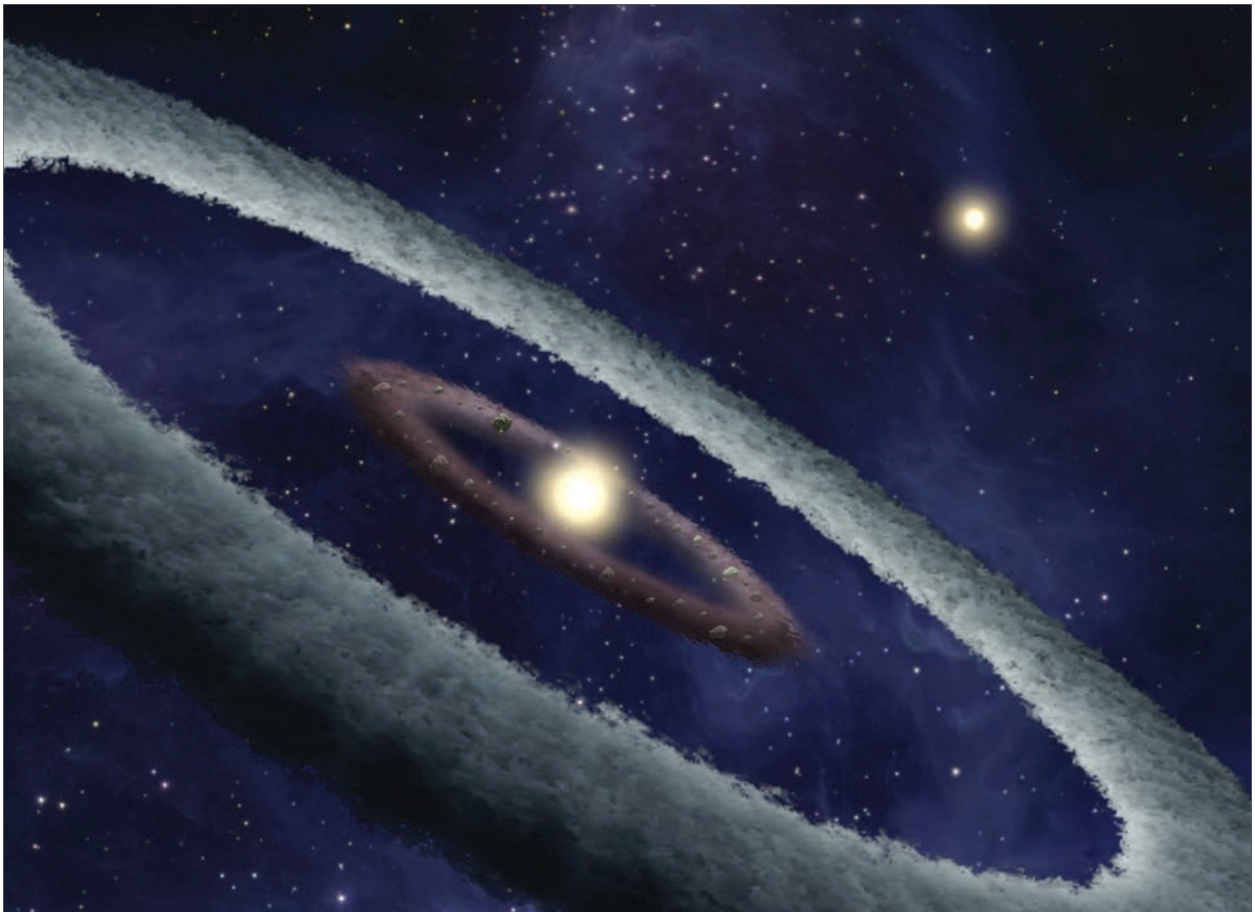

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On the Drying Efficiency of Potato Chips Using Open Sun Drying and a Locally Fabricated Solar Dryer

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ABSTRACT
In this study, the drying efficiency of potato chips processed using open sun drying and a solar dryer is reported. Equal quantities of potato chips were subjected to Open Sun Drying (OSD) and also dried using a solar dryer, constructed using locally available materials. The experiment lasted for 3 weeks and the drying efficiency of the chips from the two methods were computed. The results show that there is a significant improvement in the drying efficiency of the potato chips using the solar dryer compared to the OSD method. The average drying period for the solar dryer was two weeks while that of the open sun drying lasted longer. The drying rate of the potato chips and the system efficiency (solar dryer) were found to be 0.75 kg h^{-1} and 68.5%, indicating the potentials and effectiveness of the constructed solar dryer compared to the OSD method.

