CONSRUCTION OF A DIRECT SOLAR DRYER FOR PERISHABLE FARM PRODUCTS

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ABSTRACT

The use of the solar resource for food drying has always been a food preservation technique which is widely practiced in this part of the world but unfortunately some of the methods practiced in the rural areas, have been wrought with many disadvantages few of which are the poor quality of food derived and long drying time due to many external factors. The research looked into construction of a less technical direct solar dryer, which combined the concept of black body and thermodynamics with the aim of increasing the overall drying rate of the dryer. The dryer was designed primarily as a direct solar dryer. A set of selected samples of perishable farm produce were dried with the drier and another set in an open sun in a period of three days and was conducted at the same weather condition. The sample perishable farm produce used were Tomatoes, Okra and onion. The overall performance of the dryer after the total drying time reveals that the drying rate of the solar dryer was 2.1g/h, 3.8g/h, 2.4g/h faster than the open sun drying, and therefore requires less time for drying. This implies that the open sun drying rate is not satisfactory when compare to that of the dryer.

Keywords; *Solar Radiation, Open Sun drying, Weather condition, direct solar drying and indirect solar drying.*

1. INTRODUCTION

Drying is the process of removing moisture and in the case of drying of food; it is either to prevent the activities of microorganism for efficient storage or to reduce the bulk weight for easy transportation. It can sometimes be even a step in the food preparation process. Solar dryer expose the substance to be dehydrated in such a way that, it converts solar radiations that strikes its upper part into heat energy. In these systems the solar dryer is assisted by the movement of air (wind) that removes the more saturated air away from the items being dried.

Open sun drying is a form of drying where the food crops are directly exposed to the sun's radiation whereas a more advanced method, solar drying, houses the food in drying chambers and is directly or indirectly heated by the sun. Despite the numerous advantages of the solar drying over the open sun drying, the latter is the most preferred method in the rural areas particularly due to the fact that it is easy to execute and does not require great skill. Unfortunately this mode of drying has been wrought with many disadvantages one of which is the poor quality of food derived (Ekechukwu & Norton, 1998).

However, various researchers have found ways of improving upon this ancient method of drying in the form of the solar dryer. The solar dryer still harnesses the sun's energy but utilizes it more efficiently and subsequently results in better final products. Various forms of solar dryers exist and they vary from very simple direct dryers to more complex indirect designs (Action, 2008).

Properly designed solar dryers have the advantage of giving faster drying rates by heating the air to about 10-150C above room temperatures (Action, 2008), which reduces the relative humidity and causes the air to move faster through the dryer. The faster drying time of the solar dryer reduces the risk of Spoilage, improves quality of the product and gives a higher throughput.

2. THE OBJECTIVES OF THIS RESEARCH WORK ARE AS FOLLOW

Design and construct a direct form of solar dryer to harness solar thermal energy design and assemble solar dryer pertinent parts which includes; drying Chamber, glass lid, and air-vent allowance.

Test and evaluate the thermal performance characteristics of the fabricated Solar dryer on some selected vegetables.

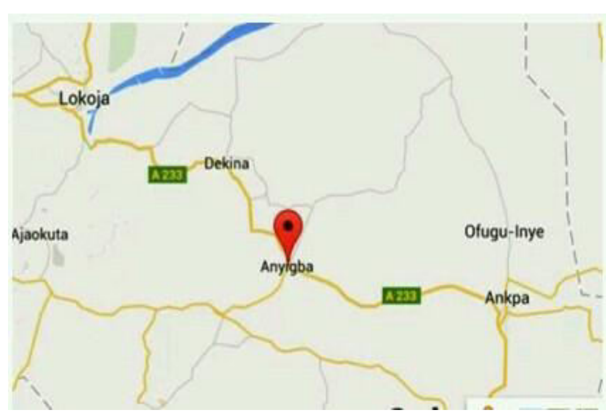

Figure 1: Google map of Dekina LGA of Kogi State

3. SCOPE OF THE STUDY

The scope of this research focused on the design and fabrication of solar vegetables dryer, appropriate for small scale farmers in AyingbaAnyigba is located in Dekina local government area of Kogi State, Nigeria and situated in latitude and longitude of 7.4934^0Nand 7.1736^0E, respectively with a mean air speed of3.64.7KM/hr. Average annualrainfall of 89.9mm and annual temperature range of 24.1^0-31.2^0C, and 71% humidity. The measured monthly mean values ofaverage temperature and wind speed were collected from a study of derived savanna environment through airborne palynomorphs, (scholars Academic Journal of Bioscience, page 314, 2013)

4. REVIEW

Drying of agricultural and marine products is one of the most attractive and cost effective application of solar dryer. Numerous types of solar dryers had been designed and developed in various parts of the world, yielding varying degrees of technical performance. The simplest of solar cabinet dryer was reported by (Fudoli, Ascagni, Appello, & Manhaeve, 2003). It was very simple, and consists essentially of a small wooden hot box. Dimensions of this dryer was 2 m × 1 m where the sides and base were constructed from wood and metal sheets. A transparent polyethylene sheet was used as cover at the upper surface. Air holes were located on the sides of the dryer for circulation.

