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Comparative Performance Evaluation of a Natural Convection Mud Brick Solar Dryer and Open Sun Drying for Drying Cassava

Ahmadu, T.O*[1], Ibrahim, T.K[2] and Seriki, A.O[1]
[1]Department of Mechanical Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria.
[2]Department of Chemical Engineering, Federal University, Wukari, Taraba.
*Corresponding author's email: talibahmadu@gmail.com

Abstract
One of the major challenges being faced by farmers in developing countries is that of post – harvest losses. This is due to poor storage facilities and techniques adopted by these farmers, especially for perishable foods. These losses significantly reduce the earnings. Solar dryers are devices developed for effective drying of farm produce by utilizing the solar radiation, as opposed to open sun drying. In this study, a natural convection solar dryer was developed using mud bricks for drying of cassava. The solar dryer was experimented for drying cassava, with ten hours drying time for three experimental days. Simultaneously, open sun drying of cassava was also conducted. Sliced cassava samples for each of the drying modes weighing 7 kg, with initial moisture content of 76% wet basis were placed on trays. One tray was placed inside the solar dryer, while the other was placed open to sunlight. Results at the end of the third day showed that moisture content of the cassava samples in the solar dryer and open sun drying were reduced to 9.3% and 34% respectively. Average drying rates of 0.046 kg/hr and 0.028 kg/hr were obtained with the solar dryer and open sun drying respectively. Average solar dryer efficiency of 13% was recorded, while the open sun drying recorded an average drying efficiency of 5.5%.

Keywords: *Solar dryer, Mud brick, Cassava, Experiment*

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1. Introduction

Post-harvest loses is one of the greatest challenges faced by African farmers as well as farmers of developing countries. These losses are estimated to be up to 40 % of farm produce and they may be as high as 80% under very adverse conditions, especially for highly perishable farm products such as tomatoes, mangoes and oranges (Ahmed, 2010). Drying is one of the earliest methods of food preservation. This involves removal of moisture from food products to retard chemical reactions and kill pathogens that lead to food spoilage. This leads to increased shelf life and reduced packaging cost (Kilanko et al., 2019). Open sun drying is process in which farm products are directly exposed to solar radiation. It is the earliest method of drying farm products and is still being practiced to date, especially in developing countries (Islam et al., 2018). The main disadvantages of this method include: contamination, theft or damage by animals as well as relatively high final moisture content (Gutti et al., 2010). Direct exposure to sunlight also affects certain vitamins present in food products (Tomar et al., 2017). Reliance on traditional drying techniques such as open sun drying by rural African farmers increases post-harvest losses, which increases their vulnerability to food insecurity (Adeyeye, 2017). Food insecurity is a factor responsible for the high level of malnutrition in African countries (Afshin et al., 2019). It is therefore necessary to develop more efficient drying methods particularly for rural African farmers. Solar drying is the use of solar drying systems to dry farm produce. Solar energy has the advantage of being available, reliable and environmentally friendly. This therefore places solar dryers in a position to minimise post-harvest losses as well as for value addition, especially in developing countries (Maunda et al., 2016). Several researchers have carried out works on developing solar dryers that would have improved performance and drying efficiencies. Mohanraj and Chandrasekar (2009) developed and experimented an indirect forced convection solar dryer integrated with different sensible heat storage materials for drying of chilli. Results indicate moisture content was reduced from 72.8% to 9.1%, while average dryer efficiency was 21%. Chavan et al. (2011) evaluated a solar tunnel dryer for fish drying. Efficiencies of 19.87% and 12% were achieved with solar dryer and open sun drying respectively. A convective solar dryer for drying sponge cotton was investigated by Aissa et al. (2014). For the five days period of operation, the dryer attained an average temperature of 58.6^{o}C and overall efficiency between 1.85 and 18.6%. Musembi et al. (2016) designed and evaluated the performance of an indirect solar dryer for drying apples. Overall efficiency of 17.9% was reported. Teja et al. (2018) constructed an experimental solar dryer for drying chilli. It was observed that moisture content was reduced by 17.6%. Mahapatra and Tripathy (2019) experimented the thermal performance of a passive solar dryer. System efficiency range from 27.6% to 41.4 % were recorded. Cesar et al. (2020), evaluated the performance of a natural convection solar dryer for drying tomatoes. Maximum temperature within the dryer of 70^{o}C was recorded, with dryer efficiency of 10.66%. Matavel et al. (2021) designed and tested a passive indirect solar dryer for amaranth leaves and maize. They concluded that the solar dryer reduced the drying time by 29%, compared to open air drying. The foregoing shows active research in developing solar dryers with improved drying efficiency for drying agricultural products. However, there is also the need to consider the use of locally available materials to rural farmers for constructing the dryer, while still designing for high efficiency. Cassava is a staple food in most countries in Africa including Nigeria. Farmers are usually faced with the challenge of effective drying of this farm product. Mud brick is a very common construction material in Africa and other developing nations. Its advantages include moderate to high thermal mass, fire resistant, durability and cheap. This research work is intended to develop and carry out performance evaluation of a natural convection solar dryer made of mud bricks for drying cassava.