Key words: Drying efficiency, potato chips, solar dryer, open sun drying, renewable energy

INTRODUCTION
Effective preservation of agricultural products is one of the most ubiquitous problems faced by local farmers especially in third world countries. In the developing nations, most farmers encounter serious post harvest losses due to the utilization of very poor and primitive preservation techniques in preserving their farm produce. It has been established recently that renewable energy have a significant role to play in extending technology to farmers in developing countries in order to increase their productivity. According to Ogwueche (2000), sweet potato (botanical name; *Ipomoea batatas*) is a dicotyledonous plant which belongs to the family “Convolvulaceae”. Sweet potatoes are large, starchy, sweet-tasting, tuberous roots and the crop is mostly propagated vegetatively from small slips or shoots growing from the tubers or vine cuttings. Sweet potatoes are highly adaptable to relatively marginal soils and erratic rainfall, offers high productivity per unit land and labour and guarantees some yield even under the most adverse weather conditions. The origin of sweet potatoes (*Ipomoea batatas*) is mostly associated to the tropical regions of the North and South America (Williams, 1968). The maturity period of sweet potato tubers is typically $\leq$4 months depending on the species (Anyanwu *et al*., 1982; Anyanwu and Komolafe, 2003). Owing to this short maturation period, sweet potato can be grown two to three times in a year with supplementary irrigation thereby increasing food abundance in the nation and the world at large.

Sweet potatoes are useful to man in so many areas which include; (1) As vegetables in some West African countries such as Guinea, Sierra Leone, Liberia and Nigeria and in North Eastern Uganda, East Africa, (2) As good source of vitamins A, C and B_2 (riboflavin), (3) As staple food in many continents including Africa, Asia, Europe, North America and South America, The Caribbean and New Zealand, (4) For biofuel production, (5) The leaves and vines are important source of hay and fodder to livestock farmers and (6) As medicines (Caroll and Melvi, 2004; Dincer *et al*., 2011;

Hartemink *et al*., 2000; Rowan *et al*., 2008; Verrill and Barrett, 1937; Chukwu, 1999; Woolfe, 1992). In Nigeria, sweet potato is not just an established staple crop but also serve as an important source of raw materials for the manufacture of wide range of industrial products including starch, liquid glucose, ethanol and as a potential substitute for wheat flour in bread production. The Federal Government of Nigeria, recently released its plan early this year to improve the productivity of sweet potato in the country from the six tonnes per hectare to 25 t ha^{-1} by 2015 and national production from 2-6 million t per annum by 2016 (http://dailyindependentnig.com). Although, some of the production constraints facing potatoes farmers in Nigeria include land fragmentation, lack of improved agricultural practices, insufficient credit facilities, poor agricultural extension services, poor road transportation and high cost of productivity, the major production threat has remained that of poor preservative and storage facilities. This ugly trend has been highlighted by other research scholars (Tewe *et al*., 2003; Odebode *et al*., 2008; Fawole, 2007; Mbanaso *et al*., 2012; Babatunde *et al*., 2005; Egbe, 2012; Adewumi and Adebayo, 2008; Egbe and Idoko, 2009). Sweet potato has the potentials for food security, job creation, as well as serving as revenue generation through export especially this time that variety of approaches to poverty alleviation are being considered by the Nigerian government and their development partners in order solve the problems of food inadequacy in Nigeria.

