Kabarak Journal of Research & Innovation Volume 5 Number 2 (2018)
ISSN 2305-784X (print) ISSN 2410-8383 (online) http://eserver.kabarak.ac.ke/ojs/

Evaluation of Performance of a Solar Tunnel Crop Dryer in Drying of Two African Indigenous Vegetables (AIVs)

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Submitted: 20th January 2017; Accepted: 14th February 2017; Published online: 15th February 2018

Abstract

Two AIVs dried were the black night shade (*solanum scabrum*) and the spider plant (*cleome gynandra*) and were spread as a thin layer on the tray during the drying processes. The tray carrying the vegetable was placed next to the outlet section of the dryer and the side towards the inlet was left bare to act as absorber plate to preheat air before passing over the drying product. The hot air from the free absorber plate supplement the heat absorbed directly by the product from the solar radiation penetrating through the transparent cover hence enhances the drying rate. The results show that the area has over six hours of peak solar hours (6 PSH) when insolation is over 1000 W/m^2; hence the site has sufficient solar energy to dry up the vegetables. The average efficiency of the dryer was determined as 24.3% and the moisture content of the spider vegetable was reduced from 88.4% to 21.0% in 2 days while that of black night shade reduced from 84.5% to 26.3% in 3 days. In addition, the drying profiles of the two vegetables consisted of four stages, with drying rates varying from 4.3 g/hr to 22.4 g/hr for spider vegetable and 2.4 g/hr to 23.7 g/hr in black night shade. Hence, the prototype dryer proved to be effective in drying both vegetables and has a relatively good efficiency.

Key words: Drying rate, vegetable, moisture content, efficiency and solar radiation, solar dryer

1.0 Introduction

Agriculture is considered as the economic backbone of most of the African countries, and both cash and subsistence crops contribute to its realization though with different proportions. For several decades, various challenges have been experienced in crop production in Africa.

Natural calamities such droughts or diseases infestations are major challenges affecting the crops while still in the farms and results usually in low yields. In addition, lack of use of mechanized systems, non-use of quality seeds and lack of post-harvest preservation methods have been cited also as further causes of the low crop yields in Africa.

The postharvest losses of food crops in the African continent is a challenge that can be mediated effectively by employing simple and cheap scientific methods to dry the crops to the right moisture content (MC) for long term storage without spoilage (Klaus, 2009). Africa is endowed with favorable climate throughout the year, where abundant sunshine is available for many hours per day even in rainy seasons. This natural resource can be tapped and used efficiently for drying of the food crops to proper MC levels for proper storage and preservation. Since time in memorial, open sun drying (OSD) of crop have been the practice or norm but various challenges are associated with this method especially the product quality. The OSD method is extremely weather

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dependent and is associated with many problems such as contamination, infestation, microbial attacks, and many other adverse effects. Additionally, the drying time required for a given commodity can be quite long and results in huge post-harvest losses (Forson *et al.*, 2007). Fortunately, scientific methods which address the challenges encountered in the OSD have been developed and used in some parts of the world, including African though on a lower level. With the high rate of population growth and unreliable rains, food production requires proper methods to reduce the huge post harvest losses and have adequate food reserves that last till the next harvest season (David and Whitfield, 2000).

The use of convectional energy as the driving energy in crop dryers is credited with faster rate of drying but it also suffers from high running cost and causes environmental pollutions hence not very useful for African continent given the economic status of prospective users. The use of renewable energy, especially solar energy, is considered as the most practical and economical method for crop drying in the African continent due to its huge endowment of this natural resource. The solar crop drying has several advantages over the open sun drying method. It dries the crops at a faster rate, efficient because it improves heat harnessing from the sun, economical because it can be constructed from cheap materials, uses free solar radiation and is environmentally benign (Akinola, 1999; Jensen, 2002; Akinola and Fapetu, 2006). In addition, solar crop dryers can be designed to meet the demand and is hygienic (Klaus, 2009). In other words, it is modular hence can be sized for both large and small scale drying, with the later being very useful for small scale farmers, who form the bulk of most prone population. Since solar crop driers can be constructed from locally available and cheap materials, and they need low running cost, renders them very economical for crop drying by peasant farmers (Jensen, 2002).

1.1 Solar crop driers

A solar crop dryer utilize the energy of the sun and hot air mass to dry agricultural products and prepares them for either proper storage or processing or even export. The dehydration of Agri-food products using solar energy is considered as a cheap and viable method for food crop drying in the African continent given the huge potential of solar energy (sunshine for that matter) throughout the continent as well as throughout the year. The solar dryers enhance the drying rates by combining direct heating of the crops by the transmitted solar radiation through transparent walls and roof and hot air mass pre-heated by an auxiliary flat-plate thermal collector attached to the dryer. The use of solar energy for crop drying is specifically ideal for vegetables and fruit crops because of their nature and typical quantities involved.

