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Design and Performance Evaluation of a Solar Dryer

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Design and Performance Evaluation of a Solar Dryer

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Abstract

One of the ways to combat food insecurity as world population rises is the reduction of food losses. Drying is one of the oldest methods of food preservation and hence reduces food losses. Solar drying uses energy from the sun and an absorber material to carry out drying of produce. In this project, a solar dryer was designed, constructed and its performance was evaluated. The dryer has overall dimensions of 1000mm by 410mm by 700mm. The inner part of the dryer compartment was lagged with aluminum foil to act as an insulator. The solar collector made of galvanized sheet and the glass on top of it have an area of 800mm by 380mm. Fresh scotch bonnet pepper was used as the produce of choice. The pepper was dried in 2 experiments for 3 weeks each. 200g of pepper was used and weighed to measure weight loss periodically. Temperature and humidity of the drying chamber and the surrounding were measured with data loggers throughout the periods of the experiments. The results showed that the ambient temperature during the experiments was higher than the temperature of the drying chamber in the early hours of the morning between 4am and 10am. During every other period, the temperature in the drying chambers was higher than the ambient temperature. An average moisture content of 81.3% w.b. was removed from the pepper during the experiments. The average efficiency of the dryer was 28.4%.

keywords: Dryer, temperature, food, pepper, solar, collector, efficiency

1. Introduction

One of the major causes of post-harvest losses in developing nations is poor storage facilities and lack of infrastructure. Fresh food and fruit products degrade or spoil in hot climates due to lack inadequate set ups for preservation of goods between harvest and market. Preservation of goods is important for long life cycles and improved sales of perishable products. Preservation takes on different methods to prevent injury, loss or decay of goods. It involves slowing or stopping bacterial decay to improve shelf life in the case of perishable goods. Any method used to prevent food from spoiling is a method of preservation. Food preservation has become more significant in this age where less and less individuals eat foods produced from their own lands and "out of season" foods are always expected. The traditional methods of preservation are: drying, freezing, refrigeration, curing, smoking, pickling, sugaring, canning and bottling.

Drying is one of the earliest methods of preservation. Drying involves removal of moisture in products to retard chemical reactions and kill pathogens that leads to spoiling. Since most micro-organisms need moisture to thrive, food is preserved by dehydrating foods up to an acceptable percentage. Specifically, for agricultural products, it provides a way to preserve produce long after harvest for food and for sale [1]. Drying involves transfer of heat and mass from products. First, the surface moisture is evaporated by provided heat. Further movement of inner moisture to the surface is forced by addition of some sort of energy. Drying is especially useful in countries with poor low-temperature and thermal processing facilities [2. There are various methods of drying such as natural air drying, application of hot air, freeze drying, indirect or contact drying, and dielectric drying.

Over 99.99% of world energy sources are derived from the sun [3]. Solar drying uses energy from the sun in forms of light and heat. Nigeria is blessed with abundant solar energy as we are in a tropical region. Solar energy is becoming widely used as it is a source of clean, renewable energy and offers a large capacity when harnessed [4], offering an alternative to non- renewable sources especially fossil based fuel energy. Energy is considered renewable if it is replenished over the life span of man. Utilization of renewable energy such as solar reduces the cost of operation than if there were a non-renewable fuel source.

The use of solar drying systems for agricultural products to preserve fruits, vegetables and other crops has been proven to be cheap, reliable, and environmentally friendly. It also provides a viable alternative to traditional techniques of drying. The traditional method of Sun drying presents issues of dust, rodents and insects as well as loss of colour. Solar dryers offer advantages of better quality produce, shorter periods of drying, reduced loss of raw materials and larger scale of production [4].

