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Original Article

Development of Solar PV Assisted Dryer for Cooking Banana Slice and Analysis of Proximate Properties

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Solar PV Assisted Dryer, Open Sun Drying, Cooking Banana, Dryer Efficiency, Proximate Properties

ABSTRACT

A solar PV-assisted dryer was developed for drying cooking banana and its performance tested. The proximate properties of the products dried in the solar PV-assisted dryer were compared to similar products dried using a laboratory oven, while open sun drying served as the control experiment. Fresh samples of cooking banana were obtained from a rural market in Ikot Akpaden, Mkpat Enin, Akwa Ibom State, Nigeria. The samples were subjected to peeling and cleaning before being sliced to a thickness of 5 mm. The dryer was embedded with a DC blower to enhance air circulation in the drying chamber. The blower was powered by a solar panel connected to a DC battery and a charge controller. 500 g of the product was loaded in the solar PV-assisted dryer, same as the other mediums. The moisture content was observed to have reduced from 67.32 to 5.80 % within 6 hours of drying as against 13 hours of open sun drying. The drying rate of the product decreased from 0.092 to 0.028 kg/hr in the solar PV-assisted dryer. The efficiency of the dryer was 40.6 %. Crude protein, crude lipid, crude fibre, and caloric value were lower in samples dried using the solar PV-assisted dryer and higher in samples subjected to drying in the laboratory oven and the control experiment. Ash content and carbohydrates were higher in products dried using the solar PV-assisted dryer than in other mediums. The study adds significant knowledge to the development of systems for post-harvest processing of cooking banana, a product highly sought for in the local market as a viable alternative to banana and plantain.

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INTRODUCTION

Traditional methods of drying food materials are becoming obsolete due to the cumbersome processes involved. Most of these processes end up turning into low-quality products with much deficiency in shelf life and economic (Gunathilake et al., 2018). The drying of agricultural materials is a function of purpose the material is meant to serve after the process. Dryers are developed to enhance the shelf life of agricultural materials by utilizing energy from solar and electricity (Patel et al., 2016). Traditional methods of drying food materials are a cheap and reliable medium for low-income farmers who cannot afford the initial cost of facilitating solar and other renewable energy sources for drying. The need to use locally available materials to fabricate dryers is imperative to ensure low cost, easy adaptation and replacement of the materials when need arises. Several researchers have used solar dryers for drying agricultural products. Significant progress has been made especially in areas relating to how the process of drying affects the product quality and shelf life. Some include Jangde et al. (2022), Hedge et al. (2015), Kumar et al. (2022), Etim et al. (2023), Lamrani et al. (2022), Firfiris et al. (2022), Adefemi et al. (2018), Alonge and Oniya (2011).

Etim et al. (2020) developed an active indirect mode solar dryer for cooking banana with special emphasis on the air inlet area design. The dryer was able to reduce the moisture content of the product from 4.53 to 1.57 kg within 9 hours of drying and conserved about 40% of the total drying time when compared to open sun drying. A solar-assisted biomass dryer embedded with a storage system for thermal energy was designed by Leon and Kumar (2008). They reported that the dryer embedded with a heat exchanger reduced the moisture content (w.b.) of chili from 76.6 to 8.4 % in about 33 hours of intensive drying. The time of drying was reduced by more than 65 % when compared to their control experiment. Yahya (2016) designed a biomass heat-assisted solar dryer. The moisture content of chili was reduced from 4.26 to 0.08 % (dry basis) within 11 hours of drying at a temperature, air flow rate and relative humidity of 70.5 ºC, 0.124 kg/s and 10.1 %, respectively. The performance of the dryer was reported to be better than open sun drying, and other passive solar drying systems used for comparison. Misha et al. (2015) developed a solar-assisted dryer for Kenaf core fibre drying in relatively minimal solar radiation. The dryer was reported to have operated continuously even at low radiation from the sun. Comparing notes with open sun drying, the time of drying was observed to have reduced from 20.75 to 15.75 hours when compared to open sun drying, because the operation of the dryer was not dependent on solar radiation.

