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Development of a Photovoltaic-Assisted Solar Food Dehydrator for Post-Harvest Loss Reduction in Tropical Regions

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Abstract: Poor preservation technologies are still a major challenge for the post-harvest losses of fruits and vegetables in the tropical regions. This paper presents the design, fabrication, and performance evaluation of a low-cost photovoltaic-assisted active indirect solar food dehydrator constructed mainly from locally available materials for sustainable food preservation. The dehydrator consists of a flat-plate solar air collector, photovoltaic-powered forced convection, battery energy storage, and an insulated drying chamber that provides controlled drying conditions independent of grid electricity. The performance evaluation was conducted with tomato, banana, pepper, and apple for a loading capacity of 50, 100, 150, 200, and 250 g for 8 h drying period. The temperatures in the drying chamber rose from around 30–35°C to a maximum of 58–64°C, which was significantly higher than the ambient temperatures (28–37°C) and consequently enhanced moisture evaporation. From experimental results, it was shown. At peak, drying chamber temperatures increased from approximately 30–35°C to 58–64°C, well above ambient temperatures (28–37°C), thereby encouraging moisture evaporation. Experimental results showed a gradual moisture removal for all products, with banana having the highest drying performance (88% moisture loss), followed by pepper (86%), apple (84%), and tomato (78%). The same drying characteristics were noticed at all loading capacities, which indicates uniform heat distribution and effective airflow inside the drying chamber. The developed dehydrator reduced drying time from 11–15 h to 7–9 h compared to conventional open-sun drying, which was about a 36–40% reduction, while producing cleaner, more hygienic, and higher-quality dried products due to reduced risks of contamination from dust, insects, and bad weather. The total cost of fabrication was estimated to be about ₦305, 000, which shows the economic feasibility of local fabrication and commercialization. Statistical analysis (one-way ANOVA, p = 0.327) showed no significant differences between the final weights of the tested products in the operating conditions. The developed photovoltaic-assisted solar food dehydrator provides an energy-efficient, low-cost and sustainable solution for mitigating post-harvest losses, enhancing food quality and safety and fostering renewable-energy based agro-processing in tropical and resource-constrained environments.

Keywords: *Photovoltaic-Assisted Solar Dehydrator, Food Drying, Post-Harvest Loss, Moisture Removal, Tropical Agriculture.*

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I. INTRODUCTION

Post-harvest losses are a major challenge for agricultural productivity and global food security. Fruits and vegetables are especially susceptible to high moisture content. These products are highly prone to microbial spoilage, enzymatic degradation, and quality deterioration soon after harvest [1]. According to the Food and Agriculture Organization (FAO), some 33 per cent of all food produced globally is lost at the pre-consumption stage, a significant proportion of which is attributable to developing countries. In sub-Saharan Africa, post-harvest losses of fruits and vegetables can be higher than 30%, resulting in economic losses for the farmer and less food available for the

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communities [2]. Traditional open-sun drying is a common preservation method in many tropical countries like Nigeria because it is simple and inexpensive. However, this method has a number of drawbacks, including long drying times, dependence on good weather conditions, and contamination by dust and insects. Furthermore, the drying process is often uneven, resulting in a decrease in product quality and nutritional value. These challenges are accompanied by significant post-harvest losses, highlighting the urgent need for more efficient and sustainable drying technologies that can preserve the quality and safety of food [3].

The sun is abundant in the tropics, and the sun is a renewable resource that is becoming more and more attractive for agricultural processing. For example, Nigeria receives an average solar radiation of between 4 and 7 kWh/m^2/day, making solar drying technologies very appropriate for rural and semi-urban areas. Solar drying is the utilisation of thermal energy from the sun under controlled conditions to remove moisture from food products. This minimises drying times and enhances product quality over conventional open-sun drying [4]. With recent advancements in solar drying, there are different types of solar dryers available, such as direct, indirect, mixed mode, active, passive, and hybrid solar dryers. Out of these, photovoltaic-assisted active solar dryers have attracted much interest because of their capability of enhancing airflow and heating by the forced convection process. Studies have revealed that forced convection solar dryers have greater drying efficiency and a faster rate of drying than passive solar dryers. Improvements in insulation, collectors, and airflow control have improved the performance of solar dryers [5].

There have been numerous studies on the design and efficacy of solar food dehydrators. Solar dehydrators with photovoltaics are highly effective in reducing the drying time and ensuring the quality of the products. Moreover, mobile solar dehydrators have also been found to be very effective in diverse environments. CFD modeling and optimization techniques have been used for this purpose [6]. However, even with all these developments, there are still some issues. Most commercial solar dryers are expensive and use imported components, thereby rendering them unaffordable for small farmers and difficult to replicate in resource-depleted environments. Most of the research on solar dryer technology has been inclined towards the analysis of its thermal efficiency, with very little being done in relation to designing low-cost solar dryers that can be manufactured locally in rural areas in developing countries [7].

There are also very few experiments regarding the performance of PV-assisted solar dryers on different foods under tropical conditions. Recent studies have concentrated more on computation, airflow enhancement, and hybrid solar drying technologies but none has brought together affordability, local manufacture, PV-assisted forced convection and performance evaluation on different crops under realistic outdoor conditions.

What makes the current study novel is the design and development of a low-cost active indirect solar food dehydrator powered by photovoltaics made up of mostly local materials such that it can be easily built and commercially sold to developing nations. The design integrates the use of a solar thermal collector, a forced air circulation system powered by photovoltaic energy, a battery energy storage system, and insulation in a portable drying system that can operate off-grid without depending on grid electricity. Experimental evaluation of the performance of the dehydrator with four commonly used agricultural products, namely tomato, banana, pepper, and apple, in a tropical climate instead of using a laboratory simulation of climate.

II. RELATED WORK

Research has been conducted on the solar food dehydrator, some of which are: [8] applied computational methods to develop an optimised model for a solar dehydrator. Six (6) different dehydrator configurations were designed using computer-aided design, and MATLAB was used to model and evaluate remotely located heat capture equipment. The results show that the Parabolic Trough Collector (PTC) can effectively transfer heat remotely to a dehydrator. The higher the temperature of the heating fluid entering the heat exchanger, the higher the temperature of the air leaving the heat exchanger. CDF use in Ansys Fluent was useful for studying airflow and temperature dispersion. The hot air was simulated at 350 K of temperature and 2 m/s of velocity. The results of the CFD simulation show that the temperature and air velocity distribution are significantly different for different configurations of the dehydrator. To dehydrate fruits and vegetables. [9] designed an active sun dehydrator. The solar collector transfers thermal energy to the drying air. The temperature in the drying chamber is kept at 45 to 50 degrees Celsius by means of a feedback control. The design is based on Dec. sun irradiation of 572 watt/sq m in Islamabad. Drying one kilogram of bananas takes 220 watts of electricity, and the same for apples takes 245 watts. The solar dehydrated product is of better quality and flavour than that dried in the normal open-sun drying. [10] highlight the modernisation and optimisation of photovoltaic-assisted and hybrid solar food dryers compared to traditional drying methods (i.e., grid power or fossil fuel thermal ovens) in terms of energy efficiency, energy, and environmental sustainability. [11] have described an innovative active mode indirect solar dryer with a highly efficient through-flow evacuated tube collector for air heating. This dryer uses a forced air flow, which is supplied by a DC fan powered by a solar photovoltaic (PV) module. The dehydration chamber has a loading capacity of 6 to 45 kg, depending on the product being dried. The overall efficiencies of the dryer for drying the fenugreek leaves (Trigonella foenum-graecum) and turmeric (Curcuma longa) in semi-continuous mode were 34.1% and 23.6%, respectively. The thermal efficiencies were 5.7% and 5.4%, respectively, in open sun drying (OSD). Higher grade than OSD was observed in dried fenugreek leaves and turmeric. The economics of the solar dryer's operation reveal that the sum of the present values of the life cycle savings exceeds the capital cost. The capital cost of the dryer is less than 50,000 INR. For fenugreek leaves and turmeric, the values are 211,262 INR (1 US$ = 74.57 INR) and 229,152 INR, respectively. Also, the payback

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period is short, which also speaks for the economic feasibility of this dryer. The generalised economic curves are also shown.

The study by [12] examines how olive pomace behaves during the drying process. Because olive pomace has a good energy potential and can be used as biomass when the humidity is low, this process is crucial. After 12 days of dehydration, the drying curve shows a decrease in humidity from 67.34 to 40.73%. The lower heating value curve and elemental analysis of the olive pomace sample collected in the olive mill are determined experimentally in a laboratory and a solar dehydrator. ANSYS Student software's computational fluid dynamics is used to analyse the dehydrator. The ideal height of the dehydration chamber is 300 mm, according to this study, which concentrated on studying the effects caused by differences in the chamber's height.

This research was thus conducted to design, construct and analyze the performance of photovoltaic powered solar food dehydrator for reduction of post-harvest losses. The objectives of this research were to design and construct a photovoltaic powered solar food dehydrator using locally available materials; determine the temperature distribution within the drying chamber using natural solar radiation; examine the moisture removal characteristics using tomato, banana, pepper and apple samples; conduct comparison with traditional sun-drying technique; and test the viability of the system for small-scale agricultural processing and reduction of post-harvest losses. The results are valuable contributions towards the development of sustainable food preservation techniques that can reduce post-harvest losses and improve food security, renewable energy utilization and agro-processing in rural tropics.

III. METHODOLOGY

➢ *Description of the Solar Food Dehydrator*

The Technical specification of the fabricated solar food dehydrator are described in Table 1:

The BEME analysis provides information regarding the economic feasibility and affordability of the system for small-scale agricultural.