Drying, particularly of crops, is an important human activity and globally the use of dried products is widespread. For preservation, quality improvement and processing purposes, moisture must often be removed from both organic and inorganic materials. Sun drying and mechanical dehydration using fossil fuels are the most common technologies used. Sun drying is a low-cost drying method but the final quality is variable, while mechanical dehydration is an energy intensive process and contributes substantially to energy use and green gas emissions. This type of dryer is a simple design and can be manufactured by farmers from local materials. It has a relatively moderate cost and is easy to use.

4.1 PRINCIPLE OF DRYING

The separation operation of drying converts a solid, semi-solid or liquid feedstock into a solid product by evaporating of the liquid into a vapor phase via application of heat. (Mujumdar & Devahastin, 2000).

The operation of drying by means of air current is of great importance at some stage of many industrial processes, and a knowledge of the fundamental principle on which the operation is based is necessary if the best result are to be expected in the performance of existing plant and if improvements are to be obtained in new designs. The rate of moisture remover is dependent of several factors which can conveniently be divided into two groups. One group embraces the physical properties of the material being dried; the other group includes the external factors known as the dried condition.

The drying condition include the temperature, relative humidity and velocity of the air, the relative geometrical arrangement of the dried substance and the air stream, and the presence in the dryer of heat radiating and conducting bodies. When any substance contain water, a vapour pressure is exerted at the surface corresponding to the temperature of the system, the water content, and the physical properties of the substance (Cowen, 1939).

4.2 OPEN SUN DRYING

Traditionally, farmers and housewives dry figs, grapes, cassava, tomato, okra and various other types of products by spreading them in thin layers on mats or on paved ground, in the field, thus expose them to the sun and wind. Despite many disadvantage associated with this system, it is still practiced in many places throughout the world where plenty of solar radiation is available. Drying is continuous process with changes in moisture content, air and crop drying and the humidity of air all occurring simultaneously. Heat is transfer. It is utilized in two ways; i.e. to increase the crop temperature in the form of sensible heat and in removal of moisture or, in other terms, mass transfer utilizing the latent heat vaporization. (Figure 2)

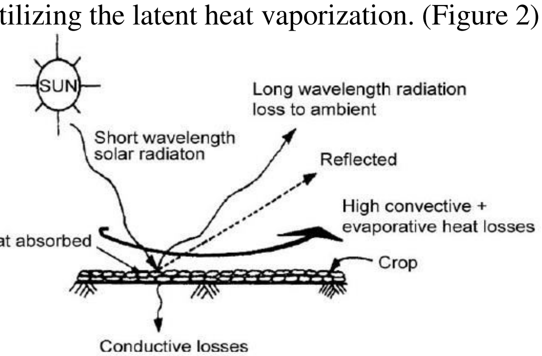

Figure 2: Working principle of Open sun drying Source:(Moore & Peterson, 2014).

An average traditional Nigerian mostly in the rural areas use the open sun drying methods of preservation on their produce like cassava, tomatoes, okra and lots more. A typical example can be seen in Figure 2. The figure shows chips of cassava being dried in open air in an open field.

The main advantages of sun drying are the low capital requirement and the fact that little or no skill is needed. However this type of drying has lots of disadvantages, some of which are exposure to dirty, microbes and animals. Unless the commodity is placed inside a shielded equipment, glass or thick plastic, getting dirt and microbes from surrounding environment.

Figure 3: Open Sun drying of cassava along Ajaokuta road, Anyigba

4.3 SOLAR DRYING

Solar drying is the drying of products in enclosed structures where the temperature of air surrounding the produce is usually higher than the ambient temperature of the dryer. It is a better means of increasing the quality of final dried product, reducing post-harvest losses and generally reduces the drying times as compared to open sun drying. (Zobaa, Canteli, & Bansal, 2011). The energy requirement for drying different products in solar dryers varies from the types of dryers, to the type of product being dried and also to the type of climate. It is usually determined from the initial and final moisture content of each product. Different types of food crops have different drying rates and maximum allowable temperatures.

