American Journal of Applied Sciences and Engineering | *ISSN 2766-7596*

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Research Article

Performance Evaluation of Solar Dryer for Drying Agricultural Produce in Ozoro

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Abstract

The solar drying system employs the radiation of solar energy to heat up air in the chambers and dry any food substance loaded in it, which is beneficial not only in reducing wastage of agricultural produce but also helps in its preservation. Conventional methods of food preservation, such as exposure to direct sunlight, even though it's simple, has its limitations, which include liability to pests and rodents' attacks, lack of proper monitoring, and the high cost of the mechanical dryers. Due to these limitations, this paper presents the design and construction of a domestic solar dryer, which was used to preserve agricultural produce. The dryer is composed of a solar collector (air heater), a solar drying chamber containing a rack of drying trays, both being integrated, a heater, an axial fan, a temperature sensor, and a thermostat. The air allowed in through the air inlet is heated up in the solar collector and channeled through the drying chamber, where it is utilized in drying agricultural produce placed in it. The design was based on the topographical location of Ozoro and climatological data were obtained for proper design specification. Locally available materials were used for the construction of the solar dryer. Testing and performance analysis were carried out using plantain, tomato and onion as agricultural samples, and with the results obtained with these samples, this solar dryer can also be used to dry other types of crops.

Keywords	*Performance Evaluation; Solar Dryer; Agricultural Produce*
Citation	Oji, I. C., Esimike, H. C., & Alumona, L. O. (2025). Performance Evaluation of Solar Dryer for Drying Agricultural Produce in Ozoro. *American Journal of Applied Sciences and Engineering 6(3) 1-10.* *https://doi.org/10.5281/zenodo.18496012*

Introduction

Food preservation, which is the oldest method practiced for preserving agricultural produce, remains the most commonly used method and it is usually employed to reduce post-harvest losses to ensure all year-round supply, since farming is seasonal (Asogba *et al*., 2024), and to keep them for a long time without further deterioration in the quality of the produce (Min *et al*., 2019). Food preservation methods include drying (dehydration), canning, and freezing (Ogundana et al., 2022). Drying, as a method of food preservation, involves the removal of moisture (dehydration) from food produce to prevent the growth of microorganisms, thereby preventing decay and spoilage and improving its shelf-life (Dare-Adeniran and Areola, 2022). It causes changes in the physical parameters of food produce, such as weight reduction and increased storability (Robert *et al,* 2014).

Drying methods can be classified into two major groups, namely: conventional methods, which include open-air method, and air dryer method that use a great quantity of fossil fuel for producing heat, and active solar-energy drying systems (Min *et al*., 2019). Conventional drying method such as the open-air method, are preferred methods usually used in rural areas of developing countries like Nigeria for small commercial-sized crops, agricultural produce, and foodstuffs such as fruits, vegetables, aromatic herbs, wood, etc. (Dare-Adeniran and Areola, 2022). This is called open-air drying. It is a simple and easy practice to execute, which does not require any great skills, since the produce is spread on the ground in open air, with a free and sustainable source of solar energy with no complexity, and it contributes significantly to the economy of small agricultural communities and farms.

Despite the numerous advantages of the open-air drying, it still has significant drawbacks, which include contamination of food produce from dust, insects, and birds, poor quality of food produce obtained, as well as dependency on favourable weather conditions, thereby affecting the quality of farm produce (Asogba *et al*., 2024). Also, the process is labour-intensive since it requires a large expanse of land for it to be effective, and the time required for drying a given commodity is quite long, which may result in post-harvest losses (Gupta *et al*., 2017). Therefore, the open-air drying method typically fails to meet the necessary quality standards, which may prevent the items from being sold in the global market (Elwakeel *et al*., 2023). Air dryer method, which is another conventional drying method, utilizes a great quantity of fossil fuel channeled toward a kiln that is designed for drying. But the increasing prices, shortage of fossil fuels, and increased environmental concern stress are major setbacks in rural areas of developing as well as underdeveloped countries (Dare-Adeniran and Areola, 2022).

Due to this limitation in the use of conventional methods, the construction of an active solar-energy drying system, which uses solar energy as an alternate energy source to dry agricultural produce, is proposed in this paper. The use of renewable energy sources to meet energy demand ecologically sustainable system in urban and rural areas has become inevitable. The drying systems working on renewable energy resources have been successfully demonstrated in the domestic, commercial, and industrial sectors. Solar energy has the potential to meet the energy demands for drying, particularly in tropical and sub-tropical countries, which receive sufficient solar radiation throughout the year. This energy could be well utilized in agriculture for crop drying.

