



Performance Evaluation and Comparison Studies on Drying Characteristics of Sliced Plantain and Maize

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Solar dryer was developed and comparison between using solar energy and air-sun drying methods with sliced plantain and maize (shelled corn) were assessed. The dryer consist of a solar collector panel (concentrator type), a thermal storage unit and a drying chamber. The solar chamber was tilted at 7° to the horizontal with the aid of four supports at two differ heights and was covered with the transparent Polyvinylchloride (PVC) film, of 0.15 mm, thickness. The absorber material used was aluminium pipe 145 cm long of external diameter 5 cm, painted black and fixed at the focal point of the parabolic mirror. The thermal storage unit and the drying chamber were built of wood because of its good insulation properties. Results showed the collector outlet, storage unit and drying chamber temperatures ranged from 37°C–47°C, 36°C–46°C, and 33°C–45° C, respectively. About 70.1% of moisture evaporated using solar dryer for plantain as compared to 45% using open air drying. Also more moisture evaporated from the maize (100%) using solar dryer than using open air drying (65%). The degree of variation between using solar dryer and open air drying was found to be statistically significant (P = 0.05) for both treatments. Results showed that using solar collector/dryer evaporated more moisture from the products than using the open –air sun drying.

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1. INTRODUCTION

Nigeria by virtue of its position in the tropics is blessed with sunshine more than 95% period of the year. Climatic data collected from the metrological station at Ikeja in Lagos State showed that the lowest mean monthly sunshine hours during the year are 111 hours on September (wet cloudy season). The amount of solar radiation received at a particular station was a major controlling factor in the designs of any solar energy system. From a purely technical standpoint, solar energy conversion was potentially capable of producing the bulk of the world's future energy demand if it was properly harnessed. In 2012, the world's total energy consumption of about 5.6×10^{20} Joules [1]. The total energy consumed equal to solar energy received every year by an area of 44,000 km² in a desert region. In other words, solar radiation absorbed on earth is 20,000 times the world's energy consumption. Solar energy was fast becoming an alternative source of energy in view of the high rate of depletion of the convectional energy source and negative effect on climate change by some other sources of energy [2]. It was estimated that the world's petroleum will last for another 30 years, coal deposits for 300 years, natural gas for 48 years and nuclear energy reserves for 90 years at known levels of technology [3]. Although there are some other alternative sources of energy like wind and shale, solar energy has attained the first phase on the list of preference due to the fact that it was vast and inexhaustible [4]. In the simplest traditional sun-drying process, produce is spread in thin layers on the ground, turned occasionally and covered or moved to a shelter when rain falls. It exposes the produce for extended periods to risks of deterioration caused by dust and dust borne organisms and to the depredation of insects, rodents, birds and other animals [5]. For fruit and vegetable produce the simple process may entail a loss of nutritive value such as destruction of vitamin C or Povitamin A and may lead to discolouration and the development of off-flavours [6]. [7] Highlighted that when ambient humidity is high the traditional sun drying process may be unreliable, even where solar radiation levels are high and extensive mould growth may take place in the produce under these conditions. [8,9] highlighted some methods used for improved sun-drying are as follows:

- (1) use of drying floors and platforms

- (2) use of blackened surfaces
- (3) use of woven matting and
- (4) Use of wire mesh trays mounted on bamboo pole supports.

Solar drying can be considered as an elaboration of sun drying and was an efficient system of utilizing solar energy [10]. Most of the advantages of solar energy are so much a part of our daily lives that we often overlook them. Some of the outstanding obvious characteristics of solar energy were highlighted by [11,12] are as follows:

- The raw material (solar energy) is free of cost and requires no purification
- The raw material is often delivered to where we want to use it, which means no transportation costs.
- The supply is essentially unlimited and is not affected by the amount used.
- Most solar energy applications are free of pollution and have no danger of fire or other hazards.
- The political problems associated with its use are minimal since no one owns the sun.
- The direct use of solar energy does not deplete the resources of earth.