Solar assisted dryers could become a reliable means of drying harvested food products by low-income farmers faced with challenges of optimizing the value of what they have produced. (Galappaththi et al. 2021) corroborated the above statement when they developed a solar assisted multi-crop dryer and reported high performance capabilities. Sopian et al. (2009) posited that solar-assisted drying systems are environmentally friendly and enhance the conversion of energy. They noted that solar-assisted dryers come with several advantages such as heat storage, an auxiliary source of energy, integrated system of control and applications to various agricultural products. In developing a photovoltaic solar drying system, Rulsan et al. (2006) observed that the blower powered by a photovoltaic source assisted in optimal airflow through the drying system, which enhanced the drying process. A

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mean efficiency of 40% was achieved and air flow rate of 0.16 kgs^{-1} with a mean daily radiation intensity of 800 W/m^2. Othman *et al.* (2006) conceptualized different solar dryers: V-groore solar collector, double-pass, solar dehumidification system, photovoltaic thermal (PVT) solar dryer and a solar collector embedded with an integrated energy storage system. They postulated that peculiar challenges associated with the variation in the amount of solar radiation incident on the collector and low intensities can be addressed if any of the systems are deployed because of noticeable merits such as heat storage, alternative sources of energy, and an integrated control process.

The need to have a control system for the heat generation medium is critical for enhancing the performance of solar dryers (Azmi *et al.*, 2012). The system generated using the above concept was observed to be more efficient and kept the drying temperature between 70-75 °C all through the drying experiment. Misha et al. (2015) tested a solid desiccant solar dryer for some agricultural products. They observed that the system produced drying air at a temperature of 52 °C, under average solar radiation of 797 to 800 W/m^2. They held that the physical and nutritional properties of the materials of the products tested could be sustained throughout drying. Quality of dried products has become a critical issue of interest in some southern parts of Nigeria amongst food processors, marketers, and end users. Several authors have used proximate and microbial analysis to evaluate the quality of dried products such as banana and cooking banana. These properties vary, depending on the method of drying, sample preparation method and other factors that influence the drying process. Etim et al. (2022) examined the proximate and microbial properties of cooking banana from a solar drying experiment. The moisture content, crude lipid, crude protein, and carbohydrate were obtained as 10.20, 3.61, 7.18 and 85.61 % respectively. These values for the moisture content and carbohydrate were significantly close to those obtained by Onwuka et al. (2015), which were 10.00 % and 79.88 % respectively. Edem (2021) reported the proximate properties of three varieties of cooking banana (Bluggoe, KM5 and Cardaba) after drying ranged as follows: carbohydrate (77.01 to 80.10 %); crude protein (3.76 to 4.75 %); crude lipid (0.67 to 0.84 %), crude fibre (0.34 to 0.57 %), moisture content (9.76 to 11.71 %) respectively. The values for crude protein, crude lipid and crude fibre were lower than what Etim et al. (2022) reported. The focus of this study was to develop a solar PV-assisted dryer for cooking banana, compare the performance of the dryer with other mediums and examine the proximate properties of the dried products. The essence of utilizing a cleaner energy source for the drying of the product is to enable food processors in rural communities of the Southern region of Nigeria to be exposed to alternative platforms to dry their products through more environmentally friendly, renewable and economically viable processes that will enhance the quality and the market value of the dried products. Some rural communities in Southern Nigeria are yet to be linked to the grid for supply of energy through known conventional means, deploying solar technology could solve their energy needs for crop processing and preservation as highlighted in this study which involves a solar PV system for powering a blower to enhance the drying of cooking banana slice.

MATERIALS

The materials for the construction of the dryer were selected based on availability, cost, and replacement options. Stainless steel was used as the main frame because of its high rust resistance, since the dried products were food materials that could be consumed by humans. Glass wool was used as insulation material. Pop rivets, screws, seating, and toggle latch were also used to firmly tighten parts of the dryer together. The choice of cooking banana as the product for the experiment was based on indices such as affordability, availability, and accessibility by consumers within the study location (Ikot Akpaden, Mkpat Enin Local Government Area of Akwa Ibom State, Nigeria). The product is a good alternative to banana and plantain in south-south Nigeria.

