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Development of an indirect active solar heating dryer (IASHD) for dwarf cavendish banana

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ABSTRACT

Fiji has the potential to export banana (*Musa spp.*) due to the volume of the product being produced annually. However, due to the country's limited export capacity, most of the products are wasted after harvest. It is important to develop technical solutions for Banana processing that increase the shelf life of bananas after harvest and during storage through efficient drying technologies. An Indirect Active Solar Heating Dryer (IASHD) was designed and manufactured for Dwarf Cavendish Banana at Fiji National University. The dryer system consists of several components. They are, a solar heating collector with heated air system, drying chamber, a trolley, ductwork, and an exhaust chimney compartment, a blower fan. Thickness of 3 -10 mm Banana pieces were peeled and sliced using a 10-inch *Tramontina* knife from fresh banana fruit. Three slice types, lengthwise, crosswise, and diagonal were used for the drying experiment. Fifty slices per tray were loaded without piling up of slices on each other during loading conditions. Data obtained indicated that the lower the RH of the heated air, the higher the temperature and the faster the drying process of sliced banana. After 2 hours of drying, moisture content of the dried slices have been drastically reduced showing the trend of drying for further experimentation. Authors need to understand the performance of the dryer in drying evaluating moisture after 2 hours. The IASHD was appropriate for the Fiji environment because of its simple design, ease of mobility to seek more sunlight, flexibility, ease of use, and efficient operation.

Keywords: Banana, drying, processing, Fiji, solar energy

1. INTRODUCTION

Fiji has the potential to export banana due to the volume of the product being produce annually. However, due to the country's limited exportation, most of the products get wasted after harvest. As of May 2024, it is on record that Fiji is not exporting banana, so the volume of banana produced are consumed locally (Vula, 2024). It is imperative to provide technical solutions to keep banana for export or future consumption by designing a drying processing technology (Senadeera, 2023) that would increase the shelf life of banana after harvest and during storage.

Sites visitations have been carried out to some banana farms located after the Vunidilo bridge on Wailoku road, Suva, Fiji are shown in the Figure 1. Reports from some banana farmers, face to face interviews and through structured questionnaires given to selected workers on farm sites suggested that there was an urgent need to revamp the current dying banana production industry and improve the economic conditions of banana farmers in Fiji. The current sun-drying crop systems, not suitable for drying banana due to contamination. Figure 2, shows a sun drying platform used in Fiji need to be upgraded to accommodate the large volume banana processing (Weiss and Buchinger, 2012). The new dryer has protection for the drying crop from infestation from insect and use for large volumes of banana processing per day.