Equipment which depends on solar energy as the energy source involves no running costs, only routine maintenance cost is incurred. Therefore, the development of efficient solar drying processes would help to increase the production of dried agricultural and food products while reducing the dependence of industries on fossil fuels [13]. [14-16] highlighted the compared products dried by solar dryers and natural sun drying. Their study indicated that using solar dryers gives more advantages than natural sun drying, especially in terms of drying time and moisture removal. The study was performed to evaluate the developed solar dryer and compared on drying characteristics of sliced plantain and maize that will be economically feasible for the rural farmers and compatible with solar limitations. Hence no auxiliary equipment and other energy source are needed other than solar energy. This paper reported a preliminary study of rates of drying maize and sliced plantain tests which were conducted in May and June when the rainy period was picking up momentum.

2. MATERIALS AND METHODS

2.1 Description of a Solar Product Dryer

The design concept of the solar dryer is to collect the solar energy through a solar collector and use it to heat up a mass of air and pass it through a drying chamber by natural convection established by buoyancy of airflow. The experimental solar dryer was made up of a collector and a drying chamber. The collector which makes use of a stationary non-tracking concentrator was constructed from four reflective sheets of tin-plates mounted on a parabolic frame structure with 4 cm thick coconut fibre insulation between them. The frame structure was made from plywood. The parabolic frame formed has a focal length of 25 cm and the square shape structure with dimension of 120 cm x 120 cm x 60 cm. The collector was made from aluminium pipe 145 cm long of external diameter 5 cm painted black and fixed at the focal point of the parabolic mirror. The pipe was placed concentrically in a glass tube, 129 cm long 8.8 cm diameter with the aid of two wooden corks. A transparent Polyvinylchloride (PVC) film, 0.15 mm, was served as the cover plate materials. The parabolic was placed at angle 7° to the horizontal with the aid of four supports at two different heights. The base of the supports was fitted with rollers for easy movement. The drying chambers were constructed from 1.27 cm thickness of plywood and of square shape with dimensions 48 cm x 48 cm x 123 cm. It rests on 43 cm supports and has a plenum chamber 48 cm x 48 cm x 25 cm. The aluminium pipe from the collector goes into the plenum chamber from the rear of the drying chamber through a 5.3 cm hole. The outlet air vent is the chimney which is situated on the top of drying chamber. It is made of Polyvinylchloride (PVC) tube, 15 cm long and 10 cm diameter with PVC lip cover. Lagos State is situated in the South West of Nigeria. It fall within longitudes 03° 50' E and 03° 38' E and latitudes 06° 20' N and 06° 18' N. The mean daily sunshine hours in Ikeja-Lagos State for 30 years (1985 – 2014) is presented in Table 1.

2.2 Experimental Procedure and Samples Preparation

Preliminary tests were carried out to determine the temperature profile and history of the drying chamber. This was to get an ideal of the temperature distribution across and along the chamber during day (7.00 am – 7.00 pm). Drying

tests were performed with maize faro 6 and yellow plantain sliced into 5 mm thickness. The maize was loaded in the tray to 4 mm initial bed depths and the sliced plantain was loaded in single layer 5 mm bed depth. The plantain tests were conducted in May and those of maize were done in June. Maize and plantain were conditioned to moisture content levels ranging from 36 to 56 (kg/kg) and 73 to 80 (kg/kg) wet basis respectively. Each sample was dried to the pre-determined moisture content level by placing on the drying tray. Trays with samples were placed in an oven set at 80°C. Moisture content of each sample was controlled by the initial weight, initial moisture content and pre-determined moisture content. Samples were mixed thoroughly and sealed in the plastic container after cooling to room temperature. Samples were stored in the cooler at 2°C for four weeks to ensure moisture homogeneity of the two samples. Before determining the moisture, container of samples were taken out, kept in laboratory for 24 hours to bring the samples temperature to room temperature. Moisture contents of both the wet and dried products were determined from weights of samples before and after drying by an oven at temperature of 80°C. Moisture content was calculated as kg/kg dry solids. The loss in product moisture during drying was assumed to be equivalent to the product weight loss. Drying was done for a total 9 hours and four tests were performed for each product. The first three (1, 2, 3) tests was done using solar dryer and fourth (4) was done using open air-sun drying as control. The moisture content of the maize was brought to the required value by wetting it with the approximate amount of water and freezing it for 9 weeks. The loaded open-air tray was appropriately supported, so that the air could flow through the top and below. Temperatures were measured using mercury in bulb thermometers. Ambient air temperature was measured from a wet and dry bulb thermometer. The ambient air, collector outlet, storage unit and dry chamber temperatures were all manually measured hourly between 8.00 am to 7.00 pm. The results were presented in Tables 2 and 3 respectively.

