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Performance Evaluation of Forced Air-Convection Vegetable Drying System

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ABSTRACT

Drying of vegetable crops has been a major problem over the years most especially in the developing nations because of their high moisture content. In this work, a forced air–convection vegetable dryer with a capacity of 20kg of vegetable per batch was designed, constructed and test-run using tomato and okro. From the series of test-run carried out using okra of sliced size of 3mm and 6mm and tomato of 3mm, the results showed that both okro and tomato were dried in 5 hours and 5.4 hours respectively as against minimum of 48 hours in open sun drying. It was also observed that the average rate of drying was 7.23×10^{-4} kg/s and the critical moisture contents (m.c.) reached for 6mm and 3mm sizes of okro were 72% (wet basis) and 70% (wet basis) respectively and that of tomato was 87% (wet basis). The equilibrium moisture content attained at the end of the drying period for 3mm and 6mm sliced sizes of okro were 19% and 21% respectively while that of tomato was 15%. Proximate analysis of the dried okro and tomato compared favourably with the literature values and the dried okro and tomato were free from dust and any form of contamination.

KEYWORDS: Drying, moisture content, okro, tomato, vegetable, forced- air convection.

INTRODUCTION

Drying is an integral part of agricultural processing and is usually the last step of operation before storage. It is generally defined as the removal of moisture by heat from a substance that yields a solid product [1]. In food processing industry, the major reason for drying is to prevent the development of favourable environment for the growth of moulds and insects that normally cause spoilage of agricultural products during storage. This helps in preserving its quality, nutritive value as well as viability of seeds [2, 3].

Drying of vegetable is highly energy intensive operation because of its high moisture content usually above 70% (wet basis). For this reason, large amount of energy is needed to bring it down to safe storage moisture level (usually 7-15%) and temperature range of $35^{O}C$ to $63^{O}C$ are quite recommended for drying vegetables and fruits [4].

There are many approaches to crop drying which include natural field drying, open sun drying, free and forced-convection solar crop drying and conventional artificially heated air-drying [5 ,6]. The natural field drying is the system whereby the agricultural products are left in the field to dry down to safe- storage moisture level. This approach may lead to considerable losses, and is limited to the northern part of Nigeria with relatively favourable outdoor weather. Thus, only crops that mature for harvesting during the dry season can effectively dry in the field. Open sun drying is the traditional system of drying generally used in Nigeria. Over 90% of agricultural products are sun dried in Nigeria and most of the developing African countries [4]. Traditionally, farmers spread their crops in the sun on mats, top of rocks, roofs or road sides and by hanging on trees to dry. Although, sun drying requires little capital and work force, it is associated with many problems and short-comings. Beside longer drying period and possibility of contact with unwanted particles such as stones and dirt, the crops dried along roadsides stand the risk of contamination with greenhouse gasses (CO_2, CO, N_20, SO_2,etc) release from the exhaust of moving vehicles, hence denaturing their nutritional value. Furthermore, large quantity of the crops are consumed or damaged by insects, rodents, birds and other animal pests. In addition to that the crops are further spoilt by microorganisms, especially moulds, and possibly rewetting by rains or dew resulting in a considerable percentage lost or deterioration due to slow rate of drying in this process [7].

Free convection solar drying employs principle of density difference between heated air in the dryer due to solar energy and ambient air. Unlike, forced-convection solar drying system requires additional units such as blower to force the heated air into the drying chamber. In both cases, the rate of drying is slow resulting in a considerable lost or deterioration of the vegetable. The application of solar dryers in drying vegetables has become popular in recent times due to increasing demand of dried vegetable and rapid rise in their prices. Unfortunately, variation and uncertainty of solar energy incident in Nigeria and some parts of the world are some of the limitation associated with solar dryers. Incidentally, these problems are more pronounced during peak period of harvesting when relative

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humidity is generally high resulting in deterioration of the vegetable in the solar dryer because of the slow rate of drying under these conditions [5].

In this study, forced-air convection vegetable drying system was designed, fabricated and test-run in National Research Institute for Chemical Technology (NARICT), Zaria, Nigeria using okro and tomato as source of the vegetable. The effectiveness of the drying system in terms of period of drying, critical and equilibrium moisture contents of the dried okro and tomato were evaluated.