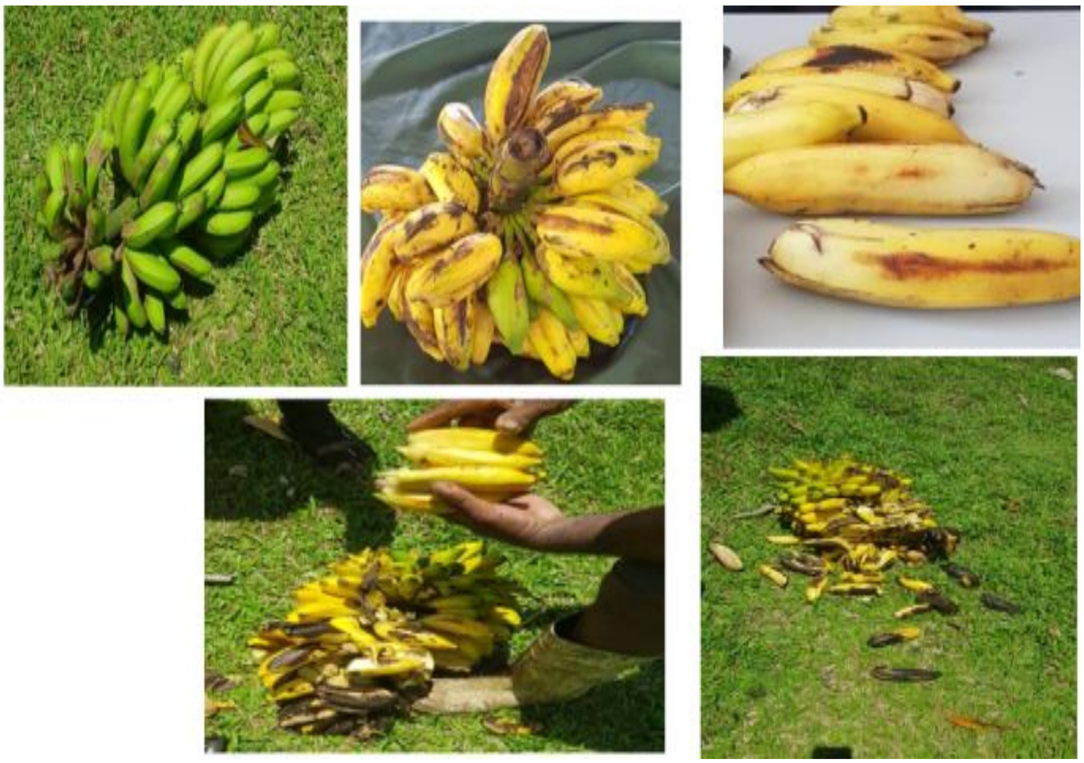

Figure 1: Site visitation to farms to ascertains the need for a dwarf cavendish banana solar dryer in Fiji

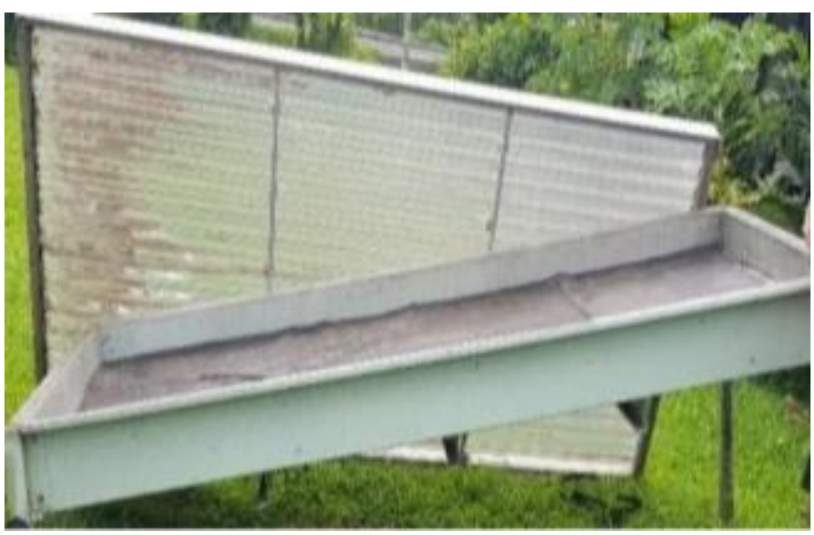

Figure 2: The available sun drying platform for drying crops cited in Fiji

Currently in Fiji, the sun drying is prevalent. Usually, it was an inclined box like raised platform constructed with galvanised steel painted inside black to absorb insolation from the sun (Hii et al., 2012). It has a plastic cover to prevent rain, the crop to be dried are spread inside open to the sun for drying. It takes 3-4 days to thoroughly dry the crop, depending on the availability of rain, the rising cost of labour, and energy. In Fiji, effects of climate change (water resources) and the increasing threat of low-cost competition from processors in other nations such as India, Brazil and China, are contributing to a challenging environment for the industry (Ignat et al., 2024). To address these challenges and establish a more substantial base for international competitiveness, the industry is positioning itself as an innovative sector, value adding to products while maintaining a reputation for quality. To achieve this, industry should use more flexible and innovative management techniques, improve productivity and efficiency, focusing more on enhancing cost-effectiveness and competitiveness etc.

This paper presented a developing Energy Conservation through optimization of process of solar drying crops system to revamp the secondary processing technology of perishable crop such as banana (*Musa spp*). The drying technology study was to find an improved method of increasing their shelf life through drying and thereby increase their economy value for exportation.