Materials and Methods of Study

Components and Materials Used

The materials used for the construction of the solar dryer are cheap and were obtained in the local market. These materials include low-carbon steel, galvanized steel and wire, wool fibre, black-painted aluminum roofing sheet, transparent glass, and black/green paint. The solar dryer consists of the solar collector (air heater), the drying chamber, heater, axial fan, temperature sensors, thermostat, and drying trays. The main components of the solar dryer, which include the drying compartment, heating elements, rack and trays, chimney with removable cover, solar panel, solar collector, and DC fan, as seen in Figure 1.

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Figure 1: The solar dryer with its components

The construction of the drying chamber, which was built with a low-carbon steel material, and made of polystyrene walls and held securely with iron angles, has a volume of 0.3024 m^3. It has a silver-coloured interior to reduce heat loss by radiation, and is then insulated with wool fibre. The wool fibre, which is enclosed between the outermost layer made of low-carbon steel (painted green) and the innermost layer made of silver aluminum sheet, was used as the insulating material to achieve a minimal heat loss of 5% from the drying chamber. Low-carbon steel was used for constructing the rack, which was positioned at 0.2 m apart to enable easy insertion of individual trays. The trays were constructed with low-carbon steel, with their base made of fine wire gauze to allow the heated air to circulate and pass through the agricultural produce that is being dried. The drying chamber is protected by a door whose inner and outer layers are also insulated with wool fibre between them. Glass was used to cover the solar collector, which encloses the absorber plate, to prevent dust and rain from coming in contact with the absorber, retards heat from escaping and also allows easy transmission of the sun rays through the absorber plate. A black painted aluminum sheet was used as the absorber plate for easy absorption of solar radiation, this was placed below the transparent glass cover to absorb the incident solar radiation transmitted by the transparent glass cover, thereby heating the air between it and the cover, the interior of the solar collector was painted black to improve the absorption of solar radiation, the removable chimney was constructed with low-carbon steel and painted green on the exterior to reduce loss of heat. Two exhaust fans of 12V each are used to remove the air from the drying chamber and also to remove moisture from the product before drying.

Design Considerations and Specifications

Topographical and Climatological statistics of the location

Ozoro is a town located in Isoko North Local Government Area of Delta State. It lies within the southern part of Nigeria with Latitude 5.5447^0 N and Longitude 6.2323^0 E, and it's one of the two administrative units of the Isoko region, covering a land area of 1.136 km^2 with a population of approximately 186,000 at the 2006 census. The climate is tropical with average annual temperature ranging from 20^0 C to 32^0 C and precipitation of 302 mm respectively. Agriculture and small-scale retailing are the major businesses of the populace, with few working as civil and public servants. Ozoro is the host town of Delta State University of Science and Technology (now Southern Delta University) in Nigeria. The solar radiation of the location (Ozoro, Delta State, Nigeria) was considered as a case study for the design of non-toxic and non-corrosive construction materials that were used.

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Design Calculations

1. *Solar Collector Design*

A black painted corrugated iron sheet was used for the solar absorber of the collector with an area of 0.1435 m^2 and a thickness of 0.55 mm, and it was mounted in a box constructed of the same area; the black body of the absorber makes it a good transmitter of heat. Corrugated black iron sheet was used because of its availability in the local market and also its low cost. A single-layer transparent glass sheet of 5 mm thickness was placed on top of the absorber at a distance of 0.11m apart. Glass was used as glazing due to its low cost, high value of transmittance for long and short-wave radiations (80%), non-flammable and have high melting point. It also protects the absorber from wind and dust, thereby allowing solar radiation to easily reach the absorber.