MATERIALS AND METHOD

Design Concept

The schematic diagram of the vegetable dryer is shown in Fig. 1.The drying system consists of tray dryer (D), heat exchanger (B), air blower (A) and combustion chamber (C). The vegetable to be dried were arranged in the tray dryer on perforated shelves. Dried husk, maize cobs, dry plant stalk or peanut shell available on the farm were burnt in the combustion chamber and the flue gas produced resulting from the burning of maize stalk, etc was channelled into annular section of double-pipe heat exchanger at the rate of 2.8×10^{-2} kg/s. Drying air at 33°C from air blower at the rate of 9.3×10^{-2} kg/s entered the tube side of the heat exchanger where it exchanged heat with the flue gas from the combustion chamber. The heated air from the heat exchanger at a temperature of 57°C entered the bottom of the tray dryer and continuously removed moisture from the vegetable arranged on the perforated shelves. The moist air (drying air and water evaporated from vegetable) was sent out of the dryer through the chimney. The innovative strength of this drying system is that the system require shorter drying time and can be used throughout the year irrespective of the relative humidity of air which is the main hindrance factor in solar dryers. Table 1 presents dimensions of the drying units obtained from the relevant design equations [8].

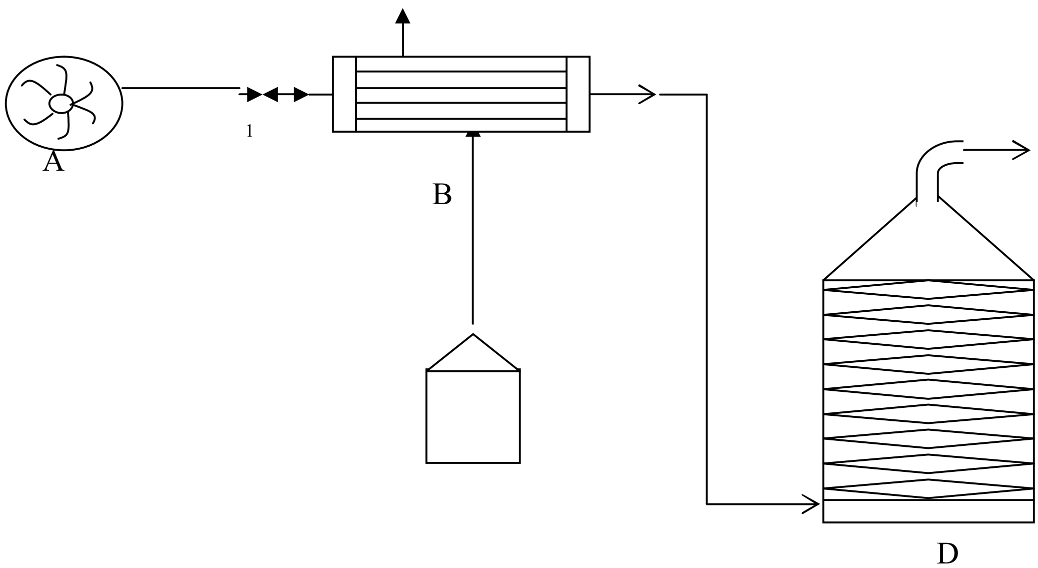

Fig . 1. A forced air- convection vegetable dryer.

Dimensions of the Drying Units

Table 1. Dimensions of the drying units based on the designed equation

Equipment	Item	Specification
Dryer	Material of construction	Plywood
	Capacity(max)	20kg/batch
	Number of trays	6
	Spacing between two trays	0.14m
	Height	1.2m
	Width	0.5m
	Breadth	0.5m
Heat exchanger	Material of construction	Galvanized steel
	Annular pipe diameter	$7x10^{-2}$m
	Outer pipe diameter	$8x10^{-2}$m
	Heating load	2.36kJ
	Air flow rate	9.3×10^{-2} kg/s
	Flow type	Counter-current
	Overall transfer coefficient	$38.49J/sm^{2\,0}C$
	Heat transfer area	$0.946m^2$
	Pipe length	4.3m
Blower	Material of construction	Aluminium
	Material thickness	$3x10^{-3}$m
	Total pressure head	457m
	Power required	1.5hp

Measurement of Air and Flue gas Flow rates

The velocity of drying air and flue gas were measured using orifice meter inserted along the air and flue gas flow pipes using water as manometer fluid [9]. The flow rates were controlled with a damper also inserted along the two pipes. The height of the manometer fluids for both the drying air and flue gas were measured and their velocities were calculated using equation (1) and presented in table 1.

$$V = \left[\frac{\frac{2(p_1 - p_2)}{\rho_a}}{\frac{D_1^4}{D_2^4} - 1}\right]^{0.5} \qquad (1)$$

Where V=velocity in m/s, p_1=pressure at any point before orifice plate in Pa, p_2=pressure at any point after orifice plate in Pa, ρ_a=density of air or flue gas kg/m^3, D_1= flow pipe diameter in m and D_2=orifice diameter, m.