In many cases, only a small temperature rise in the air is necessary to achieve proper drying conditions (Zobaa et al., 2011). In dealing with solar dryers, it is often useful to investigate some two key characteristic of the dryer before use. These are the drying rate and the drying efficiency. These indicators give an overall assessment of the dryer in relation to their performance. It can be used to effectively compare different types of solar dryers to be selected for use. The factors which have said to influence the drying efficiency are basically (Green & Schwarz, 2001):

a) Factors pertaining to the crop like the size, type of crop, the moisture content.
b) Factors relating to the peculiar characteristics of the dryer in question and
c) Factors relating to the environmental conditions such as the climate.

4.4 SOURCE OF SOLAR ENERGY

Solar energy is energy that comes from the sun. The sun is a common feature in our sky, it is seen crossing the sky from one extreme horizon to the other every day, giving us light and heat. Every day the sun radiates an enormous amount of energy (Green & Schwarz, 2001). The sun radiates more energy in one second than people have used since the beginning of time.

The average amount of solar energy radiated to Earth is about 1360kW/m2, depending on latitude and regional weather pattern (Babatunde, 2007). All this energy comes from within the sun itself. Like other stars, the sun is a big gas ball made up mostly of hydrogen and helium. The sun generates energy in its core in a process called nuclear fusion. During nuclear fusion, the sun's extremely high pressure and high temperature cause hydrogen atoms to break apart and their nuclei to fuse or combine. Some matter is lost during nuclear fusion. The lost matter is emitted into space as radiant energy. It takes millions of years for the energy in the sun's core to make its way to the solar surface, and then approximately eight minutes to travel the 93 million miles to earth. The solar energy travels to the earth at a speed of 186,000 miles per second, equivalent to the speed of light.

4.5 MAJOR FACTORS AFFECTING SOLAR DRYING WEATHER CONDITION

The performance of solar dryer is significantly dependent on the weather condition. Both the heat required for removing the moisture as well as the electricity necessary for driving the fans are generated in the most cases by solar energy only. In addition to the pre-treatment of the product, the weather conditions have biggest influence on the capacity of product that can be dried within a certain time period.

4.6 TEMPERATURE

Temperature has been defined by Seveda, Rathore, and Kumar (2011), as one of the main factors which affect the drying process most specifically the drying rate. Solar radiation received by a solar dryer is converted to heat which increases the temperature of the air in the drying chamber. This increase in temperature of the air in turn heats up the crop surface which causes the moisture in the crop to migrate to the surface and is vaporized.

4.7 SOLAR IRRADIATION

Solar irradiance can be referred to as the "the rate at which solar energy reaches a unit area on the earth" (Stine & Geyer, 2001). It is composed of three components; the direct normal, indirect and reflected solar irradiance.

4.8 RELATIVE. HUMIDITY

The Relative humidity is defined as "the ratio of the amount of water vapor in the air at a given temperature to the maximum amount of air at the same temperature" (Encarta, 2008).

4.9 MOISTURE CONTENT

Most agricultural food products which require drying contain some amount of water in their fresh state. This water which is also termed moisture, when present might render the products unsafe for storage as it might lead to deterioration. The initial phase where water is evaporated directly from the produce surface is the constant rate.

4.10 DIRECT SOLAR DRYING

Direct mode of drying usually consists of the drying chamber covered by a transparent material. This transparent material acting as the glazing, allows solar radiation into the chamber to heat up and increase the temperature of the air and the crop being dried. The main disadvantage of this type of dryer is its inability to control the crop temperature because of the direct absorption of radiation by the crop, which might cause some crops sensitive to sunlight to lose some of its nutrients e.g. Moringa.

4.11 INDIRECT SOLAR DRYER

These differ from direct dryers with respect to heat transfer and vapor removal. Figure 2.4describes the working principle of indirect solar drying. The crops in these indirect solar dryers are located in trays or shelves inside an opaque drying cabinet and a separate unit termed as solar collector is used for heating of the entering air into the cabinet. The heated air is allowed to flow through/over the wet crop that provides the heat for moisture evaporation by convective heat transfer between the hot air and the wet crop.

Drying takes place due to the difference in moisture concentration between the drying air and the air in the vicinity of crop surface.