African Indigenous Vegetables (AIVs) is a name given to edible leaves of species growing wild as weeds specifically in the African continent (Abukutsa, 2007; 2010). These vegetables were eaten traditionally in large quantities but with the coming of exotic vegetables, many people reduced or even abandoned consuming them. However, the trend has changed more recently where more and more people all over the world are reverting back to consumption of AIVs in large quantities, and these vegetables are now available in both local and international markets. Vegetables are a vital component of human diet as they provide essential micronutrients that ensure proper development of the human body and good health. Vegetables have also been known to contain substantial amounts of chemicals normally classified as anti-oxidants. These chemicals are essential for scavenging and binding harmful radicals in the body and if left unchecked could cause diseases like cancer and diabetes. Most of the AIVs are highly perishable with a shelf life of less than 24 hours at room temperature (Abukutsa, 2007), hence needs proper preservation immediately after its harvesting. Many researchers in the horticulture sector, especially vegetable farming, have been seeking economical and sustainable drying methods in order to increase the shelf life and for value addition for their products. Solar driers can provide an efficient, low cost and easy to operate drying method for the AIVs at the place of production, i.e. in the farms.

The drying beds solar crop driers are painted black to enhance absorption of solar radiation and a provision of hot air inlet at the bottom of the dryer and exhaust flaps at the top are some of the major construction considerations included. The drying chamber is enclosed using transparent cover either glass or polythene paper. The moisture released from drying sample, slows down the drying rate or re-hydrates the crop; hence it is necessary to be removed immediately. The moisture laden air mass above the crop may be removed effectively by using an air fan, but requires source of electricity. The need for electrical source can be solved by using the photovoltaic (PV) panel. Since the PV system converts solar energy into electricity directly and modular, it can be sized to meet the load demand of the fan. In addition, the fan speed will be regulated naturally, where high sunshine will generate high power which in turn increases fan speed and hence increases air mass flow-rate and vice-versa.

In this study, one type of solar crop dryer, which is simple to construct using locally and cheap materials, was considered for drying of two indigenous vegetables commonly consumed in the Baringo County, Kenya. This county is among the regions classified as Arid and Semi-Arid Lands (ASAL) and during drought season, the place is completely dry and there is acute shortage of green vegetables. The vegetables harvested during the rainy seasons may be dried effectively and hygienically using solar energy and preserved for use in the dry seasons of the year. The tunnel type solar crop dryer was selected for use in this work because of its simplicity in construction and cost. The dryer was designed and experimented on to investigate its performance in drying of black night shade and spider plant under the local climate.

1.2 Drying kinetics

During the drying process of a product, its water content, called moisture content, is driven out and lost as vapor to the surrounding air. Several empirical equations have been formulated for analyses of drying kinetics of the samples being dried, and some of these equations are presented in this section.

The moisture content on wet basis (Mc_{wb}) can be expressed as a percentage of initial weight as follows:-

$$Mc_{wb} = \frac{(W_i - W_f)}{W_i} \times 100 \qquad (1)$$

1.3 Dryer efficiency

Solar dryers raise the drying chamber temperature to a higher value for effective drying. The efficiency, η_d of solar dryer system can be obtained using the following relation (Tiris and Dincer, 1996):

$$\eta_d = \frac{M_w L_V}{I_C A_c t} \qquad (2)$$

where I_C is incident solar radiation on the plane of the collector (W/m^2), A_c is the area of solar collector (m^2), and t is time (s).

2.0 Material and methodology

The data in this work were measured experimentally on the designed and constructed solar tunnel crop dryer (STCD).The major parameters considered were temperatures at various parts in the STCD such as inlet air temperature, which is also the ambient temperature (T_a), the temperature inside the STCD (T_d), outlet temperature (T_{out}), and solar radiations striking the transparent polythene cover on the outside (S_{out}) and that transmitted into the inside (S_{in}).The parameters were measured after every 15 minutes between 8.00 am and 4.00 pm each day while the mass of the products placed in a drying tray were measured after every one hour between 8.00 am and 4.00 pm daily until final moisture content was attained

2.1 Construction Materials and Instrumentation

The STCD was constructed from locally available material so as to make it economical mainly for the peasant farmers who are financially handicapped. Temperature, solar radiation and moisture content of the two crops dried were the measurements carried out.

