Performance Of A Conventional Solar Dryer Under Local Climatic Conditions Of Mbarara

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ABSTRACT

Open-air sun drying of agricultural products is still practiced largely in ways unchanged from ancient times after harvest. There is always contamination, theft or damage by birds, rats or insects; slow or intermittent drying and no protection from rain or dew. In addition, large areas of land are needed for the shallow layers of food; laborious since the crop must be turned, moved if it rains; reduction in quality (color and vitamin content) of some fruits and vegetables. These problems can be solved through the use of a solar dryer. A solar dryer which is cheap (purchase and maintenance costs) for the population and environmentally friendly was constructed. The agricultural products considered for experimentation were sweet potatoes and cassava. Their drying rates inside and outside the solar dryer were determined. It was observed that the average drying rates inside the solar dryer and in open-air are 0.21 g/h and 0.17 g/h for sweet potatoes and 0.29 g/h and 0.22 g/h for cassava, respectively. The conventional solar dryer, in addition to saving time, protecting the products from dirt and animals and drying products without cracking which minimizes the exposure of the crops to fungal and bacteria infestation and wastage, it dries products faster than open-air sun drying.

Keywords: Agricultural products; Solar energy; Solar dryer

1. INTRODUCTION

Food drying is a very simple and ancient skill. Open-air sun drying of agricultural products is still practiced largely in ways unchanged from ancient times after harvest. The common agricultural products in Uganda that are dried after harvest include, cassava, potatoes, maize, bananas, millet, coffee, cocoa, tobacco, rice etc. Open-air Sun drying is done by exposing the products to direct sunlight. It is a possible and common process because in the tropical region and Uganda, in particular, the weather allows foods to be dried immediately after harvest. Uganda is blessed with abundant solar energy through out the year (Twindell and Weir, 1986; Yamoah et al., 2014).

The low capital and operating costs of open-air sun drying and its little expertise required make it attractive. However, there is always contamination, theft or damage by birds, rats or insects; slow or intermittent drying and no protection from rain or dew that lowers the quality of products due to under-drying (Lipinski et al., 2013). Open-air sun drying also requires large areas of land to create shallow layers of food; laborious since the crop must be turned and moved when it rains. While still using this system of drying, most of these obstacles may not be controlled. As a result, the quality (in terms of color and vitamin content) is reduced and production of uniform standard products is not expected (Madholpa et al., 2002).

Some of the problems associated with open-air Sun drying can be solved through the use of a solar dryer(Madholpa et al., 2002). Solar dryers have been developed and used to dry agricultural products to improve shelf life (durability) (Esper and Muhlbaue, 1996; Talbot et al., 2016; Wanyama, 2016). However, most of these either use an expensive source of energy such as electricity or a combination of solar energy and electricity and so not adopted by the small farmers (El-Shiatry et al., 1991; Talbot et al., 2016). The use of solar technology has often been suggested for the dried fruit industry and other agricultural product stores both to reduce energy costs and economically speed up drying, which would be beneficial to the final quality of the dried agricultural products (El-Shiatry et al., 1991; Lambert et al., 1980; Wanyama, 2016).

Solar dryers, at low temperatures and relative high humidity of the year, enable products to be dried without cracking which minimizes the exposure of the crops to fungal and bacteria infestation and wastage (Butter and Goodrum, 1998). Minimizing wastage saves food for the increasing demand, bearing in mind that the global population is predicted to exceed eight billion by the year 2025[1].

In Uganda the use of solar dryers is already in existence though upgrading is needed because most of them use wood for example MS-Uganda (Danish Association for International Cooperation), together with Hoima Nursery School Association, and Gukvatamazi Farmers Association (Arafoui, 2001). These organizations invest in solar dryers (Fig. 1[2]), because they are cheap (maintenance costs) since they are constructed from available local materials such as wood. However, if practiced on large scale it results in deforestation and its associated problems (Ramage et al., 2017). In addition, wood is not resistant enough to moisture and fungi. Therefore, solar dryers which are constructed with materials that are friendly to the environment and cheap for the community are required.

Fig. 1: Solar dryers made from local materials in Uganda. (a) mango drying and (b) pineapple drying

Solar dryers that only use solar energy also contribute towards the achievement of the government energy policy goal i.e. "meeting the energy needs of Ugandans for social and economic development in an environmentally sustainable manner"[3], since no carbons are produced. The conventional solar dryers can help farmers improve the quality of the dried agricultural products with limited post-harvest losses, since they are free from rain,

1 http://www.eolss.net/Eolss-sampleAllChapter.aspx
2 https://www.monitor.co.ug/Magazines/Farming/Use-solar-dryer-to-curb-postharvest-losses/689860-4253512-842e7kz/index.html
3 http://energyandminerals.go.ug/downloads/EnergyPolicy.pdf

wind-borne dirt and dust, insects, rodents and other animals (Ajao and Adedeji, 2008; Bux, 2002). This can help farmers preserve their products, consequently increasing their bargaining power as well as their income. In this study a solar dryer was constructed and its performance analysed relative to the oven and open-air sun drying.