2.3 Data Analysis

2.3.1 Determination of moisture content

Samples were kept in a convective electrical oven, maintained at 80±1°C, for 5 hours. Initial (w) and final mass (d) at time (t) of samples were recorded using electronic balance and repeated

every one hour interval till end of drying. Sample moisture content is expressed as:

$$M_w \text{ (wet basis)} = \frac{w - d}{W} \quad (1)$$

$$M_d \text{ (dry basis)} = M_w \text{ (wet basis)} = \frac{w - d}{d} \quad (2)$$

W = wet weight

D = dry weight

M = Moisture content on a kg/kg basis

Table 1. Mean daily sunshine hours in Ikeja - Lagos State for thirty years (1985 – 2014)

Months	Hours	% of possible sunshine hours
January	6.11	56
February	6.50	55
March	6.45	53
April	5.25	43
May	6.25	57
June	4.33	34
July	4.96	40
August	3.76	38
September	3.48	29
October	5.23	44
November	6.90	58
December	6.93	34
Mean	6.40	54

Source: Department of Metrological Services, Lagos

3. RESULTS AND DISCUSSION

Table 1 showed the means daily hour sunshine in the studied area. The means daily sunshine hour ranged from 3.48–6.93 hours and the minimum and maximum daily sunshine hours occurred at months of September and December respectively. Table 2 showed the variation of the

dryer mean system temperatures. The result shows that the average ambient air temperature ranged between 29°C-34°C, collector outlet temperature ranged from 37°C-47°C, storage unit temperature ranged from 36°C-46°C and drying chamber temperature ranged from 33°C – 45°C. The result also indicated that the air heater (collector) has the capacity to heat air between 7°C–12°C depending on solar energy or insolation. Table 3 shows the hourly experimental results which also indicate the weights of the final product in each test. The initial moisture content of sliced plantain was 80% (wet basis) or 73% (dry basis) and that of maize was 56% (wet basis) or 36% (dry basis). Because the months of May and June are the period of rains appreciable overcasts were present during the drying tests. Therefore, the mean sunshine hours were about 60% of that expected on a clear dry season, hence the solar energy or insolation was about 60 to 70% of a normal clear dry day. Fig. 2 shows the drying curves of the sliced plantain and maize. It shows that the open air tray was slower in drying than any of the three other trays in the solar dryer. The trial products moisture content at the end of the day was higher in the open air tray than the solar drying chamber. One reason for this was likely caused low ambient air temperature. Because of the season (rainy season) the mean ambient air temperature was low (34°C) compared to that in the drying chamber of the solar dryer (45°C). Although the final moisture content required for the safe storage of the plantain sliced (8% wet basis) was achieved in both drying in open air and solar drying (Fig. 4). It was important to note that about 70% of the total required moisture was evaporated in the drying chamber, 9 hours of tests. On the other

Table 2. Showed the variation of the dryer mean system temperatures with the drying conditions for the products

Product	Test no.	Initial moisture (kg/kg)	Tray loading (kg.m ²)	Ambient temp. (°C)	Collector temp. (°C)	Storage unit temp. (°C)	Drying chamber temp. (°C)
Plantain	1	7.33	16.2	32	45	36	44
	2	7.33	16.2	34	47	46	45
	3	7.33	16.2	30	42	40	38
	4	7.33	16.2	29	37	36	33
Maize	1	6.58	10.1	32	45	36	44
	2	6.58	10.1	34	47	46	45
	3	6.58	10.1	30	42	40	38
	4	6.58	10.1	29	37	36	33