The materials used for the construction of the dryer were:

(i) Transparent polythene paper cover.
(ii) Metallic absorber plate.
(iii) Timber boards and frames.
(iv) Nails.
(v) Flexible PVCpipes(diameter 1 cm).
(vi) Thin polyurethane foam.
(v) Air fan (model: KL-2390 and 19W).
(vi) PV module (9W).

The measuring instruments used, which depends on type of measurement, were:

(i) Pyranometer (model: LPO2).
(ii) Voltmeter (model: DT9205A).
(iii)Type-K Thermocouple (nickel – chromium alloy).
(iv)Digital thermometer (model: TM 305B).
(v) Digital balance (model:SF-400).,
(vi)Metallic tray.

This study focuses on solar drying of two types of AIVs, which were:

(i) Spider plant vegetables (*cleome gynandra*).
(ii) Black night shade vegetables (*solanum scabrum*).

2.2 Construction of the dryer

The STCD was designed and constructed using locally available materials. Figure 1 shows the structural appearance of the dryer that was build and used to dry the crops.

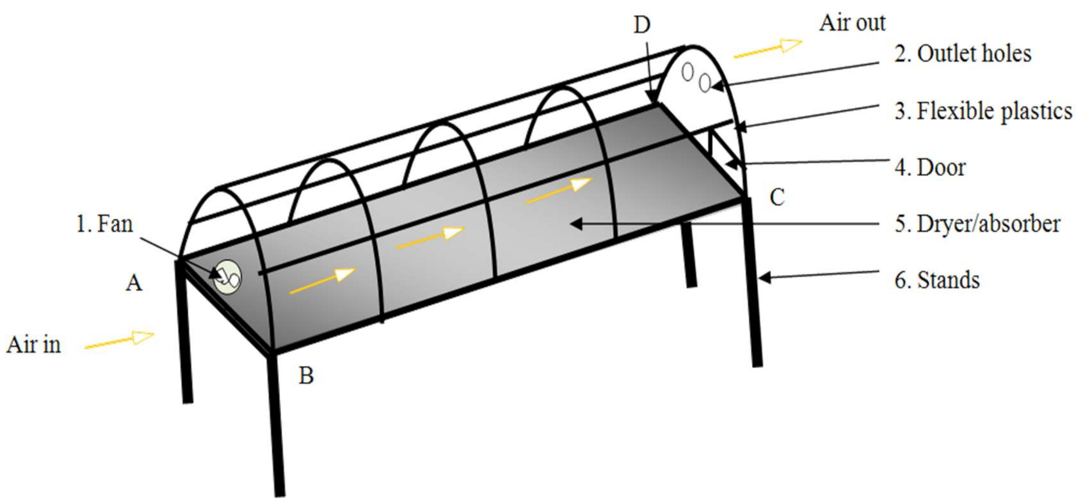

Figure 1: Layout of the structure of STCD.

The STCD system constructed measured 1.65 m long, 0.9 m wide and 0.3 m high. The dryer was provided with four stands of 0.6 m high to raise it above the ground. The wooden frames were used to construct the structural layout or frame work including the stands. The nails were used for fastening the frame works together.

The timber was used to construct the base of the STCD in order to provide a strong mechanical support for the metallic absorber plate placed on top of it. In between the base and the absorber plate, a thin polyurethane sponge was placed to provide additional insulation on the back of the absorber plate in order to reduce back losses by conduction heat transfer process. The front side of the absorber plate was painted black in order to increase radiation absorption and fixed into the wooden base using nails.

The roof of the longer side of the STCD was constructed with a parabolic shape using the PVC pipes, which also doubles as a mean of stretching smoothly the cover. The shorter sides of the STCD had a gable structure and the inlet and outlet were provided on these sides. The highest point of the gable end of the STCD was 0.3 m. The walls and roof of the STCD was then covered with the transparent polythene paper to let the solar radiation enter and be trapped inside the drying chamber due to greenhouse effect raising the drying temperature.

The inlet and outlet for air flow were provided on opposite gabled sides (Figure 1). An air fan was fitted on the air inlet to suck in ambient air, which is then heated by absorber plate before passing through the sample being dried. The drying rate increases with air flow rate hence the air fan is necessary to increase the flow rate. To reduce the operating costs of the forced flow mode and also to take care of areas with no electricity supply, a photovoltaic module was used in this study to provide power to run the fan. The moist laden air inside the STCD was let outside the drying chamber through outlet holes. Figure 2 shows the actual pictures of the complete STCD used for experimentations.