Previous research works by Duffi and Beckman (2013); El-Shiatry et al., (1991); EI-Sebaii and Shalaby (2012); Ekechukwu and Norton (1997); Ertekin and Yaldiz (2004); Giuseppina et al., (2016); Green and Schwarz (2001); Hii et al., (2012); Otiti (1991); Raju et al., (2013) Santos et al., (2005); Saxena and Goel, (2013); Spillman (1981); Ignat et al., (2024); Tolstorebrov et al., (2024) and Weiss and Buchinger (2012) on the development of various components of a dryer and solar energy studies were conducted. Some of their suggestions served as a guide in the development of the IASHD. Table 1 shows the solar radiation data and some dimensions of the IASHD.

2. METHODOLOGY

2.1. Study Area, Collection of Bananas and Cutting of Banana Slices

Fiji, a country in the South Pacific with coordinate 17.7134° S, 178.0650° E. has a population less than one million. Fiji has many islands and majority of the population live in two major islands, Viti Levu and Vanua Levu. Statistics suggested about 87% of the total population live on these islands. 50-100 kg of native varieties of banana were purchased from the Fiji markets, and they were stored in refrigeration for preservation before use. Peeling of bananas were with a 10-inch *Tramontina* machete and cut into three different sizes. The slicing method: the lengthwise, crosswise and, diagonal types as presented in Figure 3. The thickness of the slices ranged from 3 to 10 mm. This thickness was selected because the thinner the slice, the faster the drying, because of their surface area and higher evaporation. Properly disposal of banana peels was needed to avoid waste build up in ground and secure environment from insects especially flies around the testing of IASHD.

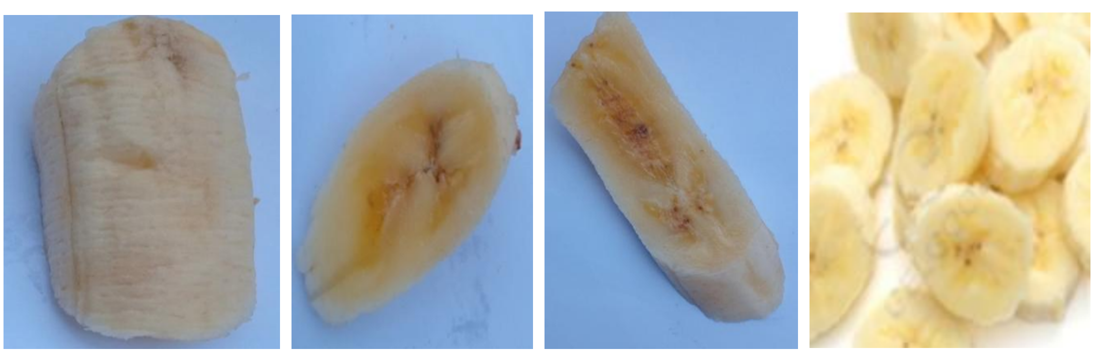

Figure 3: Different slices cut from banana fruit before drying

Table 1: Data From Solar Energy Calculation and Other Dimensions For the IASHD

The diameter of the Tray mesh	10 mm
Slice diameter	3 -5 mm
Tray length	850 mm
Tray width	500 mm
Number of slices	50 -120 mm
Number of trays	10 mm
Collector area	2 m²

Banana Species:	Dwarf Cavendish (Local)
Moisture removal	(80% to 10%) wb
Specific heating capacity of the air	1.012 KJ/kg^{o}K
Expected Drying time in hours	8-12 hours
Heat energy required for drying original material	Approx. 6 kWh/kg
Calculated irradiation component	1.36 MJ/hm^2
Calculated beam component of irradiance	0.94 MJ/hm^2
Calculated angle between the beam and the collector	Tilt angle latitude of Fiji (18 degree) + 19^0
Calculated for the irradiance on the collector & beam (neglecting diffuse radiation)	1.19 MJ/hm^2

2.2. Design Consideration of the IASHD

1. The complete drying system, the dry chamber, the trolley, and the duct work was a stand-alone solar energy dryer. Mobility was for easy movement of the drying system with the attached J-castors
2. Size of the dryer was compact, and the total length of the drying system is not too long, and the area covered was smaller.
3. Banana slice of thinner thickness 3-10 mm were cut to reduce drying time.
4. The air blower with airflow rate 2.8 m^3/min fan was selected to have enough speed to move adequate volume of air from the surrounding through the collector to the drying chamber and out through the chimney.
5. Power consumption of the air blower was at running time of 2 Ah being considered adequate. Extra one rechargeable battery was provided with the blower for easy replacement when one battery is flat.
6. Locally made materials used for construction for the drying chamber-stainless-steel the duct work-copper, and the trolley-galvanized steel tubing for the overall cost affordability of the dryer. Materials that can withstand heat were preferred, covering the drying chamber with black jacket to absorb heat was considered an option to prevent heat loss to the surrounding.
7.