2. CONSTRUCTION OF THE SOLAR DRYER

2.1 MATERIALS

The solar dry was fabricated using a 2.5 cm x 2.5 cm angle iron bars, M S plates (metal sheets) 0.8 mm thick, wool blanket, corrugated galvanized black metal sheet, Masonite sheets (50.0 cm long and 50.0 cm wide), a roll of Aluminium foil sheet 50.0 cm wide, a panel of transparent glass (water-white glass, 4 mm thick, 50.0 cm long and 50.0 cm wide), a tube of Silicon rubber sealant, wire mesh, hinges and casters. Sweet potatoes and cassava were the agricultural products studied and were obtained from Nyamitanga, a village in Mbarara municipality, Mbarara district.

A conventional solar dryer in Fig. 2[4] was modified by changing the dimensions of the inlet vent and outlet vent to 24.0 cm × 10.4 cm, making the slanting (previously at an angle of 15 °C) top flat to suit the conditions in Mbarara-Uganda. The modified version is shown in Fig. 2. Some of the conditions in Mbarara are summarised in Table I.

Table I: Design Conditions

Property	
Location	Mbarara (Uganda)
Elevation	1413 m
Longitude	30.6 °E
Latitude	0.6 °S
Average Wind speed	11 km/h
Volumetric air flow rate	273.3 m^3/h
Air flow rate	328 kg/h

A conventional solar dryer shown in Fig. 2 was constructed as follows: a simple box frame 50.0 cm long, 50.0 cm wide and 50.0 cm high made of angle irons (2.54 cm × 2.54 cm) was fabricated. Sheets of mild metal sheet were welded onto three sides and bottom of the fabricated frame. Wool blanket was folded to make a thickness of approximately 5.0 cm and an area of 0.25 m^2 and placed above the bottom mild metal sheet. A 48.0 cm x 48.0 cm corrugated galvanized metal sheet was placed above the wool blanket and fitted to the bottom of the box by nails and rivets to form a good heat absorber. Two tray holders made of angle iron and 15.0 cm apart were welded in such away to hold trays inside the drying chamber with the lower holder 15.0 cm above the absorber plate.

4 http://www.fao.org/docrep/T1838E/T1838E0v.htm

Masonite sheets (used as insulators) were fitted to the three inner sides of the frame. Aluminium foil sheets (used as reflectors) were glued to the Masonite sheets. One panel of transparent glass (49.0 cm x 49.0 cm) was glued to the top part of the frame with silicon rubber sealant. Two movable wire mesh trays with angle iron frames of dimensions of (44.0 cm × 44.0 cm) were placed on their holders. A door that was constructed of metal sheets and angle iron frame was hinged on the open side of the box frame. Masonite sheet was then fitted on the inner side of the door and Aluminium foil sheets also glued on the surface of the Masonite sheet. The door was sealed to prevent air leakage between the surroundings and the drying chamber. An inlet air vent was created above the base of absorber plate; 24.0 cm long and 10.4 cm wide and provided with an adjustable cover. The outlet vent (rear air vent); 24.0 cm × 10.4 cm was located at the back top edge (opposite side of the door) and also provided with an adjustable cover.

2.2 AIR VENT DIMENSIONS

The area of the air vent was calculated using Equation 1:

$$A_v = \frac{V_a}{V_w} \qquad (1)$$

where, A_v is the area of the air vent in m^2, V_a is the volumetric air flow rate in m^3/h and V_w is the average wind speed in m/h. The average wind speed, V_w, of Mbarara region is 11000 m/h. The volumetric airflow rate, V_a , is given by,

$$A_v = \frac{Airflow\ Rate\,(m_a)}{Air\ Density\,(\rho_a)}, \qquad (2)$$

where, $m_a = 328\ \ kg/h,\ \ \rho_a = 1.2\ \ kg/m^3,$ and V_a was found to be 273.3 m^3/h. The value of the air vent area, A_v , was found to be 0.0248 m^2. The length, L_v , of the air vent was set to 0.240 m. The width, W_v , of the air vent, obtained from $W_v = A_v / L_v ,$ was found to be 0.104 m.