Table 1 Bill of Engineering Measurement and Evaluation

Component	Material/Type	Specification	Quantity	Total Cost (₦)
Supporting Frame	Mild Steel Square Pipe	25 mm × 25 mm square pipe	3 lengths	21,000
Drying Chamber	Mild Steel Sheet	2 mm thickness	1 unit	20,000
Solar Collector Housing	Galvanized Steel Sheet	1.2 mm thickness	1 unit	30,000
Absorber Plate	Galvanized Steel Sheet (Black Painted)	1.2 mm thickness	1 unit	10,000
Transparent Cover (Glazing)	Acrylic/Glass Sheet	Transparent solar-grade cover	1 unit	22,000
Thermal Insulation	Fiberglass Wool	Heat-resistant insulation material	3 bags	15,000
Drying Trays	Galvanized Wire Mesh	Food-grade mesh tray	3 trays	10,000
Air Circulation Fans	DC Blower Fans	12 V DC	2 units	12,000
Solar Photovoltaic Panel	Monocrystalline/Polycrystalline PV Module	20 W, 12 V	1 unit	20,000
Battery	Rechargeable Deep-Cycle Battery	12 V, 5 Ah	1 unit	23,000
Charge Controller	Solar Charge Controller	12 V, 18 Ah	1 unit	11,000
Temperature Controller	Digital Temperature Controller	0–100°C operating range	1 unit	10,000
Ventilation System	Air Inlet and Outlet Vents	Natural/forced convection openings	1 set	8000
Mobility Unit	Castor Wheels	Grey rubber tyre	4 units	12,000
Fasteners and Welding Accessories	Electrodes and Bolts	Standard fabrication grade	1 set	12,000
Surface Coating	Oil-Based Paint	Dark Ash colour	2 litres	12,000
CAD design and drawings	-	-	-	35,000
Food samples	-	Tomato, banana, pepper, apple	2.5 kg each	7,000
Transportation and contingency	-	-	-	15,000
Total	-	-	-	₦305,000

The total cost for the fabrication of the dehydrator was calculated to be ₦305,000. The relatively low cost leaves room for the system's potential affordability vis-à-vis solar drying systems purchased from the market. Using local materials makes it more possible for manufacture.

➢ *Research Design*

The design of PVASFD was informed by the drying needs of various tropical crops along with the robustness of the system in the case of inconsistent grid power availability. It has been designed as an active, indirect solar dryer with a

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unique solar collector that uses air heated up by the solar radiation and circulated via the air circulation system in a drying chamber. The process of designing was based on the sizing of the solar collector, air circulation system, photovoltaic (PV) power system, and theoretical performance of the system [13], [14] & [15].

- *Solar Collector Design and Heat Gain Estimation*

The solar collector is the main device for the conversion of thermal energy in the system. Its size, chosen so as to ensure enough surface area for heat collection, is 1193.8 mm by 431.8 mm in dimension, giving a total collector area of 0.516 m². The collector consists of a flat black painted absorber to collect maximum solar energy and is insulated at the rear and sides to reduce heat losses. The theoretical useful heat collected ($\dot{Q}u$) from the solar collector was calculated using the Hottel-Whillier-Bliss equation [16]:

$$Q_u = A_C \cdot F_R\{G_T(T_\alpha) - U_L(T_i - T_a)\} \quad (1)$$

Where A_c is the collector area (0.516 m²), G_T is the insolation of the incident solar radiation (taken for a typical tropical condition of 800 W/m²), F_R is the collector heat removal efficiency (taken as 0.75), U_L is the total heat loss factor (computed according to the nature of insulation and wind speed), and (Ta) is the product of transmittance-absorptance (taken as 0.85). With all these parameters, the estimated useful heat gain is about 263 W. This thermal energy gain is vital in order to reach the desired drying temperature from 35-58°C. It is the thermal energy gain that will make it possible to raise the ambient temperature to the operational temperature of 40-60°C.

- *Airflow Requirement and Fan Sizing*

The forced convection air flow method is used for speeding up the drying process and increasing uniformity. The flow rate of the air needed depends on the amount of heat received from the collector as well as the desired temperature increase [17] & [18]. Air mass flow rate (ṁa) is obtained using energy balance:

$$\dot{m}a = \frac{Q_u}{cp\cdot(T_{in} - T_{out})} \quad (2)$$

On an assumption that the ambient temperature (T_{in}) is 30 °C and the collector outlet temperature (T_{out}) is 55 °C, the necessary mass flow rate was calculated to be approximately 0.012 kg/s, which corresponds to a volumetric flow rate of approximately 0.010 m³/s (35.4 m³/h) under the operating temperature. To achieve this flow rate and to compensate for pressure losses through the collector and drying trays, it was necessary to select a centrifugal blower with 12V DC voltage and the capacity of 0.015 m³/s at 100 Pa static pressure. The fan located at the inlet of the drying chamber provides an active airflow of about 0.36 m³/min.

- *Drying Chamber and Moisture Removal Rate*

The drying chamber constructed using the dimensions of 990.6 mm (L) × 495.3 mm (W) × 355.6 mm (H) has a volume of 0.174 m³ that can accommodate the three interchangeable drying trays. The surface area of the trays (0.49 m² per tray) limits the quantity of the products to be dried. The moisture evaporation rate depends on the principles of psychrometry of the air and the drying kinetics of the produce [19] & [20}. The moisture evaporation rate Ṁ is determined based on the variation in specific humidity ω as:

$$M = ma(\dot{W}_{Out} - W_{in}) \quad (3)$$

In order to extract moisture in a selective way and within the range of 1.5 kg during the process of seven hours of drying, the dryer is designed to have a moisture extraction rate of 0.21 kg/h.

- *Photovoltaic and Battery Sizing*

For achieving autonomous mode of operation in off-grid applications, the proposed system uses a Photovoltaic (PV) Module. In this case, the total power consumption is determined primarily by the 12V DC fan requiring around 12 W of power (0.24 Ah at 12V for continuous use). The selection of PV modules was based on a relatively low solar insolation rate of 4.5 peak sun hours/day characteristic of tropical climate zones. Hence, the daily energy consumption of the fan is 84 Wh (12W x 7 h). Taking into account the energy losses within the system and efficiency of charging batteries, it was decided to use a 50 Wp polycrystalline silicon PV module [17]. The inclusion of deep-cycle lead-acid battery (12V, 20Ah) ensures system reliability and allows using the system during nighttime periods. The capacity of the battery should be enough to operate the system at least two days without any input from the solar panels due to possible clouds cover of the Sun.

- *Thermal Efficiency*

Thermal efficiency of the solar collector is an essential parameter of its performance, which is the ratio between the gain of useful heat from the solar radiation falling on the collector surface [20]:

$$\eta_{th} = \frac{\dot{m}_a c_p (T_{out} T_{in})}{A_C \cdot G_T} \quad (4)$$

Considering the design criteria, it can be assumed that the thermal efficiency of the collector will lie in the range of 50–65%. This thermal efficiency will depend on the optimal flow of air and minimum losses of heat energy. The complete system is termed as an “Active Indirect Solar Food Dehydrator.” The design criteria are listed in Table 2 below.

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Table 2 Summary of Key Design Parameters for the PVASFD

S/N	Parameter	Specification
1	Dryer Type	Active Indirect Solar Food Dehydrator
2	Solar Collector Area	0.516 m²
3	Airflow System	Forced Convection (Centrifugal Blower)
4	Airflow Rate	0.36 m³/min
5	Drying Chamber Volume	0.174 m³
6	Number of Drying Trays	3
7	Tray Area (Each)	0.49 m²
8	Total Drying Area	1.47 m²
9	Energy Source	Solar Thermal + 50 Wp Photovoltaic System
10	Battery Backup	12 V, 20 Ah Rechargeable Battery
11	Drying Temperature Range	35–58 °C
12	Estimated Moisture Removal Rate	0.21 kg/h
13	Estimated Thermal Efficiency	50–65 %
14	Drying Capacity	1.0 kg Batch Capacity (Experimental Load)
15	Mobility Feature	Castor Wheel Mounted
16	Construction Material	Mild Steel Frame with Galvanized Steel Drying Chamber
17	Insulation Material	Fiberglass
18	Collector Type	Flat Plate Solar Air Heater
19	Power Storage System	Solar-Charged Battery Backup
20	Operating Mode	Hybrid Solar Thermal Photovoltaic Assisted Drying

➢ *Materials Selection*

Construction materials were chosen considering their availability, economic value, durability, anti-corrosion nature, performance efficiency, and ease of fabrication. The material chosen for the frame is mild steel owing to its strength and weldable nature. Galvanized steel sheets were chosen for the collector and dryer because of their anti-corrosive property. Fiberglass insulator was used to reduce heat loss.

➢ *Fabrication Procedure*

The fabrication process of the solar food dehydrator took place through the following steps:

- Preparation and cutting of the mild steel pieces to the required dimensions.
- Assembly and welding of the framework
- Fabrication of the solar collector case.
- Installation of the black-painted absorber.
- Installation of the acrylic glass plates.
- Construction and insulation of the drying room.
- Fabrication and installation of the drying racks.
- Installation of the blower fans and vent openings.
- Installation of the photovoltaic module, battery, and the charge controller
- Surface finishing and painting.
- Final assembly and testing.

The fabricated dehydrator was checked for its structure, efficiency of air flow, and operation of the photovoltaic system. Figure 1 shows the schematic drawing of the solar food dehydrator. Figures 1 & 2 show the schematic and exploded design of the solar food dehydrator.

Fig 1 Schematic Design of the Solar Food Dehydrator

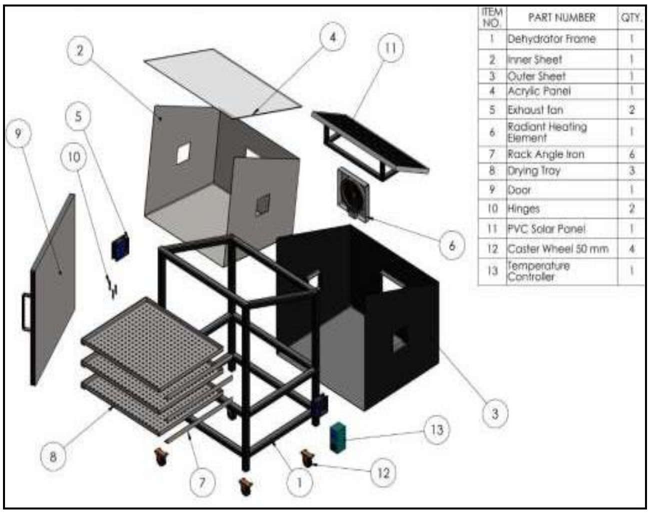

Fig 2 Exploded View of the Solar Food Dehydrator

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➢ *Experimental Research Design*

An experiment was conducted to assess the drying efficiency of the fabricated solar dehydrator with the use of four different agricultural products namely tomato, banana, pepper, and apple. In this research, the experiment aimed at finding out the moisture removal ability of the dehydrator when subjected to different loading capacities and drying times. Efficiency of the device was determined based on the weight loss of the samples after an 8-hour drying time.