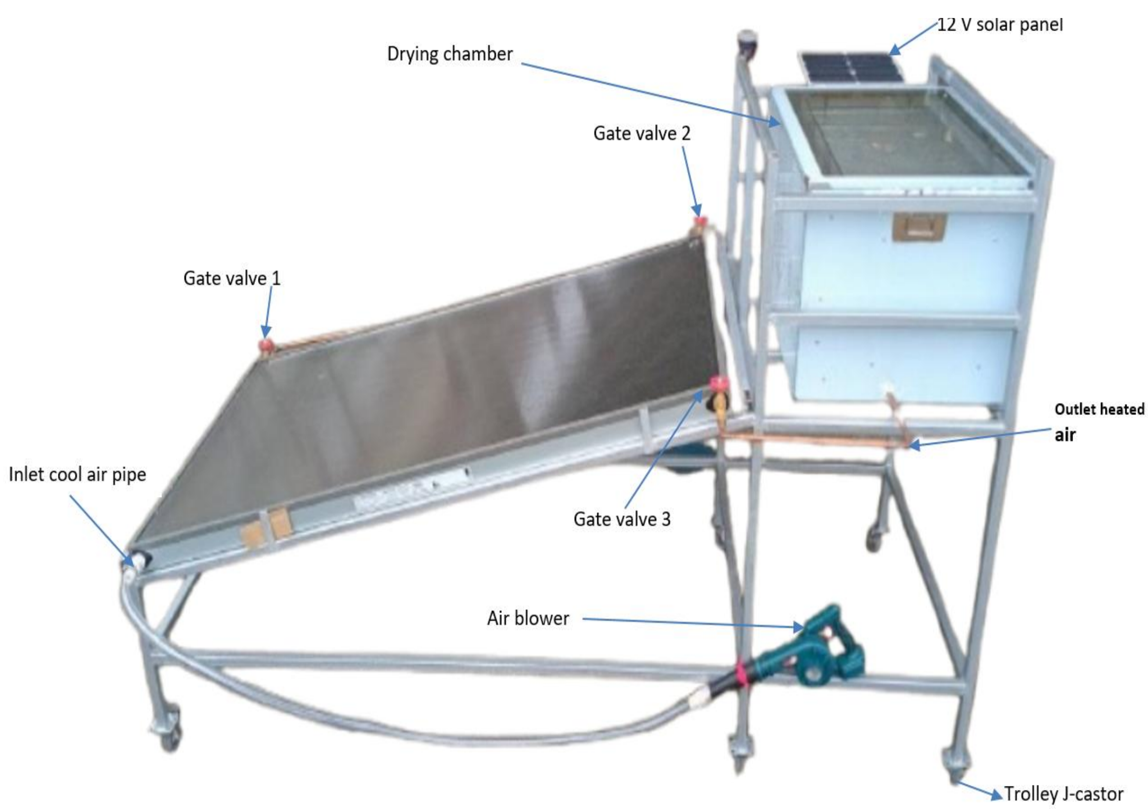

Figure 4: The Indirect Active Solar Heating dryer under no loading condition

2.3. Fabrication of the Dryer Components

The drying chamber, the ductwork and the trolley of the IASHD were fabricated and assembled at the workshop of the College of Engineering and Technical Vocational Education and Training (CETVET), at Fiji National University (FNU). In addition, the materials used for construction of the dryer components and other accessories for proper functioning of the dryer were purchased in Fiji (listed in Table 2). The length of the heating collector, the *Rheem* NPT20007 Solar collector of dimension 1941mm x 1023mm x 83mm was purchased in Suva Fiji. The total height of the dryer from back side was 1.57 m and front side 0.56 m respectively. The trolley was made from 5 lengths of 30 mm galvanized steel tubing pipes that was cut and welded along with 6 J-castor swivel rollers touching the ground surface for mobility. The dryer has a horizontal total length of 3.03 m. The dimension of the perforated tray was 850 mm X 500mm with mesh dimension of 10 mm. The drying chamber has a capacity of 0.4 m^3(1.04 m x 0.62 m x 0.57m) was made of stainless-steel plates. The ductwork accessories such copper pipe, gate valves, block ends, elbow joints bought locally and were fitted together using standard procedure to convey heated air from the collector to the drying chamber. Gaps were filled with sealant, gap filler and silicon filler to produce an airtight chamber to avoid heat losses during drying. The insulated long and short copper ducts connected air from the collector to the drying chamber provide saving of heat for the drying minimizing heat losses. The developed Indirect Active Solar Heating dryer under no loading and loading conditions, as presented in Figures 4 and 5.