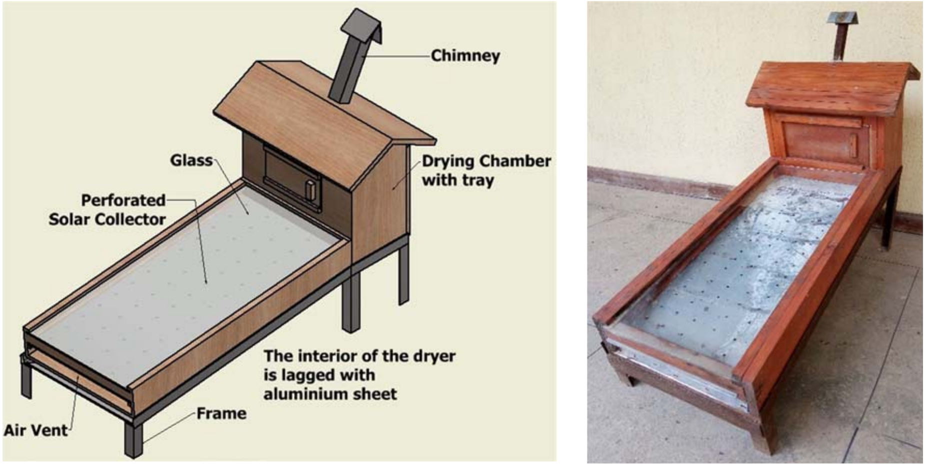
2. Material and methods

The natural convection solar dryer consists of the collector, the drying chamber and drying trays

2.1 Solar dryer description

Figure 1 shows the diagram of the natural convection solar dryer. The collector consists of a wooden compartment of rectangular shape with an area of 800 by 100 by 400mm. The inner part of this compartment is lined with aluminum foil for lagging and to act as an insulator. The top of this compartment is a flat glass panel 5mm thick with 800 by 380 area. It has a transmittance of about 0.7 for wave lengths in the range 0.2 – 2.0μm and opaque to wavelengths greater than 4.5μm at a distance below the glass, 5mm thick metal sheets with the same area as the glass panel. For the collector of the dryer, galvanized steel sheet metal is used with thermal conductivities of 18W/mK. On the metal sheet, holes of equal diameter are drilled and evenly distributed. The rectangular channel for air flow has an area of 0.016m^2 with one end open to the environment and the other leading to the drying chamber.

The drying chamber is made of the same seasoned wood as the wooden part of the compartment which will withstand termite and insect infestation. The roof is an open gable type roof to ensure rainwater run-off. The walls and inner parts of the roof are lagged with aluminum sheet. It also consists of wooden supports for three drying trays. A small metal chimney of square cross-section was added to the top of the chamber to improve drying rate by increasing buoyancy forces. The window in the front and back are sealed and lagged with aluminum sheet metal. The drying tray was placed in the drying chamber during the duration of the experiments. They were constructed with galvanised steel and made rectangular. The tray have evenly spaced holes of equal diameter.



(a) (b)

Figure 1: Natural convection solar dryer (a) diagram of solar dryer (b) fabricated solar dryer

2.2 Design analysis of solar dryer

Amount of moisture removed(kg), $\boldsymbol{m_w}$;

$$\boldsymbol{m_w} = \frac{m_p(M_i - M_f)}{(100 - M_f)} \qquad (1)$$

Where;
m_p = Initial mass of product to be dried.
M_i (%) = initial moisture content
M_f (%) = final moisture content

Moisture Content (M.C);

$$\boldsymbol{M.C} = \frac{M_i - M_f}{M_i} \times 100 \qquad (2)$$

Where;
M_i= Mass of sample before drying
M_f = Mass of sample after drying

Quantity of heat needed to evaporate water (KJ), Q;

$$\boldsymbol{Q = m_w \times h_{fg}} \qquad (3)$$

Note; amount needed is a function of temperature and moisture content of the crop.