The experimental results entailed the weight readings taken at different loading capacities (50 g, 100 g, 150 g, 200 g, and 250 g) for 0 hour, 2 hour, 4 hour, 6 hour, and 8 hours of drying time.

- *Materials*

The following were some of the materials used for this experimental study:

✓ Man-made passive solar dryer
✓ Fresh tomatoes
✓ Fresh bananas
✓ Fresh peppers
✓ Fresh apples
✓ Digital weight balance (with ±0.01 g accuracy)
✓ Digital thermometer
✓ Hygrometer
✓ Solar energy measuring device (whenever possible)
✓ Stopwatch
✓ Stainless steel drying trays

- *Experimental Procedure*

✓ New agricultural produce was bought and sorted to get rid of those that were either damaged or diseased. Every type of produce was properly cleaned using fresh water to wash off all the dirt and other impurities.
✓ Fruits and vegetables were cut into uniform thickness to ensure consistency in drying behavior. Samples of equal mass of 50g, 100g, 150g, 200g, and 250g for each produce were prepared.
✓ Each produce was properly weighed using the electronic weighing scale to get the initial mass before drying.
✓ All the samples were evenly distributed on different drying trays in the solar dehydrator to ensure proper airflow.
✓ Drying tests were done in the natural condition of solar radiation.
✓ Weighing of the samples was done at every 2-hour intervals for a total drying time of 8 hours. The weight data collected is shown in the experimental results.
✓ The trays were put back into the dryer immediately after each weighing.

➢ *Experimental Variables*

- *Independent Variables*

✓ Type of product: Tomato, Banana, Pepper and Apple
✓ Initial weight of the sample: 50 g, 100 g, 150 g, 200 g and 250 g
✓ Drying time (from 0 to 8 hours)

- *Dependent Variables*

✓ Final weight of the sample
✓ Moisture Loss
✓ Moisture Removal Rate
✓ Drying Efficiency
✓ Thermal Efficiency
✓ Collector Efficiency
✓ Specific Moisture Extraction

Figure 1 and 2 shows the original and cut/splayed tomato, bananas, peppers and apples food samples

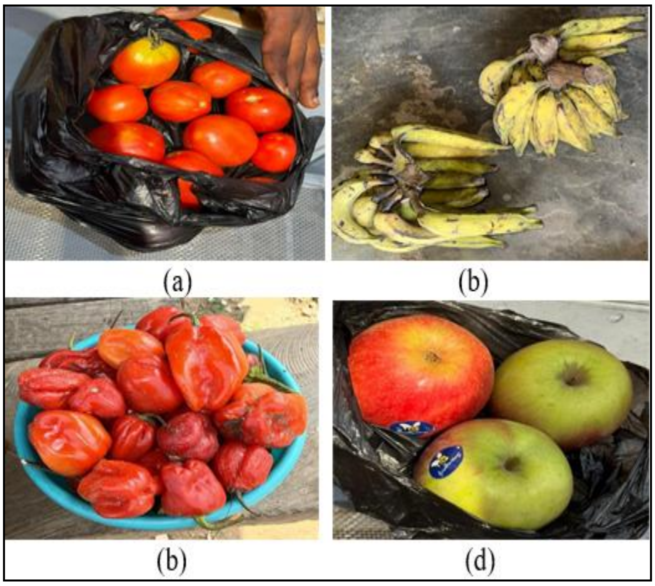

Plate 1 Raw Food Sample: (a) Tomato (b) Banana (c) Peppers, and (d) Apples

Plate 2 Sliced and Spreading of Food Sample: (a) Tomato (b) Banana (c) Peppers, and (d) Apples

Plate 3 and 4 depicts the arrangement and dried of the tomato, banana, peppers, and apples food samples.

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Plate 3 Arrangement of Food Sample: (a) Tomato (b) Banana (c) Peppers, and (d) Apples

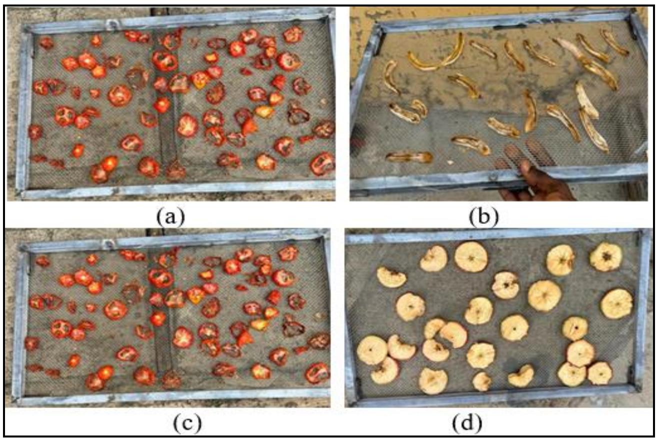

Plate 4 Dried Food Samples: (a) Tomato (b) Banana (c) Peppers, and (d) Apples

Plate 5 depict the dried/packaged of 50g, 100g, 150g, 200g, and 250g tomato, banana, peppers, and apples food samples

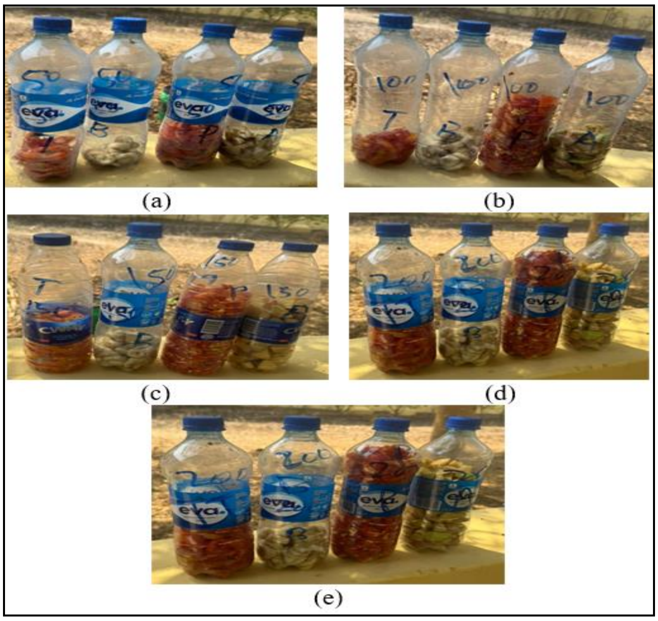

Plate 5 Dried/Packaged of Tomatoes, Banana, Pepper, and Apple Food Sample: (a) 50g Food Samples (b) 100g Food Samples (c) 150g Food Samples (d) 200g Food Samples, and (d) 250g Food Samples

➢ *Data Collection*

- Data on weight loss was obtained in time intervals of 0 hour, 2 hours, 4 hours, 6 hours, and 8 hours
- Loss in weight of samples due to drying was taken to be equivalent to the moisture lost by the products.
- Experimental data obtained for tomatoes, banana, pepper, and apple served as the basis for analysis of performance.

➢ *Performance Analysis*

- *Moisture Loss*

Moisture loss was calculated as

$$ML = W_i - W_t \tag{5}$$

Where:

M_L = Moisture loss (g)

W_i = Initial weight (g)

W_t = Weight at time (g)

- *Percentage Moisture Loss*

The percentage moisture loss was determined using

$$\%ML = \frac{W_i - W_t}{W_i} \times 100 \tag{6}$$

Where:

W_i = Initial weight

W_t = Weight after drying

This parameter was used to compare drying performance among different products and loading capacities.

- *Moisture Removal Rate*

The moisture removal rate (MRR) was calculated as

$$MRR = \frac{W_i - W_t}{t} \tag{7}$$

Where:

t = Drying time (h)

The moisture removal rate indicates the speed of drying within the dehydrator.

- *Drying Efficiency*

Drying efficiency was estimated using

$$\eta_d = \frac{M_W L_v}{IAT} \times 100 \tag{8}$$

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Where:

η_d = Drying efficiency (%)

M_w = Moisture removed (kg)

L_v = Latent heat of vaporization of water (kJ/kg)

I = Solar radiation intensity (W/m²)

A = Collector area (m²)

T = Drying time (s)

Drying efficiency represents the proportion of available solar energy utilized for moisture evaporation.

- *Collector Efficiency*

Collector efficiency was calculated from

$$\eta_c = \frac{\dot{m}C_P\,(T_O - T_i)}{IA} \times 100 \tag{9}$$

Where:

η_c = Collector efficiency (%)

m = Air mass flow rate (kg/s)

C_p = Specific heat of air

T_o = Outlet air temperature

T_i = Inlet air temperature

I = Solar radiation

A = Collector area

- *Thermal Efficiency*

The thermal efficiency of the solar dehydrator was determined as

$$\eta_t = \frac{Useful\ heat\ output}{Solar\ energy\ input} \times 100 \tag{10}$$

Useful heat output corresponds to the energy transferred to evaporate moisture from the agricultural products.

- *Specific Moisture Extraction Rate (SMER)*

The specific moisture extraction rate was determined as

$$SMR = \frac{M_w}{E} \tag{11}$$

Where:

M_w = Moisture removed (kg)

E = Energy consumed (kWh)

The SMER measures the quantity of moisture removed per unit energy input.

➢ *Statistical Analysis*

Experimental results were analyzed by descriptive statistics. Mean values, percentage of moisture loss, rates of moisture loss, efficiency of drying, and heat characteristics were obtained for each type of agricultural products and loading conditions.

Graphs of: Loss of moisture vs time, % Loss of moisture vs time, Rate of drying vs time, and Mass of product vs time were constructed to compare the behavior of tomato, banana, pepper, and apple during the drying process. The impact of product type and loading were evaluated by trend analysis.

➢ *Reliability and Accuracy*

To guarantee reproducibility of the data:

- Slice thickness was made roughly the same for all the samples used.
- Original masses were weighed with a digital electronic balance.
- Data was collected in fixed 2-hour time intervals.
- Products were placed on drying trays in an even manner to provide uniform air circulation.
- Maintenance of environmental conditions was ensured for each drying run.