hand only 45% of the total required moisture was evaporated in the open air tray. Similarly, drying curves for maize shows the same trends as on plantain, but here, the trial moisture content required (10% wet basis) achieved by the seventh hours of the test in the solar drying chamber, whereas this was not achieved in the open air drying throughout the 9 hours of the test (Fig. 3). Therefore, the difference between results for tests with solar drying chamber and those of open air drying were greater in the

maize tests. The total amount of moisture evaporated in the solar drying chamber was far more than that evaporated in the open air drying (100% Vs 65%). These findings collaborate with other researchers [10,13,14] that solar dryer gives more advantages than sun drying in terms of moisture removal, efficient and drying time. These preliminary drying tests have shown that solar concentrators is more efficient for drying than open air drying and have provided guidance for further process development.

Table 3. Products weights during drying tests

Time (Hr)	Plantain (kg)				Maze (kg)			
	1	2	3	4	1	2	3	4
0	3.28	3.28	3.28	3.28	2.05	2.05	2.05	2.05
1	2.91	2.98	2.90	3.14	1.94	1.95	1.94	2.00
2	2.64	2.61	2.63	2.91	1.80	1.82	1.81	1.89
3	2.24	2.20	2.21	2.60	1.68	1.67	1.67	1.75
4	1.92	1.90	1.92	2.26	1.58	1.58	1.57	1.70
5	1.67	1.68	1.67	1.99	1.52	1.52	1.53	1.67
6	1.45	1.47	1.44	1.75	1.49	1.49	1.49	1.64
7	1.25	1.28	1.25	1.56	1.47	1.47	1.47	1.62
8	1.11	1.13	1.11	1.46	1.46	1.46	1.46	1.61
9	0.99	0.99	0.99	1.39	1.45	1.44	1.45	1.61