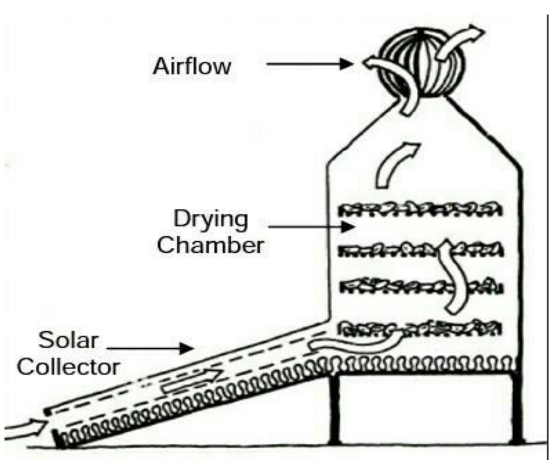

Figure 4: Working principle of an Indirect Solar Drying (ISD) Source; Sharma el ta 2009

The incident radiation is absorbed by another surface and converted to heat which is transferred by convection into the drying chamber to heat the crop located within the opaque chamber. This mode of drying is usually good for some vegetable or herbs or other food species which are colour sensitive or reduces in quality when exposed to direct sunlight especially food containing beta-carotene such as spinach, coriander etc.

This is an advantage the indirect mode has over the direct mode dryer. But the major disadvantage of this type of dryer is the financial involvement, in equipment and incurs larger maintenance costs than the direct drying units.

4.12 MATERIAL AND METHOD WORKING PRINCIPLE OF DIRECT SOLAR DRYING (DSD)

The working principle of direct solar crop drying is shown in Figure 2-3, also known as a solar cabinet dryer. The moisture is taken away by the air entering into the cabinet from below and escaping through the top exit as shown in the Figure. In the cabinet dryer, the total solar radiation impinging on the glass cover, a part is reflected back to atmosphere and the remaining is transmitted inside the cabinet. A part of the transmitted radiation is then reflected back from the crop surface and the rest is absorbed by the surface of the crop which causes its temperature to increase and thereby emit long wavelength radiations which are not allowed to escape to atmosphere due to the glass cover.

The overall phenomena cause the temperature above the crop inside the cabinet to be higher. The glass cover in the cabinet dryer thus serves in reducing direct convective losses to the ambient which plays an important role in increasing the crop and cabinet temperature

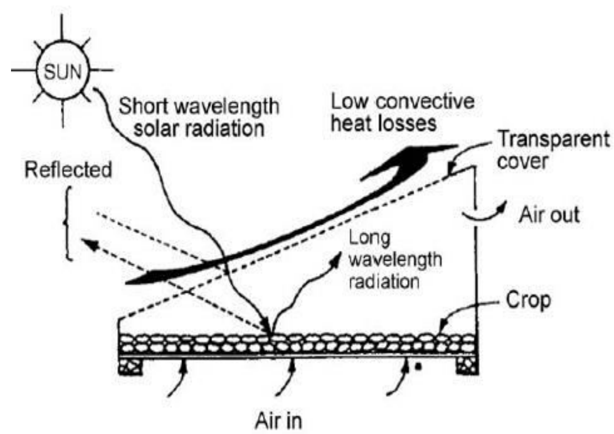

Figure 5: Working principle of direct solar drying.

4.13 TOTAL SOLAR RADIATION AND USEFUL HEAT GAINED BY DRY AIR LEAVING THE COLLECTOR

Due to the elliptical orbiting of the earth around the sun, the distance between the earthand the sun fluctuates annually and this makes the amount of energy received on the earth's surface (Isc) to vary in a manner given by Equation.

$$I_{SC} = I_{sc} * \{1 + 0.033 \cos \frac{360n}{365}\} \quad (1)$$

Where Isc is the solar constant which is valued at 1367 W/m2 and n is the day of the year which varies from n = 1 to n = 365. The direct solar radiation, I_b, reaching a unit area of a horizontal surface in the absence of atmosphere can be expressed as in Equation. 3

$$I_{b} = I'_{sc}\{\sin(\varphi-\beta)\sin\delta + \cos\delta\cos\omega\cos(\varphi-\beta)\} \quad (2)$$

Where φ is latitude (degrees), β is angle of inclination of surface from horizontal, δ is angle of declination (degrees) and ω is hour angle (degrees). The angle δ; (angle between the sun's direction and the equatorial plane) is evaluated from the Equation (3).

$$\delta = 23.45 \sin\{360 \frac{(284+n)}{365}\} \quad (3)$$

On the other hand, ω is computed by Equation (3),

$$\omega = 15\ (12 - H_r) \quad (4)$$

Where Hr. is the hour of the day in 24 hour time.