Total heat energy, E(kJ)
E(kJ) required to evaporate water;

$$\boldsymbol{E = m(\, h_f - h_i)\, t_d} \qquad (4)$$

Where;
$\dot{m}$ = mass flow rate of air, kg/hr
h_f, h_i = final and initial enthalpy of drying and ambient air, respectively
t_d = drying time in hours

Average drying rate, $\boldsymbol{md_r}$ *(*$\boldsymbol{kg/hr}$)

$$\boldsymbol{md_r = m_w/t_d} \qquad (5)$$

Mass of air needed for drying;

$$\boldsymbol{m} = \frac{\boldsymbol{md_r}}{(\boldsymbol{W_f} - \boldsymbol{W_i})} \tag{6}$$

Where;
md_r = average drying rate
$W_f - W_i$ = difference between final and initial humidity ratio respectively

Area of the collector in $\boldsymbol{m^2}$, *A_c*

$$\boldsymbol{A_c I_{\dot{\eta}} = E} \tag{7}$$

Where;
$i_{\dot{\eta}}$= total global radiation in the horizontal surface,kJ/m^2
E = total useful energy, kJ
$\dot{\eta}$ - Collector efficiency

Drying Efficiency

$$\eta = \frac{E}{\mathrm{Ac} \times \mathrm{I}} \quad \text{or} \quad \frac{W \times \Delta Hl}{Ac \times Ic} \tag{8}$$

E = total useful energy, kJ
η – Drying efficiency, W – moisture evaporated (kg)
DHl – Latent heat of vaporization of water (2320 kJ/kg)
I_c – Hourly insolation upon collector (Wm^2)
A_c – Area of collector (m^2)

2.3 Experimentation

The location of the dryer was recorded (longitude and latitude). Ota is located in Ogun state, Nigeria at l6.42°N, 3.14°E. The climatic data (solar radiation) for the location was gotten over a period. Data loggers for temperature and relative humidity were calibrated to record data every two hours. The dryer was placed in an open space where there was ample sunlight. The dryer was placed facing south as it is in the northern hemisphere as prescribed by Bolaji and Olalusi [5]. 200g of scotch bonnet pepper was weighed and then placed in the drying chamber. The data loggers to measure temperature and humidity were placed in the drying chamber, on the metal collector and outside the dryer. At three intervals during the day, the weight of the pepper was measured. This process was repeated each day for three weeks until desired moisture content was achieved or no further change in weight was observed. On the first day of drying, a sample of pepper of the same lot was heated in an oven (at 105°C) till there was no more weight loss to obtain the total moisture of the sample. The experiment was performed twice (i.e. for six weeks). The data from the experiments was used for the calculation of mass loss and moisture content. The drying rate and efficiency of the solar collector was estimated.

3. Results and discussion

Figures 2 and 3 show the weight loss per day for experiments 1 and 2. The pepper lost an average of 5-10 g per day except on rainy days, where the mass remained constant. In both experiments, the pepper lost an average of 0.16 kg over a period of three weeks. In Figure 3, it was observed that the pepper that was placed outside beside the solar dryer for sun drying had a faster rate than the pepper in the dryer; however, it showed physical degradation and loss of colour.

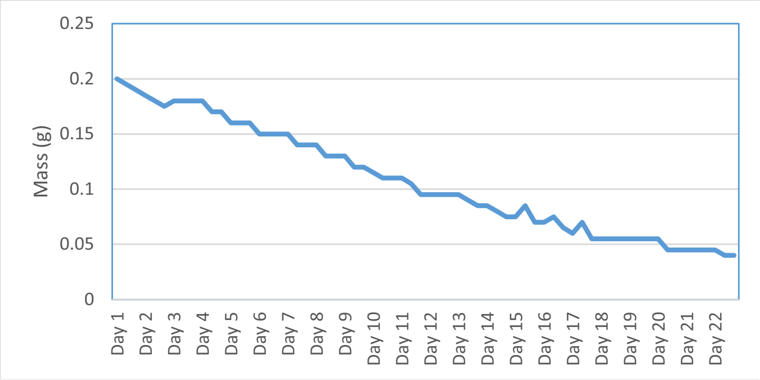


Figure 2: Weight against time (Experiment 1)