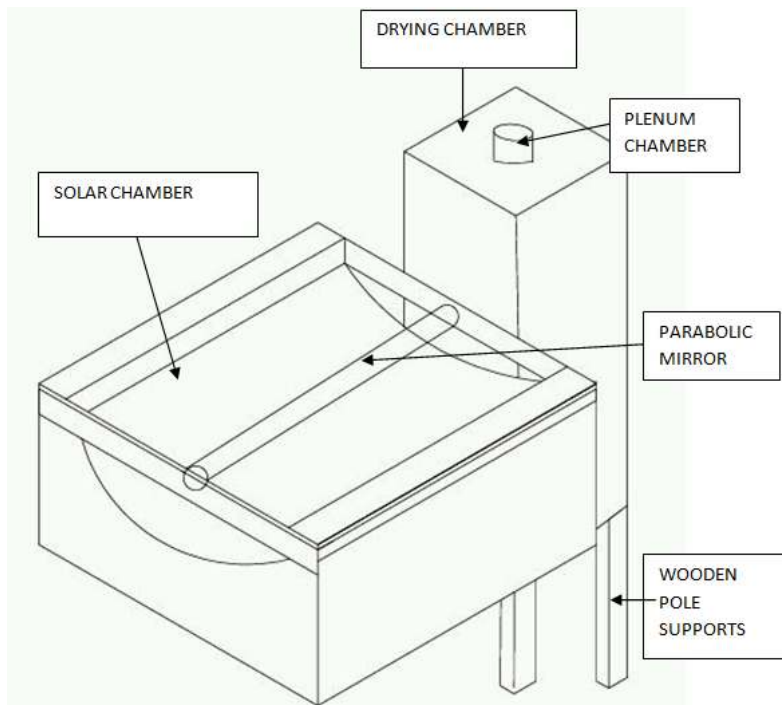


Fig. 1. Solar dryer

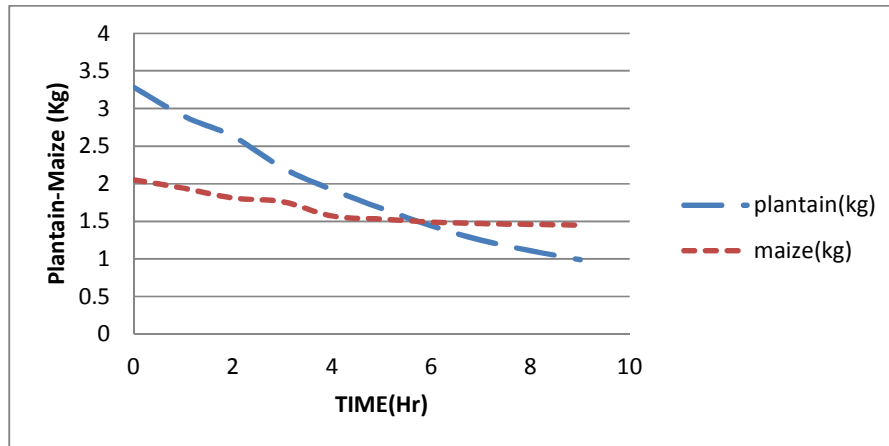


Fig. 2. Drying curves for maize and plantain

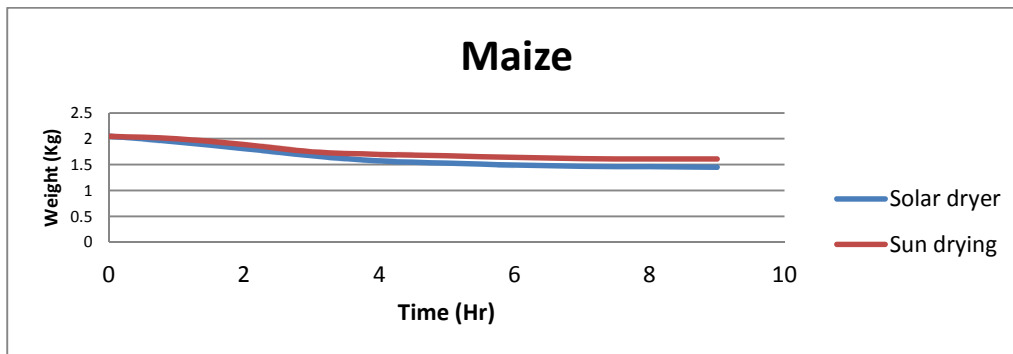


Fig. 3. Drying curves for maize

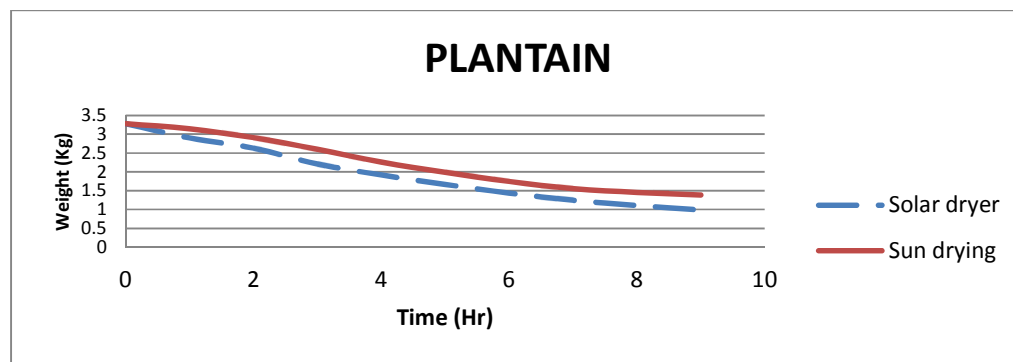


Fig. 4. Drying curves for plantain

4. CONCLUSION

The following conclusions were drawn from the study:

Solar dryer was developed in Lagos State, Nigeria with the locally made materials. The mean values drying rate of the dryer was 0.23 kg/hr per every 3.28 kg of plantain whereas sun

drying rate was 0.21 kg/hr comparatively while the mean values drying rate of the dryer was 0.17 kg/hr per every 2.05 kg of maize whereas sun drying rate was 0.05 kg/hr comparatively. Solar dryer efficient almost twice that of the sun drying in case of maize, resulted time saving as compared to traditional sun drying method. Hence, it can be used at community level for subsistence farmers. For further improvement of

the dryer, there is need to increase the volumetric air flow across the drying chamber.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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