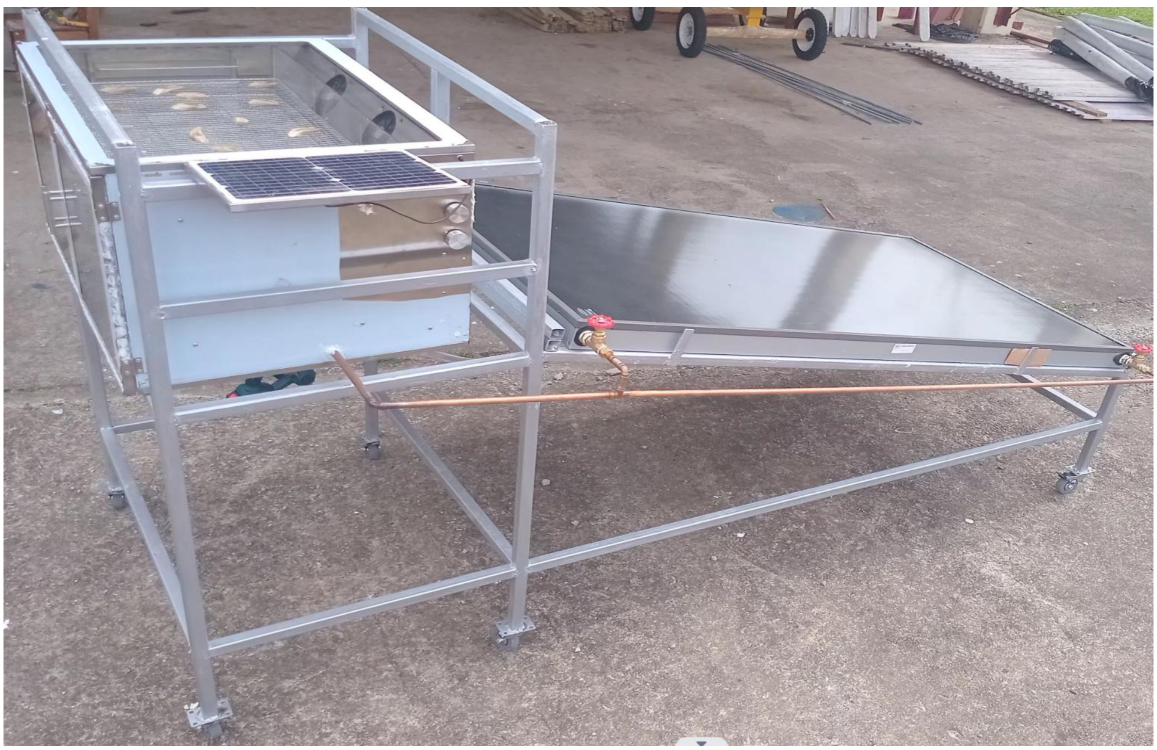

Figure 5: The Indirect Active Solar Heating dryer under loading conditions

2.4. The Working Operation of the Developed IASHD

The fresh ripe *Cavendish* banana fruits were peeled and sliced using a 250 mm *Tramontina* machete at thickness of 3 -10 mm. Different slice types were cut from the banana namely the lengthwise, crosswise and diagonal. Fifty slices were loaded per trays after opening the drying chamber door and care was taken not to piling up on each other. Non-stick baking paper was used to prevent stickiness of the slices to the trays by placing underneath before loading the slices on each tray. There was enough space between tray layers at 45 mm intervals so that they didn't touch others. The IASH dryer was pushed outdoor to receive sunlight, with the solar power cord was plugged into the solar power port and facilitate the two air ventilators to rotate and circulating hot air inside the drying chamber over the loaded slices. The heating collector component of the dryer was then positioned toward the sun for about 3-5 minutes to get heated up to receive maximum solar insolation at Tilt angle of 35^{o}C. Subsequently, the air blower was switched on, control gates valve 1 is closed when control gate valves 2 and 3 are open. One of the heating collector ports that served as cool air inlet was permanently opened to facilitate continuous air movement. The blue rubber tube of the air blower tubing was permanently glued to the 20 mm, 2m long clear hose and sealed with silicon type sealing at the joint to prevent air losses from the blower to the collector through to the drying chamber. There was a provision for a dust bag to suck dirt from the incoming air, before flowing inside the collector and to dissipate heat from the blower.

Cooler air from the blower flowed through the absorber pipes of the collector, which was already heated, producing heated air that was forced into the drying chamber. Hot air moved into the drying chamber first through the copper pipe duct and second, through the perforated copper duct which led heated air into the drying chamber. There was a copper pipe duct inside the drying chamber that was 90 mm long, consisting of 18 holes of 9 mm diameter, drilled at 50 mm intervals to release heated air inside the drying chamber. During no load condition two air flow directions were tested. The long and short copper pipes duct leading heated air to the drying chamber; however, the shorter copper pipe duct was better, and it was used throughout the drying experiment. Two gate valves at the elevated two port openings of the collector were raised and one gate valve at one of the bottom port openings were closed, while hose pipe of the air