The pressure drop ($p_1 - p_2$) in equation (1) was related to fluid densities and manometer height by equation (2).Thus;

$$\Delta P = (p_1 - p_2) = (\rho_f - \rho_a)gd \qquad (2)$$

Where ΔP=pressure drop in the pipe in Pa, g = acceleration due to gravity in m/s^2 and d = manometer height in m.

Measurement of Wet-bulb, Dry-bulb Temperatures and Relative Humidity

The wet-bulb temperature, dry-bulb temperature and relative humidity of the drying air were measured using a sling psychometer.This instrument consists of two thermometers mounted side by side and attached to a handle. One of the thermometer bulb was covered with a cloth wick (wet-bulb) and the other was kept dry (dry-bulb). Drying air was blown across the two thermometers and the two temperatures were noted and read out on a humidity table and the corresponding relative humidity was estimated and presented in table 2.

Table 2. Drying air conditions used in this study

Parameters	Value
Wet-bulb temperature, °C	22
Dry-bulb temperature, °C	33
Relative humidity,%	60
Heated air temperature, °C	57

Material Sourcing and Preparation

100kg of fresh okro and 50kg of fresh tomato were purchased from Institute of Agricultural Research farm, Ahmadu Bello University, Zaria, Nigeria. The okro was manually sliced with a knife to an average size of 3mm and 6mm while tomato was sliced to 3mm.

Determination of Moisture Contents

Initially, moisture contents of the okro and tomato were determined in accordance with the standard procedure described elsewhere [11]. 20kg of fresh sliced okro of size 3mm was charged into perforated shelf dryer with each shelf having 3.33kg. Heated air at 57°C from heat exchanger was sent to the dryer at the rate of $9.3x10^{-2}$kg/s to dry the okro. At interval of 20 minutes, sample of okro were collected from each shelf and weighed. The moisture evaporated was calculated using equation (3) until constant weight was obtained. Same procedure was repeated for okro of 6mm size and tomato of 3mm size.

$$M_E = W_o - W_t \qquad (3)$$

Where M_E = moisture evaporated at anytime in kg, W_o = initial weight of okro in kg and W_t= weight of okro at anytime t, kg.

Proximate Analysis

100g each of both fresh and the dried okro and tomato were analyzed in terms of Vitamin C, Phosphorous, Niacin, Protein, Calcium and Iron according to the procedure given by the Association of Official Analytical Chemist [11, 12].

RESULTS AND DISCUSSION

Moisture Contents Estimation

Figure 2 presents effect of moisture evaporation with time in okra of different sizes (3 and 6mm) and tomato (3mm). It can be seen that at the initial stage of the drying process an unsteady state condition was observed as shown by the relatively horizontal portion in the drying curve. At this condition, both the okra and tomato adjusted their initial temperature (33°C) to the temperature of the drying air (57°C) until steady state condition was reached represented by the decline portion of the drying curve. It is evident from Figure 1 that the unsteady state condition or warm–up period was 45 minutes for okro of size 3mm and 50 minutes for okro of size 6mm and that of tomato was 40 minutes. The slight difference in the warm-up period in okro (3mm and 6mm) is as the results of decreased in surface area exposed to drying.