To optimize the performance of the solar dryer, the solar collector was appropriately tilted and oriented to maximize solar radiation intake during operation. The angle of tilt (β) The area of the solar collector is given by the formula (Onigbogi *et al*., 2012; Dare-Adeniran and Areola, 2022).

$$\beta = 10 + latitude\ \theta \qquad 1$$

where the study area's latitude ϑ is the latitude of the town, which is 5.5447 ^{0} N. Therefore, the collector inclination angle is equal to

10° + 5.5447 ^{0} N = 15.5447 ^{0}

2. *Solar Power Consumption*

The power consumption of the main components used for the construction of the solar dryer is detailed below

Power of heating element	=	$2 \times 60\ w = 120\ w$
Power of DC fan	=	$2 \times 10\ w = 20\ w$
Power of other components used	=	$4\ w$
Total power consumed ($P_1 + P_2 + P_3$)	=	144 *w* 2

3. Solar panel current

A 50W solar panel was used for this design, and it provides power at 12V. The current given out by the solar panel was obtained as

$$Solar\ panel\ current = \frac{\text{Solar panel power}}{\text{Solar panel voltage}} \qquad 3$$

$$Solar\ panel\ current = \frac{50}{12} = 4.17\ A$$

Operation of the Solar Dryer

The solar dryer was placed in the open space in the direction of solar radiation, which is not obstructed by shade throughout the time of operation. A solar collector was used as the main heat source. In the afternoon, when the intensity of solar radiation was high, the solar rays were transmitted through the glass cover and easily absorbed by the absorber plate. The hot air was transmitted into the drying chamber through the inlet window by a natural and partially forced convection system, which was assisted by a DC fan that gradually removes moisture in the process.

The tomatoes, onions, and plantain samples used for this study were obtained from the Esekpe market in Ozoro town. The samples were thoroughly washed and cleaned with an absorbent paper. The tomato, onion, and sliced plantain samples were placed on the wire mesh and spread evenly to ensure proper air circulation. The dryer was then closed properly to prevent heat loss. The drying process was checked and monitored at equal time interval to ensure uniform drying. The record of the mass before drying and after drying was obtained for tomato, plantain and onion samples using pocket measurement scale in order to calculate the moisture loss. Also, the chamber temperature record was taken using K- type digital thermometer so as to obtain the dryer's component temperature for performance evaluation analysis.

Performance Evaluation of the Solar Dryer

The maximum temperature of the dryer was confirmed when it is empty, temperature of the ambient air and the drying chamber was also monitored. The solar dryer was loaded with onion, tomato and plantain samples to determine the minimum drying time obtainable to reach a desirable final moisture content level of the sample. The parameters that were monitored include the temperature of the drying chamber and weight of loaded tomato, onion and plantain samples measured at interval of drying time in order to determine the moisture loss

Efficiency of the Solar dryer

The efficiency of the solar dryer for each sample products indicate the hourly performance efficiency for each sample products and expressed in Equation 4

$$Dryer\ Efficiency\ (\%) = \frac{mass\ of\ water\ removed \times 2.257\ kJ/kg}{Total\ Energy\ Collected}\ x\ \frac{100}{1} \qquad 4$$

where the mass of water removed is the difference between the initial mass and the final mass of sample, 2.257 kJ/kg is the minimum theoretical energy required to remove each kilogram of water and the total energy collected is expressed in Equation 5.

$$Total\ Energy\ collected = Solar\ radiation\ intensity \left(\frac{kJ}{m^2/hr}\right) \times Area\ of\ collector(m^2) \times drying\ time(hr) \qquad 5$$

where the average daily solar radiation intensity for a tropical zone like Ozoro town at latitude 15.5447 ^{0}N on a tilted surface is given as 5.75 kJ/m^2/hr (Ohiero and Ogbeche, 2018). From Equation 5, the total energy collected by the solar dryer was calculated as 7.426*kJ*

The overall thermal efficiency performance of the solar dryer based on its impact on the agricultural produce, which includes the efficiency of a solar collector, the drying chamber and any other component added to the system, was calculated by using Equation 6.

$$Efficiency\ (\%) = \frac{Work\ Output}{Work\ Input}\ x\ \frac{100}{1} \qquad 6$$

where work output is the final mass of the crop after drying and work input is the initial mass of the crop before drying.

Results and Discussions

The results of the experimental performance test conducted on the solar dryer are shown in Tables 1 – 3. The tables show the analysis of moisture content removed, percentage moisture losses and the dryer efficiency for each of the sampled agricultural products at equal time interval. Figures 2 and 3 show the responses of the agricultural product samples when they were loaded into the solar dryer. These show the typical results of the hourly variation of the mass of moisture loss, its corresponding percentage moisture loss as well as the dryer percentage efficiency for each sampled product while Figures 4 and 5 show the dryer efficiency for each sampled produce as well as the variation of the temperatures for each component of the solar dryer.