Figure 2: Pictures illustrating experimental model of STCD.

2.3 Experimental Measurements

The samples of the vegetables dried were placed on a metallic tray and placed on the absorber plate towards the outlet end. The use of the tray to hold the drying samples was necessary to ease the process of loading and unloading the sample during the periodic process of measuring the mass in order to determine the moisture content of the drying sample. The section of the absorber near the air inlet port was left bare so as to act as absorber plate for pre-heating of inlet air before passing through the sample.

Various operating parameters were measured which included solar radiation (both inside and outside), ambient temperatures (inside and outside), inlet and outlet temperature. The moisture content of the drying vegetables was also measured.

2.3.1 Solar and ambient temperature measurements

The solar intensity inside and outside the STCD were measured using a pyranometer (SP LITE model). The pyranometer sensor is basically a solar cell which converts solar energy into electricity and has a sensitivity of 74µV/ (Wm^2) as calibrated by the manufacturer. The output voltage of the pyranometer was measured by a digital voltmeter that was set in the range of 0-200 mV and the readings were converted into solar isolation using the sensitivity given above. The solar radiation was measured both inside and outside the drying chamber of the STCD at horizontal levels. Figure 3 shows the pictures of the pyranometer and digital voltmeter respectively used.

Figure 3: Pictures of (a) Pyranometer, and (b) digital voltmeter.

Temperature, absorber plate temperature, and inlet and outlet air temperatures were measured by using Type-K Thermocouple an alloy of Nickel and Chromium. A digital thermometer was used to read the temperatures and Figure 4 shows the picture of the Type-K thermocouple hooked to the digital thermometer used for temperature measurements.

Figure 4: Picture of the Type-K thermocouple (Attached at top) and digital thermometer.

2.3.2 Moisture content measurements

As the vegetables dry, they dehydrate hence their moisture content decreases. The decrease or loss of moisture content of the drying samples was measured at intervals of one hour during drying process by measuring the mass of the sample. The mass of the empty tray was first measured and recorded and then a sample of the vegetable was placed on it and measured again before returning the tray and its content inside the STCD. A digital balance was used for the mass measurements.

The moisture loss by the drying sample was monitored until it reached the final moisture equilibrium, called equilibrium relative humidity (ERH), where the sample mass remained constant. At the end of each day's drying session, the sample was left inside the chamber in a dark cool room overnight but covered with a polythene paper to minimize further loss of moisture in order to proceed with the process the following day. The air fan (model: KL-2390) driven by a PV module (solar panel of 8 W) was used to force the air flow inside the STCD chamber in order to increase the flow rate hence drying rate.

3.0 Results and discussions

Results obtained experimentally on the drying of the two vegetables (spider plant and black night shade) are presented. The drying conditions and the MC reductions were measured and the data collected tabulated and analyzed using the common spreadsheet software (Origin). The drying conditions include solar radiation, ambient temperature and dryer temperatures at various locations within the drying chamber. The MC reduction was measured by measuring the mass of the product and the drying were continued on subsequent days till the final equilibrium MC was attained and then the drying was stopped for that particular batch. Several drying batches of the two vegetables were used and experiments were done between December, 2014 and March, 2015 in Baringo County, Kenya located at latitude $0^{0}28'00''$N, longitude $35^{0}38'00''$E and altitude 1090 m. The experiments were started at 8:00 am and continued till 4:00 pm, on specific days with clear sky conditions.

3.1 Drying conditions

Figure 5 presents representative results on the drying conditions and it shows the typical solar radiation and temperatures variation measured during the drying of the spider vegetable in the month of February, 2015. These results show that all the parameters increases when the experiment is started and attained almost constant values but at different times of the day.