2. Materials and methods

2.1 Description of the solar dryer

The dryer is a rectangle box-like structure, constructed of mud brick of 12cm thick. The inner part which served as the collector section was lined with zinc sheet on the sides and bottom and was painted black for absorption of solar radiation. The base of the collector has an area of 1.26 m^2. While the mud brick walls served as side insulator, saw dust was placed underneath which served as base insulator. Water-colour glass, framed with wood, was mounted as the top cover. The space between the top cover and the absorber plate is the air plenum. Circular vents were constructed on opposite sides of the walls for air flow. The drying chamber was equipped with a tray for drying the products. Schematic of the dryer is shown in Fig. 1.

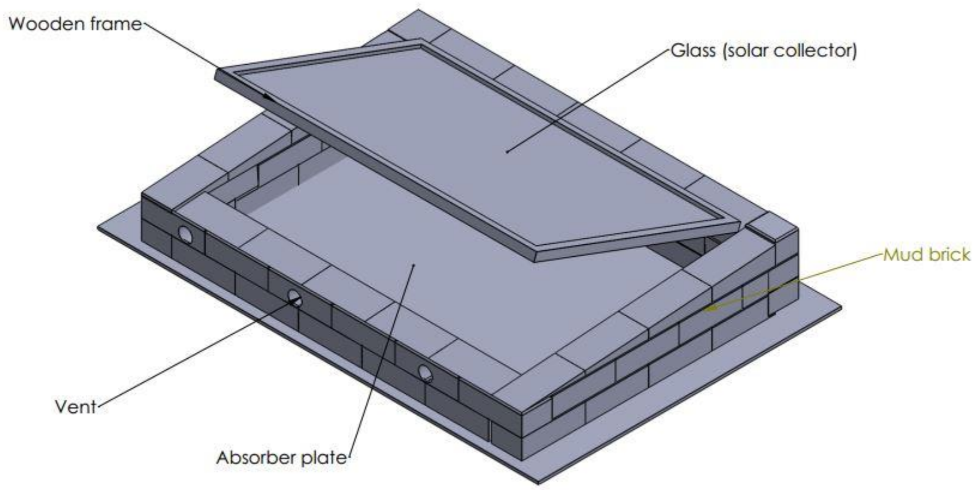

Fig. 1: Schematic of mud brick solar dryer

2.2 Experiment

The experiments were conducted at the Department of mechanical engineering, Ahmadu Bello University, Zaria. Freshly harvested cassava was obtained and sliced into pieces. Experiments were conducted using 7 kg of sliced cassava having an initial moisture content (wet basis) of 76%, placed inside the tray in the solar dryer. Simultaneously, an equal weight of sliced cassava of same initial moisture content was open dried by placing on a tray exposed to direct sunlight. Ten hours drying time was done for each experimental day, starting at 8:00 am and terminating at 6:00 pm each day, for three consecutive days. Solar radiation, temperature and weight measurements were made every half an hour. Moisture content, drying rate and drying efficiency were computed according to Aissa et al. (2014). Moisture content (M_c) was calculated as:

