International Journal of Agricultural Research and Review
Abbreviated Key Title: Int. J. Agric. Res Rev.
ISSN: 2360-7971 Open Access: doi.org/10.54978
Vol. 14, Issue 3, Pp.: 27-34, March, 2026.

OPEN ACCESS

Construction and Performance Evaluation of a Single Chamber Domestic Passive Solar Crop Dryer

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Abstract

Solar drying is an effective and sustainable method for reducing post-harvest losses of agricultural products, particularly in developing countries where access to conventional drying technologies is limited. This study presents the construction and performance evaluation of a single-chamber domestic passive solar crop dryer fabricated using locally available materials. The dryer consisted of a solar collector and a drying chamber covered with transparent polythene film to enhance solar heat absorption. Cassava mash was used as the test crop to evaluate the drying performance of the device. A comparative drying experiment was conducted between the solar dryer and traditional open sun drying. Temperature measurements and weight reductions were recorded hourly between 9:00 am and 3:00 pm over a three-day drying period. The results indicated that the maximum temperature inside the dryer reached **70°C**, while the ambient temperature during open sun drying was 46°C. The drying rate achieved in the solar dryer was 0.354 kg/day**,** compared to 0.236 kg/day for open sun drying. The results demonstrate that the developed passive solar dryer significantly improves drying efficiency and reduces drying time relative to traditional methods. The system provides a low-cost and energy-efficient solution suitable for rural farmers.

Keywords; Dryer, moisture, ambient, performance, drying rate

Accepted 15-02-2026. Published 16-03-2026.

1.0 INTRODUCTION

Sun drying is the oldest and most widespread method of drying because of abundant sunshine year round. It is a major processing activity, which involves dehydration of moisture from crops for easy handling and storage. However, in most locations, most crops are harvested when the outdoor air conditions are not suitable for natural air drying, and usually the crops have a relatively short time before spoilage unless the moisture is removed. This means a considerable amount of energy must be available immediately when the crops are harvested to provide higher drying potential, which will eventually prolong their storage life. It is a preventive technique against post-harvest losses which amount to food insecurity and could be tamed if adequate precautionary measures are taken as soon as the farmer harvests his crops. The issue of food holds a key position in the development of any country. Itodo *et al*. (2002) reported that the situation of post-harvest losses has caused a setback in the level of carbohydrate food consumption. The extent of post-harvest losses in agricultural produce influences the stability of food prices. Farmers produce a large quantity of crops, but they lose a significant portion during harvesting, primarily because they lack effective methods for preserving the produce for extended storage. One of the major problems of lack of food availability is the method of drying.

Despite the availability of cheap artificial methods of food drying in Nigeria, most farmers still employ the open air (sun drying) technique in order to dry their crops. Open-air or sun drying is prevalent and very common in the rural areas because it has been the traditional way of drying crops. A greater percentage of farmers spread their crops along major roads on hard rock surfaces, tarpaulin, etc. to get them dried. These methods have several disadvantages because the crops are exposed to contamination, decay, insect and rodent attacks, mould build-up due to prolonged drying periods, and a reduction in nutritional value. These crude and outdated methods of open-air (sun dryinging) processes had inherent limitations, which include dust contamination, decay, insect and rodent attack, and mould (fungal) build-up due to prolonged drying periods.

Many methods of solar energy storage materials are available to trap solar energy and use it for drying, but they have not been exploited. A possible alternative cheaper crop drying system that could be used is a passive solar drying system in which the heat energy is trapped and raised up to 60-70°C to enhance the drying of a variety of agricultural produce (Sambo, 1995). The performance of a solar dryer depends on the availability of solar radiation. The abundance of solar radiation in Nasarawa State of Nigeria could make crop drying with a solar dryer very easy and simple, since the environmental impact of a solar dryer is considered friendly, non-contaminating and non-polluting (Habou *et al*., 2003). Studies by Arinze (1985) and Adesuyi (1991) showed that the use of solar energy in crop drying is possible. However, the exploitation in Nigeria is low because of a lack of incentive from the government for the advancement of the technology. Research and technology on solar dryers imported from other countries have difficulties because of a lack of competent hands and a lack of spare parts.