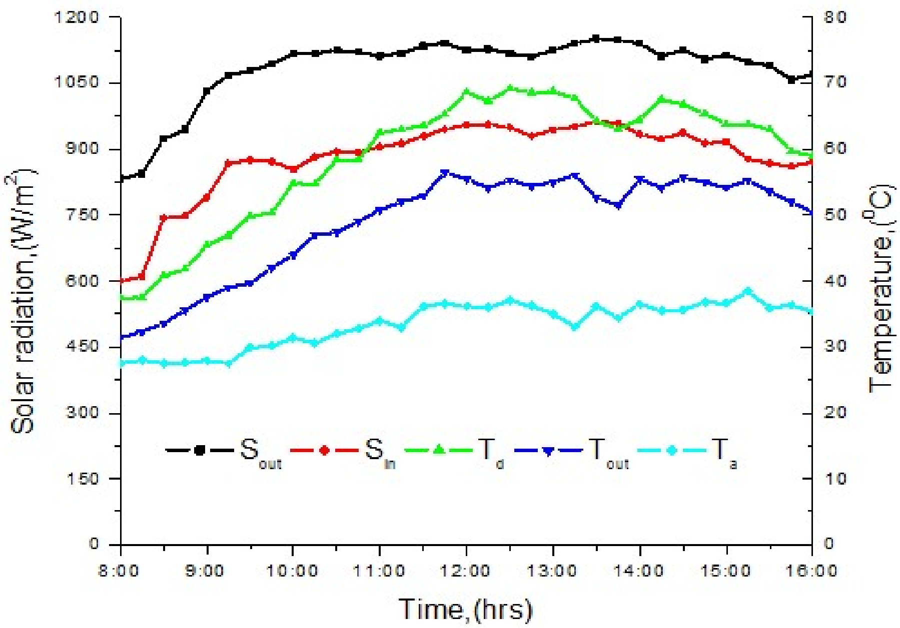

Figure 5: Drying conditions of spider vegetable (27/02/2015).

The results in Figure 5 show that the solar radiation outside and inside the STCD have similar trends but the inner values are lower than that on the outside. This is because the transparent polycarbonate cover of the dryer reflects part of the incident solar radiation. From these results, the average values of reflectivity and transmittance of the cover were determined to be 17.8% and 82.2% respectively. Thus, the solar radiation incident on the dryer absorber plate and the drying products is lower than that on the outside, which is a loss. It is also observed from these results that the solar radiation (both inside and outside) increases from 8:00 am and attained constant values around 9:00 am. It is seen that the solar insolation attains a value of over 1000 Wm^{-2} as early as 9:00 am and this value is maintained up to 4:00 pm when the experiment was stopped. The maximum values recorded on the outside of the dryer is 1084.1 W/m^2, hence the site is a high radiation zone with over six peak solar hours (6 PSH), hence sufficient for effective drying of crops or electricity generation.

In addition, the results in Figure 5 show also the variations of ambient temperature, as well as the absorber plate temperature and outlet temperature of the dryer. The temperature curves show that all the temperatures increase in tandem with the solar radiation which is the driving force of the earth's climatic systems. It is observed from the figure that the ambient temperature increases gradually from the 8:00 am when experiment was started and attains a high value of about 35 ^oC at around 11:00 am and this value was maintained, with some small fluctuations, till the experiment was stopped. This shows that the area is very hot at this time of the year and is expected because the location is semi-arid. The ambient temperature represents also the inlet air temperature and since it is relatively high, it is likely to lower the drying efficiency.

The absorber plate and outlet temperatures have similar trends where it is observed to increase gradually when the experiment starts at 8:00 am and attain maximum temperatures of over 69.2 ºC and 50 ºC respectively around 12.45 pm. Thus, the temperature rise inside the drying chamber is very high, over 20 ºC, which will then accelerate the drying rates of the vegetables inside the chamber. It is noticed from the graph that there is a time lag between the peaking of the absorber plate and outlet temperatures of the dryer compared to the solar radiation. This time lag is due to the thermal masses of the absorber plate and vegetables being dried where the heat absorbed is first used to warm up the absorber and the product before their temperatures begin to rise. It is observed that the high temperature inside the dryer as compared to ambient is as a result of the greenhouse effect and the large rise more than compensates the reduced solar insolation inside the dryer.

Figure 6 illustrates typical solar radiation and temperatures variation measured during the drying of the black night shade vegetable in the month of March, 2015.