The total solar radiation, I_T.
IT incident on the horizontal surface is therefore given by adding the direct and diffused components of solar radiation as shown in Equation (3). The total solar radiation is of great importance for solar dryers since it captures the required components of solar energy that is harnessed in the dryer (Ezekoye & Enebe, 2006).

$$I_T = I_b(1 + 0.5C) \quad (5)$$

Moisture Content (M.C.):
The moisture content is given as:

$$MC(\%) = (\frac{M_i - M_f}{M_i}) \times 100\%$$; wet basis (6)Where;

M_i= mass of sample before drying and
M_f= mass of sample after drying.

The mass of water evaporated or moisture loss:

$$m_w = (\frac{m_i(M_i - M_e)}{100 - M_e}) \quad (7)$$

Where:
Mi = initial mass of the food item (kg);
Me = equilibrium moisture content
(% dry basis);
Mi= initial moisture content (% dry basis).

During the process of drying, water at the surface of the substance evaporates and water in the inner part migrate porosity of the substance and the surface area available. Other factors that may enhance quick drying of food items are; high temperature, high wind speed and low relative humidity

Average drying rate
Average drying rate, M_{dr}, is determined from the mass of moisture to be removed by solar heat and drying time by the following equations

$$M_{dr} = \frac{m_w}{t_d} \quad (8)$$

Where:M_{dr} = average drying rate, kg/hour;
mw = mass of water evaporated and
td= overall drying time

Dryer or drying process efficiency therefore is given as;

$$\eta_{syst} = \frac{(M_w \times L_v) + (M_g \times Cp_g \times \Delta T)}{Q_a} \quad (9$$

Where;
Qa =MaCpa ($T_{\text{into drying chamber}} - T_{\text{ambient temperature}}$),
Mw = mass of evaporated water, LV= latent heat of vaporization,
Mg = mass of the tomatoes dried, Cpg = specific heat capacity of the tomatoes and ΔT = change in temperature of the chamber. (Ezekoye & Enebe, 2006),

4.14 DESIGN CONSIDERATION
In designing a solar cabinet system the following points are considered;

a) **The amount of moisture** to be removed m_w from a given quantity of crop to bring the moisture content to a storage level in a specified time which is calculated from the equation below-
Equation:

$$m_w = m_p \frac{(M_i - M_f)}{(100 - M_f)} \quad (10)$$

Where;
m is the initial mass of the drying sample;
m_f and m_i are final and initial moisture content for storage on percent (%)-wet basis respectively.
m_p [kg] is the initial mass of product to be dried;
M_i [%] and M_f [%] wet basis are the initial moisture content and the final
Moisture content, respectively.

b) The mass of air needed for drying is calculated using equation given as follows:

$$\dot{m}_a = \frac{m_w}{t_d[W_f - W_i]} \quad (11)$$

Where:

m_w = amount of moisture to be removed, kg
w_f and w_i = final and initial humidity ratio, respectively, kg H2O/kg dry air
t_d = total drying time, hrs

c) Average drying rate
Average drying rate, mdr, would be determined from the mass of moisture to be removed by solar heater and drying time by the following equation:

$$M_{dr} = \frac{M_w}{t_d} \quad (12)$$

d) Absorber Surface Area;the surface area of the absorber A_{ab} is approximately equal to the area of the collector surface area, Ac; this is related to the length, Lc and width, W of the solar collector as follows:

$$A_{ab} = A_c = L_c \times W \quad (13)$$

e)Final relative humidity or equilibrium relative humidity; ERH **[%]** of moist air at the exit of drying process can be calculated using sorption isotherms equation given as follows

$$a_w = 1 - exp[-\exp(0.914 + 0.5639 \ln M)] \quad (14)$$

$$M = \frac{M_f}{(100 - M_f)} \quad (15)$$

f) The quantity of heat required to evaporate the water would be:

$$E = m_a(h_f - h_i)t_d \quad (16)$$

Where:

E = total heat energy, kJ, m_a = mass flow rate of air, kg/hr
h_f and h_i = final and initial enthalpy of drying and ambient air, respectively, kJ/kg_{da} read using psychometric charts, td= drying time, h

5. RESULTS AND DISCUSSION

The result of this research can be presented in two forms; the result obtained from the construction of the dryer, and the result obtained on the drying of the selected vegetables.