$$M_c = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Drying rate (D_r) was computed as:

$$D_r = \frac{\Delta W}{t} \quad (2)$$

The drying efficiency(η_d) was computed as:

$$\eta_d = \frac{\Delta W \Delta H_L}{A_c I_d t} \quad (3)$$

where W_1 and W_2 are the weight of the sample before and after drying respectively (kg), ΔW is the weight loss (kg), t is the time interval (s), ΔH_L is the latent heat of vaporization (kJ/kg), A_c is the collector area (m^2), the same area was used for the open sun drying, and I_d is the solar radiation on the collector surface (W/m^2) as well as on the open sun drying surface. The measuring instruments used in the experiment are shown in Table 1.

Table 1: Measuring instruments

S/N	Instrument	Model No.	Measuring range	Accuracy
1	Digital solar power meter	DBTU 1300	0 – 2000 W/m^2	$\pm$ 5% of reading
2	Digital thermocouple thermometer	T407291	-50 – 1300^{o}C	0.1%+1^{o}C
3	Digital weighing scale	SF – 400	0 – 7000g	$\pm$ 0.1 g

3. Results and discussion

Results from the experiments carried out on cassava drying using the solar dryer as well as open sun drying are presented here. Fig. 2 to 4 show the variation of solar radiation, ambient temperature, open sun drying temperature and solar dryer temperature with time of the day for the three experimental days. As observed from Fig. 2 to 4, the open sun drying temperatures as well as the solar dryer temperatures increase and decrease with increase and decrease in solar radiation respectively. This is an indication that the solar radiation is a major factor in the temperatures attainable for both drying modes. The solar dryer attained much higher temperatures than the open sun drying throughout the period of drying for the three experimental days, as seen from Fig. 2 to 4. This is an indication that the solar dryer was able to absorb the solar radiation and convert to heat for drying the cassava. Peak solar radiations of 986 W/m^2, 932 W/m^2 and 950 W/m^2 were recorded for the first, second and third experimental days respectively. Maximum solar dryer tray temperatures of 96^{o}C, 88^{o}C and 90^{o}C were recorded for the first, second and third experimental days respectively. While maximum open sun drying tray temperatures of 49^{o}C, 46^{o}C and 48^{o}C were recorded for the first, second and third experimental days respectively.