Just as other developing countries in the tropical regions, one of the major method of removing moisture from agricultural products in most parts of Nigeria is by open sun drying. This method is not only very primitive and barbaric but also exposes the products to dust, stains, rodents, birds and flies, such that the product becomes a potential vector for different ailments. Another serious disadvantage of the OSD method is that it is very unhygienic and more labour intensive since the crops are being moved frequently in and out during the day and night and from unfavourable weather conditions e.g. increased humidity in the atmosphere or rain. This method also prolongs the drying period and could result in the deterioration of the quality/decay of the crops. According to Kurtbas and Turgut (2006), solar air heaters are simple devices that heat up the air by tapping solar energy from the sun and are mostly applied in solar thermal devices that requires low to moderate temperatures $\leq$80°C. Such requirements are suitable for crop drying purposes.

The major objective of this research is to develop a less expensive way of preserving potato chips through a modern, locally fabricated cost-effective drying equipment in order to reduce the post harvest wastes and food contamination that is usually encountered by farmers in the developing nations like Nigeria. In order to achieve this noble objective, a solar dryer that works on the principle of simultaneous crop drying was developed. The simultaneous drying of the potato chips are made possible through tapping of the direct solar radiation from the transparent walls of the solar dryer and the cabinet roof, coupled with the heated air from the solar collector. The results of the reserach will go long way to alleviating the post harvest challenges usually encountered by potato farmers in Nigeria and in other regions of the world with similar scenario and thus leads to increased global food availability.

MATERIALS AND METHODS

The solar dryer used in the study was constructed with cheap and locally available materials that were sourced from the local markets. The experiment lasted for 3 weeks (January 7-28, 2015). The most important parts of the constructed solar dryer include; the collector, drying cabinet and drying trays. The architectural design is relatively close to that reported by Bolaji and Olalusi (2008) but differs in the dimensions and properties of the materials used as well as the

Fig. 1: Solar dryer

orientation and location of the study area. Figure 1 gives a picture of the solar dryer. Adegoke and Bolaji (2000), noted that the best stationary orientation for solar dryers is to face it due South in the Northern hemisphere and due North in Southern hemisphere and with a tilt angle>the local latitude of the study area. The study area (Abakaliki, Ebonyi State, Nigeria) is located on 6.3333° N, 8.1000° E (Menakaya, 1980), hence the solar collector is oriented south with a tilt of 20.33° for increased air circulation and performance of the fabricated solar dryer.

Design equations and theoretical considerations: In the literature, there a lots of different design equations that have been utilised in the construction of solar dryers. In the present investigation, the design equations presented in the works of Okonkwo and Okoye (2005) and that contained in Sabarez and Price (1999), were utilised. In this regard, the optimum angle of inclination of the collector was obtained to be 21.33° (local latitude+latitude of Abakaliki), determined using the relation described in Eq. 1:

$$\theta = L+15 \tag{1}$$

where, θ is the tilt angle and L is the local latitude of the study area.

Declination (δ): The declination is the angle between the sun's direction and the equatorial plane and is mathematically given as (Tiwari, 2002) in Eq. 2:

$$\delta = 23.45 \sin [0.9863 (284+n)] \tag{2}$$

where, n is the day in the year which varies from n = 1 to n = 365.

Collector efficiency (η): The collector efficiency is given by equation defined as (Bolaji and Olalusi, 2008) in Eq. 3:

$$\eta_C = \frac{\rho V C_p \Delta T}{A I_C} \tag{3}$$

where, ρ is the density of air (kg m^{-3}), T is the temperature elevation, C_p is the specific heat capacity of air at constant pressure (J kg^{-1} K^{-1}), V is the volumetric flow rate (m^3 sec^{-1}), A is the effective area of the collector facing the sun (m^2) and I_c is the insolation received by the collector in watts per meter squared (W m^{-2}).

Dryer efficiency (η_D): The dry efficiency can be deduced from the relation as given in Eq. 4:

$$\eta_D = \frac{\Delta M\, L}{AI_D\, t} \tag{4}$$

where, ΔM is the change in the mass of the crop, L is the latent heat of vaporization of water, t is the time of drying, I_D is the insolation received by the dryer and A is the effective area of the dryer.