5.1 CONSTRUCTION RESULTS.

The dryer is essentially designed as a direct solar dryer which consists of wood, transparent glass, rubber tube, vent holes, hose and collection surface.
Since wood is poor conductor of heat, it was preferred over other materials for this construction, the interior part (the drying chamber) is equally made of wood of a black coated surface which makes it a black body. The glazing also allows direct solar radiation Incident parallelto the axis while the dryer is positioned to absorb the incoming solar radiation. By convention the hot air in the interior of the dryer are frequently passed out through the vent gaps situated at both sides of the dryer. The collector hose was fixed on the frontal and upper part of the dryer to harness condensed vapor in days of excesses heat and high evaporation rate. The dimensions of the dryer are all given in [table 1] below;

Table 1: The materials used and their measurements

S/N	Description	Dimension(inches)
1	Glazing	Thickness= 16mm Length = 33 Breadth= 17
2	Drying chamber	Length= 36 Breath= 19 Height= 9
3	Back view	Length= 13 Height= 24
4	Dryer's lid	Breath=17 Height= 13
5	Side view	Length= 36
6	Font view	Height= 18 Length= 13

Water Content of Samples (%);

i. Tomato- the average initial water content of fresh tomatoes is given as 98% of the total mass (g) in its wet basis, while 4% of the total mass was obtained after drying.
ii. Onion – onions contains an average water content of about 87% of its total mass (g) at their wet basis and 6% water content when dried.
iii. Okra – this contains an average water content of about 88% of it mass at its wet basis and 4% of its mass when dried, as shown in [table 2] below

Table 2: Average water content of tomatoes, onions and

Samples	Water content %	Dried %
Tomato	93	4
Onions	87	6
Okra	88	4

The average weight (g) of tomatoes is generally estimated based on the considerations of their size. [Table 2] gives the average weight of tomatoes based on their respective diameters and size. The average weight of onions is given as 0.11kg (110g), while an average weight of Okra measures 18g per fruit.

Table 3: Average tomato mass due on diameter

Size of tomatoes	Diameter	Weight
Large whole	3	182g
Medium whole	2-3/5	123g
Small whole	2/5	91g
A cherry	Less than 2/5	17g

5.2 MOISTURE CONTENT

From equation 3.18 the moisture content of each of these samples could be determined by

$$MC(\%) = \left(\frac{M_i - M_f}{M_i}\right) \times 100\%;\ \text{wet basis} \qquad (17)$$

Where; m_i = mass of sample before drying and M_f = mass of sample after drying.

Medium whole tomatoes are used in course of the experiment. From table 3 above the average mass is given as 123g and table 2 gives the water content before and after drying, therefore the mass of each sample before and after drying m_i, m_f can be calculated using equation 3.18 above;

- ***Tomato;*** the initial weight is given by $\left(\frac{123}{100} \times 93\right) = 114.39g \ldots\ldots mi$

  Also from table 2 dried tomatoes contains 4% water content, thus the final weight will be given as; $\left(\frac{123}{100} \times 4\right) = 3.64g \ldots\ldots Mf$

  ⇨ The moisture content (MC)= $\left(\frac{114.39-3.64}{114.39} \times 100\right) = 96.82g$

- ***Onion;*** the initial weight is given by $\left(\frac{87}{100} \times 110\right) = 95.7g \ldots\ldots mi$

  Also from table 2 dried onions contains 6% water content, thus the final weight will be given as; $\left(\frac{110}{100} \times 6\right) = 6.60g \ldots\ldots Mf$

  ⇨ The moisture content; $MC(\%) = \left(\frac{M_i - M_f}{M_i}\right) \times 100\%$; wet basis = $\left(\frac{114.39-3.64}{114.39} \times 100\right) = 96.82g$

- ***Okra;*** the initial weight is given by $\left(\frac{88}{100} \times 18\right) = 15.84g \ldots\ldots mi$

  Also from table 2 dried okra contains 4% water content, thus the final weight will be given as; $\left(\frac{4}{100} \times 18\right) = 0.72g \ldots\ldots Mf$

  ⇨ The moisture content; $=\left(\frac{15.84-0.72}{15.84} \times 100\right) = 96.82g$.

From the experimental data gotten, and by observation the total drying time, effective drying time (hr), moisture content (MC), change in colour of samples (after drying) and the pungent aromas of okra, onions and tomato were compared as shown in table 4.

5.3 AVERAGE DRYING RATE

From equation 3.20, the average drying rate, M_{dr}, is determined from the mass of moisture to be removed by solar heat and the total effective drying time is shown below:

$$M_{dr} = \frac{m_w}{t_d}$$

Where:

M_{dr} = average rying rate, kg/hour; mw = mass of water evaporated and td= overall drying time.

⇨ The average drying rate of tomato of tomato using;

Solar dryer is given by $\left(\frac{93}{10}\right) = 9.3g/hr$

Open sun is given by $\left(\frac{93}{13}\right) = 7.2g/hr$

Okra

The average drying rate of okra using;solar dryer is given by: $\left(\frac{88}{7}\right) = 12.5g/hr$

Open sun is given by: $\left(\frac{88}{10}\right) = 8.8g/hr$

For **Onion;** solar dryer; $\left(\frac{87}{12}\right) = 7.25g/hr$

While by direct sun is $\left(\frac{87}{18}\right) = 4.83g/hr$.