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Material Preparation

The samples for the experiment were locally harvested in Ikot Akpaden, Mkpat Enin. Preparation of the samples involved peeling and slicing to a thickness of 5 mm, based on observations from previous studies (Etim et al., 2021). The experimental setup was done for the same quantity of products using a laboratory oven and open sun drying, which served as the control experiment. 500 grams of the samples were loaded on the dryer, similar quantity was also loaded on the laboratory oven, the same as the control experiment.

Design Considerations and Assumptions

The following considerations were made in developing the dryer:

- A temperature of 60 °C was recommended. A similar temperature was set for the laboratory oven, while the open sun served as the control.
- Air vent of 5 cm by 5 cm for passage of air into the chamber.
- Trays were made of mesh wire with dimensions 40 cm by 40 cm.
- The slice thickness of the products to be dried was uniform (5 mm).
- The materials used were locally sourced.
- The average solar radiation received in the location was 570 W/m^2.
- The temperature of the dryer was controlled to enhance the final product quality, which was examined alongside other methods of drying for the same product.

Data from the experiment was taken at hourly intervals.

Design Analysis

Different factors were considered for the development of the dryer. The parameters considered were determined using relevant literature and are carefully highlighted. The core design parameters were the amount of moisture removed from the product, the amount of that would raise the product temperature to the surface, the amount of heat that would facilitate moisture evaporation from the product surface and the power required by the dryer and the efficiency of the dryer.

Drying Chamber

The drying chamber was made of perforated stainless-steel trays and had a dimension of 40 cm by 40 cm. The choice of materials was to ensure the limited effect of rust when the tray contacts moisture and possible expansion when the surface is heated during the process of drying. A door was embedded for easy loading and unloading of the product. Circulation of air in the chamber was enhanced through the aid of a blower.

Air Heater

A 300 Watts DC heater was embedded into the dryer for heat generation and circulation of hot air within the chamber. The heater was powered by a solar panel. The solar panel was connected to a 12 Volts charge controller and a battery to store charge and service the heater and blower when solar radiation is low.

Blower

A DC blower of 12 cm by 12 cm dimension was attached to enhance the distribution of hot air within the chamber. The blower (Model 4710NL-04W-B30 by Minebea Co. Ltd) composed of five blades and rated 36W. It was also powered using the solar panel. The schematic representation of solar PV system and the electrical component of the dryer is presented in *Figure 1*.

Drying Temperature

Drying of fruits and vegetables can be achieved at temperature of between 45 to 60 °C (Alonge and Adeboye, 2012). Drying food materials at higher temperatures could potentially change the physical state of the final product, burn the surface of the product, or render such products unfit for human consumption (Loemba et al., 2022). A microcontroller was embedded into the dryer to monitor the temperature of the solar-assisted drying which averaged 60 °C for most of the

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drying experiment. The oven temperature was regulated as 60 °C, while the control experiment (open sun drying) was entirely dependent on solar radiation on an hourly basis.

Dryer Capacity

The capacity of the dryer was estimated at 500 g and consisted of two drying trays. The products were evenly distributed in the two trays.

Amount of moisture removed

$$M_R = M_p(\frac{Q_1 - Q_2}{100 - Q_2}) \quad (1)$$

Where; M_s - Mass of product (wet) (g), Q_1 - Initial moisture content (%), Q_2 - Final moisture content (%)

Moisture content

$$M.C.(\%\, d.b) = \left(\frac{W_1 - W_2}{W_2}\right) \times 100 \quad (2)$$

Where; *M.C. (% d.b.)* - The moisture content of the product (dry basis), W_1 - The initial (wet) weight of the product (g), W_2 - The final (dry) weight of the product (g)

The moisture content of the product was determined across the three mediums as drying progressed to a point where very insignificant change in weight of the product was observed.