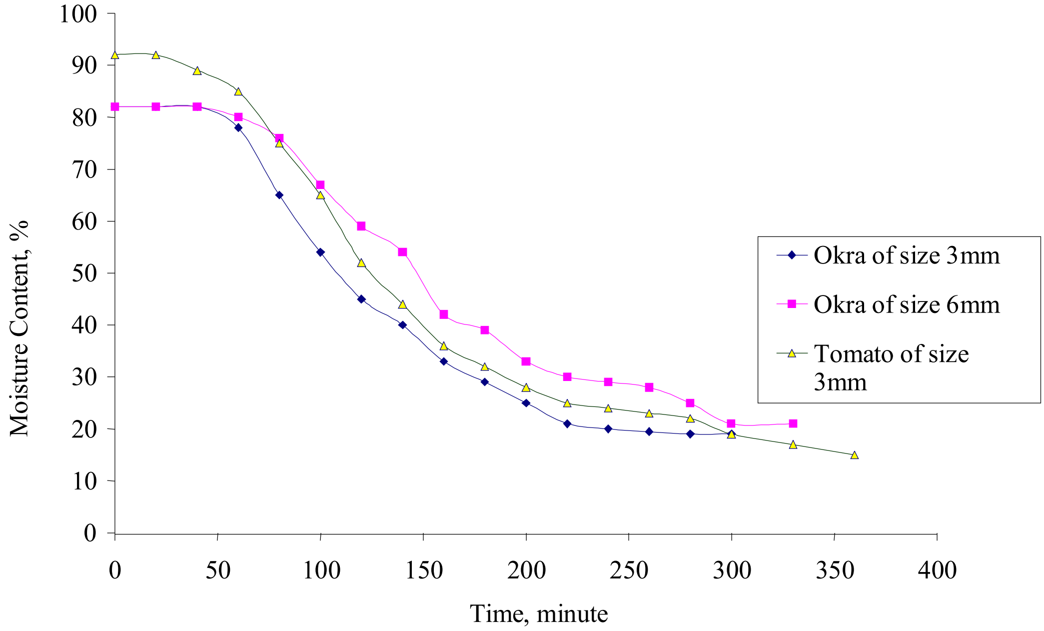

Fig. 2. Moisture content (wet basis) evaporated as a function of time.

At the end of warm –up period the moisture content uniformly decreased with increased in drying time and reached 280 minutes for okra of size 3mm,320 minutes for 6mm and 360minutes for tomato. These decreased in moisture content with time followed an exponential law of evaporation [13]. However, beyond these drying times (280,320 and 360 minutes), the moisture evaporation was insignificant and corresponds to equilibrium moisture content of 19% (wet basis) and 21% (wet basis) for okro of size 3mm and 6mm respectively. In the case of tomato, the moisture evaporation was insignificant beyond 350 minutes which corresponds to equilibrium moisture content of 15% (wet basis) under the same drying air conditions (see Table 2). Therefore, the average rate of moisture evaporation from both the okro and tomato was $8.99x10^{-4}$kg/s.

Effect of Drying Rate on Moisture Content

Fig. 3 represent rate of drying as a function of time. This drying rate curve was obtained by differentiating Fig. 2 at various times and moisture contents. It is evident from Fig.3 that at the initial stage of the drying process the drying rate significantly increased with time until it reached maximum of 7×10^{-2}kg water/minute for 3mm size of okro at a corresponding time of 80 minutes and 5×10^{-2} kg water/minute for 6mm size at a corresponding time of 95 minutes. In the case of tomato, maximum drying rate of 7.3×10^{-2} kg water/minute was achieved in 100 minutes. Beyond these drying times (80, 95 and 100 minutes),the drying rate of both the okra and tomato gradually decreased until no further drying occurred at 280 300 and 350 minutes for 3mm size(okra), 6mm size (okra) and tomato respectively. This difference in the drying rates is due to the fact that at the initial stage, the drying rate is mass transfer controlled process (constant- rate period) and at later stage is heat transfer controlled (falling- rate period) [14].