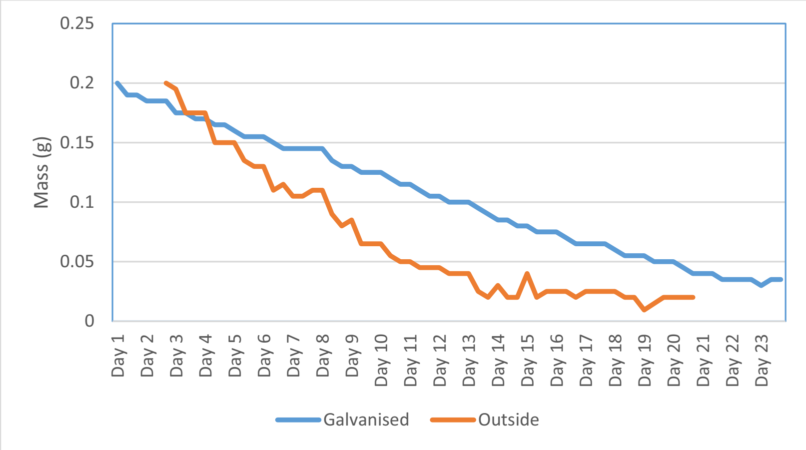


Figure 3: Graph of Weight against Time (Experiment 2)

The temperature trends of ambient temperature, drying chamber and solar collector are shown in figure 4 to figure 7. The temperature in the drying chamber of the dryer was almost the same for both experiments (figures 4 and 6). The ambient temperature during the experiments was higher than the temperature of the drying chamber in the early hours of the morning between 4am and 10am. This difference ranged from 2℃ to 12℃. During every other period, the temperature in the drying chamber was higher than the ambient temperature as observed by Bolaji and Olalusi [5]. The difference was the highest in the afternoon (between 12noon to 8pm) within the range of 4℃ to 14℃. Between the hours of 8pm to 4am, the difference was between 1℃ to 2℃. Figures 5 and 7 shows the temperature of the solar collector against time. It was observed that the temperature on the collector was much higher than the temperature in the drying chamber for the two experiments. This was expected as the collector received solar energy directly from the sun through radiation. Since the energy flow from region of higher potential to lower potential, the energy collected on the galvanized sheet metal was transfer through confection to the drying chamber.

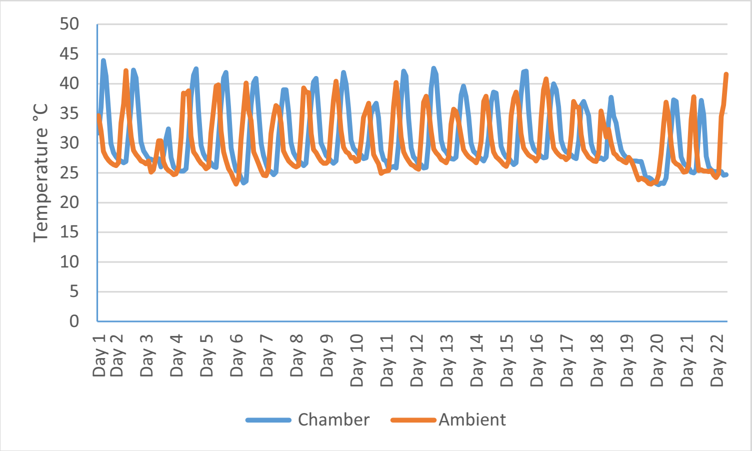


Figure 4: Drying chamber temperature against time (Experiment 1)

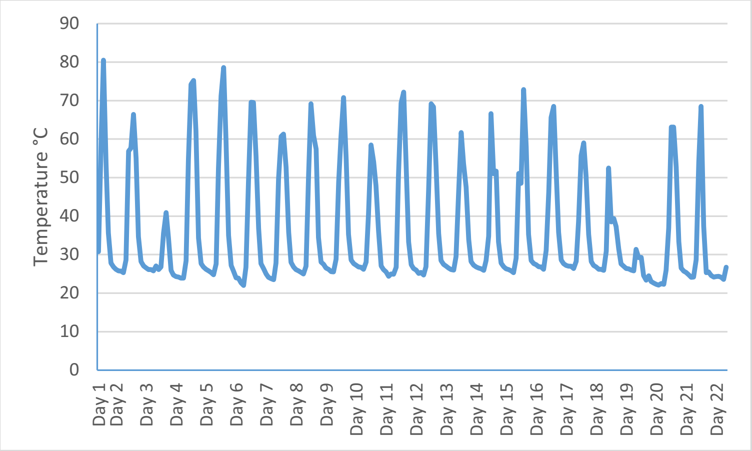


Figure 5: Solar collector temperature against time (Experiment 1)