Amount of heat that would raise the product temperature to the surface

The amount of that would raise the product temperature to the surface for possible removal of water was computed using the equation (3).

$$Q_1 = M_R \times C_p \times \Delta T \quad (3)$$

Where; M_R - mass of water removed, C_p - specific heat capacity of water, ΔT - difference in temperature between dried samples and initial temperature of dryer.

Amount of heat that will facilitate evaporation of moisture from the surface of the product

As the product temperature rose, the heat required to evaporate moisture from the product was determined using equation (4).

$$Q_2 = M_w \times L \quad (4)$$

Where; Q_2 - Amount of heat that will facilitate evaporation of moisture from the product surface (J), M_w - Quantity of moisture removed from the product, L - Latent vapourization heat.

Total amount of heat required for drying

The total heat required for drying was the sum of the amount of that would raise the product temperature to the surface (Q_1) and mount of heat that will facilitate moisture evaporation from the product surface (Q_2).

$$Q_T = Q_1 + Q_2 \quad (5)$$

Power Required by the Dryer

$$P = Q_T/t \quad (6)$$

Where; Q_T = Total heat required, t = Drying time interval, Drying rate

$$Mdr = \frac{M_r}{t_d} \quad (7)$$

Where M_r = moisture removed, t_d = time of drying, Dryer Efficiency

$$E = \frac{Q_{evap}}{Q_T} \text{ x } 100 \quad (8)$$

Where: Q_{evap} - Heat required to evaporate moisture from the product surface, Q_T - Total heat required for drying

Dryer Design

The D.C. heater was rated 300 W and the blower 36 W. A total of 336 W was required to run the system. Two solar panels of 300 W were selected to give a total of 600 W, which was higher than the desired 360W for both the DC heater and blower. This was to compensate for losses that could be experienced from poor efficiency of the solar system during periods were low illumination was recorded.

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Table 1: Design Parameters

S/N	Parameter	Value (Unit)
1	Drying temperature	60 °C
2	Initial Moisture Content	72.62% (d.b.)
3	Final Moisture Content	8.85 % (d.b.)
4	Amount of moisture removed	0.126 kg
5	Amount of that would raise the product temperature to the surface	121 KJ
6	Amount of heat that will facilitate moisture evaporation from product surface	284.26 KJ
7	Total heat required	405.26 KJ
8	Power Required for design	336 W
9	Drying rate	0.0148 kg/hr
10	Efficiency of the dryer	40.6 %

Figure 1: Block diagram showing conversion of electrical energy to powering of the blower and air heater.