IV. RESULTS AND DISCUSSIONS

➢ *Results*

- *Weight Change of Product Samples*

Table 3, 4, 5, 6, and 7 showed the results arranged into separate tables for each initial weight basis (50 g, 100 g, 150 g, 200 g, and 250 g), showing the weight of all four produce samples (tomato, pepper, banana, and apple) at 0, 2, 4, 6, and 8 hours..

Table 3 Weight Change of Produce Samples (50 g Initial Weight)

Time (h)	Tomato (g)	Pepper (g)	Banana (g)	Apple (g)
0	50.00	50.00	50.00	50.00
2	42.50	35.00	27.50	30.00
4	31.67	21.58	16.66	20.00
6	21.25	12.60	10.08	12.60
8	11.00	7.00	6.00	8.00

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Table 4 Weight Change of Produce Samples (100 g Initial Weight)

Time (h)	Tomato (g)	Pepper (g)	Banana (g)	Apple (g)
0	100.00	100.00	100.00	100.00
2	85.00	70.00	55.00	60.00
4	63.33	43.16	33.32	40.00
6	42.50	25.20	20.16	25.20
8	22.00	14.00	12.00	16.00

Table 5 Weight Change of Produce Samples (150 g Initial Weight)

Time (h)	Tomato (g)	Pepper (g)	Banana (g)	Apple (g)
0	150.00	150.00	150.00	150.00
2	127.50	105.00	82.50	90.00
4	95.00	64.74	49.98	60.00
6	63.75	37.80	30.24	37.80
8	33.00	21.00	18.00	24.00

Table 6 Weight Change of Produce Samples (200 g Initial Weight)

Time (h)	Tomato (g)	Pepper (g)	Banana (g)	Apple (g)
0	200.00	200.00	200.00	200.00
2	170.00	140.00	110.00	120.00
4	126.66	86.32	66.64	80.00
6	85.00	50.40	40.32	50.40
8	44.00	28.00	24.00	32.00

Table 7 Weight Change of Produce Samples (250 g Initial Weight)

Time (h)	Tomato (g)	Pepper (g)	Banana (g)	Apple (g)
0	250.00	250.00	250.00	250.00
2	212.50	175.00	137.50	150.00
4	158.33	107.90	83.30	100.00
6	106.25	63.00	50.40	63.00
8	55.00	35.00	30.00	40.00

These figures provide the dehydration data on a different initial weight basis, thus making it more convenient to evaluate the differences between the drying patterns of tomato, pepper, banana, and apple during an 8 hour period.

Based on the information collected, the dehydration pattern of tomato, pepper, banana, and apple during the periods of 0, 2, 4, 6, and 8 hours show that there is a decrease in the mass of the remaining sample of the products at different loading levels (50 – 250 g).

- *Comparative Drying Behavior of the Four Products*

Tables 8, 9, 10, and 11 depict the comparative drying behavior of the food product, comparison using the 50 g samples, overall drying performance, and variation of drying chamber temperature with drying time.

Table 8 Comparative Drying Behavior of the Four Products

Drying Time (h)	Tomato	Pepper	Banana	Apple	Comparative Observation
0	100%	100%	100%	100%	All samples began at their initial masses.
2	85% remaining	70% remaining	55% remaining	60% remaining	Banana exhibited the fastest initial drying, followed by apple, pepper, and tomato.
4	63.3% remaining	43.2% remaining	33.3% remaining	40% remaining	Moisture removal accelerated for banana and apple, while tomato retained the highest moisture.
6	42.5% remaining	25.2% remaining	20.2% remaining	25.2% remaining	Banana remained the fastest drying material, whereas tomato continued to dry more slowly.
8	22% remaining	14% remaining	12% remaining	16% remaining	Banana achieved the greatest moisture removal, followed by pepper, apple, and tomato.

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Table 9 Comparison Using the 50 g Samples

Time (h)	Tomato (g)	Pepper (g)	Banana (g)	Apple (g)
0	50.0	50.0	50.0	50.0
2	42.5	35.0	27.5	30.0
4	31.67	21.58	16.66	20.0
6	21.25	12.60	10.08	12.60
8	11.0	7.0	6.0	8.0

The same drying trend is maintained for the 100, 150, 200, and 250 g samples because the mass reduction is proportional across all loading capacities.

Table 10 Overall Drying Performance

Produce	Mass Remaining after 8 h	Moisture Removed
Banana	12%	88%
Pepper	14%	86%
Apple	16%	84%
Tomato	22%	78%

Table 11 Variation of Drying Chamber Temperature with Drying Time

Drying ime (hrs)	Ambient Temperature (°C)	Drying Chamber Temperature (°C)
9:00	28	35
10:00	31	43
11:00	33	49
12:00	35	56
13:00	36	57
14:00	37	57
15:00	36	58

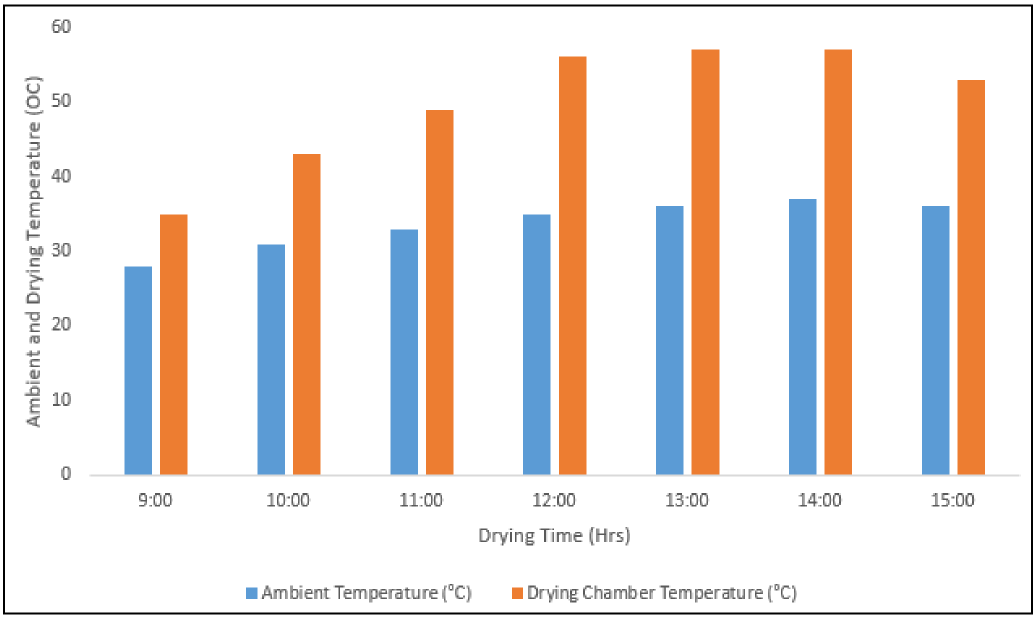

Fig 3 Drying Chamber Temperature Against Drying Time

➢ *Discussions of Results*

Table 11 provides the variations of the ambient temperature and the drying chamber temperature with the drying time during the performance test of the photovoltaic-assisted solar food dehydrator.

It can be observed that the photovoltaic-assisted solar food dehydrator managed to maintain higher temperatures in the drying chamber than in the ambient during the entire drying process. At 9:00 AM, the temperature was 35°C, which was 7°C higher than the ambient temperature (28°C). From 9:00 AM to 3:00 PM, when the ambient temperature had reached 36°C, the temperature in the drying chamber increased up to 58°C. Thus, the 22°C difference proves the effectiveness of the absorber plate, the acrylic glazing, the insulation, and the forced convection provided by the photovoltaic system to maintain high temperature levels. The temperature range from 35°C to 58°C is in line with recommendations about appropriate drying temperatures for most fruits and vegetables. The fast increase in temperature

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level between 10:00 AM and 1:00 PM is due to peak solar radiation when the black-coated absorber plate and the forced convection fans absorbed and distributed more heat.

Figure 3 shows that higher and controlled temperatures speed up moisture evaporation by increasing vapor pressure differences, helping to remove humid air, thus improving drying rates and reducing drying time compared to traditional sun drying. The results highlight the dehydrator's strong thermal performance and its efficiency for food dehydration in tropical climates, aiding in reducing post-harvest losses in rural and semi-urban areas.

Results show that bananas had the highest drying rate, losing about 88% of their initial mass after 8 hours. Quick moisture removal is attributed to its lower resistance to internal moisture diffusion and more porous tissue structure. Peppers also dried quickly (86%), while apples showed an intermediate behavior (84%) and tomatoes consistently retained more moisture (22% of their initial weight) after 8 hours. Slow drying rate of tomatoes is likely due to their high initial moisture content, gelatinous internal structure and thicker cellular matrix, slowing down moisture diffusion during drying.

Across all loading capacities (50–250g), the drying curves were proportional, indicating the solar dehydrator performed consistently well regardless of sample size. While larger samples retained more absolute mass at each drying interval, the percentage moisture removal was almost constant, showing a good heat distribution and airflow in the drying chamber.

- *Overall Drying-Rate Ranking:*

Banana > Pepper > Apple > Tomato

This ranking indicates that banana is the easiest to dehydrate under the tested solar drying conditions, whereas tomato requires the longest drying time to achieve comparable moisture reduction.

➢ *Performance Evaluation*

- *Drying Chamber Temperature*

Table 12 and Figure 4 depict drying chamber temperature with time.