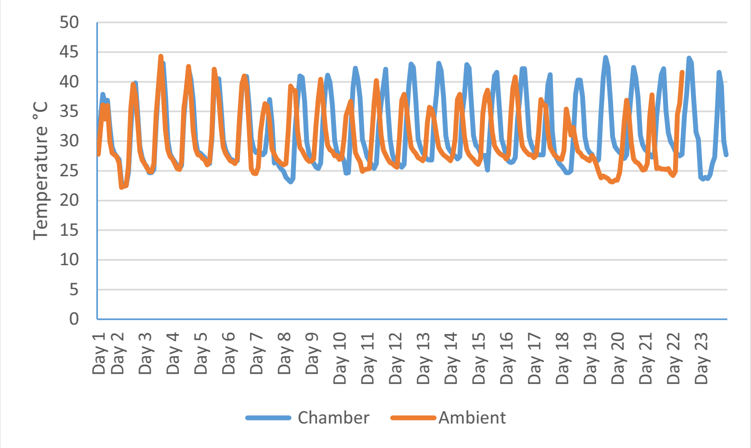


Figure 6: Drying chamber temperature against time (Experiment 2)

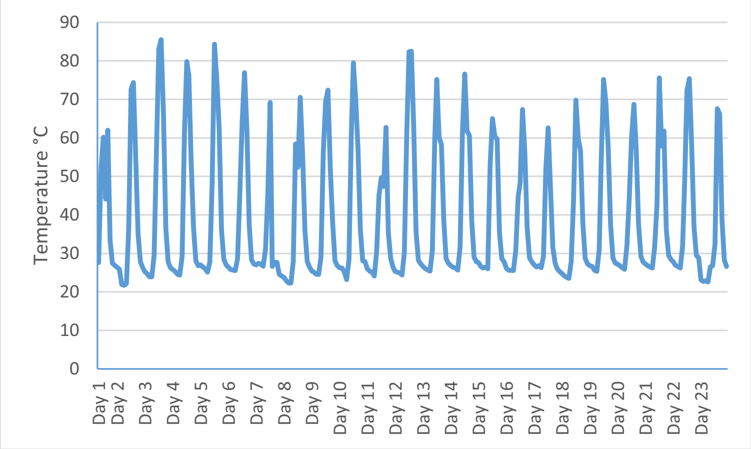


Figure 7: Solar collector temperature against time (Experiment 2)

In Figures 8 and 9, the change in relative humidity with time during the experiments are shown. It was observed that the relative humidity of the surrounding was higher than the relative humidity in the drying chamber for the two experiments.

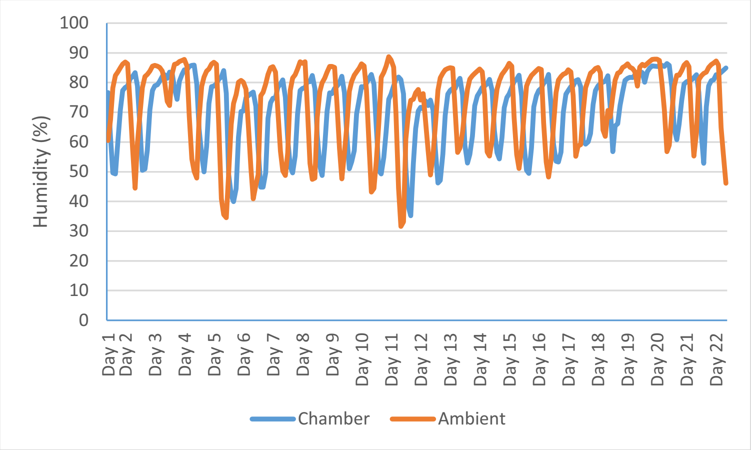


Figure 8: Relative humidity against time (Experiment 1)