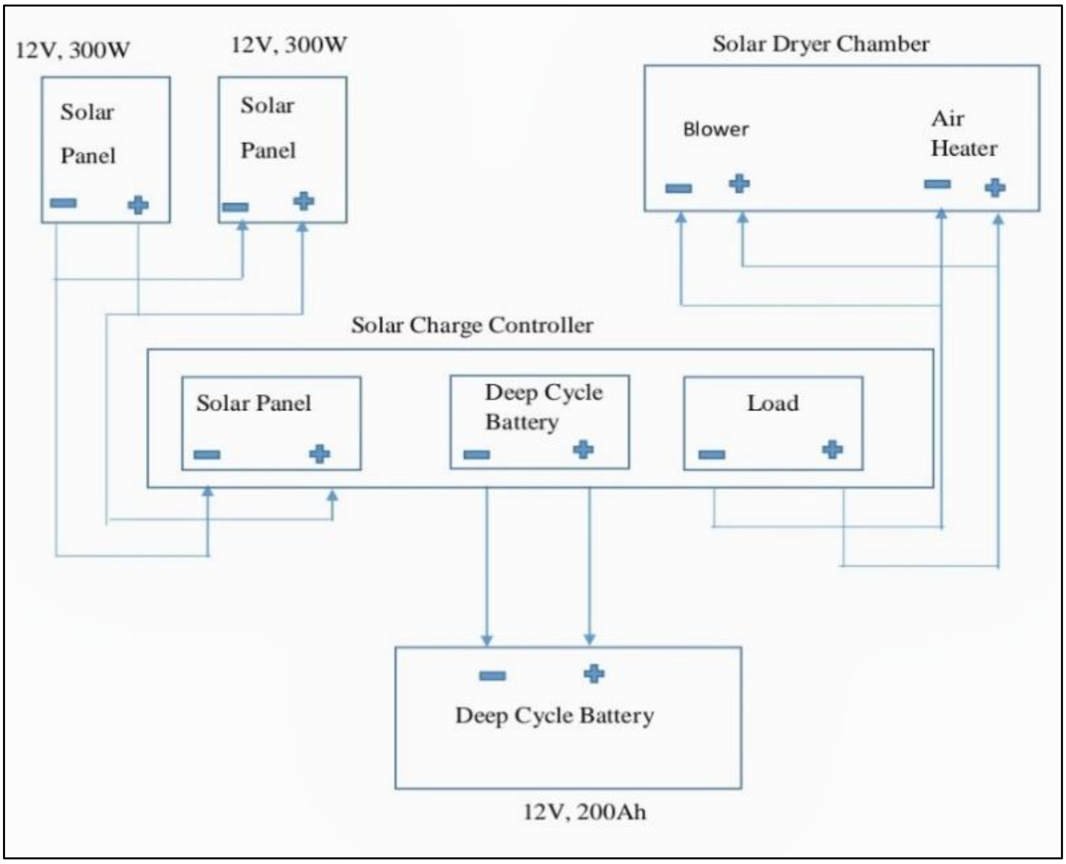

Plate 1: Set up of the experiment showing the dryer and solar panels

Plate 2: Charge Controller and Deep Cycle Battery

Article DOI: https://doi.org/10.37284/eaje.7.1.1862

Experimental Procedure

The samples after peeling cleaning and slicing were stored in a desiccator for about an hour to allow for even distribution of moisture before being subjected to drying in three different mediums namely: Solar PV assisted dryer (*Plate 1*), laboratory oven (*Plate 3*) and open sun drying (*Plate 4*). The initial weight of the product in each drying medium was 500g. The weight of the product was measured on an hourly basis, with open sun drying serving as the control experiment. The process was continuous until it was observed that there was not much significant change in weight between successive measurements. A stopwatch was used to monitor the time of drying using a digital weighing balance (DT 1000 Model by G&G instruments). A similar process was done for the products in the laboratory oven (DHG-9101-2SA model by Search Tech Instruments). The samples were subjected to proximate analysis after drying in the three different mediums to evaluate the effect of each drying method on the quality of the final product in comparison with existing literature. The set up of the experiment is as shown in *Plate 1*, while the battery and the charge controller are captured in *Plate 2*.

Plate 3: Oven drying of samples

Plate 4: Open sun drying of samples

Evaluation of the Dryer

The performance of the dryer was evaluated based on the rate of drying of cooking banana and its efficiency. The workability of the dryer was evaluated through a no-load test. It was observed that the temperature of the drying chamber and that of the system attained equilibrium in less than fifteen minutes of the drying experiment.

Determination of Proximate Properties

The proximate properties of the dried product were determined using the standard methods of analysis of the Association of Official Chemists (AOAC, 2023). Moisture, crude protein, ash content, carbohydrate and crude lipid in the samples were analysed. Proximate analysis of the dried samples was carried out at the Central Chemistry Laboratory of the University of Uyo, Uyo. The process was done for samples from the three different mediums with open sun drying serving as the control experiment. Crude protein content was determined using the Kjeldah method, which measured the total amount of Nitrogen in the dried product. The crude fat was determined using acid hydrolysis methods, where the hydrolysed lipid content of the dried product was mixed with ethers and heated at a constant weight at 100 °C, with the residue expressed as a percentage of crude fat. The residue of the dried sample after solvent extraction following digestion with dilute acid and alkali was obtained as the crude fibre content. The ash content of the dried product was determined by heating the product at a very high temperature (600 ° to remove all moisture and volatiles. The ash content

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was then analysed from the loss of weight. The carbohydrate content in the dried sample was calculated as the difference obtained from subtracting the lipids, ash and fibre values obtained from the total dry matter.