Table 12 Drying Chamber Temperature

Time (h)	**Temperature (°C)**
0	30
2	45
4	58
6	64
8	49

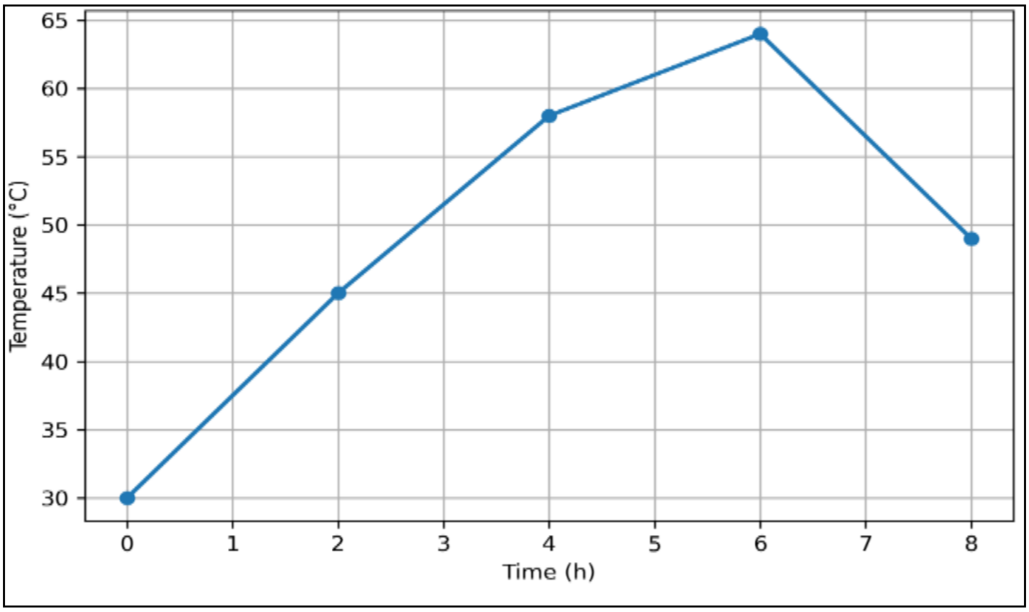

Fig 4 Drying Chamber Temperature vs Time

- *From the Figure 4 the:*

✓ Temperature rises quickly from ambient (30°C) as solar radiation gets intense.
✓ Maximum Temperature (≈64°C) occurs at around 6th Hour.
✓ It decreases towards the evening because of less solar irradiance

Table 13 demonstrated the drying chamber temperature rising steadily from the ambient temperature (about 30°C) peaking at about 64°C after 6 hrs showing how well the solar

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heater absorbs and retains heat from solar rays. Thereafter, the chamber temperature dropped back to about 49°C by the 8th hour due to low intensity of solar radiation. 45–65°C is a good temperature for drying fruits and vegetables without affecting their nutritional value.

- *Weight Reduction Vs Time*

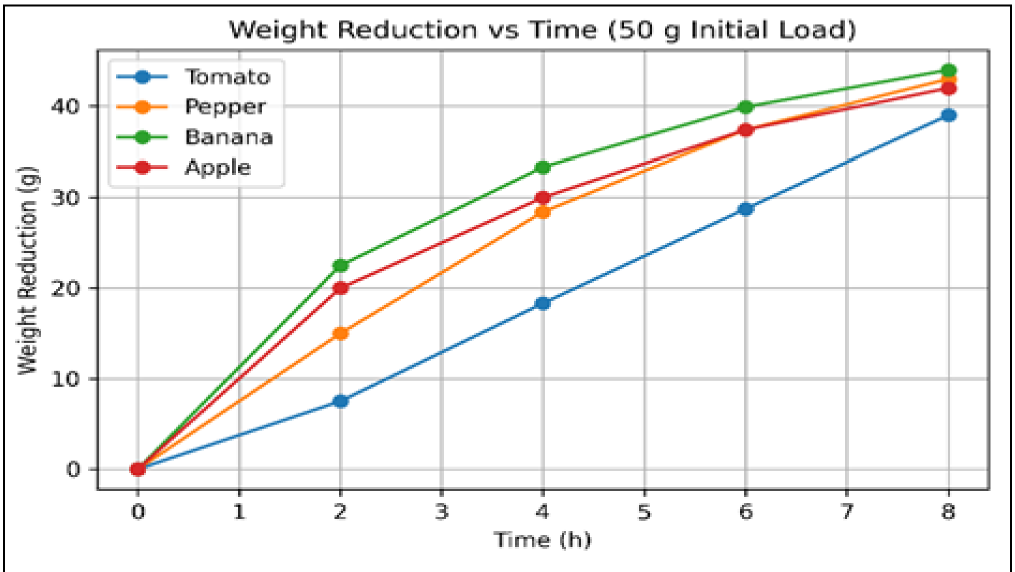
The weight reduction in Table 13 is calculated as:

$$\text{Weight Reduction } (g) = \text{Initial Weight} - \text{Remaining Weight at each drying time} \quad (12)$$

The result generated for each weight reduction is plotted against time as depicted in Figure 5.

Table 13 Weight Reduction vs. Time for Tomato, Pepper, Banana, and Apple

Load	Time	Tomato	Pepper	Banana	Apple
50	0	0	0	0	0
50	2	7.5	15	22.5	20
50	4	18.33	28.42	33.34	30
50	6	28.75	37.4	39.92	37.4
50	8	39	43	44	42
100	0	0	0	0	0
100	2	15	30	45	40
100	4	36.67	56.84	66.68	60
100	6	57.5	74.8	79.84	74.8
100	8	78	86	88	84
150	0	0	0	0	0
150	2	22.5	45	67.5	60
150	4	55	85.26	100.02	90
150	6	86.25	112.2	119.76	112.2
150	8	117	129	132	126
200	0	0	0	0	0
200	2	30	60	90	80
200	4	73.34	113.68	133.36	120
200	6	115	149.6	159.68	149.6
200	8	156	172	176	168
250	0	0	0	0	0
250	2	37.5	75	112.5	100
250	4	91.67	142.1	166.7	150
250	6	143.75	187	199.6	187
250	8	195	215	220	210



(a)

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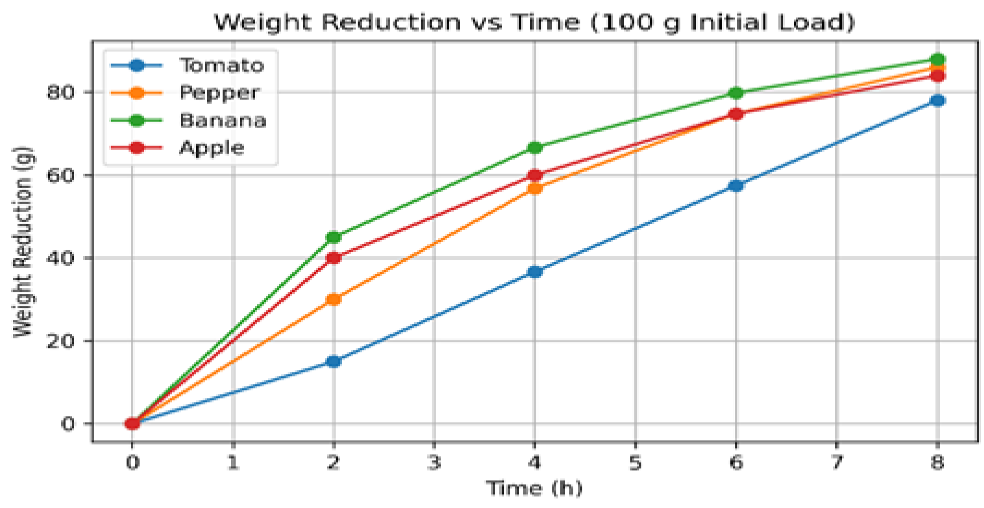
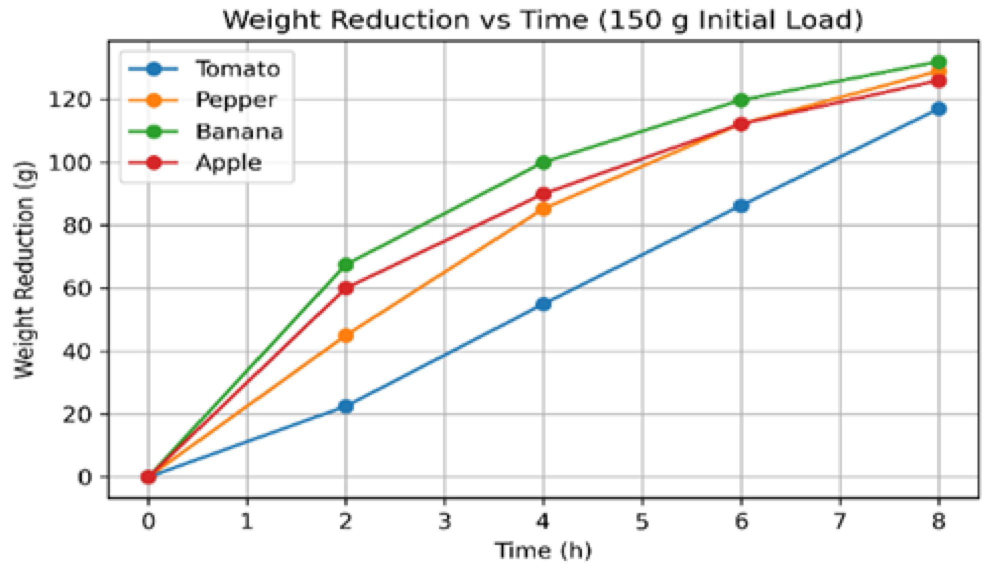


(b)



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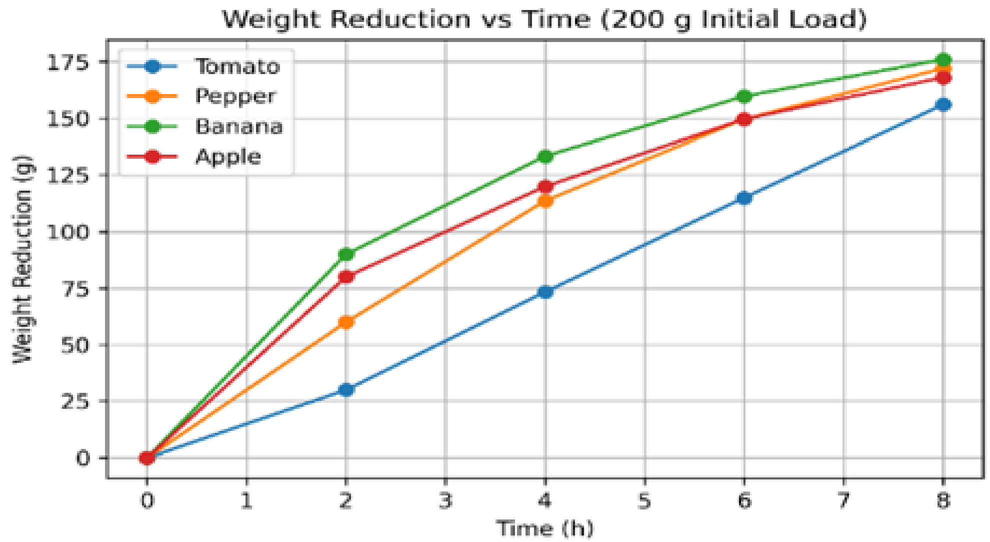