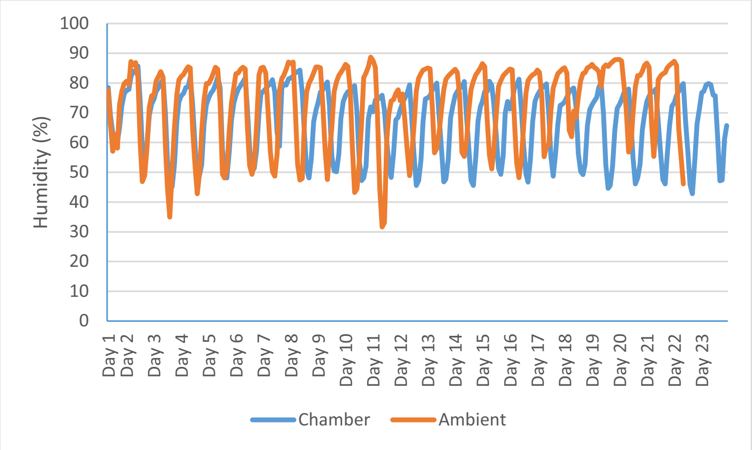


Figure 9: Relative humidity against time (Experiment 2)

Table 1 showed the moisture content of the scotch bonnet pepper dried with oven method and solar drying. In the two experiments, the moisture content of the pepper was dried almost completely. This was in the same range as the 80% moisture loss recorded by Wankhade *et. al* [1] in the drying of pepper.

Table 1: Moisture Content Values

	Oven Method (%w.b.)	**Solar Drying (%w.b.)**
Experiment 1	80.0	80.0
Experiment 2	87.5	82.5

The average drying rate and total moisture removed for the total drying period of three weeks for each experiment are shown in Table 2. An average drying time of 10 hours per day was used. These drying rates are lower than 2.35×10^{-5} kg/s in mixed mode dryer of Abubakar *et. al* [6] and 0.07 kg/s in forced convection dryer for chilli pepper of Fudholi *et. al* [7]. The red colour of the peppers was preserved after drying.

Table 2: Drying Rate and Total Moisture Removed

	Amount of moisture removed (kg)	**Average drying rate (kg/hr)**
Experiment 1	0.16	5.91×10^{-4}
Experiment 2	0.155	6.14×10^{-4}

The efficiency of the dryer was calculated using equation (8). The value of total insolation was retrieved from Nigerian Meteorological Agency (NiMET) solar insolation data for Ota station using an average of the insolation from years 1999 through 2008. The data was measured using Gunn-Bellani distillate measured in millilitres (ml) and converted to MJ/(m^2 .day) using the factor 1.1364 Ohunakin *et. al* [8]. The average value for the months of February and March when the experiments were carried out were 11.73ml and 11.98ml. Using these values in the equation, the drying efficiency of each day was calculated. The results are given in Table 3 below.

Table 3: Mass loss per day and daily efficiency for the two experiments

	Experiment 1		**Experiment 2**	
	Mass loss per day (kg)	**Efficiency (%)**	**Mass loss per day (kg)**	**Efficiency (%)**
Day 1	0.010	0.4947	0.010	0.4843
Day 2	0.010	0.4947	0.000	0.0000
Day 3	0.000	0.0000	0.005	0.2422
Day 4	0.010	0.4947	0.005	0.2422
Day 5	0.000	0.0000	0.005	0.2422
Day 6	0.000	0.0000	0.010	0.4843
Day 7	0.010	0.4947	0.000	0.0000
Day 8	0.010	0.4947	0.015	0.7265
Day 9	0.010	0.4947	0.005	0.2422
Day 10	0.005	0.2473	0.010	0.4843
Day 11	0.015	0.7420	0.010	0.4843
Day 12	0.000	0.0000	0.005	0.2422
Day 13	0.010	0.4947	0.010	0.4843
Day 14	0.010	0.4947	0.005	0.2422
Day 15	0.005	0.2473	0.005	0.2422
Day 16	0.005	0.2473	0.010	0.4843
Day 17	0.005	0.2473	0.000	0.0000
Day 18	0.000	0.0000	0.005	0.2422
Day 19	0.000	0.0000	0.005	0.2422
Day 20	0.010	0.4947	0.010	0.4843
Day 21	0.000	0.0000	0.005	0.2422
Day 22	0.005	0.2473	0.000	0.0000
Average Efficiency		**0.2923**		**0.2752**