Analysis of Data

Data from the experiments were obtained in three replicates for each of the mediums (solar assisted dryer, laboratory oven and open sun drying). The average values from the three experiments were used as reference data. The values obtained for the respective parameters were averaged and used as reference data. Graphical analysis using Microsoft Excel (Version 365) was used to establish trends for the parameters

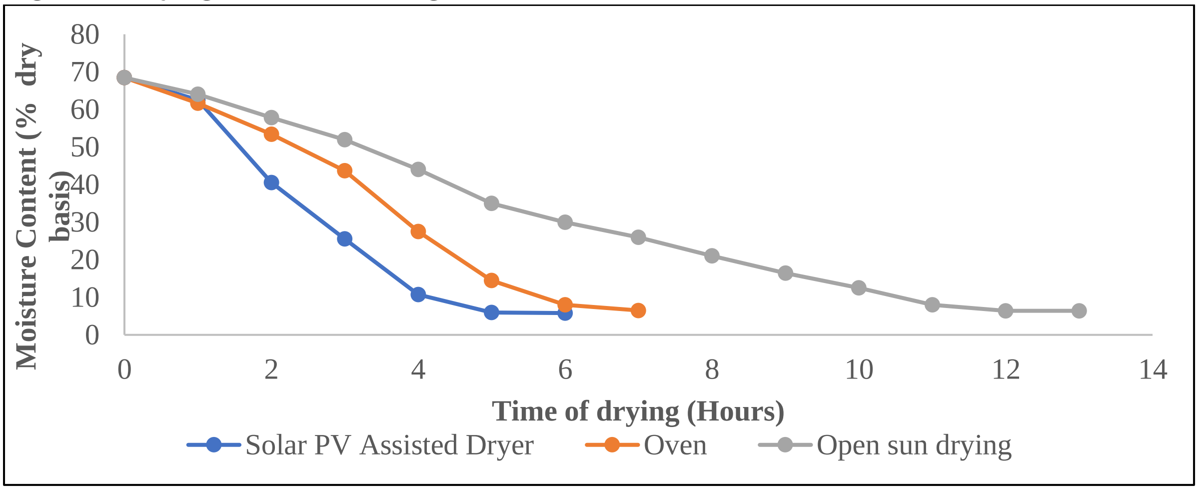
RESULTS AND DISCUSSION

Effect of Drying Time on Moisture Content

The product weight was observed to have decreased as the moisture level (dry basis) decreased (*Figure 2*). The weight of the samples dried in the solar-assisted drying decreased from 500 to 133 g within 6 hours of drying, while those dried using the oven reduced from 500 to 135.5 g within 7 hours. However, the samples in the control experiment (open sun drying) decreased from 500 to 138.85 g in 13 hours.

The value was double the time to achieve similar results using oven drying and six hours higher when compared with other drying mediums. The moisture level of the product in the oven was reduced from 68.07 to 5.29 % (dry basis) in 330 minutes. The product moisture in the dryer reduced from 67.32 to 5.8 % (dry basis) in 420 minutes, while the moisture level of the product dried in the control experiment reduced from 68.45 to 6.01 % (dry basis) within 840 minutes. The moisture reduction noticed was in sync with the findings of Etim et al. (2022). Drying was observed to have been uniform across the three different mediums within the first two hours of drying before the product in the solar PV assisted dryer and the laboratory oven dried faster than the control experiment. Minor heat losses were observed as a result of the continuous removal of the product from the dryer for readings to be taken.