A passive solar dryer has therefore been developed, which will be appropriate for crop drying during the low temperature and high relative humidity period of the year. To enable the crop to be dried without cracking and hence minimise the exposure of the crops to fungal and bacterial infestation and wastage, the transparent cover and the walls serve as barriers.

The main objectives of the study were to construct and evaluate the performance of a passive solar dryer using cassava mash and to optimise the parameters needed for the optimal performance of the passive solar dryer that will be economically feasible and simple for the rural farmers to use.

Despite the increasing interest in solar drying technologies, the adoption of solar dryers among small-scale farmers in developing countries remains limited due to high cost, lack of technical knowledge, and the absence of simple and locally adaptable designs. Many existing solar dryers require external power sources or complex fabrication techniques, which makes them unsuitable for rural communities, particularly in areas where access to electricity is limited and where farmers may lack the skills to build complicated systems. Therefore, there is a need for the development of low-cost, passive solar drying systems that can be easily constructed using locally available materials while maintaining acceptable drying performance.

1.1 Objectives of the Study

The objective of this study was to design, construct, and evaluate the performance of a single-chamber passive solar crop dryer using cassava mash as the test material. Specifically, the study aimed to:

(i) Develop a low-cost solar dryer using locally available materials,

(ii) Evaluate the thermal performance of the dryer in terms of temperature variation and drying rate, and

(iii) Compare the drying performance of the solar dryer with conventional open sun drying.

2.0 METHODOLOGY

1.1 Materials and Method

The device was constructed, and the performance was assessed at the works department, College of Agriculture, Science and Technology, Lafia. The dryer was placed in the open free from shade throughout the day. Cassava mash was used as test material. The material selection was based on simplicity and ease of construction.

2.1 Experimental Procedure

The performance evaluation of the solar dryer was conducted using cassava mash as the drying material. A total sample weight of **1 kg** was placed inside the solar dryer, while another **1 kg sample** was simultaneously exposed to open sun drying for comparison. Temperature measurements were taken using calibrated mercury thermometers positioned inside the drying chamber and in the ambient environment. The weight of the samples was recorded at hourly intervals between **09:00 h and 15:00 h** using a digital weighing balance. The drying experiment was conducted for **three consecutive days** until the samples attained constant weight, indicating the completion of moisture removal.

2.2 Description of the Passive Solar Dryer

Plates 1 and 2 are the internal and external features of the dryer. The passive solar dryer consists essentially of wood which forms the main framework, plywood forms the base, a corrugated metal sheet painted black as the absorber serves as the floor, polythene films are used as the roof, and wire mesh is at the inlets and outlets. The dryer is made up of two units: the absorber and the drying chambers.

Plate 1: Front view of the device

Plate 2: Side view of the device

2.2 Solar Collector Unit

This is made up of a corrugated metal sheet painted black to absorb the solar energy that falls on it. The thickness of the corrugated sheet is 0.001m. The length, width and height of the collector units are 0.97 m, 0.725 m and 0.26 m, respectively. The area is 2.287 m^2, while the volume is 0.1828 m^3. There is an outlet for air to blow the heat from the absorber to the drying unit to remove the condensed moisture.

2.3 The Drying Unit

This is made up of a single drying tray constructed from 1/3 inch of plywood for drying inside the dryer. A tray 0.47 m in length and 0.47 m in width was used for drying the crop. The height of the drying unit is 0.26m. The total area of the drying unit is 1.303 m^2. The drying unit has a volume of 0.0886 m^3. There is also an outlet which allows the escape of condensed moisture.
The dryer is raised 0.372 m and 0.159 m in front and back, stands above the ground level and is capable of drying about 30 - 40 kg of food products at a time. The solar collector is inclined at an angle of 18.33° for proper collection of solar radiation.