The overall average collector efficiencies for both experiments were 29.2%, and 27.5% for galvanized steel collector. These values were in the same range with the mixed mode natural convection dryer without storage made by Abubakar *et al*. [6] with efficiency of 24.2% and the forced convection dryer with auxiliary heating made by Fudholi *et al*. [7] with efficiency of 28%. These were lower than 39.6% in the forced convection dryer without dehumidification [9] and higher than 13.45% achieved in the solar tunnel drying of garlic [10].

3. Conclusions

The use of solar dryers for preservation of various crops is an area of growing interest for the agricultural sector and is especially useful for small holder farmers in locations of high solar insolation like North Central and Northern Nigeria. The quality of produce obtain via this method provides longer shelf life and greater sale value. In this experiment with 200g of scotch bonnet peppers, an average of 81.3% w.b. moisture content was removed from the scotch bonnet pepper within three weeks. Similar to other dryers in literature, the temperature of drying chamber was higher than the ambient temperature during most hours of the day. The efficiency of the dryer has an average of 28.4% for galvanized steel solar collector.

4. Recommendation

In conjunction with local governments, a number of dryers should be deployed to small holder farmers to determine the significance of having a better method of drying in practice. These dryers maybe solar powered forced convection dryers to handle large quantities in the absence of electricity.

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References

[1] Wankhade, P. K., Sapkal, R. S., & Sapkal, V. S. (2014). Design and Performance Evaluation of Solar dryer. *IOSR Journal of Mechanical and Civil Engineering,* 11, 70-73

[2] Hegde, V. N., Hosur, V. S., Rathod, S. K., Harsoor, P. A., & Narayana, K. B. (2015). Design, fabrication and performance evaluation of solar dryer for banana. *Energy, Sustainability and Society*, 5(1), 23.

[3] Bababola, Engr. P. O. (2009). Non-convective Solar Pond as a Thermal Energy Source. Published at International Conference/ Workshop on Renewable Energy and Climate Change Mitigation, Covenant University, Ota, Nigeria, July 13-17, 2009. www.scribd.com/doc/39657995/SolarPond-Scribd

[4] Wang, W., Li, M., Hassanien, R., Hassanien, E., Wang, Y., & Yang, L. (2018). Thermal performance of indirect forced convection solar dryer and kinetics analysis of mango. *Applied Thermal Engineering*, 134, 310–321.

[5] Bolaji, B. O., & Olalusi, A. P. (2008). Performance Evaluation of a Mixed-Mode Solar Dryer. *Assumption University Journal of Technology*, 11(4), 225–231.

[6] Abubakar, S., Umaru, S., Kaisan, M. U., Umar, U. A., Ashok, B., & Nanthagopal, K. (2018). Development and performance comparison of mixed-mode solar crop dryers with and without thermal storage. *Renewable Energy*, 128, 285–298.

[7] Fudholi, A., Sopian, K., Yazdi, M. H., Hafidz, M., Gabbasa, M., & Kazem, H. A. (2014). Performance analysis of solar drying system for red chili. *Solar Energy*, *99,* 47–54.

[8] Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2013). Correlations for estimating solar radiation using sunshine hours and temperature measurement in Osogbo , Osun State. *Frontiers in Energy*, 7(2), 214–222.

[9] Chramsa-Ard, W., Jindaruksa, S., Sirisumpunwong, C., & Sonsaree, S. (2013). Performance evaluation of the desiccant bed solar dryer. *Energy Procedia*, 34, 189–197.

[10] Arjoo, N., Yadvik, & Yadav, Y. K. (2017). Performance Evaluation of Solar Tunnel Dryer for Drying of Garlic. *Current Agriculture Research Journal*, *5*(2), 220–226.