The average drying rate of both the solar dryer and open sun can also be seen in comparison in [table 4] below

Table 4. Comparative table of all the samples. Source; from the text, observation and assumption

S/N	Crop	Nature of crop	Method of drying	Average drying rate; $M_{dr}=M_w/t_{dg}$ /hr	Total drying time (hr)	Effective drying time(hr)	Moisture content(MC) Wet basis (%)		Colour rated on 5-point scale	Pungent Aroma rated on 5-point scale
							Initial MC	Final MC		
1	Fresh Tomato									
		Dried	Solar Drier	9.3	27:5m	9h:33m	93	3	4	1
			Open Sun	7.2	27:15m	13h:06m	93	4	5	1
2	Fresh Okra									
			Solar Drier	12.6	25h:3m	7h:26m	88	4	5	1
		Dried	Open Sun	8.8	24h:25m	10h:14m	88		4	1
3	Fresh Onion									
			Solar Drier	7.25	47h	12h:20m	87	6	4	2
		Dried	Open Sun	4.83	46h	18h:06m	87	6	4	4

The curve of the average drying rate for all the samples (onion, tomato and okra) based on the table 4 above is as shown in figure 6 to figure 8 Below;

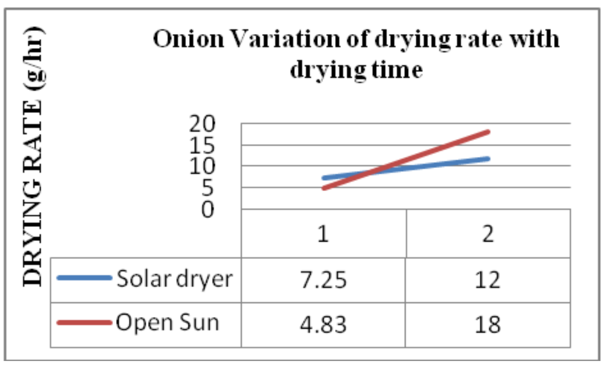

Figure 6; Variation of Drying Rate with drying time (hour) of onion using solar dryer and open sun. Source; from table 4 above

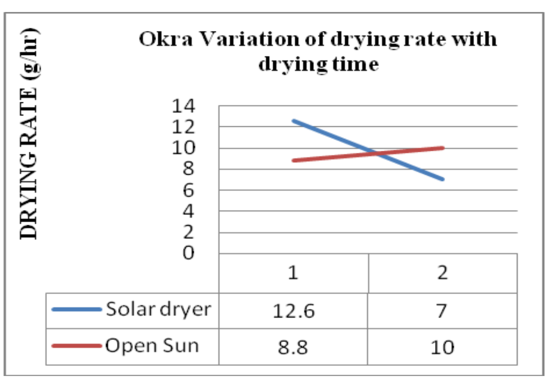

Figure 7; Variation of Drying Rate with drying time (hour) of okra using solar dryer and open sun. Source; from table above.

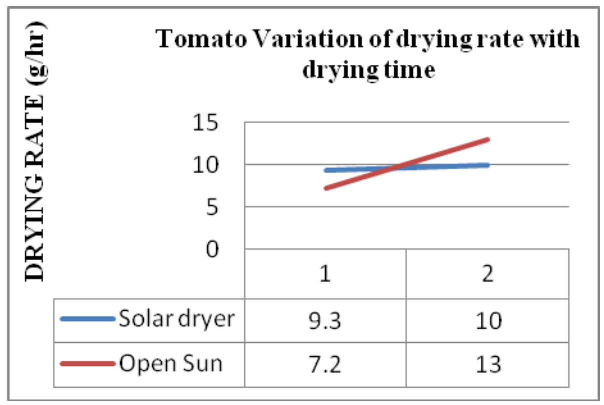

Figure 8;Variation of Drying Rate with drying time (h) of Tomato using solar dryer and open sun. Source; from table 4 above

6. DISCUSSION

Figure 6-8 shows the drying curve obtained for Onion, Okra, and Tomato during the open sun and solar drying.It was attained by plotting the drying rate versus drying time for the effective drying duration for both kinds of drying method.

Onion

Figure 6 shows the variation of drying rate of onion with effective drying time and from the curve, it is shown that, the drying rate of solar dryer is 7.25gram per hour while the open sun system dried at a rate of 4.83 gram per hour. This implies that, the rate at which moisture is been removed from the okra inside the direct solar dryer is 2.42g higher than those spread directly under the sun. It also implies that due to this variation in the drying rate, the onion under-go the drying process for extra 6 hours with the open sun method before it satisfactory dried.