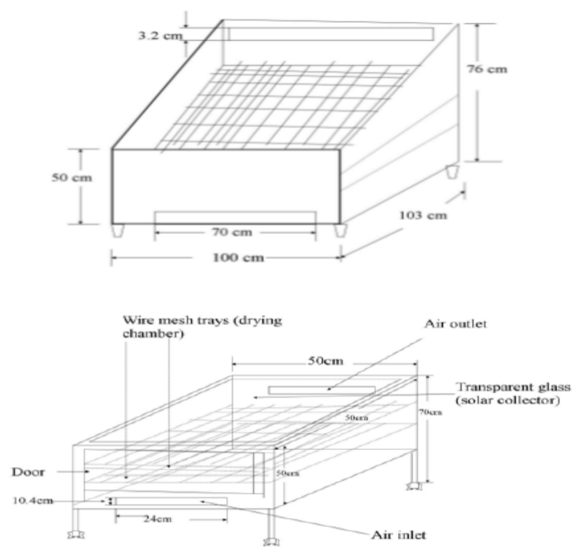

Fig. 2: A conventional solar dryer. (a) before modification and (b) after modification.

2.3 PERCENTAGE MOISTURE LOSS $(P_{\Delta M})$

The oven was used as the ideal drying method. The oven gave the approximate percentage moisture needed to be removed from the agricultural products. For experimental purposes, cassava and sweet potatoes were the considered agricultural products. Initial mass, M_i, of each of the wet agricultural products was measured using an electronic balance. The wet samples of the products were put in an oven set at 70 °C for 24 hours and dried to safe moisture content. Final mass, M_f, of the dried samples was measured and recorded. The moisture loss, ΔM, in the sample was calculated from Equation 3;

$$\Delta M = M_i - M_f. \quad (3)$$

Table II: Potato And Cassava Samples In An Oven At 70 °C For 24 Hours

Products	M_i (g)	M_f (g)	ΔM	$P_{\Delta M}$
Potatoes	28.0	10.0	18.0	64.3
	31.0	11.0	20.0	64.5
	36.0	12.0	24.0	66.7
	37.0	13.0	24.0	64.9
	39.0	14.0	25.0	64.1
	40.0	14.0	26.0	65.0
	29.0	11.0	18.0	62.1
	43.0	15.0	28.0	65.1
Cassava	25.0	9.0	16.0	64.0
	25.0	10.0	15.0	60.1
	29.0	11.0	18.0	62.1
	39.0	14.0	25.0	64.1
	39.0	15.0	24.0	61.5
	43.0	15.0	28.0	65.1
	46.0	16.0	30.0	65.1
	22.0	8.0	14.0	63.6

Note: M_i is the initial mass of the sample, M_f is the final mass of the sample, ΔM, is the moisture loss and $P_{\Delta M}$, is the percentage moisture loss.

The percentage moisture loss for each sample, $P_{\Delta M}$, was obtained from;

$$P_{\Delta M} = \frac{\Delta M}{M_i} \times 100\%, \quad (4)$$

The results are presented in Table II.

2.4 AVERAGE DRYING RATE IN SOLAR DRYER AND OPEN-AIR

In each of the two drying criteria (solar and open-air drying), we considered 8 samples for each agricultural product (cassava and potatoes). Mass of each sample of potatoes and cassava was measured and the samples were simultaneously put on each side of the trays in the solar dryer. At the same time, approximately equal masses of samples of potatoes and cassava were put in open-air, outside the solar dryer and the initial time, t_i, recorded. Masses of the sample products were then measured using an electronic balance at an interval of 5 hours and the percentage moisture loss was calculated using Equation 4. At the same time, the ambient and dryer temperatures were measured using a liquid-in-glass thermometer. The minimum percentage moisture loss attained from the oven was 60% (see; Table II). Therefore, the process of drying, timing and measuring was repeated until the percentage moisture loss, $P_{\Delta M}$ was approximately above 60% and the final time, t_f, recorded.

Fig. 3: A constructed convectional solar dryer

The period, T, taken for each sample to dry to safe moisture content was determined from;

$$T = t_f - t_i. \quad (5)$$

The average drying rate, R_d, of each sample was obtained from;

$$R_d = \frac{\sum (\Delta M/T)}{N}, \quad (6)$$

where N is the number of samples and for our case $N = 8$.

3. DISCUSSION

Data in Table I were used in the determination of the air vent dimensions: the length and width of air vents are 0.240 m and 0.104 m, respectively (see; subsection II-B; for calculations). The constructed solar dryer is shown in Figure 3. The results of the eight samples of two agricultural products (cassava and potatoes) oven dried at 70 °C for 24 hours are shown in Table II.

Above 60 % of moisture was to be removed from the products to attain their safe moisture content. The eight samples of the two agricultural products of known masses that were subjected to drying inside the natural conventional solar dryer and those in open-air (control) were dried for four days, ten hours each day. The respective temperatures were continuously recorded as well. The results of the measured properties of agricultural products inside and outside the solar dryer are presented in Fig. 4.