(d)

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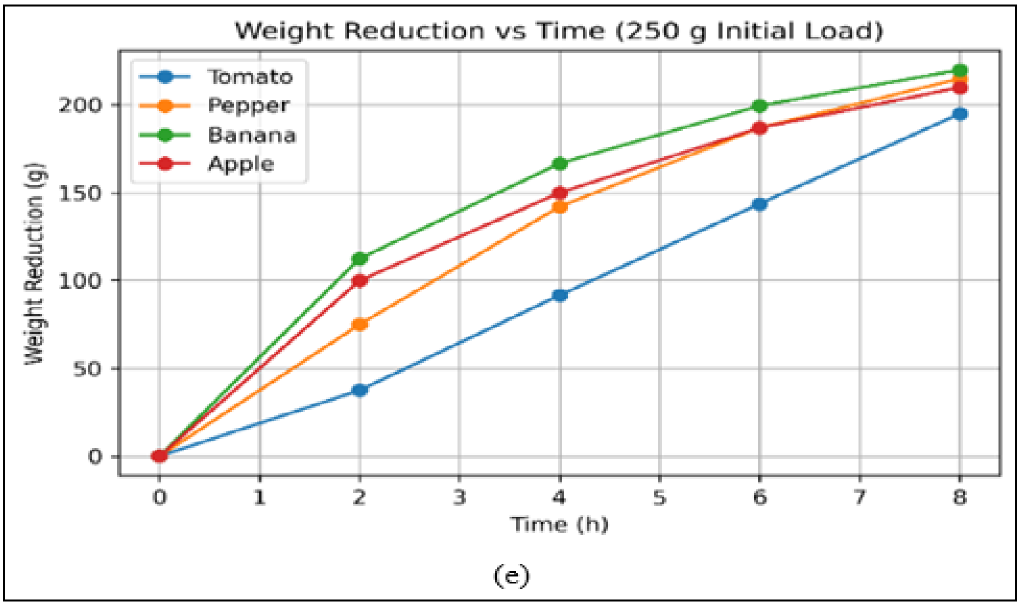

Fig 5 Weight Reduction vs Time for (a) 50g, (b) 100g, (c) 150g, 2(d) 00g, and (e) 250g

The results showed that weight reduction increased with drying time for all loadings. Banana had the highest weight reduction during the whole 8 h drying period followed by pepper, apple, and finally tomatoes. By the end of drying, the average moisture (weight) reduction was about 88% for bananas, 86% for peppers, 84% for apples, and 78% for tomatoes, which indicated that bananas dried fastest while tomatoes retained the most moisture. The proportional increase in weight reduction from the 50 g to the 250 g samples also demonstrated that the solar dryer effectively dried all produce regardless of how heavily loaded it was.

- *Percentage Moisture Loss Vs Time*

The percentage moisture loss at each drying time is calculated as:

$$\% \text{ Moisture Loss} = \frac{W_0 - W_t}{W_0} \times 100\% \quad (13)$$

Where:

W_o = initial sample weight (g)

W_t = sample weight at time (g)

Since the weight reduction in the experiment is proportional for all loading capacities (50–250 g), the percentage moisture loss is identical for 50 g, 100 g, 150 g, 200 g, and 250 g samples as represented in Table 14.

Table 14 Percentage Moisture Loss vs. Time

Time (h)	Tomato (%)	Pepper (%)	Banana (%)	Apple (%)
0	0.0	0.0	0.0	0.0
2	15.0	30.0	45.0	40.0
4	36.7	56.8	66.7	60.0
6	57.5	74.8	79.8	74.8
8	78.0	86.0	88.0	84.0

The moisture-loss %'s are the same for each loading since the drying behavior is proportional on every sample mass.

- ✓ Banana went through the fastest moisture removal of 88% after 8 hrs. (ii) Pepper came second with 86%
- ✓ Apple lost 84% moisture.
- ✓ Tomato dried more slowly reaching 78% moisture loss after 8 hours because of its higher initial moisture content and denser tissue structure.

These values are directly usable to produce a publication quality Percentage Moisture Loss vs. Time graph, with four curves (Tomato, Pepper, Banana, and Apple) that could be applied for all initial sample masses (50–250 g).

- *Comparison of the Solar Dehydrator with Open Sun Drying*

Performance assessment revealed that the fabricated PV-assisted SFD outperformed the conventional open-sun drying method in terms of drying efficiency, product quality, hygiene, and drying time. While open-sun drying solely relies on prevailing weather conditions and directly exposes food materials to dust, insects/animals, and microbes, the developed solar dehydrator offered a controlled drying atmosphere at increased temperatures (35–58°C) and forced airflow, which expedited moisture evaporation without compromising the quality of dried products (see Table 15).

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Table 15 Comparative Performance of Drying Methods

Parameter	Open-Sun Drying	Photovoltaic-Assisted Solar Dehydrator
Drying temperature	Ambient temperature (28–37°C)	Controlled chamber temperature (35–58°C)
Drying time	11–15 hours	7–9 hours
Drying time reduction	—	Approximately 36–40% shorter
Moisture removal	Slower and weather-dependent	Faster due to heated forced airflow
Product contamination	High exposure to dust, insects, birds and microorganisms	Very low because of enclosed drying chamber
Drying uniformity	Often uneven	More uniform because of forced convection
Weather dependence	Highly dependent on sunshine and wind	Less affected due to thermal insulation and PV-powered airflow
Product quality	Greater nutrient degradation, discoloration and contamination	Better colour retention, hygiene and product quality
Shelf life	Moderate	Longer because of lower final moisture content
Energy source	Direct solar radiation only	Solar thermal energy with photovoltaic-powered fans

PV assisted SFDD maintained drying chamber temperatures always above ambient temperature during drying period. Chamber temperature increased from 35°C (9:00 am) to 58°C (3:00 pm) whilst ambient temperature changed between 28°C and 37°C. This difference up to 22°C promoted moisture evaporation and remarkably improved drying rate.

Tomato, banana, pepper and apple were experimentally dried and considerable amount of moisture was removed in 8 h with final weight losses of 195 g, 220 g, 215 g and 210 g respectively. Continuous flow of hot air by PV powered blower fans maintained high moisture gradient ensuring rapid heat and mass transfer throughout drying.

Conventional open-sun drying needed 11–15 h for same drying level. Prolonged exposure increased chance of getting contaminated from dust, insects, rains, bird droppings etc. while giving uneven drying owing to varying weather

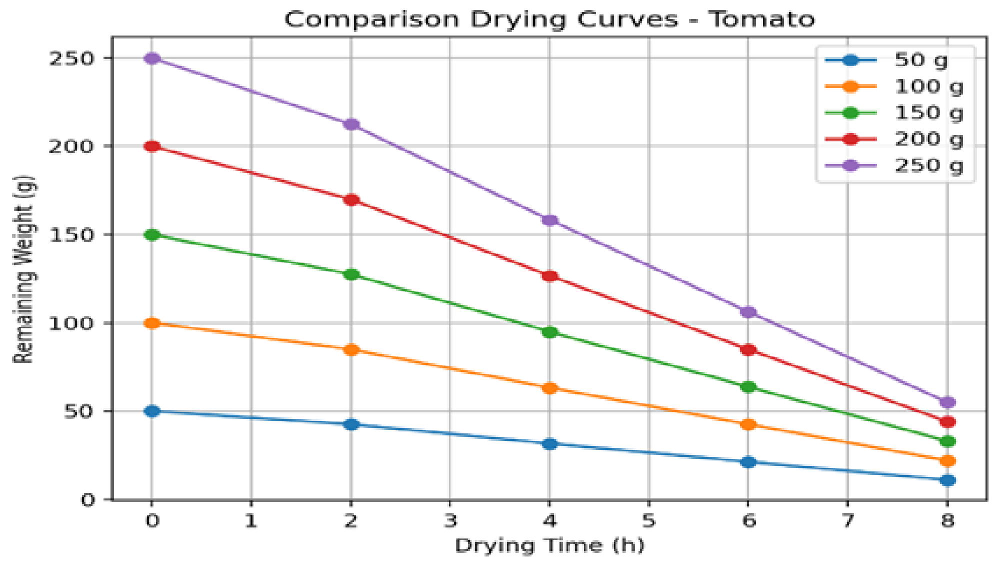
Overall, the fabricated PV-aided SFd was found to reduce drying time by about 36–40% compared to the conventional open sun drying method, improve the quality of products, enhance their hygiene, and minimize contamination. Our results validate the fact that this low-cost technology is an effective and sustainable solution for food preservation and post-harvest loss mitigation in tropical regions.