blower was directly connected to the fourth bottom port. This method was used as the best route to transfer hot air from the collector to the drying chamber and was used throughout the experiment. Extra rechargeable battery served as a backup for the air blower whenever its current battery run flat. The blower worked for up to 1 hour before any battery replacement at a lower speed. Hot air moved out the perforated vents and rises vertically upward in the drying chamber across the sliced layers. Moisture evaporation from the slices and saturated air left across the slice's layers through the chimney. The two solar-powered fans assisted the circulation of air inside the drying chamber. This inner copper pipe duct that carried hot air was placed 20 mm above the floor of the drying chamber.

The drying chamber, was maintained air-tight throughout, prevented leakages, and holes were sealed with gap fill sealant. The top and bottom temperature and humidity of the ambient air of drying chamber were recorded using the *ProsKit* meter 4616 and their readings were recorded for 1-2 hours /3 days at 15-minute intervals. Sealed bags were used to keep dried slices to avoid absorbing moisture/ humidity.

3. RESULTS AND DISCUSSION

The Relative Humidity (RH) and Temperature data obtained on July 22 to 24, 2025 at intervals of 15 minutes was presented in Table 3. Table 4 shows the moisture reduction with time. The diameter of the vented copper pipe duct inside the dryer was 9 mm allowed free movement of heated air vertically upward to the drying chamber. More sunlight insolation was received at the experimental location from 11 a.m., and it increased until midday from day 1 to 3. The more the speed of the air blower the more air flow through the collector, and more heat generated in the drying chamber. However, this reduced the longevity of the air blower battery and needs frequent replacement. The trend was the higher the speed of the air blower, the more air flow from the collector, the more heat delivered to the drying chamber. At lower speeds, the recorded temperature range was between 40-50 ^{o}C while at higher speeds 50 – 60 ^{o}C was recorded. In addition, the data obtained (Figures 4 and 5) indicated that lower relative humidity in Fiji favoured the quick drying of banana slices. The highest temperature recorded during the experiment was 62 ^{o}C. Dried banana slices after 2-hour drying were shown in Figure 5. It was observed that the temperature/relative humidity at the topmost part of the dryer was higher, so layers positions were changed periodically to receive more heat from this region of the dryer. This might be unconnected to proper distribution of the air by the DC fans in this area of the dryer.