Minimum heat energy Q_{min} required for crop drying: The minimum quantity of heat needed for crop drying is given by the relation given in Eq. 5:

$$Q_{min} = M_W\, L = \rho C_P\, V\, (T_{amb}\text{-}T_{dryer}) \tag{5}$$

where, L is the latent heat of vaporization of water, M_w is the mass of crop before drying, ρ is the density of water, T_{amb} is the ambient temperature and T_{dryer} is the dryer temperature.

Moisture Content (MC): The moisture content from the crop is calculated using the formula given in Okonkwo and Okoye (2005), Adegoke and Bolaji (2000) and Bolaji and Olalusi (2008) as described in Eq. 6:

$$\text{MC}\,(\%) = \left[\frac{M_i - M_f}{M_i}\right]\times 100 \tag{6}$$

where, M_i is the mass of sample before drying and M_f is the mass of sample after drying.

Theoretical considerations: In general, the three major modes of heat energy transfer in physics are radiation, convection and conduction. The sum of these and other processes taking place in the system is necessary to determine the energy balance of the device. The energy balance of the absorber can be adequately approximated to the heat equations by assuming that the total heat energy lost by the solar collector is equal the total heat energy gained and can be represented mathematically as given in Eq. 7:

$$I_C\, A_C = Q_A + Q_C + Q_V + Q_R + Q_{RR} \tag{7}$$

where, I_C and A_C retain their usual meanings, Q_A in watts (W) is the rate of useful heat collected by air, Q_C in watts (W) gives the rate of heat loss from the absorber due to conduction, Q_V in watts (W) is the rate of heat loss from the absorber due to convection, Q_R in watts (W) gives the heat loss from the absorber due to re-radiation of long wavelengths and Q_{RR} in watts (W) is the heat loss from the absorber due to reflection losses. According to the literature (Gatea, 2011), the energy loss due to conduction, convection and radiation can be unified to a simplified form as is given in Eq. 8:

$$Q_L = Q_C + Q_V + Q_R \tag{8}$$

Research done by Sodha *et al.* (1985) and Sodha and Chandra (1994), indicate that Eq. 8 can be written in the form of Eq. 9:

$$Q_L = U_L\ A_C\ (T_C - T_{amb}) \tag{9}$$

RESULTS AND DISCUSSION

Figure 2 gives the variation of the temperature and the time of the day within the period of the research investigation. The temperatures, relative humidity of the dryer and ambient conditions were monitored with thermometers and a relative humidity sensor. The potato chips were carefully sliced into uniform dimensions of 2.25 cm^2 by surface area and 200 g of the sliced chips was measured out. The dryer trays were then lightly filled with the potato chips. The control experiment contained similar quantity and size of potato chips but were spread outside under open sun drying. The result shows that a maximum temperature range of 49-50°C was recorded in the collector between 13.00-14.00 pm. This implies that the collector retains the heat sensibly, such that effective drying takes place longer. The difference between the ambient temperature and the dryer is very wide (20°C), indicating the effectiveness of the dryer. Research done by Gatea (2011), indicate that the drying efficiency of a product is a complex heat and mass transfer process which depends largely on other external variables such as temperature, humidity and velocity of the air stream and internal variables which depend on other parameters such as the surface characteristics, chemical composition, physical structure and size and shape of product. In this study, the difference in the dry kinetics was attributed to the more efficient drying rate of the solar dryer compared to the open sun drying approach. The observation reported herein is in agreement with the reports of other authors in the literature (Kurtbas and Turgut, 2006; Bolaji and Olalusi, 2008).