3.0 ANALYSIS OF THE DOMESTIC PASSIVE SOLAR DRYER TEMPERATURE

Two thermometers were used to assess the temperature of the dryer. One is outside the dryer for the measurement of ambient temperature; the second is placed in the drying chamber for measuring the temperature of the device.

Performance Evaluation and Efficiency

i. Drying Rate: The drying rate of the device is computed from this equation (kg/day). The quantity of materials to be dried is placed in the drying chamber, and the same quantity is placed in the sun to compare the drying rate of the device and sun drying. Readings were taken 7 times in a day, from 9:00 am to 3:00 pm until there was no loss in weight of the product.

ii. Drying Efficiency: This is the relationship which involves the heat utilised and the heat available for drying under the environmental conditions that prevails. This efficiency is used when comparing the performance of dryers.

$$\eta_d = \frac{WL}{I_C A_C t}\, x\, 100$$

Where:
W = Weight (kg)
L = Latent heat of evaporation (KJ/kg or KJ/mol)
K = Intensity of solar insulation (w/m^2 or W_m^{-2})
T = Drying time (hr)
A_c = The Effective Area of the Collector Facing the Sun (m^3)

iii. Moisture Content: The moisture content on a dry basis is the weight of moisture contained in the sample as a percentage of dry matter; it is expressed as follows:

$$\frac{W_1 - W_2}{W_1}\, x\, 100 \qquad \text{(Mohsenin 1970)}$$

Where
W_i= weight of crop (kg)
W_f = Final weight of crop (kg)

iv. Collector Area
The collector area was computed from this equation

$$A_C = \frac{V \rho C_P \Delta T}{\eta_C} \qquad \text{(Ojha and Michael, 2014)}$$

Where:
ρ = The density of air (kg/m^3)
ΔT= Temperature elevation (°c)
C_p= Specific heat capacity of air at constant pressure (J/kgk)
V = The volumetric flow rate (m^3/s)
η_c = Collector efficiency(%)

v. Pressure Drop across Collector (ΔP_C)
The pressure drop across the first stage collector and the dry chamber was computed from the equation;

$$\Delta P_C = \mathrm{F1G_d^2} / 2\rho \mathrm{R_h} \qquad \text{(Ojha and Michael, 2014)}$$

Where
ΔP_c =Pressure drop across collector (N/m^2)
F = Fanning coefficient of friction
G_d = Mass flow rate of air per unit duct area
K = Thermal conductivity ($W_m^{-1}k^{-1}$)
ρ = Density (kg/m^3)
R_h = Hydraulic radius (m)

Vi. Pressure Drop Across Commodity (ΔP_d)
The pressure drop across the commodity being dried was computed from this equation;

$$V = A_a (\Delta P_d / h_b)^b / \rho$$

(Ojha and Michael, 2014)

Where:
V = Volume of commodity (m^3)
A = Area occupied by the crop(m^2)
a and b = Constant
ΔP_d = Pressure drop across commodity (N/m^2)

h_b =Height of product bed (m)
ρ = Density (kg/m^3)

The total energy transmitted and absorbed by the cassava mash is expressed as;
$Q = Q_c + Q_r + Q_k$

Where:
Q_c = is the convective heat transfer(J)
Q_r = Radiative heat transfer(J)
Q_k =Conductive heat transfer(J)
These are expressed as;
$Q_c = h_c(T - T_{ch})A$
$Q_r = h_r(T - T_{ch})A$
$Q_k = U_k(T - T_{ch})A$

Where;
h_c = convective heat transfer coefficient W/m^2.K
h_r = radiative heat transfer coefficient W/m^2.K
U_k =thermal conductivity of material W/m^2
T_{ch} =temperature of chamber (temperature of material)^{O}C
A =drying area of material(m^2)
T = temperature of hot air coming from the solar collector, ^{O}C

4.0 RESULTS AND DISCUSSION

The performance evaluation of the solar dryer was conducted by monitoring temperature variations and moisture reduction during the drying process. The results showed that the temperature inside the solar dryer was consistently higher than the ambient temperature throughout the drying period. The maximum temperature recorded inside the dryer was **70°C**, while the maximum ambient temperature during open sun drying was **46°C**. The elevated temperature within the dryer enhanced moisture removal from the cassava mash, thereby increasing the drying rate compared to the traditional sun drying method.