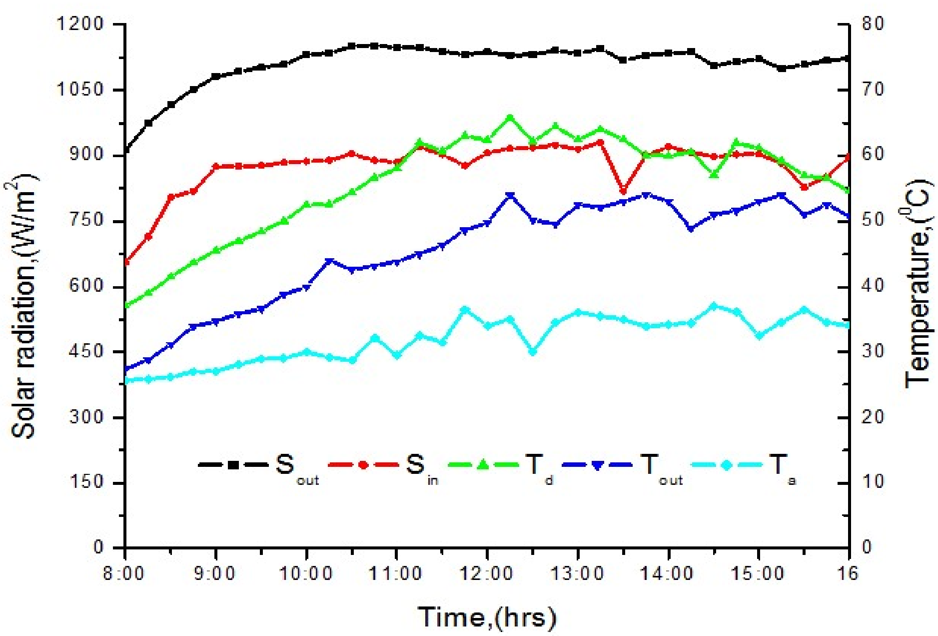

Figure 6: Drying conditions of black night shade (06/03/2015)

The results in Figure 6 demonstrate similar trends as those obtained in Figure 5. It is determined from these results that the reflectivity and transmittance of the cover are 21.1% and 78.9% respectively. The peak value of the solar insolation on the outside is over 1100 Wm^{-2}, which is very good for solar energy exploitation. The temperatures are also high with ambient reaching over 30 ºC, absorber plate has over 60 ºC and outlet temperature of over 50 ºC from around midday onwards.

3.2 Moisture content reduction during drying

The mass of the test samples of both vegetables were measured initially before commencing the drying experiments. A metal tray was used to load and unload the vegetables during the drying process to facilitate ease of measurement of mass. The dimensions of the tray used were 25 cm length, 15 cm width and 3 cm high. Its mass was measured when empty and when loaded with vegetable using a digital weighing balance. The mass of the product being dried is determined by subtracting the mass of the empty tray from the total mass when loaded with the product. The mass of the empty tray was as 143.2 g. The initial sample masses used were respectively 168.7 g and 279.0 g for spider and black night shade vegetables. The loaded tray was placed towards the outlet side of the absorber and the free area of the absorber plate towards the inlet was left intentionally for pre-heating air for drying.

3.3 Drying profile of spider vegetable

The drying of each vegetable was done on separate days and their drying profiles were determined. The drying rates at every stage of the drying curves/profiles were determined by measuring the mass lost and dividing with the time duration it took to achieve that loss. The drying profiles for the two vegetables are given in Figure 7 and Figure 8 respectively for the spider vegetable and black night shade vegetable.

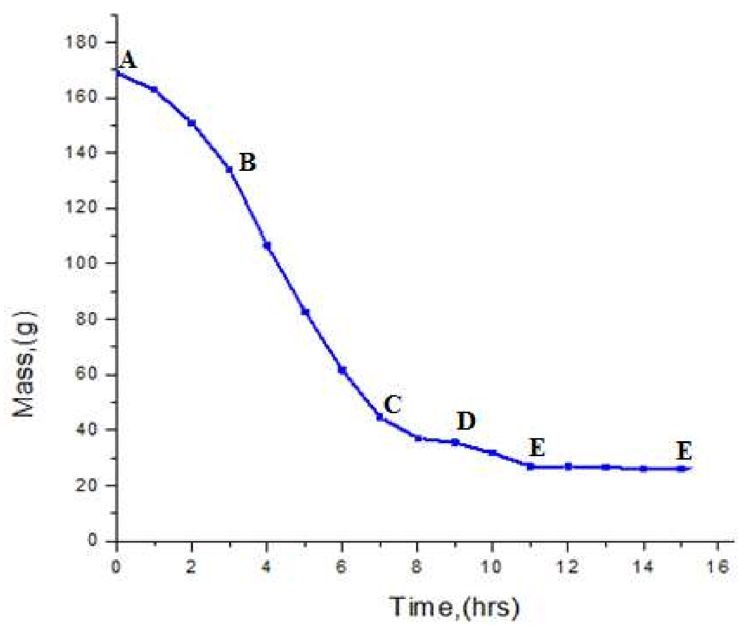

Figure 7: Drying profile for the spider vegetable that was measured in 23rd to 24th, February 2015 depicting moisture reduction in spider vegetable

The results in Figure 7 depict the expected four stages represented by AB, BC, CD and DE. The section AB has a gentle gradient which is due to moisture content reduction through evaporation of surface water. This occurred in the first three hours on commencement of the drying processes and the mass of the product reduced from 168.7 g to 134.2 g, giving an average drying rate of 11.5 g/hr.