Figure 3 gives the result of mass loss in kilograms for both methods used for drying the potato chips. The results of the solar dryer show that the mass loss was more pronounced compared to the

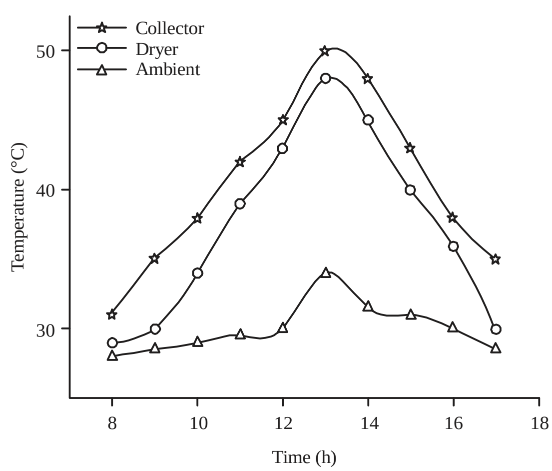

Fig. 2: Variation of temperature with time of the day

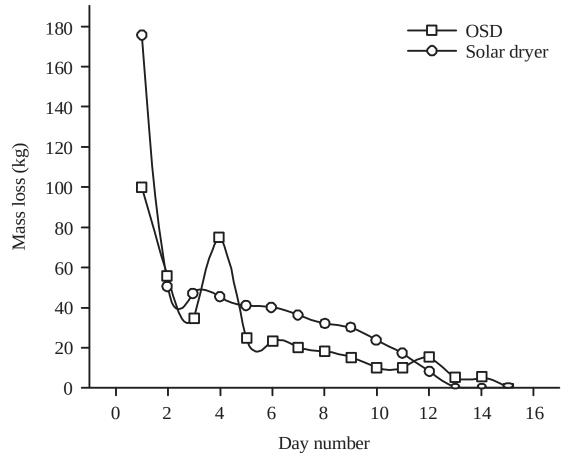

Fig. 3: Variation of the mass loss with the day number

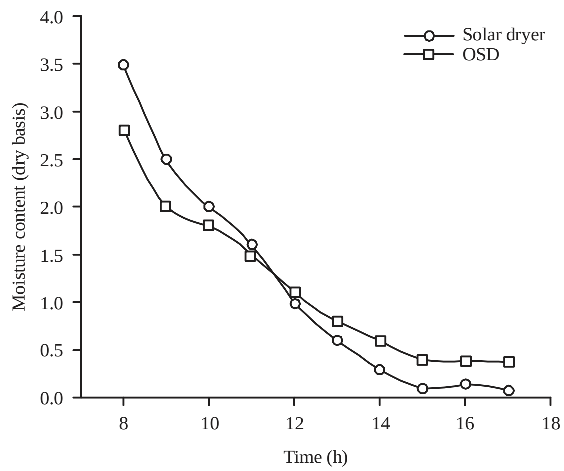

Fig. 4: Variation of the moisture content with the time of the day

open sun drying method. The materials dried faster, resulting in zero mass loss from the 13th day while the materials subjected to the OSD technique exhibited zero mass loss on the 16th day. This wide difference is a clear indication that the drying done using the solar dryer is more efficient, less time consuming, less energy demanding and more cost effective compared to the open sun drying approach. The decreased drying rate that was observed in the open sun drying method was attributed to a variety of factors including; varying temperatures, humidity, velocity of the wind, wind direction, dust particles and shadowing effects from nearby buildings/trees amongst other factors.

Figure 4 shows the change in the moisture content with the time of the day. The moisture content removal for each day was computed on daily basis. It was observed that the potato chips dried from an initial moisture content of 85% to an average storage moisture content of 15.5% in 4 days of the drying process, using the solar dryer. However, for the open sun drying case, it took about 6 days for the potato chips to attain a moisture content of 18.5% from the same initial moisture content. Physical observation of the potato chips dried using the solar dryer, indicates that it maintained its colour while those dried under open sun drying conditions exhibited a colour change from white to milky-brown. This was attributed to some dust particles and debris that it