Cassava mash was chosen because it can be processed into different forms, such as flour or chips, and its strategic importance in Nigeria's economy is highlighted by its role as a staple food and a source of income for many farmers. Equal quantities of cassava mash were dried at the same time in the dryer and in the open sun.

Table 1 shows the result of research carried out in drying 1.00 kg of cassava mash in the dryer until there was no loss in weight.

Table 1: Result for drying of cassava mesh inside the dryer for the three days.

	First Day			Second Day			Third Day		
Time (hr)	**T_1 (^{0}C)**	**W_1(g)**	**Reduction In weight (g)**	**T_2 (^{0}C)**	**W_2(g)**	**Reduction In weight (g)**	**T_3 (^{0}C)**	**W_3(g)**	**Reduction In weight (g)**
9am	31	1000	_	42	440	_	40	292	
10am	52	900	100	54	420	20	56	292	
11am	56	800	100	56	400	20	67	292	
12noon	61	700	100	59	370	30	74	292	
1pm	62	600	50	73	350	20	74	292	
2pm	63	500	100	68	320	20	71	292	
3pm	63	440	60	65	292	22	61	292	

The temperature of the dryer was observed to be well above the ambient temperature. This was as a result of the absorber raising the temperature above the normal ambient temperature. A constant weight of 292g was attained on the second day. Two thermometers were used to take the readings of the temperature in the dryer and open sun-drying hourly.

From the table (1), a constant drying rate was obtained on the second day around 15:00. The highest temperature reached was 70°C, while that of the ambient was 46°C. This shows that a solar dryer offers excellent drying performance compared to open sun drying.

The improved drying performance of the solar dryer can be attributed to the greenhouse effect created by the transparent polythene cover, which traps solar radiation and increases the internal air temperature. The black-painted metal absorber also contributes to efficient heat absorption and transfer to the drying chamber. Similar findings have been reported in previous studies where passive solar dryers demonstrated higher drying efficiency and shorter drying times compared to open sun-drying methods.

The drying rate of the dryer is 0.354 kg/day. However, Itodo and Fulani (2004) recorded a dryer drying rate of 1.5 kg/day and 1.6 kg/day for the dryer and sundry, respectively. Equally, their research indicated the highest temperature of 720°C. Itodo *et al*. (2002) recorded a dry rate of 0.74 kg/day. Okonkwo and Okoye (2004) recorded the highest temperature of 72°C for the absorber.

The moisture content at the start and end of the research for the dryer was 56% and 34%, respectively.

Table 2 shows the result of open-sun drying. The result revealed that the temperature of the ambient (open sun drying) was observed to be below that of the dryer, with a maximum temperature of 51°C. The drying rate of the sun-dry was also 0.236 kg/day, but the ambient temperature was lower than that of the device; it attained a constant weight of 290 g on the third day. The moisture content at the start and end of the research for sundry was 55% and 34%, respectively.

Table 2: Result obtained for drying of cassava mash in the open air for three days

	First Day			Second Day			Third Day		
Time (hr)	T_1 (^{0}C)	W_1(g)	Reduction In weight (g)	T_2 (^{0}C)	W_2(g)	Reduction In weight (g)	T_3 (^{0}C)	W_3(g)	Reduction In weight (g)
9am	31	1000	_	32	450	_	34	350	0
10am	36	800	200	35	440	20	43	345	05
11am	39	700	100	42	410	20	46	330	15
12noon	42	650	50	43	390	10	48	305	25
1pm	43	600	50	45	385	20	51	290	15
2pm	43	510	90	46	373	20	50	290	0
3pm	45	450	60	48	350	10	48	290	0