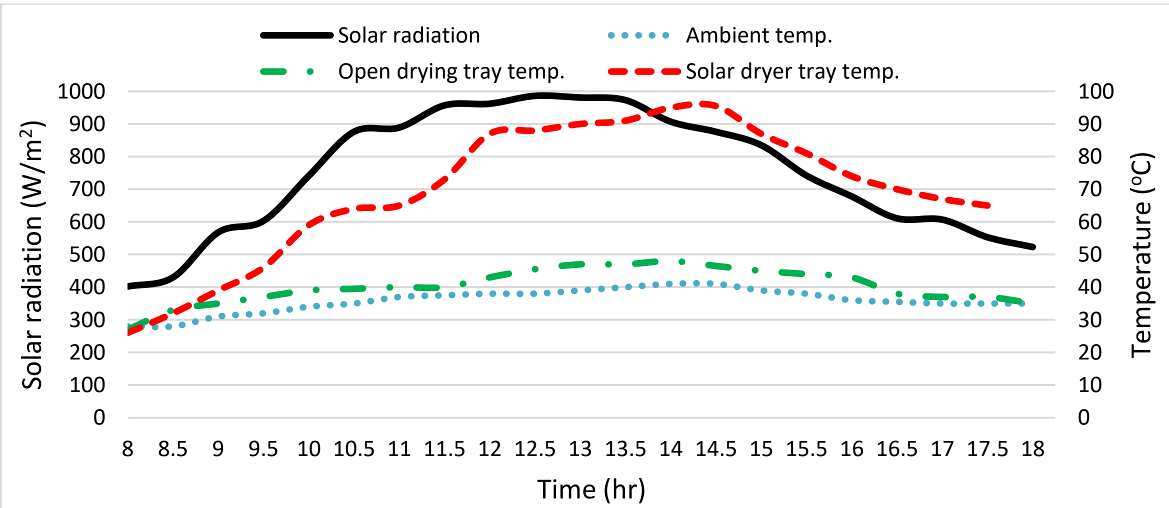

Fig. 2: Variation of solar radiation and temperatures with time for day 1

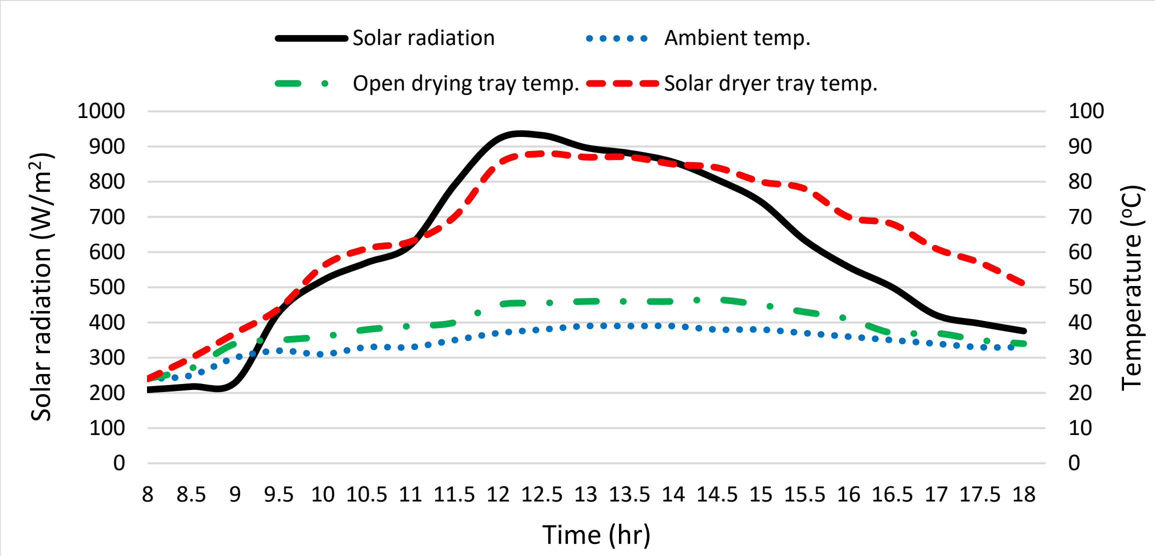

Fig. 3: Variation of solar radiation and temperatures with time for day 2

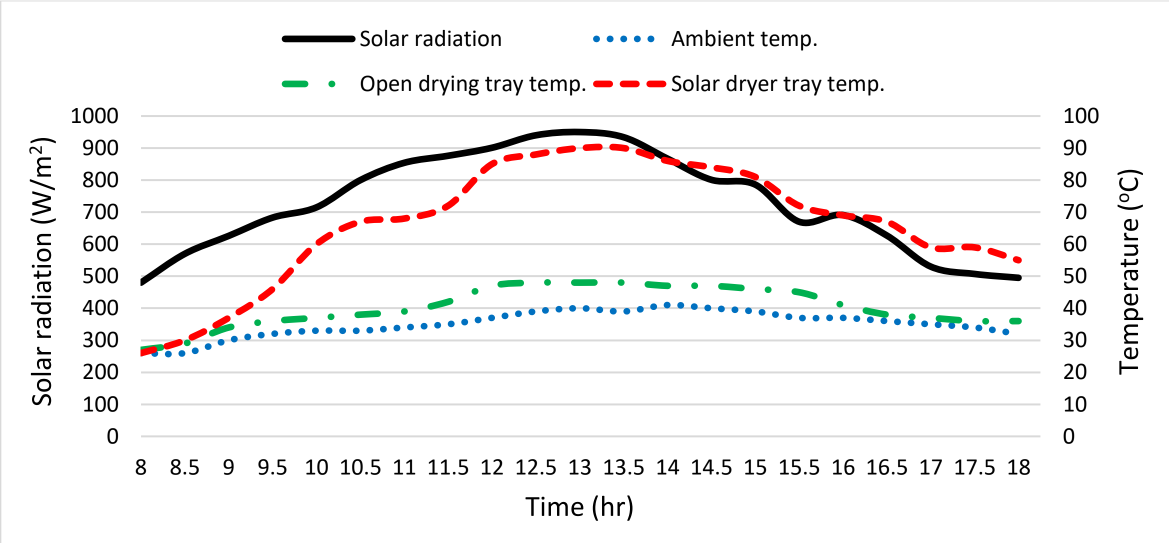

Fig. 4: Variation of solar radiation and temperatures with time for day 3

Fig. 5 shows variation of moisture content with cumulative time for the samples in the solar dryer and open sun drying for the period of three experimental days. It can be observed that, while both samples started with an initial moisture content of 76%, the sample in the solar dryer attained faster reduction in moisture content compared to the sample that was open sun dried. This is because of the higher temperatures attained in the solar dryer, which generated the required heat that caused a faster evaporation rate of the moisture. It can be observed that the curves are steeper in the first day than the second and third days. This is because much of the moisture was removed within the first day. A final moisture content of 9.3% and 34% were achieved with the solar dryer and open sun drying respectively at the end of the three days drying period. This shows effectiveness in moisture removal by the solar dryer over open sun drying. Mohanraj and Chandrasekar (2009) reported a reduction in moisture content from 72.8% to 9.1% while using a solar dryer to dry chilli. Chavan et al. (2011) reported reduction in moisture content from 71.6% to 16.09% and 71.6% to 30% for solar dryer and open sun drying of fish respectively. Results from the present work compare favourably with those from literature.