Okra

Figure 7 shows the variation of drying rate in Okra with drying time. From the curve it is shown that, the drying rate of solar dryer is 12.6g/hr gram per hour while the open sun system dried at a rate of 8.8g/hr. This implies that, the rate at which moisture is been removed from the onion inside the direct solar dryer is 3.8g higher than those spread directly under the sun. It also implies that due to this variation in the drying rate, okra spent 3hours in the drying process more than those dried using solar dryer

Tomato

Figure 8, also shows that higher time is required in the drying of tomatoes in an open sun process than the solar dryer method of drying. Since the drying rate is higher with the later, the drying process became faster, and from the table the moisture remover rate is 2.1gram higher in solar dryer than the open sun drying method.

7. CONCLUSION

A comparative analysis of the drying rate of the solar dryer and open sun drying concludes that the solar dryer performed better. This was confirmed by the very low average drying rate of the open sun drying system calculated in cause of this research work which was found lower when compare to the average drying rate for all the samples. The open sun drying method did not also record any appreciable decrease in drying hours for all what is been dried with its corresponding solar dryer method. However, the dried samples using solar dryer, (by observation) was found with less pungent and offensive aroma when samples compared to the former.

Visible light is produced within the spectrum of electromagnetic energy that includes radio waves, microwaves, X-rays and ultraviolet (UV) rays, this cause of fading is due to a photochemical reaction involving UV and visible light.

Shorter period of time are required for drying farm perishable farm produce using the solar dryer method. With the aid of this method the rate of food wastage, damages caused by mucus, sudden rain on produce while drying can be greatly victimized.

8. RECOMMENDATION

- It is recommended that in order to improve the overall dryer efficiency, the solar dyer should have a lot of air-gaps for effective hot air circulation in and out of the drying chamber or to be constructed in such a way that any affordable type of drying alarm should be put in place to avoid adverse effect of an excessive heat on samples after they are dried up.
- It is also recommended to use a metallic drying tray for drying in the drying chamber.
- Glazing material selected should also have high transmittance value.

REFERENCE

[1] Action, Practical. (2008). Promoting adaptation to climate change in Nepal. *Policy Briefing, Nepal*.

[2] Babatunde, Elisha. (2007). Solar Energy, A Friendly Renewable Energy Option for Nigeria. *Solar Energy, A Friendly Renewable Energy option for Nigeria, 1*(15).

[3] Cowen, W. (1939). Some principles of drying. *Coloration Technology, 55*(6), 290-302.

[4] Ekechukwu, OV, & Norton, B. (1998). Effects of seasonal weather variations on the measured performance of a natural-circulation solar-energy tropical crop dryer. *Energy conversion and management, 39*(12), 1265-1276.

[5] Encarta, MSN. (2008). Online Encyclopedia. *Dictionary, Atlas and Homework-Windows Internet Explorer http://encarta. msn. com, 15*.

[6] Ezekoye, BA, & Enebe, OM. (2006). Development and performance evaluation of modified integrated passive solar grain dryer. *The pacific journal of science and technology, 7*(2), 185-190.

[7] Fudoli, Alessandra, Ascagni, Alberto, Appello, Davide, & Manhaeve, Hans. (2003). *A practical evaluation of I/sub DDQ/test strategies for deep submicron production test application. Experiences and targets from the field.* Paper presented at the Test Workshop, 2003. Proceedings. The Eighth IEEE European.

[8] Green, Matthew G, & Schwarz, Dishna. (2001). Solar drying technology for food preservation. *GTZ publication Eschborn, Germany*.

[9] Moore, Erin E, & Peterson, E Eva. (2014). *SELCO Credit Union: a case study in quantifying the environmental impacts of design for deconstruction.* Paper presented at the ARCC Conference Repository.

[10] Mujumdar, Arun S, & Devahastin, Sakamon. (2000). Fundamental principles of drying. *Exergex, Brossard, Canada*.

[11] Seveda, Mahendra S, Rathore, Narendra S, & Kumar, Vinod. (2011). Solar Tunnel Dryer—A Promising Option for Solar Drying. *Handbook of Renewable Energy Technology*, 289-320.

[12] Stine, William B, & Geyer, Michael. (2001). *Power from the Sun*: Power from the sun. net.

[13] Zobaa, Ahmed Faheem, Canteli, Mario Manana, & Bansal, Ramesh. (2011). *Power quality: Monitoring, analysis and enhancement*: Intech Open Access.