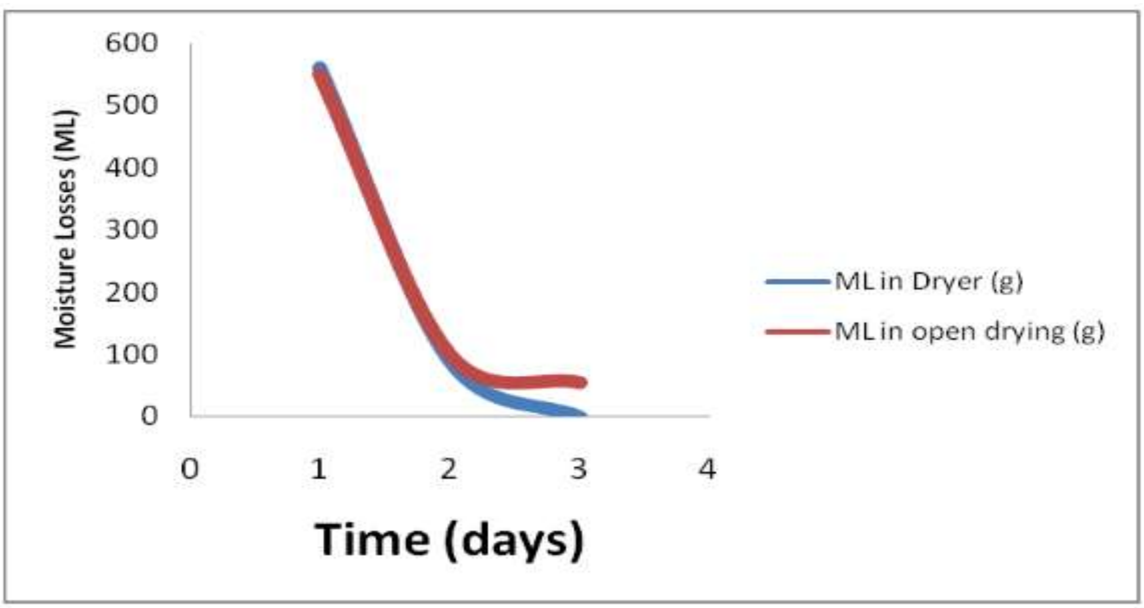

Figure 1: A plot of graph of moisture loss for dryer and open sun drying vs time (days)

Figure 2 is the graph of the average temperature of the dryer and sun-dried.

Table 3: Shows the summary result for moisture losses (ML) for three days within which the research was conducted. It revealed that the moisture loss in the dryer was greater than that of the ambient. This is due to the rise in temperature by the dryer.

Figure 1: Shows a plot of moisture loss for the dryer and the ambient against time, which also revealed that the dryer has the higher curve (rise in temperature).