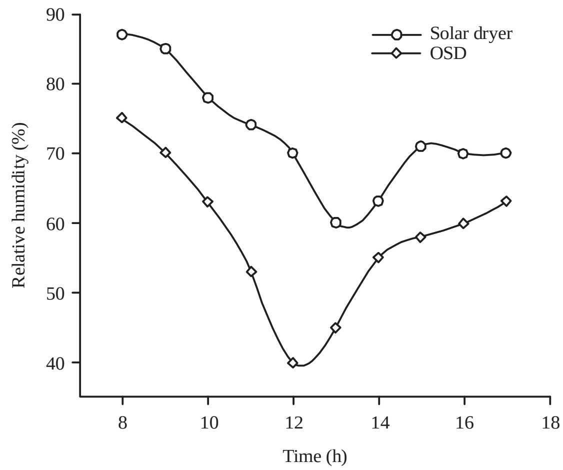

Fig. 5: Variation of the relative humidity with time of the day

picked up during the drying process. Some sign of contamination and smell was also noticed, indicating that the potato chips are gradually attaining stages of deterioration and decay. This is possibly due to flies and other vectors/rodents that perch on them as they were exposed to the open environment in the OSD method.

Figure 5 shows the variation of the relative humidity with time of the day. The relative humidity is usually least at noon as the atmosphere is clearest at noon. Similar behaviour has been reported by other research groups for other agricultural products (Bolaji and Olalusi, 2008; Kassali, 2011; Aloys and Angeline, 2009). However, the values observed for the solar dryer is relatively higher compared to that obtained for the open sun drying as shown in Fig. 5. Such behaviour can be attributed to the difference in the atmospheric conditions of the open environment compared to the solar dryer during the research period.

CONCLUSION

In this study, the comparative studies of the drying efficiency of potato chips using open sun drying and a locally fabricated solar dryer is presented. This results showed that the potato chips processed with the solar dryer, gives faster drying rate, yields high quality products and is more time saving compared to that of the open air sun drying. Post harvest losses is a serious issue to farmers especially in developing nations. This not only leads to wastage of food and agricultural products due to poor preservation techniques but also to food contamination and to the build-up of municipal solid wastes. In most third world countries, problems of unsustainable waste management is common and the negative consequences of poor waste management to man and to the environment to such nations including Nigeria is quite disturbing. Use of cost-effective solar dryer by farmers to replace the age-long solar drying method in Nigeria will add a significant quota towards increased food availability, increased revenue generation, job creation and environmental sustainability in Nigeria and other countries with similar challenges.

REFERENCES

Adegoke, C.O. and B.O. Bolaji, 2000. Performance evaluation of solar-operated thermosyphon hot water system. Int. J. Eng. Eng. Technol., 2: 35-40.

Adewumi, M.O. and F.A. Adebayo, 2008. Profitability and technical efficiency of sweet potato production in Nigeria. J. Rural Dev., 31: 105-120.

Aloys, N. and N. Angeline, 2009. Traditional fermented foods and beverages in Burundi. Food Res. Int., 42: 588-594.

Anyanwu, A.C., B.O. Anyanwu and V.A. Anyanwu, 1982. A Textbook of Agriculture for School Certificate. Africana Educational Publishers, Nigeria, Pages: 168.

Anyanwu, C.O. and B.T. Komolafe, 2003. Agricultural Science for Schools and Colleges. Longman Publishers, Ibadan, Nigeria, Pages: 213.

Babatunde, R.O., J.A. Akangbe and A. Falola, 2005. Resource use efficiency in sweet potato production in Kwara State of Nigeria. J. Agric. Res. Dev., 4: 187-199.

Bolaji, B.O. and A.P. Olalusi, 2008. Performance evaluation of a mixed-mode solar dryer. AU J. Technol., 11: 225-231.

Carol, R.E. and E. Melvin, 2004. Encyclopedia of Medical Anthropology. In: Health and Illness in the World's Cultures, Carol, R.E. and E. Melvin (Eds.)., Springer US, USA, Pages: 596.

Chukwu, G.O., 1999. Scheduling of irrigation on sweetpotato (*Ipomoea batalas* (L.) Lam). Afr. J. Root Tuber Crops, 3: 1-3.

Dincer, C., M. Karaoglan, F. Erden, N. Tetik, A. Topuz and F. Ozdemir, 2011. Effects of baking and boiling on the nutritional and antioxidant properties of sweet potato [*Ipomoea batatas* (L.) Lam.] cultivars. Plant Foods Hum. Nutr., 66: 341-347.