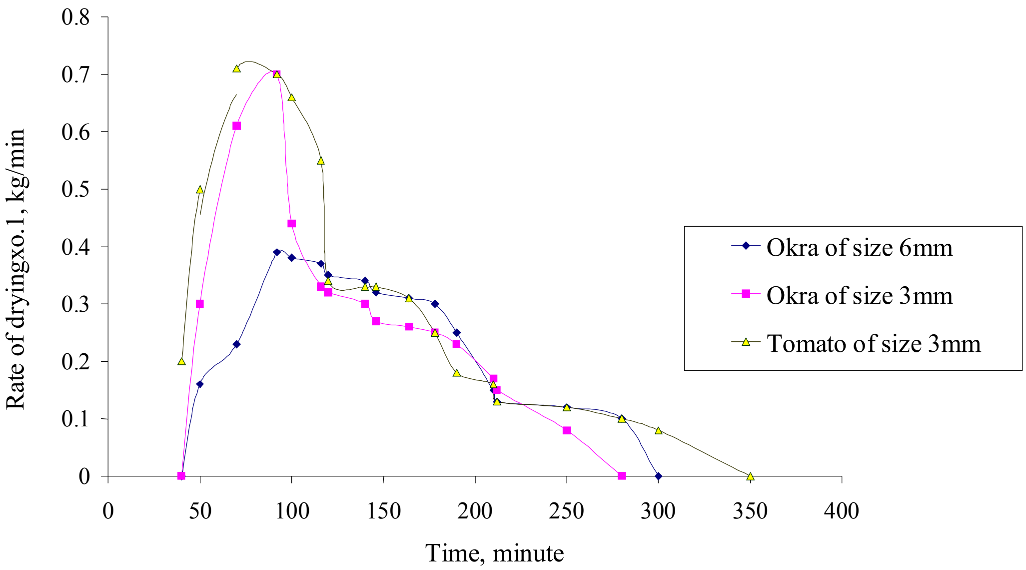

Fig. 3. Effect of rate of drying as a function of time

The effect of drying rate on moisture contents is shown in Fig. 4. It evident in Fig. 4 that for both okro and tomato, the rate of moisture removal slightly increased until it reached moisture content of about 58%.Beyond this moisture content, the drying rate sharply increased to a critical moisture contents of 70% for 3mm size, 72% for 6mm size of okra and 87% for tomato (peak points in Fig.4). At the end of this drying period, constant rate drying period began, in which case, drying proceed from the entire exposed surface saturated with water and the okra and tomato fibre not directly influencing the drying rates and was essentially controlled by heat transfer. At the end of the constant rate period drying regime, the drying process continued with diffusion being the rate controlling mechanism [8, 14]. The mechanism and consequently the rate of this water evaporation from the okro and tomato varied markedly with their structure which resulted in short constant –rate period and high critical moisture content (see Fig.4).

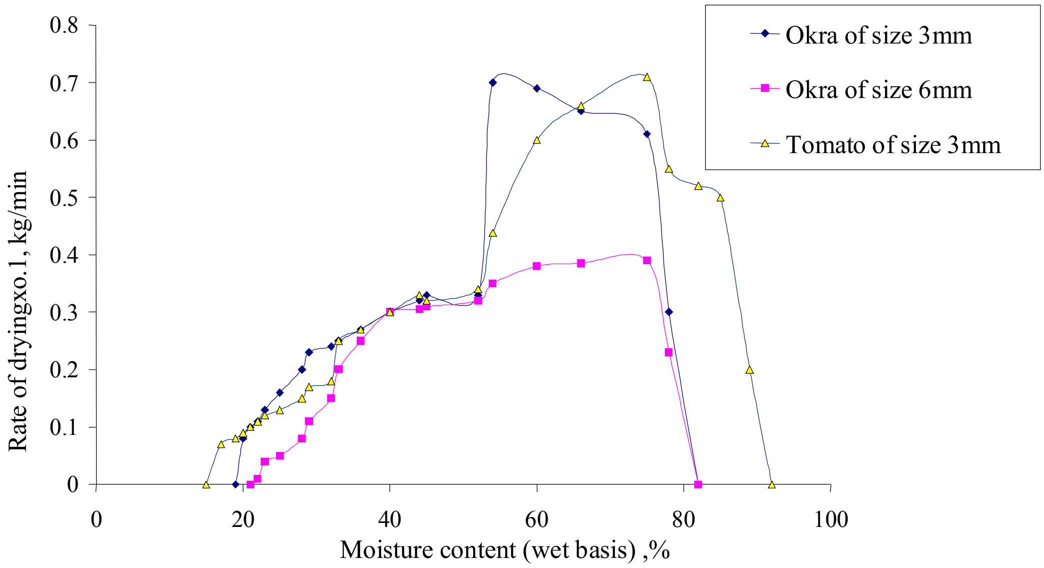

Fig.4. Rate of drying as a function of moisture content

Beyond critical moisture content, the surface of the okro and tomato became more and more depleted in water because the rate of liquid movement to the surface was slower than the rate of mass transfer from the surface due to the decreased in the surface area of the diffusion path and at this point the vapor pressure of water in the okro and tomato were equal to the partial pressure of water vapor in the incoming drying air and an equilibrium was reached [15]. The equilibrium moisture contents were found to be 19% for 3mm size, 21% for 6mm size of okra and 15% for tomato as shown in Fig. 2 and 4.