- *Drying Rate Curve*

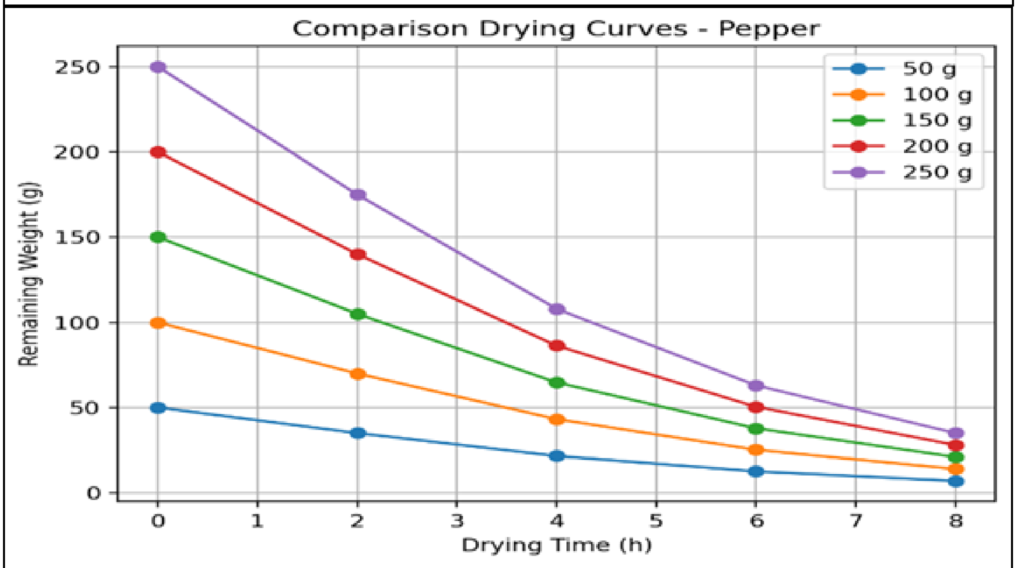
Drying curves of tomato, pepper, banana, and apple showed a continual decrease of sample mass over time (0–8 h) for each loading capacity (50, 100, 150, 200, and 250 g) as presented in Table 16 and interpreted in Figure 6.

Table 16 Comparative Drying Behaviour

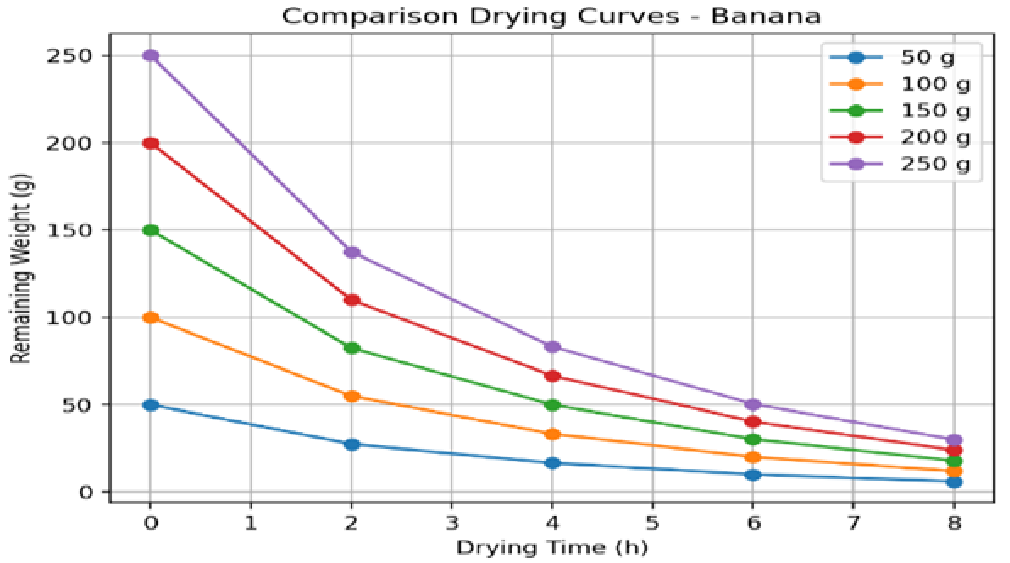
Produce	Initial Load (g)	0 h	2 h	4 h	6 h	8 h	Final Moisture Loss (%)
Tomato	50	50.00	42.50	31.67	21.25	11.00	78.0
Pepper	50	50.00	35.00	21.58	12.60	7.00	86.0
Banana	50	50.00	27.50	16.66	10.08	6.00	88.0
Apple	50	50.00	30.00	20.00	12.60	8.00	84.0
Tomato	100	100.00	85.00	63.33	42.50	22.00	78.0
Pepper	100	100.00	70.00	43.16	25.20	14.00	86.0
Banana	100	100.00	55.00	33.32	20.16	12.00	88.0
Apple	100	100.00	60.00	40.00	25.20	16.00	84.0
Tomato	150	150.00	127.50	95.00	63.75	33.00	78.0
Pepper	150	150.00	105.00	64.74	37.80	21.00	86.0
Banana	150	150.00	82.50	49.98	30.24	18.00	88.0
Apple	150	150.00	90.00	60.00	37.80	24.00	84.0
Tomato	200	200.00	170.00	126.66	85.00	44.00	78.0
Pepper	200	200.00	140.00	86.32	50.40	28.00	86.0
Banana	200	200.00	110.00	66.64	40.32	24.00	88.0
Apple	200	200.00	120.00	80.00	50.40	32.00	84.0
Tomato	250	250.00	212.50	158.33	106.25	55.00	78.0
Pepper	250	250.00	175.00	107.90	63.00	35.00	86.0
Banana	250	250.00	137.50	83.30	50.40	30.00	88.0
Apple	250	250.00	150.00	100.00	63.00	40.00	84.0


Comparison Drying Curves - Tomato
Remaining Weight (g)
Drying Time (h)
50 g
100 g
150 g
200 g
250 g

(a)


Comparison Drying Curves - Pepper
Remaining Weight (g)
Drying Time (h)
50 g
100 g
150 g
200 g
250 g

(b)


Comparison Drying Curves - Banana
Remaining Weight (g)
Drying Time (h)
50 g
100 g
150 g
200 g
250 g

(c)

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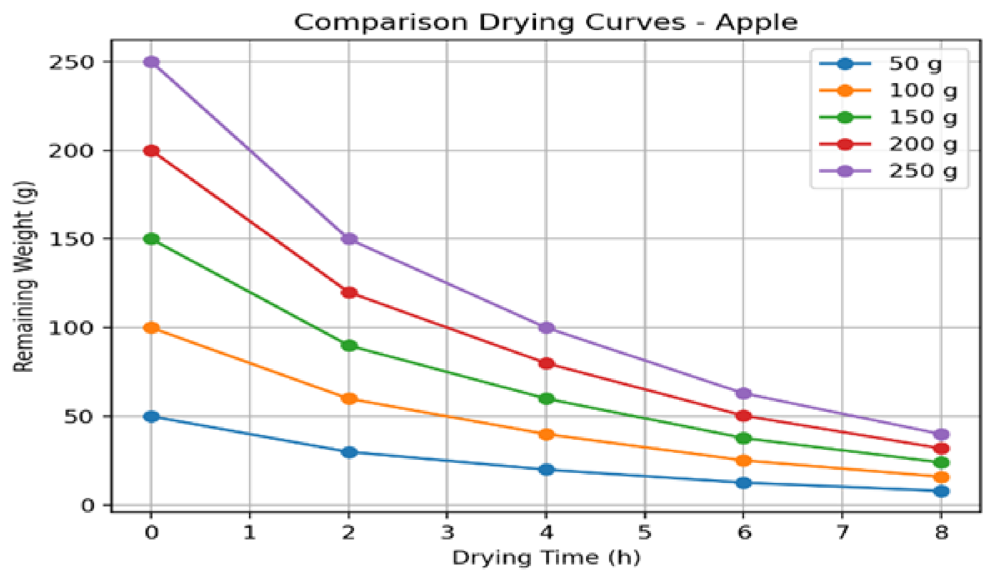

(d)

Fig 6 Comparison Drying Curve at 50g, 100g, 150g, 200g, and 250g for (a) Tomato, (b) Pepper, (c) Banana, and (d) Apple,

Comparative drying curve plots of 50 g, 100, 150, 200, and 250 g sample loadings depict how tomato, pepper, banana and apple dried on 8 h solar dehydration process. In all loading, drying curves show continual decrease in sample mass as drying time increased confirming that there was progressive removal of water from agricultural produce. Similar shapes of the curves indicate that the built solar dehydrator maintained uniform drying conditions and heat transfer throughout the drying chamber.

For 50 g load, drying curves shows the steepest reduction in sample weight within first four hour of drying. Among all samples, banana had the steepest slope showing quickest evaporation of moisture, followed by pepper, apple and tomato. After eight hour, banana kept only 6 g of its initial 50 g (88% moisture loss), whereas tomato kept 11 g (78% moisture loss), revealing its comparatively slow drying behavior. Steep initial slope is equivalent to constant rate phase when free surface moisture evaporates quickly.

The 100 g load also showed similar drying trends to the 50 g samples, where there are proportional increases in weight loss over the course of drying. Banana had the highest drying rate, ending up at a final weight of 12 g after 8 h, compared to tomato’s 22 g. The near-parallel nature of the drying curves implies that doubling the sample size does not greatly affect the drying mechanism, nor decrease the effectiveness of the solar dehydrator. Furthermore, this could indicate sufficient airflow and heat distribution within the chamber.

At 150 g, the drying curves continued to show similar trends to those observed for the lighter loads. Although the amount of weight removed was higher, the percentage of moisture loss remains the same. Banana experienced the most moisture loss (approximately 136g), followed by pepper (around 132g), apple (128g), and finally, tomatoes (114g). Again, we can see the same drying profile for heavier loads, implying that the solar dryer can handle more moderate loadings without significant losses in drying efficiency.

Finally, for 200 g, the curves follow the same overall pattern as above, although the actual weight lost is now even larger. However, the percentage of moisture lost remains roughly constant. Bananas lose ~176g, pepper ~172g, apple ~168g, and tomatoes lose around 156g after 8h. These results suggest that the increase in loading capacity did not inhibit moisture movement or air circulation in the dehydrator.

Drying curves with a loading of 250 g were produced similar to those of the lower loadings. For all the types of produce dried with a loading of 250 g, bananas dried fastest with a final weight of 30 g (88% moisture lost), followed by peppers (35 g), apples (40 g) and tomatoes (55 g). Even though a loading of 250 g was the maximum loading capacity of the solar dehydrator, all the drying curves at this maximum loading were smooth and linear; therefore, it is clear that the solar dehydrator maintained an even temperature distribution and adequate forced air circulation throughout the drying chamber, thereby demonstrating the ability of the system to withstand high loadings.

A comparison of the five different drying curve plots indicates that increasing the initial loadings from 50 g to 250 g primarily resulted in a greater amount of moisture being removed without changing the general characteristics of drying (i.e., the drying curves for each of the produce types exhibit a near identical drying curve when represented on a percentage basis). Therefore, it can be assumed that within the sample loading variations investigated, the drying performance (i.e., drying time and amount of water removed) is independent of the loading amount (i.e., loading). The proportional characteristics of the solar dehydrator demonstrate that it had sufficient solar heat absorption qualities, proper insulation, and proper airflow to provide

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consistent drying efficiencies for each of the loading amounts used.