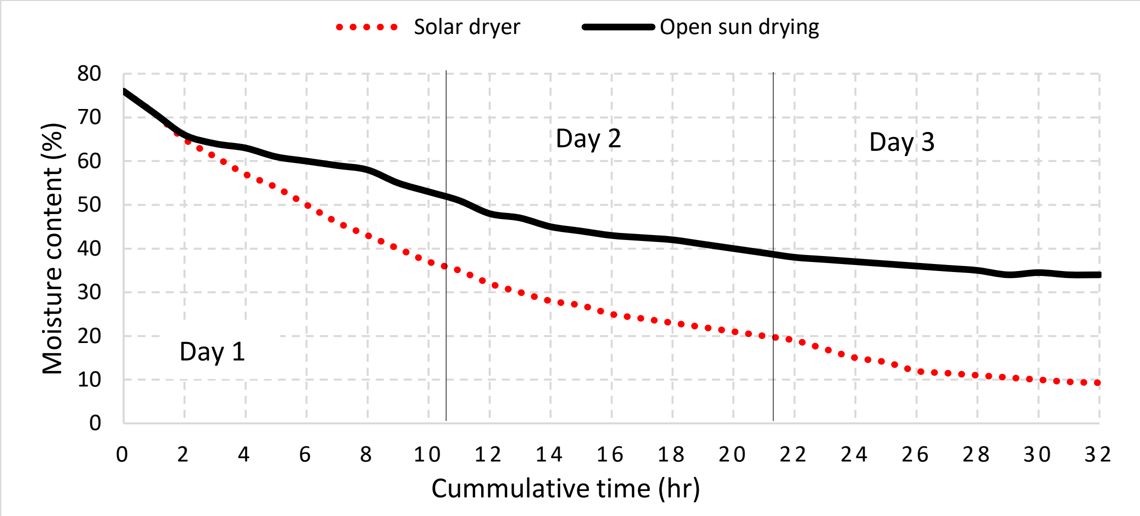

Fig. 5: Variation of moisture content with cumulative drying time

Fig. 6 shows the variation of efficiency with cumulative time, for the solar dryer and open sun drying. For the three cumulative experimental days, the efficiency of the solar dryer can be seen to range from 4% to 34%, while the open sun drying efficiency can be seen to range from 0.7% to 29%. For both drying modes, the efficiency can be seen to decrease from the first day through to the third day. The highest efficiencies can be seen to have been recorded on the first experimental day, ranging from 10% to 34% and 3.9% to 29% for the solar dryer and open sun drying respectively. The peak of the efficiency curve is also seen to be in the first experimental day for both drying modes. This is because, in the first day, the samples have very high moisture content. With sufficient solar radiation, heat is absorbed to vaporize most of the moisture within the samples. As the experiment progressed into the second and third days, much of the moisture had previously been evaporated. With continuous solar radiation over the second and third days, the moisture removed continuously gets smaller, therefore efficiency decreases for both drying modes as indicated in the figure. Average solar dryer efficiency over the three days drying period was 13%, while the open sun drying had an average drying efficiency of 5.5% over the same period. Chavan et al. (2011) reported average efficiencies of 19.87% and 12% for solar dryer and open sun drying respectively. Musambi et al. (2016) reported average dryer efficiency of 10.25%, while Cesar et al. (2020) reported average dryer efficiency of 10.66%. Results from present work fall within the range of those reported in literature.