Figure 2: Drying curve for cooking banana



Drying Rate

The rate of drying of cooking banana in the solar PV assisted dryer decreased (0.092 to 0.028 kg/hr) as the time of drying of the product increased as shown in *Figure 3*. A similar trend was observed for samples dried in the laboratory oven and the control experiment. This trend agreed with the assertion of Mahendran and Prasannath (2008) and Muritala et al. (2022) in their respective studies on banana and plantain. It was observed that the drying rate of the product dried using open sun was the least of the mediums used for the experiment. This was traced to the ability of the product in the medium to absorb moisture as against the other mediums which were enclosed, and moisture penetration reduced drastically

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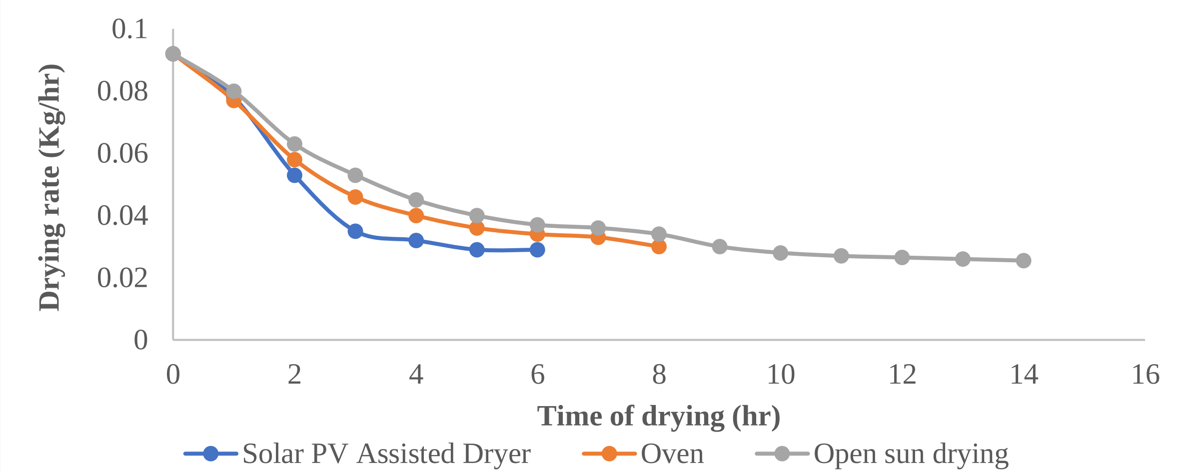
except when reading was taken and the samples were exposed to the atmosphere.

Figure 3: Drying rate of the product on the three different drying mediums.



Solar Dryer Efficiency

The efficiency of the dryer was obtained as 40.6 %. The value was subjected to comparison with what was obtainable in other similar studies. The efficiency of the system was better than what Etim et al. (2020) reported at 34.06 % for indirect solar dryer, and lower than the 66.7 % reported by Aremu et al. (2020) for a hybrid dryer which utilized solar energy and electrical energy. However, the result did not corroborate with the findings of Oseni et al. (2021), when they evaluated the performance of a small-scale solar dryer and reported a minimum and maximum efficiency of 62.1 and 65.5 % respectively. The drying system promises satisfactory performance for small-scale drying of cooking banana and can be improved upon. A similar projection was made for a low-cost dryer for cocoyam chips designed and developed by Ndukwu et al. (2022).

Product Appearance

The appearance of the product after the drying experiment was in close affinity with dried samples from the oven. The samples on the solar-assisted dryer and the oven had a canary yellow colour (*Plate 5* and *Plate 6*), while products obtained from the control experiment tilted toward burnt orange (*Plate 7*). The colour discrepancies were because the sun-dried samples were directly exposed to direct sunlight and changes in environmental features, as against samples dried using the solar assisted dryer and the oven, which were not directly exposed to sunlight. The observation was in tandem with the findings of Belayneh et al. (2014) for the same product. At variance with the study in focus, Falade and Oyeyinka (2014) reported that cooking banana showed yellowish dis-colouration after being subjected to using a foam-mat, oven and open sun drying. The variation in colour for the three different drying mediums was linked to exposure to the atmosphere and the configuration of the drying system. The products dried on the solar PV assisted dryer were more appealing in terms of appearance and crispier than the other mediums as shown in *Plates 5, 6* and *7*.