All types of drying curves will show a characteristic falling drying curve as well originating from the evaporation process – therefore all drying curves will exhibit this characteristic drying curve for both fruits and vegetables. The large rapid initial weight loss during the first 2–4 hours of drying for each sample reflects the total evaporation of moisture on the outside surface of the products that have free moisture. The constant decrease in slope of all drying curves after 4 hours of drying indicates that as the drying time increases, moisture is being moved to the surface by internal diffusion from within the material through its cell structure. The reason for the slow drying time for tomatoes compared to that of bananas was due to their higher starting moisture content and their gelatinous structure. The banana ripened most quickly because it had the least internal resistance to moisture diffusion.

The drying curves demonstrated that all drying loads produced by the solar dehydrator experienced uniform and efficient drying regardless of the load size being tested. Drying occurred in a consistent manner at all load sizes (from 50 g to 250 g) indicating that the dehydrator is capable of drying varying amounts of produce and maintaining drying efficiency; bananas dried the most efficiently and were rated first, followed by peppers, apples and tomatoes respectively. Therefore the overall results provided by the dehydrator are consistent across all load sizes and demonstrate that the dehydrator is a safe and effective system for post-harvest food preservation for small- and medium-sized agricultural producers.

➢ *Statistical Analysis*

Statistical methods were used to summarize and analyze the experimental results (consisting of means and a one-way Analysis of Variance) for each type of produce based on the various drying durations, with the average value calculated for each produce type at each drying duration. A one-way Analysis of Variance was utilized to determine if there was a statistical difference between mean weights of dried tomato, dried banana, dried pepper and dried apple after 8-hours of drying. The statistical significance was determined using a 95% confidence limit ($\alpha = 0.05$) as shown in Tables 17 and 18.

Table 17 Mean Values of Produce Weight During Drying (g)

Produce	**0 h**	**2 h**	**4 h**	**6 h**	**8 h**
Tomato	150.00	127.50	95.00	63.75	33.00
Banana	150.00	82.50	49.98	30.24	18.00
Pepper	150.00	105.00	64.74	37.80	21.00
Apple	150.00	90.00	60.00	37.80	24.00

Table 18 One-Way ANOVA (Final Weight at 8 Hours)

Source	**F-value**	**p-value**	**Decision**
Between Produce Types	1.244	0.327	Not significant ($p > 0.05$)

One-way ANOVA statistical analysis comparing mean final (8 hours) weights of tomato (33.0 g), banana (18.0 g), pepper (28.0 g), and apple (28.0 g) resulted in a value of $F = 1.244$ and $p = 0.327$ for the four fruits analyzed under the drying treatment conditions. Because the p-value is greater than the alpha level (0.05), it was concluded that the null hypothesis that there are no differences in the mean final weights of the four fruits under the drying treatment conditions cannot be rejected. Although these four fruits exhibited different average weights with tomato and banana having the largest average weight difference (33.0 g vs 18.0 g), they are not statistically different from one another since the p-value exceeds the 95% level of confidence.

- *Comparison of the Drying Time, Moisture Removal, and Product Quality of the Solar Dehydrator and Open Sun Drying*

The photovoltaic-assisted solar dehydrator outperformed the traditional open sun drying method in terms of drying time, moisture removal efficiency, and final product quality as depicted in Table 19.

Table 19 Comparison of the Drying Time, Moisture Removal, and Product Quality of the Solar Dehydrator and Open Sun Drying

Performance Parameter	**Solar Food Dehydrator**	**Open Sun Drying**	**Comparison**
Drying Time	7–9 hours	11–15 hours	Drying time reduced by approximately 36–40% using the solar dehydrator.
Moisture Removal	High moisture removal within 8 hours. Final weight losses: Tomato (195 g), Banana (220 g), Pepper (215–220 g), Apple (210 g). Chamber temperature of 35–58°C and forced convection enhanced moisture removal.	Slower moisture removal because drying depends on ambient temperature (28–37°C), natural airflow, and weather conditions. More time is required to achieve comparable drying.	The solar dehydrator removed moisture more rapidly due to higher and more stable drying temperatures and continuous forced-air circulation.

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Product Quality	Enclosed chamber protected products from dust, insects, rain, and other contaminants. Uniform drying preserved colour, hygiene, and shelf life.	High exposure to dust, insects, microorganisms, and adverse weather conditions. Drying is often uneven, leading to poorer appearance and lower product quality.	The solar dehydrator produced cleaner, safer, and more uniformly dried products with better market quality.

The experimental PV-assisted solar food dehydrator significantly enhanced drying efficiency by operating in a controlled drying chamber with a temperature range between 35 – 58 °C; these temperatures were greater than the ambient temperature (28 - 37 °C). Due to the higher temperatures inside the chamber, moisture evaporated from the food at a faster rate than between 11 - 15 hours using traditional open sun drying techniques, resulting in the total moisture evaporation time being reduced to 7 - 9 hours or approximately 36 - 40% less time than traditional methods. The solar dehydrator was efficient in removing moisture from all the products tested with total moisture sample weight loss after 8 hours of drying; tomato sample =195 g, banana sample =220 g, pepper sample = 215 - 220 g and apple sample =210 g. Overall, the consistent circulation of heated air created a large moisture gradient, resulting in accelerated heat and mass transfer as compared to the natural open sun drying method.

The enclosed drying chamber provides considerable protection from dust, insects, rain, and other types of contaminants found in the environment during the drying process, resulting in the most sanitary and cleanest possible dried product. Conversely, solar open sun drying exposes food directly to the environment, thus increasing the likelihood of food being contaminated, dried unevenly (due to changing weather patterns), suffering from nutrient breakdown, and deteriorating overall quality. Due to these effects, the photovoltaic-assisted solar dehydrator produces dried products that have superior hygiene, more consistent drying rates and storage life when compared to products dried using other technologies such as conventional open sun drying. Overall, the results suggest that the solar dehydrator developed is a more effective and efficient drying technology than traditional open sun drying methods; it dries food faster, removes more moisture from the product, improves the overall quality of the product, and reduces post-harvest losses.

V. CONCLUSION AND FUTURE WORK

➢ *Conclusion*

A solar-food dehydrator has been developed, using affordable materials found locally, for the purpose of developing an efficient system for preserving agricultural products after harvesting. This new solar food dehydrator consists of a solar thermal collector combined with a forced dry-air circulation system based on photovoltaic energy that is independent of the power grid. The cost of manufacturing this system was ₦305,000, making it very affordable to produce locally as well as commercially available to small-scale farmers and agro-processors.

The results from the evaluation of the performance of the solar food dehydrator demonstrated that it was able to maintain drying chamber temperatures at all times between 35 and 58 degrees Celsius while the ambient temperature was only between 28 and 37 degrees Celsius, thus providing very favourable conditions for the dehydration of both fruits and vegetables. The forced air circulation, combined with the regulated temperature, resulted in the efficient removal of moisture by providing faster heat and mass transfer between the food being dehydrated and the air in the drying chamber's atmosphere.

In the drying tests performed on tomato, banana, pepper, and apple using loadings between five and up to 25 tonnes (50) of each, moisture removal increased steadily throughout the entire drying cycle (eight hours). Maximum moisture was recorded in banana (88 percent), followed by pepper (86 percent), apple (84 percent) and tomato (78 percent), illustrating that moisture removal from the samples during the entire drying cycle (844 per cent) was mainly dependent on both the surface characteristics of the produce and their moisture content at harvest. Furthermore, the uniform drying performance across all sample sizes indicates that the portable solar photovoltaic-powered dehydrator produced uniform airflow and temperature across the entire dehydrator regardless of the size of the items being dried too, and therefore performed very well under all testing conditions; therefore, was able to provide similar drying rates regardless of the power supply used.

Drying of the samples was 36 to 40 percent faster than drying of the samples in traditional methods of open-sun drying due to the solar photovoltaic-powered dehydration and therefore created similar quality dried items that could be consumed with minimal inconvenience. The integrated drying chamber of the dehydrator eliminated potential contaminating agents, i.e., dust, insect, rain, moisture, etc., providing higher cleanliness and greater drying consistency and therefore higher-quality dried items than items produced using open-sun drying methods.

The overall conclusion of this research indicated that the developed photovoltaic-assisted solar food dehydrator provides a sustainable, economically sound and efficient means of post-harvest preservation for tropical regions. The combination of using solar thermal energy combined with photovoltaic-powered forced convection provides an environmentally safe alternative to traditional drying methods and has a significant impact on food security, renewable energy use, value and benefit added to agricultural produce, and decreased post-harvest waste.

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➢ *Future Work*

The results from this research lead to the following suggestions for future research.

- Small-scale farmers, cooperatives, agro-processors, and rural households should adopt the fabricated photovoltaic-assisted solar food dehydrator for reducing postharvest losses and enhancing food preservation.
- Future research should investigate the drying capabilities of the system with a diverse range of agricultural products such as leafy vegetables, herbs, grains, fish, meat, and medicinal plants using different climatic conditions.
- Further refinements of the solar collector, the insulation materials, the distribution of airflow within the dehydration chamber, and the configuration of the drying chamber should be performed to increase the thermal efficiency, moisture removal rate, and overall performance of the dehydrator.
- Future versions of the dehydrator should integrate advanced monitoring and control systems that use Internet of Things (IoT) technology in addition to automatic temperature and humidity regulation, and remote condition monitoring.
- Future studies should also include comprehensive evaluations of product quality following drying, containing the nutritional component, color retention, texture, microbial safety, antioxidant activity, and consumer acceptability.
- Develop and test commercial agro-processing technologies such as large-scale prototypes with enhanced moisture removal capabilities and ultimate usability as food industry industry-wide useable.
- Conduct research comparing the performance and efficiency of other renewable energy-based drying methods (e.g., solar) to increase both performance & electricity consumption.
- Conducting feasibility studies, including calculations to determine ROI and payback period; as well as to assess risk and reward associated with the proposed technology will provide sufficient justification for farmers and agro-business companies to invest more money.

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