Egbe, O.M. and J.A. Idoko, 2009. Agronomic assessment of some sweet potato varieties for intercropping with pigeonpea in Southern Guinea Savanna of Nigeria. ARPN J. Agric. Biol. Sci., 4: 22-32.

Egbe, O.M., 2012. Relative performance of three sweet potato varieties in sole and intercrop systems in southern guinea savanna ecology of Nigeria. Global J. Sci. Front. Res. Agric. Biol., 12: 37-43.

Fawole, O.P., 2007. Constraints to production, processing and marketing of sweet potato in selected communities in Offa Local Government Area, Kwara State, Nigeria. J. Hum. Ecol., 22: 23-25.

Gatea, A.A., 2011. Performance evaluation of a mixed-mode solar dryer for evaporating moisture in beans. J. Agric. Biotechnol. Sustain. Dev., 34: 65-71.

Hartemink, A.E., S. Poloma, M. Maino, K.S. Powell, J. Egenae and J.N. O'Sullivan, 2000. Yield decline of sweet potato in the humid lowlands of Papua New Guinea. Agric. Ecosyst. Environ., 79: 259-269.

Kassali, R., 2011. Economics of sweet potato production. Int. J. Vegetable Sci., 17: 313-321.

Kurtbas, I. and E. Turgut, 2006. Experimental investigation of solar air heater with free and fixed fins: Efficiency and exergy loss. Int. J. Sci. Technol., 1: 75-82.

Mbanaso, E.O., A.E. Agwu, A.C. Anyanwu, and G.N. Asumugha, 2012. Assessment of the extent of adoption of sweetpotato production technology by farmers in the Southeast agro-ecological zone of Nigeria. J. Agric. Social Res., 12: 124-136.

Menakaya, J.C., 1980. Junior Atlas for Nigerian Secondary Schools. Macmillan Publishers, Nigeria.

Odebode, S.O., N. Egeonu and M.O. Akoroda, 2008. Promotion of sweetpotato for the food industry in Nigeria. Bulgarian J. Agric. Sci., 14: 300-308.

Ogwueche, N.I., 2000. Essential Agricultural Science for West African Schools and Colleges. Rejoint Communication Services, Enugu State, Nigeria, Pages: 78.

Okonkwo, E.C. and E.C Okoye, 2005. Performance evaluation of a pebble bed solar crop dryer. Niger. J. Technol., 24: 67-73.

Rowan, M., S. Dean, M. Rowan, C. Jean-Bernard and S. Dean, 2008. Papua New Guinea and Solomon Islands. 8th Edn., Lonely Planet, Melbourne, Australia, Pages: 64.

Sabarez, H.T. and W.E. Price, 1999. A diffusion model for prune dehydration. J. Food Eng., 42: 167-172.

Sodha, M.S., A. Dang, P.K. Bansal and S.B. Sharman, 1985. An analytical and experimental study of open sun drying and a cabinet tyre drier. Energy Conver. Manage., 25: 263-271.

Sodha, M.S. and R. Chandra, 1994. Solar drying systems and their testing procedures: A review. Energy Convers. Manage., 35: 219-267.

Tewe, O.O., E.E. Ojeniyi and O.A. Abu, 2003. Sweet potato production, utilization and marketing in Nigeria. Proceedings of the 7th Triennial Symposiun of the International Society for Tropical Root Crops-Africa Branch, October 11-17, 2003, Nairobi, Kenya, pp: 65-74.

Tiwari, G.N., 2002. Solar Energy: Fundamentals, Design, Modelling and Applications. Alpha Science International, UK., Pages: 19.

Verrill, A.H., and O.W. Barrett, 1937. Foods America Gave the World: The Strange, Fascinating and Often Romantic Histories of Many Native American Food Plants, Their Origin and Other Interesting and Curious Facts Concerning Them. Boston,L.C. Page and Co., New York, Pages: 47.

Williams, P.J., 1968. Tropical Crops: Dicotyledons. Longman Scientific and Technical. John Wiley and Sons, New York, Pages:156.

Woolfe, J., 1992. Sweetpotato: An Untapped Food Resources. Cambridge University Press, Cambridge, UK.