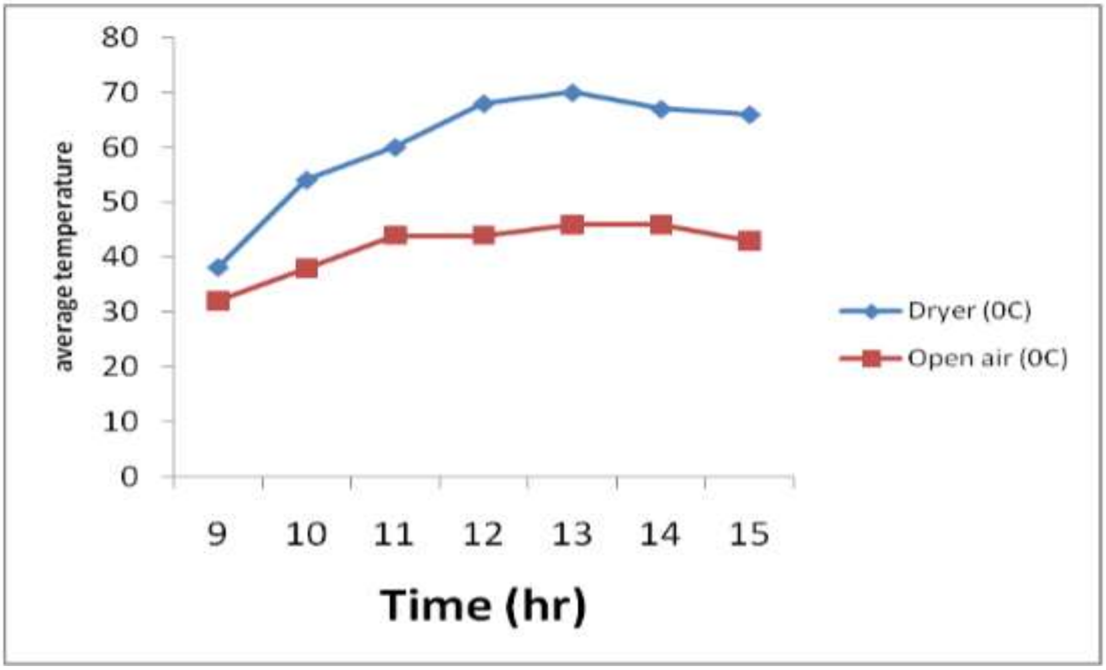

Figure 2: Result of average temperature of drying cassava mash in the dryer and open air drying

Table 3: Result for moisture loss (ML) in weight and time (day) for the drying of cassava mash in the dryer and open air drying.

Time (days)	1	2	3
ML in Dryer (g)	560	90	0
ML in open drying (g)	550	100	55

Key:
ML= Moisture Loss

Table 4: Shows the average temperature of the dryer and sun-dry with time (hr), which also recorded the maximum temperature of the device and the ambient temperature to be 70°C and 40°C, respectively.

Figure 2: Shows a plot of the summary result of the average temperature (°C) of the device and ambient versus time. The plot revealed that the device's temperature curve is higher than that of the ambient temperature.

Table 4: Average Temperature of Drying Cassava in the Dryer and Open Air

Time (hr)	9	10	11	12	13	14	15
Dryer (^{0}C)	38	54	60	68	70	67	66
Open air (^{0}C)	32	38	44	44	46	46	43

5.1 Conclusion and recommendation

The result of the performance evaluation showed that under all weather conditions, the solar dryer performs better than the natural sun-drying method. The dryer is characterised by a moderate temperature of 70°C, which is needed for passive solar grain dryers, and its dry rate was 0.354 kg/day.

The dryer can be enlarged for large-scale drying and commercial purposes by increasing the collector size and adding more trays in the drying chamber. There is no need of carrying the crops inside during the night in order to avoid re-wetting since the dryer is sealed with transparent polythene film and wood to protect the samples from dew or rain.

The performance of a domestic passive solar dryer can be improved by installing another channel flow system, thereby reducing the time taken for drying, e.g., the use of a thermostat and fan to regulate the temperature. Rural farmers should endeavour to access the dryer, as it does not require electrical energy, which is completely absent in their area of domain.

The next level of this study should be to carry out construction and evaluation performance of a double or triple tray dryer.

In all, the study successfully demonstrated the design and performance evaluation of a single-chamber passive solar crop dryer fabricated using locally available materials. The experimental results showed that the solar dryer achieved higher temperatures and faster drying rates compared to conventional open sun drying. The maximum temperature recorded in the dryer was **70°C**, which significantly enhanced the drying process of cassava mash. The dryer achieved a drying rate **of 0**.354 kg/day**,** indicating improved efficiency relative to traditional drying methods. The developed system offers a cost-effective and environmentally friendly solution for small-scale farmers to reduce post-harvest losses. Future studies should focus on improving the design by incorporating multiple drying trays and optimising airflow within the drying chamber.

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