The next section, BC is a stage where the rate of water removed per unit drying surface is constant is referred to as constant rate period; it depicts a steeper gradient due to more heating of the product from the accumulated heat inside the STCD, both from the heated air and increased solar radiation inside the drying chamber. The increased heating causes more evaporation, hence the steeper slope. The mass of the product reduced from 134.2 g to 44.7 g in four hours, giving average drying rate of 22.4 g/hr.

The section CD referred to as falling rate period shows again a gentler slope with lower evaporation rate. The crop reduces in size due to loss in mass and stills some moisture content needs to be removed; in this stage water removal per unit drying surface varies with surface area. The mass of the product reduced from 44.7 g to 35.4 g in two hours, giving an average drying rate of 4.7 g/hr.

The process exhibited between D and E took another two hours reducing mass to 26.9 g from 35.4 g giving a drying of 4.3 g/hr, the drying rate reduced drastically due to drying process approaching its equilibrium.

The section DE indicates that there is practically no moisture content removal, and this represent the stage where the moisture content is at resents to the equilibrium state.

The moisture content wet basis in each stage of the drying profile in Figure 7 were calculated using equation (1) and the results are tabulated in Table 1.

The moisture content at the beginning of each drying stage is evaluated and the final mass, M_f = 26.1 g.

Table 1: Moisture content wet basis in drying of spider vegetable

Stages	Mass ,M_i (g)	Mass lost (M_i - M_f) (g)	Moisture content, MC_{wb} %
AB	168.7	34.5	84.5
BC	134.2	89.5	80.6
CD	44.7	13.0	41.6
DE	35.4	4.9	26.3

Final constant mass (M_f) attained at the end of drying of spider vegetable is 26.1 g is attained at stage E. The moisture content at every stage were calculated using equation (1) giving initial moisture content and final moisture content wet basis at 84.5 % and 26.3 % respectively.

3.4 Drying profile of black night shade vegetable

Figure 8 shows drying profile of the black night shade vegetable, which was measured in 2nd to 4th, March, 2015.

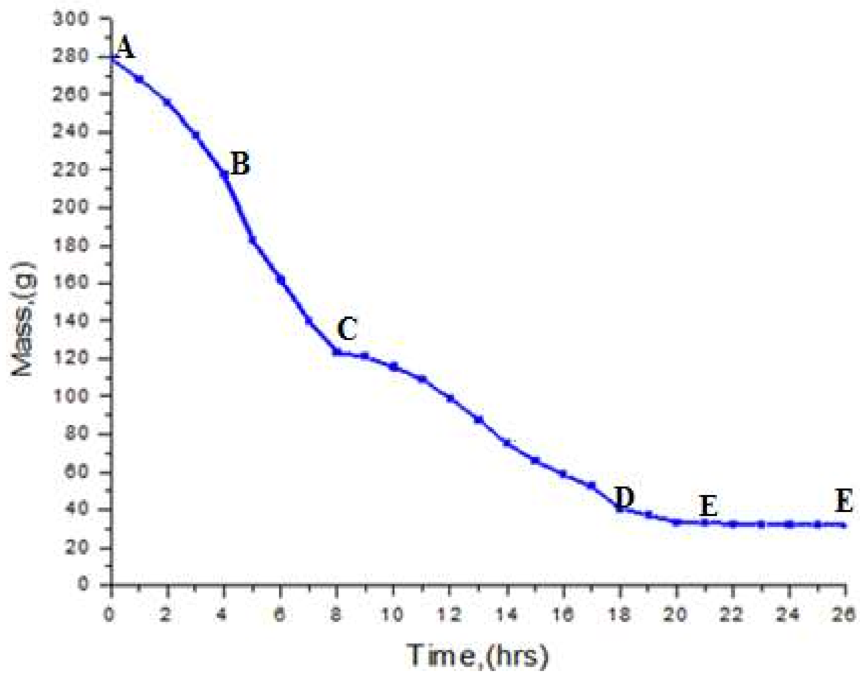

Figure 8: Drying profile depicting moisture reduction in black night shade vegetable