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Table 1: Mass of Plantain Samples and Their Respective Moisture Content Losses

Time (hours)	*Mass (g)*	*Mass of water removed (Moisture Loss) (g)*	*Moisture Content Loss (%)*	*Dryer Efficiency (%)*
9:00	6.7	-	-	
10:00	6.6	0.1	1.49	3.03
11:00	6.4	0.2	3.03	6.08
12:00	6.0	0.4	6.25	12.16
13:00	5.6	0.8	13.33	24.31
14:00	5.1	0.4	7.14	12.16
15:00	4.7	0.4	7.84	12.16
16:00	4.4	0.3	6.38	9.12
17:00	4.2	0.2	4.55	6.08
18:00	4.1	0.1	2.38	3.03

Table 2: Mass of Tomato Samples and Their Respective Moisture Content Losses

Time (hours)	*Mass (g)*	*Mass of water removed (Moisture Loss) (g)*	*Moisture Content Loss (%)*	*Dryer Efficiency (%)*
9:00	10.8	-	-	
10:00	10.7	0.1	0.93	3.03
11:00	10.4	0.3	2.80	9.12
12:00	10.0	0.4	3.85	12.16
13:00	9.5	0.5	5.00	15.20
14:00	8.9	0.6	6.32	18.24
15:00	8.4	0.5	5.63	15.20
16:00	8.1	0.3	3.57	9.12
17:00	8.0	0.1	1.23	3.03
18:00	7.9	0.1	1.25	3.03

Table 3: Mass of Onions Samples and Their Respective Moisture Content Losses

Time (hours)	*Mass (g)*	*Mass of water removed (Moisture Loss) (g)*	*Moisture Content Loss (%)*	*Dryer Efficiency (%)*
9:00	30.7	-	-	
10:00	30.6	0.1	0.33	3.03
11:00	30.4	0.2	0.65	6.06
12:00	30.2	0.2	0.66	6.08
13:00	29.7	0.5	1.65	15.20
14:00	29.2	0.5	1.68	15.20
15:00	29.0	0.2	0.68	6.08
16:00	28.9	0.1	0.34	3.03
17:00	28.8	0.1	0.35	3.03
18:00	28.7	0.1	0.35	3.03

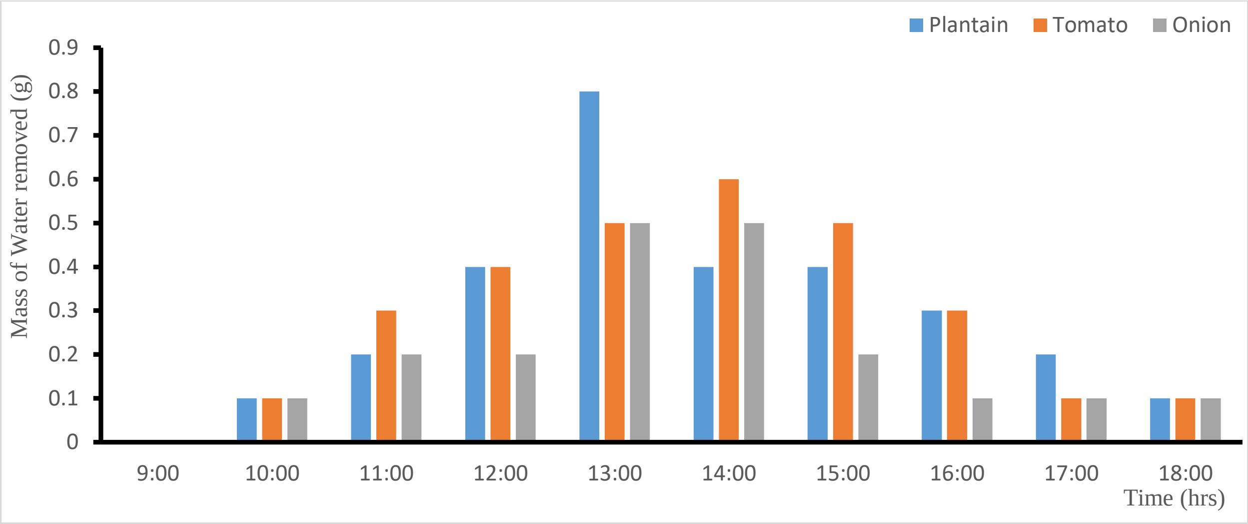

Figure 2: Variation of mass of water removed from agricultural products during the day