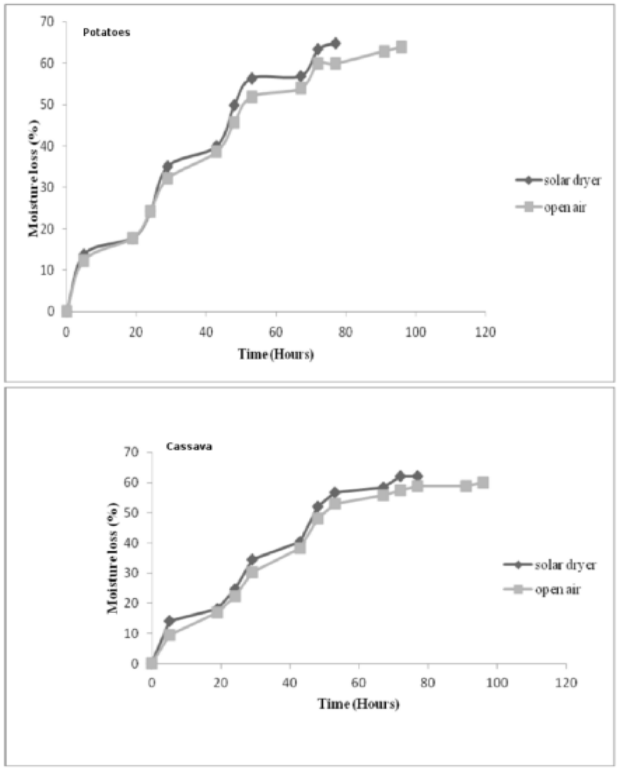

Fig. 4: Drying curves for agricultural products inside and outside the solar dryer. Top: average percentage moisture loss in samples of potatoes. Bottom: average percentage moisture loss in cassava samples. The vertical axes represent the cumulative percentage moisture loss from the products. The horizontal axes represent time in hours from the beginning to the end of the drying process.

The top panel of Fig. 4 shows that the percentage moisture loss in potato samples in the solar dryer and in the open air increased rapidly in the first 5 hours and then it became almost constant in the next 15 hours (during the night) i.e. on the first day. It increased again on the second day for 9 hours (between the 21 st hour and the 30 th hour) and became almost constant for 15 hours (between the 31 st hour and the 45 th hour). On the third day (between the 46 th hour and the 70 th hour), the trend was the same as that for the second day. On the fourth day, it sharply increased for 3 hours and became constant. The drying rate of samples inside the solar dryer was always higher and the samples dried faster than those in the open air though during the 19 th to the 24 th hour, the rates were the same. This is attributed to similar temperatures in both areas at that time. For the sweet potato samples, the average drying rates in the solar dryer and in open air are 0.21 g/h and 0.17 g/h, respectively. The rate of drying of sweet potato samples was higher in the solar dryer than in the open-air (see; Fig. 4).

From Fig. 4, the drying rate of cassava was observed to be higher than that of potatoes, though the trend of drying is the same. The drying rates of the cassava in the solar dryer and in open air were found to be 0.29 g/h and 0.22 g/h, respectively. The rate of drying of cassava samples was also higher in the solar dryer than in the open air. The drying rates of the products were generally low compared to 0.95 g/h drying rate of the products in the oven at 70 °C. This was because the average sun intensity was low based on the average ambient temperature of 27.2 °C and average dryer temperature of 35.0 °C.

Based on the temperatures, on average the solar dryer was about 50 % and open-air was about 38 % efficient with respect to the oven. In addition, the solar dried products were cleaner than those dried in open-air. The oven would be the best for drying agricultural products but it is very expensive for the farmers to attain and to maintain because of the source of energy it uses. This indicates that for the people in Uganda, a solar dryer is the best option. The two agricultural products displayed approximately the same drying trend in both solar dryer and open-air. This implies that the trend maybe the same for other agricultural products. However, the drying rates maybe different because different agricultural products have varying moisture contents.

4. CONCLUSIONS

The study was to find a means of cheaply drying agricultural products without harming the environment and attain good quality dried products. Drying rate of agricultural products in the solar dryer was higher than when in open air for both sweet potatoes and cassava. The products in the solar dryer reach safe moisture content, approximately a full day, earlier than those in open-air. This implies that the solar dryer is time saving. The solar dryer does not use electricity and therefore suitable for use in rural areas. It was observed that the products in the dryer were cleaner than those in open-air, so the solar dryer improves the quality of the dried agricultural products. This is because contamination by dirt, fungi, insects, rain and animals were reduced.

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