Table 2: Relative Humidity (RH) and Temperature (Temp.) ^{o}C data on July 22 Tuesday,2025

Day 1 Time:12.08 (Temp in ^{o}C)	**Second reading during drying** (Temp in ^{o}C)	**Second reading during drying** (Temp in ^{o}C)
RH: 78.8 Temp. 27.6^{o}C	RH: 60.1, Temp. 35.6^{o}C	RH: 57.9, Temp.37.7^{o}C
Time:1.07 RH:67.6, Temp. 30.6^{o}C	RH:57.6, Temp. 34.5^{o}C	RH: 49.0, Temp. 41.7^{o}C
Time:1.22pm RH :65.4, Temp. 31.7^{o}C	RH:57.6, Temp. 34.5 ^{o}C	RH):57.8, Temp.31.6^{o}C
Time:1.37pm RH:73.0, Temp. 28.3^{o}C	RH:58.8, Temp. 36.0^{o}C	RH:58.8, Temp.36.2^{o}C

Time:1.52 pm RH:81.7, Temp. 25.7°C	RH:67.7, Temp. 30.0 °C	RH:67.6, Temp.30.0 °C

Table 3: The RH and Temperature °C data on IASHD on July 24 Thursday, 2025

	Time:9.30 am (Temp in °C)	**Second reading during drying** (Temp in °C)	**Second reading during drying** (Temp in °C)
1	RH: 66.0 Temp 27.4°C Dew point: RH: 65.1, Temp: 21.1 °C	RH: 44.3, Temp 28.6 °C	RH: 58.5, Temp 31.8 °C
2	Time: 9.45 (higher speed of the fan) RH: 62.2; Temp.28.7 °C	RH: 53.6, Temp 31.7 °C	RH: 59.5, Temp 31.2 °C
3	Time:10.00 am (higher speed of the fan) RH: 61.0; Temp 30.5 °C	RH: 49.5, Temp 35.1 °C	RH: 54.1, Temp 32.8 °C
4	Time:10.15 RH: 53.4; Temp 31.8 °C	RH: 50.2, Temp 34.3 °C	RH: 48.8, Temp 34.8 °C
5	Time: 10.30 am RH: 57.5; Temp 31.0 °C	RH: 51.4, Temp 33.2 °C	RH: 54.3, Temp 30.6 °C
6	Time:10.45 am RH: 64.1; Temp 28.6 °C Dew point 63.4; Temp.21.1 °C	RH: 56.7, Temp 31.3 °C	RH: 58.6, Temp 30.00 °C
7	Time: 11.15 am RH: 59.2; Temp 29.2 °C	RH: 55.5, Temp 31.5 °C	RH: 51.4, Temp 31.1 °C
8	Time: 11.30 am RH: 63.6; Temp 28.7 °C	RH: 61.0, Temp 30.1 °C	RH: 43.3, Temp 38.0 °C
9	Time: 11.45 pm RH: 52.5; Temp 32.6 °C	RH: 44.5; Temp 37.1 RH: 45.7; Temp 35.8 °C	RH: 47.2, Temp 35.4 °C
10	Time: 10.36 am RH :65.8, Temp 27.3 °C	RH :60.0, Temp 30.0 °C	RH: 58.2, Temp 30.5 °C
11	Time:10.45 (higher speed of the fan) RH: 63.5; Temp 27.2 °C	RH: 36.6; Temp 42.2 °C RH: 34.1; Temp 43.0 °C	RH: 33.7; Temp 44.7 °C RH: 32.5; Temp 44.3 °C
12	Time:10.52 (higher speed of the fan) RH: 50.0; Temp 33.2 °C	RH: 36.8; Temp 42.2 RH: 39.7; Temp 40.7 °C	RH: 41.9; Temp 38.5 °C RH: 39.3; Temp 40.4 °C RH: 36; Temp 41.1 °C
13	Time:11.08 RH: 58.7; Temp 29.4 °C	RH: 44.9; Temp 37.9 °C (top of the dryer) RH: 41.5; Temp 38.6 °C (bottom of the dryer)	RH: 38.6; Temp 40.7 °C RH: 39.4; Temp 41.8 °C
14	Time: 11.11 am RH: 61.1; Temp 28.4 °C	RH: 54,3; Temp 33.6 °C RH: 42.4; Temp 38.6 °C	RH: 43.0; Temp 39.0 °C RH: 42.3; Temp 37.6 °C
15	Time: 11.35 RH: 61.1; Temp 28.4 °C	RH: 35.0; Temp 44.8 °C RH: 32.3; Temp 46.0 °C	RH: 28.3; Temp 50.1 °C RH: 19.7; Temp 69.2 °C
16	Time: 11.52 RH: 49; Temp 33.0 °C	RH: 30.7, Temp 45.4 °C RH: 26.2; Temp 52.8* °C (blower at full speed)	RH: 30.6; Temp 45.7 °C (full speed) RH: 34.8; Temp 41.0 °C