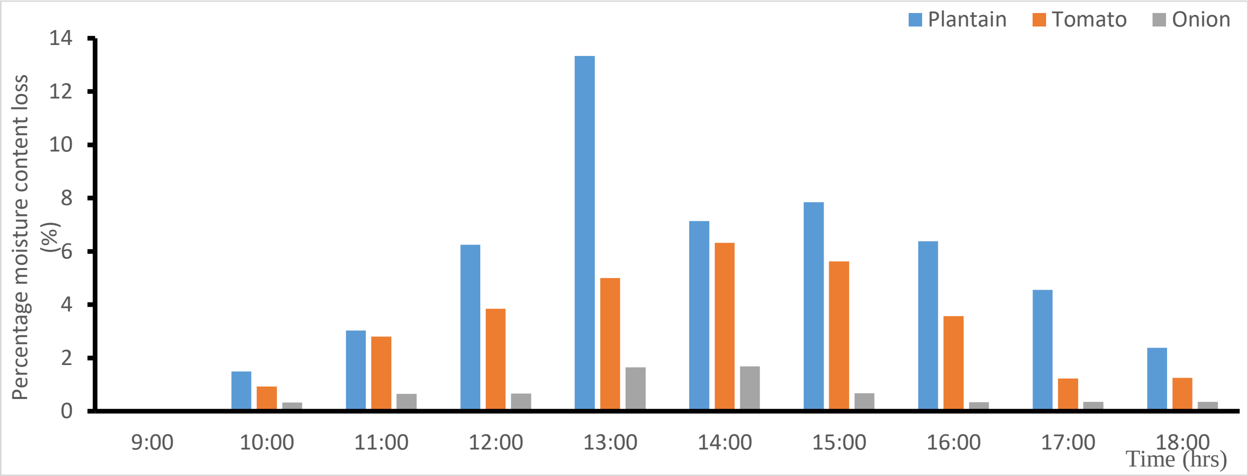

Figure 3: Variation of percentage moisture content loss from agricultural products during the day

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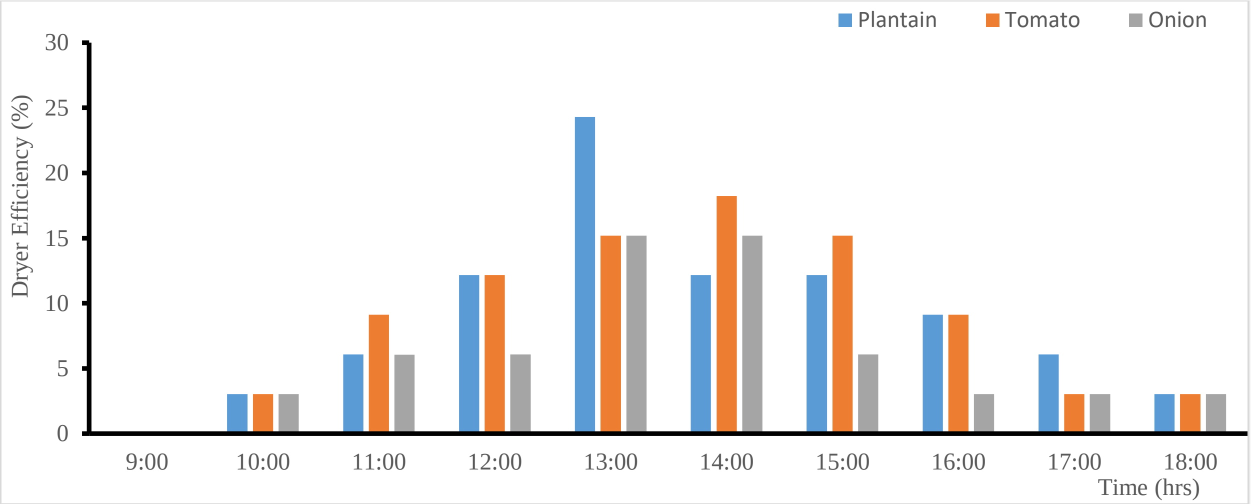