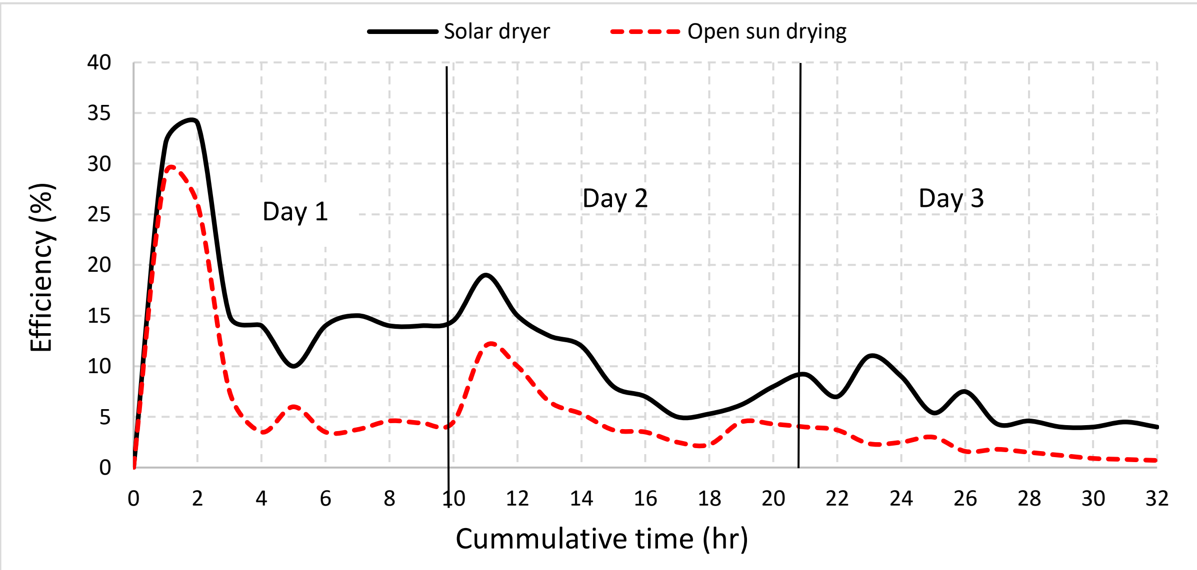

Fig. 6: Variation of efficiency with cumulative drying time

Fig. 7 shows the comparison of drying rate for the two drying modes for the three experimental days. It can be observed that the solar drying achieved higher drying rate than the open sun drying for all the experimental days. This is because the solar dryer was able to absorb more heat from solar radiation, leading to higher evaporation rate of moisture. Drying rates of 0.078 kg/hr and 0.036 kg/hr were achieved by the solar dryer and open sun drying respectively in the first experimental day. 0.037 kg/hr and 0.032 kg/hr drying rates were achieved by the solar dryer and open sun drying respectively for the second experimental day. While 0.024 kg/hr and 0.016 kg/hr drying rates were achieved by the solar dryer and open sun drying respectively for the third experimental day.

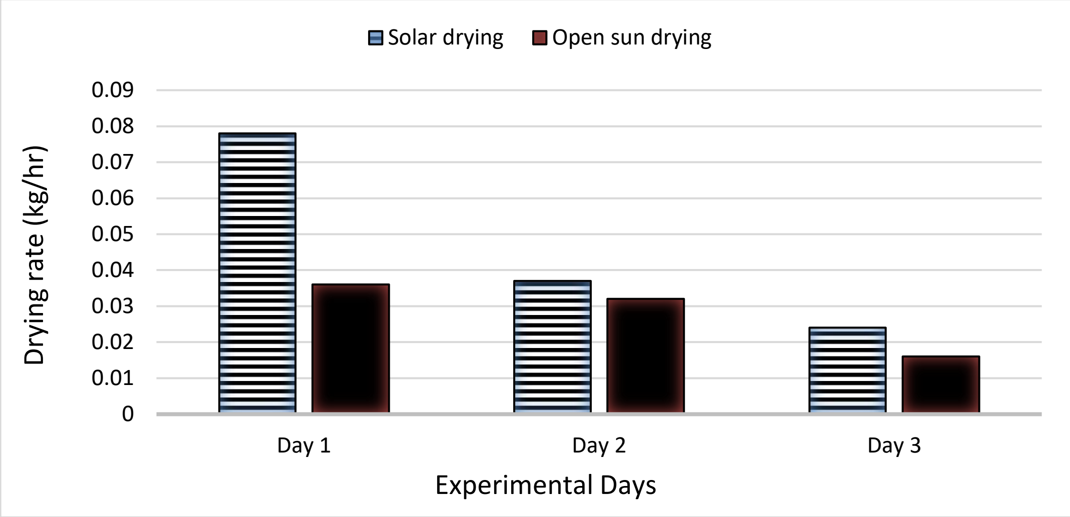

Fig. 7: Comparison of drying rate for the two drying modes

Fig. 8 shows the cassava samples before and after drying. Comparing Fig. 8b and 8c which show the cassava samples after open sun drying and solar drying respectively, it is observed that the samples from the solar drying look finer and neater than those from open sun drying. The sample from solar drying seems to have maintained its initial colour, when compared to the sample before drying, as seen in figure 8a, while that from open sun drying seems to have changed colour, looking darker. This is due to exposure to dirt and retention of moisture, which could eventually lead to spoilage.

(a) Before drying (b) After open sun drying (c) After solar drying

Fig. 8: Cassava samples before and after drying

4. Conclusions

A natural convection mud brick solar dryer has been developed and experimented. Results from the solar drying of cassava were compared to that of open sun drying of cassava, which was conducted simultaneously. Results gave a final moisture content of 9.3% and 34% for the solar drying and open sun drying respectively from an initial moisture content of 76% over three days drying period. Dryer efficiency ranged from 4% to 34%, with an average efficiency of 13%, while open sun drying efficiency ranged from 0.7% to 29% with an average efficiency of 5.5%. Maximum drying rates of 0.078 kg/hr and 0.036 kg/hr were obtained for the solar drying and open sun drying respectively. This is an indication that the developed solar dryer would be useful to farmers for drying cassava.

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