Proximate Analysis

Proximate analysis in terms of Protein, Calcium, Phosphorous, Iron and vitamin C of both okro and tomato presented in table 3 and 4 revealed that the results were in agreement with literature values [12,16]. The positive correlation of these results is an indication of the effectiveness of the drying system in terms preserving nutritive values of the okro and tomato.

Table 3. Analysis of fresh and dried okra (100g)

Nutrient and vitamin	Fresh	Dried	Literature value
Protein, g	2.0	1.9	2.1
Calcium, mg	80.1	79	84
Phosphorous, mg	73	71	71
Iron, mg	1.0	0.9	1.2
Niacin, mg	0.6	0.6	0.6
Vitamin C, mg	**45**	**44**	**47**

Table 4. Analysis of fresh and dried tomato (100g)

Nutrient and vitamin	Fresh	Dried	Literature value
Protein, g	0.8	0.7	1.0
Calcium, mg	1.2	1.2	1.1
Phosphorous, mg	26	24	27
Iron, mg	0.6	0.4	0.6
Niacin, mg	0.7	0.7	0.5
Vitamin C, mg	**24**	**21**	**23**

CONCLUSION

In this study, performance evaluation of designed and constructed forced-air convection vegetable dryer was carried out using okra and tomato. The conclusions derived from this work are as follows:

1. The drying period of okro was 5 hours and that of tomato was 5 hours 40 minutes as against minimum of 48 hours in open sun drying.
2. Increased in surface area of the okro increased rate of moisture evaporation and consequently decreased drying time.
3. The Initial, critical and equilibrium moisture contents of okro and tomato were estimated based on the drying conditions used in this work.
4. Proximate analysis of the okro and tomato remained unchanged before and after the drying
5. The dried okro and tomato were found to be free from dust, sand, metal pieces and any other form of contamination.
6. The dryer can also be employed in drying other plant material such as herbs particularly those that are sensitive to temperature beyond 60^oC.

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REFERENCES

[1] Keey, R.B. (1978). Introduction to industrial drying operation, The Pergamon Press Publishers, Oxford. 30-39.

[2] Brooker, D.B. and Fred, W.H.,(1974). Drying cereal grain. The AVI Publishing Company, West Port Connecticut. 24-30.

[3] Birewar, B.R. (1996). Development of improved on farm grain drying facility in Nigeria. J. of Agricultural Mechanization in Asia, Africa and Latin America., 27(2) :51-53.

[4] Arinze, E.A., Adefila S.S. and Eke, B.A., (1990). Experimental evaluation of various designs of free-convection solar crop dryer with and without thermal storage. Proceeding of National Conference of Nigerian Society of Agricultural Engineers*,* 15-19 June, 19-23*,* University of Agriculture, Makurdi, Nigeria.

[5] Eke, A.B. (1991). Experimental performance evaluation of laboratory and field solar and hybrids crop dryers. M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria.101-105.

[6] Munir, A. and, Abdul S.K. (1997). Design and construction of solar grain and fruit drying system. J. of Agricultural Mechanization in Asia, Africa and Latin America*.,* 28(3):62 – 66.

[7] Basuinia, M.A. and Abe, T. (2001), Design and construction of a simple three –shelf solar rough rice dryer. J. of Agricultural Mechanization in Asia, Africa and Latin America., 32(3):54-55.

[8] Mu'azu, K. (2007), Design and construction of forced air convection dryer. M.Sc. thesis, Ahmadu Bello University, Zaria, Nigeria.

[9] Harper, J.C. (1976). Elements of food engineering. The AVI publishing company, New York. 112-135.

[10] Ibitoye,A.A.,(2005).Laboratory manual on basic methods in analytical chemistry.Concept+ IT & Educational Consultants Ltd., Akure Nigeria.

[11] AOAC, (1984). Standard Official Methods of Analysis of the Association of Official Analytical Chemist. 14th ed. Williams S.W. Publishers, Washington DC.

[12] Madakson, P.B. and Okapi, S. (2004). A forced air domestic solar dryer. J. of Savannah. 19(1):107-122.

[13] Foust, A.S. (1960). Principles of unit operation. John Willey and Sons Inc. Publishers. New York. 400-465.

[14] Perry, R.H. and Green, D. (1980). Chemical engineers handbook,.7th ed. The McGraw – Hill Publishers, New York. 9- 38.

[15] Williams, C.N.P., Uzo, J.O. and Peregrine, W.T. (1991). Vegetable production in the tropics .The Longman Group Publishers, United Kingdom, 450-452.