Figure 4: Dryer Efficiency for sample products

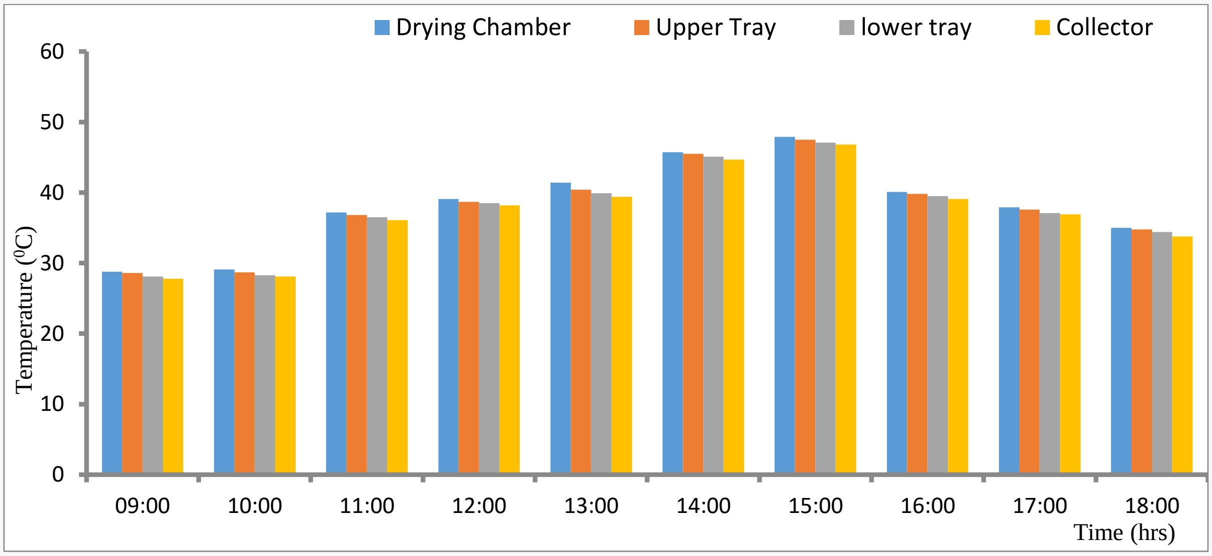

Figure 5: Temperature variations of the components of solar dryer during the day.

Figures 2 to 5 show that the maximum drying for the produce was experienced between 12.00 hours and 15 hours when the intensity of the sun is highest with the temperature of the solar dryer ranging from 38.2 ^{0}C to 47.9 ^{0}C which is the highest temperature range experienced due to the intensity of the sun. The temperatures inside the dryer and the solar collector were much higher than the ambient temperature during most hours of the daylight; this is the effect of the heat retentive capacity of the wool fibre which was used as the insulating material. Table 4 shows the summary of the initial and final masses of the sampled agricultural products which was used to determine the overall efficiency of the solar dryer using Equation 6.

Table 4: Summary of Masses of the Agricultural Products

Plantain		*Tomato*		*Onion*	
Initial Mass (g)	**Final Mass (g)**	**Initial Mass (g)**	**Final Mass (g)**	**Initial Mass (g)**	**Final Mass (g)**
6.7	4.1	10.8	7.9	30.7	28.7

For plantain samples,

$$Efficiency\ (\%) = \frac{4.1}{6.7}\ x\ \frac{100}{1} = 61.19\ \%$$

For tomato samples

$$Efficiency\ (\%) = \frac{7.9}{10.8}\ x\ \frac{100}{1} = 73.15\ \%$$

For onion samples

$$Efficiency\ (\%) = \frac{28.7}{30.7}\ x\ \frac{100}{1} = 93.49\ \%$$

Conclusion

The design and construction of solar dryer provided an alternative to the convectional way of drying agricultural product by utilizing the radiation power of the sun. The complete design and construction were made from using readily available materials sourced from the local market within the town. On completion and testing of the solar dryer, it was observed that the peak drying time was found between 12:00hr and 14:00hr when the sun intensity was highest with a maximum temperature of 47.9 ^{0}C. Although, the maximum cut-off temperature of 65 ^{0}C, which is the highest temperature required for drying of agricultural produce, was not reached, this is due to the temperature of the locality. The efficiency of the solar dryer during the test period was found to be 61.19 % for plantain samples, 73.13 % for tomato samples and 93.49 % for onion respectively. The design has also made it possible for the drying rate to be properly monitored and with the results obtained with these samples, this solar dryer can also be used to dry other types of crops.

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