Article DOI: https://doi.org/10.37284/eaje.7.1.1862

Plate 5: Oven dried samples

Plate 6: Solar assisted dried sample

Plate 7: Sun dried samples

Proximate Properties of Dried Cooking Banana

Table 2 highlights the proximate properties of dried samples of cooking bananas from the experiment. The parameters measured were moisture content, carbohydrate (CHO), ash content, crude protein, crude fibre, crude lipid, and caloric value. The values obtained for the dried samples were compared with the values obtained for the same quantity of samples dried using a laboratory oven (LFDO-A13 Model by Labtronics) and open sun drying which served as the control experiment.

Table 2: Proximate composition of the dried samples

Proximate property	Solar assisted dryer	Laboratory Oven	Open Sun Drying (Control)
Moisture content (%)	68.10	68.76	69.40
Ash content (%)	2.46	2.45	2.06
Crude protein (%)	3.50	3.49	5.11
Crude Lipid (%)	0.61	0.64	6.28
Crude Fiber (%)	0.56	0.57	9.74
Carbohydrate (%)	92.40	92.35	77.06
Caloric Value (Kcal)	389.09	389.12	402.83

The percentage ash content was obtained as 2.46 % and was higher than what was obtained for samples in the oven (2.45 %) and open sun-dried samples (2.06 %). These values were in the range of studies conducted by Etim et al. (2022), Abiodun and Adeleke (2010) and Adeniji et al. (2010). The lower ash content in the open sun-dried samples was a confirmation of the lengthy time taken for the product to dry through direct exposure to sunlight, while products in the solar PV assisted dryer and laboratory oven were of higher ash content because of a faster rate of drying of the product. The percentage crude protein for dried products from the solar-assisted dryer (3.50 %) was higher than that of oven drying but less than what was observed for sun-dried samples. The high protein content in the open sun-dried samples confirmed the strong presence of Nitrogen as compared to the other drying mediums. The data obtained for the various mediums were in affinity with the findings of Alonge and Oniya (2011), Ayodele and Erema (2010) and Onwuka et al. (2015).

The percentage of crude lipid and fibre and caloric values were highest in sun dried samples, while carbohydrates was highest in solar assisted dryer samples. Similar observations were made by Etim et al. (2022), when they compared proximate properties of the same product from an active indirect mode solar dryer and direct sun drying. The lower crude lipid observed in samples dried using the solar PV assisted dryer, suggested that the products on the dryer had better flavour and were a bit more palatable than the ones on the other mediums. The lower crude fibre observed in samples dried using the solar PV-assisted dryer suggested that the product would be easily

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digestible and contains a lesser amount of fat. This was near what was obtained for products dried using the laboratory oven, but a clear departure from the value obtained for the open sun-dried samples as shown in *Table 2*. Exposure to direct sunlight was responsible for the lower carbohydrate content in the open sun-dried samples as against what was obtained for samples in the solar PV assisted solar dryer and laboratory oven.

CONCLUSIONS

The solar assisted dryer developed has the potential to address concerns of small-scale domestic drying needs of households and food processors. The drying rate of the product decreased with increase in drying time. Similar observation was also made in others drying mediums. The dried products from the solar assisted dryer and laboratory oven had a close affinity in terms of appearance, texture and colour (canary yellow), as against the features of the products subjected to open sun drying which appeared burnt orange. Proximate properties such as crude lipid, dried fibre and calorific value were highest in products subjected to open sun drying, while ash content and carbohydrate were highest in samples dried using the solar assisted dryer.

Recommendations

The solar assisted dryer is recommended for small-scale drying of cooking banana to produce flour, to complement the high demand for the product in the local market. The proximate properties of cooking banana should further be examined after drying the products on mediums such as freeze dryer, infrared-ray dryer, spray dryer, vacuum dryer etc. Based on the performance of the dryer, exergy analysis should be done to ascertain the quantity of heat lost and proffer ways to mitigate its effect. The slice thickness should be varied to examine the effect of the product size on the performance of the dryer and the quality of the product after drying. The effect of climatic factors on performance of the dryer should also be studied to ascertain the extent to which these factors affect the drying process.

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Declaration of Competing Interest

The author wishes to state that there is no competing interest associated with publication of the findings from the study.

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