Figure 8 displays a similar trend as in Figure 7, and the drying rates vary from one stage to another in each of the four stages as given by different gradients. The first stage from A to B however took 4 hours to change to the next stage compared to drying of spider vegetable, mass at the end of the stage is 218.0 g from 279.0 g giving a drying rate of 15.3 g/hr .It is observable also that between B and C a more steeper gradient is noted reflecting an increase in drying rate due to more heat accumulation in the dryer. The mass recorded at the end of stage B to C is 123.3g from 218.0 g depicts a mass of 94.7 g lost in 4 hours in this stage giving a drying rate of 23.7 g/hr. The next stage of C to D lasted 10 hours reducing the mass to 40.9 g from 123.3 g giving a drying rate of 8.2 g/hr as reflected by the less steep gradient in the figure. The last stage D to E maintained a fluctuating mass around 33.3 g after 3 hours giving a very low drying rate of 2.4 g/hr as a result of drying approaching its equilibrium. The final constant mass of 32.3g attained at the end of drying (E) where no mass was lost.

The summary of initial moisture content wet basis at various stages (AB, BC, CD, and DE) is shown in Table .2.

Final constant mass (M_f=32.3 g) attained at the end of drying black night shade vegetable. The initial moisture content and final moisture content wet basis of 88.4% and 21.0% are determined using equation (1).

Table 2: Moisture content wet basis in drying of black night shade.

Stages	Mass ,Mi (g)	Mass lost (Mi - Mf) (g)	Moisture content ,MC wb %
AB	279.0	61.0	88.4
BC	218.0	94.7	85.2
CD	123.3	82.4	73.8
DE	40.9	6.6	21.0

3.5 Efficiency calculations

The efficiency of the STCD was evaluated using equation (2) at the different drying stages and then the average evaluated and the results are summarized in Tables 3 and 4 for the two vegetables respectively. The corresponding solar radiations were obtained for the measured values for the respective days.

Table 3: Dryer efficiencies at various stages during drying of Spider vegetable

Drying stage	Initial mass, M_i(g)	Final mass, M_f (g)	Lost Mass M_w (g)	Average solar radiation ,I_c (W/m^2)	Efficiency, η_d (%)
AB	168.7	134.2	34.5	757.7	25.4
BC	134.2	44.7	89.5	750.1	49.9
CD	44.7	31.7	13.0	738.5	14.7
DE	31.7	26.8	4.9	820.3	5.0
Average efficiency of the dryer					23.75

Table 4: Dryer efficiencies at various stages during drying of black night shade vegetable

Drying stage	Initial mass, M_i(g)	Final mass, M_f (g)	Mass removed, M_w (g)	Average solar radiation ,I_c (W/m2)	Efficiency, η_d %
AB	279.0	218.0	61.0	845.1	30.2
BC	218.0	123.3	94.7	853.3	46.4
CD	123.3	40.9	82.4	756.7	18.2
DE	40.9	33.3	6.6	809.4	4.6
Average efficiency of the dryer					24.85

These results show that the highest dryer efficiency for both vegetables occurs in the stage BC with values of 49.8 % and 46.4

% for spider and black night shade vegetables respectively. It is followed by stages AB, CD and DE. The average overall efficiency of the STCD was determined as 24.3 %.

4. Conclusions

A solar tunnel crop dryer (STCD) was designed, fabricated and its performance was evaluated experimentally on the drying of two African Indigenous Vegetables (AIVs) – spider and black night shade. The dryer was found to dry the vegetables effectively.

The results on the drying conditions showed that the site has high ambient conditions. The horizontal solar insolation outside the dryer attained over 1000 Wm^{-2} as early as 9:00 am and maintained till 4:00 pm, giving over six hours of peak solar hours (6 PSH), which is excellent for solar energy conversion systems. The ambient temperature is relatively high with an average value of about 30 ºC, and is likely to reduce drying efficiency by reducing temperature rise between inlet and outlet temperature.

The average drying efficiencies of the dryer for drying spider and black night shade vegetables are calculated at 23.75 % and 24.85 % respectively. The initial moisture content wet basis of spider vegetable of 84.5 % can be reduced to 26.3 % in two days whereas in black night shade vegetable at 88.4% reduced to 21.0 % in three days respectively.

The two AIVs were effectively dried to the safe or final moisture content of 26.3 % and 21.0% for spider vegetable and black night shade respectively, and these values represent storage MC.

There are four drying stages (AB, BC, CD and DE) in drying of the vegetables with different drying rates varying between 22.4 g/hr to 4.3 g/hr and 23.7 g/hr to 2.4 g/hr in drying of spider and black night shade respectively. The highest values of drying rates of spider and black night shade vegetables were observed in stage BC (constant rate period) of 22.4 g/hr and 23.7 g/hr respectively. Thus this prototype solar tunnel crop dryer is appropriate for the drying of black night shade vegetable and other similar species.

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