17	Time: 12.01 RH: 44.6; Temp 34.8 °C	RH: 47.9; Temp 34.0 °C RH: 32.3; Temp 46.0 °C	RH: 38.3; Temp 42.4 °C RH: 38.1; Temp 42.2 °C
18	Time: 12.20pm RH: 60.9; Temp 28.9 °C	RH: 47.1; Temp 35.2 °C RH: 44.3; Temp 36.4 °C	RH: 43.2; Temp 34.3 °C RH: 41.0; Temp 33.1 °C

Figure 5: Dried banana slice after 8-12 hours drying

Table 4: Moisture reduction of Banana

Drying time (hrs)	Moisture content % (wb)
0	74.4
1	67.8
2	59.3
3	42.4
4	40.7
5	35.6
6	25.4
7	23.7
8	22.9
9	21.2
10	20.3
11	17.8
12	16.9

4. CONCLUSION

This technical solution of solar dryer for banana minimized post-harvest loses in Fiji and surrounding countries in the pacific not only in banana but other crops. The developed IASHD has the potential to increase the shelf life of banana, avoid yearly wastage and increase farmer income and enhance food security. The trend from the obtained data during testing indicated that lower humidity favoured drying of crop in Fiji translating to better the drying rate. Most drying occurred at the top tray layer therefore periodic change of position of the layer were necessary for better efficiency and higher drying rate. The drying rate of 10 kg of banana showing half the moisture reduction within 2-3 hours and the trend of moisture removal predicted 8-12 hours needed for complete drying. Moreover, other cities in Fiji, such as Lautoka and Nadi with lesser amount of rainfall but have higher insolation and irradiance of sunlight received per day be tested with IASHD to determine the device most suitable location. Further testing such as the physical property analysis (shrinkage), quality determination (organoleptic and colour evaluation), modelling of drying using different approaches (simple, page and quasi-stationary approaches) on the IASHD and automation of the IASHD's operation to minimized down time be carried out. The IASHD is appropriate for Fiji environment, because its design was simple, mobile for sunlight search, flexible, easy-to-use, and efficient.

Acknowledgement

We thank the participants who were all contributed samples to the study.

Author Contributions

Dr. Atojunere, E.E, was responsible for the overall leadership of the project, the Design, Fabrication, experimentation and supervision respectively. He was also involved for the drying trials and its modelling. He is an Assistant Professor in Biosystem Engineering, Fiji National University.

Dr Wijitha. S. is an expert in physical properties of food materials and drying. He was involved in the Design, experimentation and analysis stages of the project through several virtual meetings and multiple visits to Fiji National University, from Australia. He is an Adjunct Research Professor in Biosystem Engineering. Fiji National University.

Dr Lako J., was involved in the project's conceptualization, physical property analyses of the slice banana before and after drying to determine organoleptic properties-chemical properties, and colour evaluation. She is an Associate Professor in Food Science and Technology, Fiji National University.

Prof Paul A, Iji, Professor Paul oversaw the management aspects of the project. He is a Professor at Fiji National University.

The authors, contribution was summarized as follow:

conceptualization, Lako, J, Wijitha. S and E.E Atojunere, Prof Paul A, Iji;

Methodology, Wijitha.S and E.E Atojunere; data curation, E.E Atojunere, and Lako, J. and Wijitha. S.;

Writing-original draft preparation, E.E Atojunere and Wijitha. S.;

Writing-reviewing and editing. E.E Atojunere and Wijitha. S.;

Funding acquisition, Prof Paul A, Iji, E.E Atojunere, and Lako, J. and Wijitha, S.

Supervision: E.E Atojunere, and Lako, J. and Wijitha. S.;

Project administration, E.E. Atojunere, and Lako, J. and Wijitha. S. and Prof Paul A, Iji.

Ethical issues

Not applicable. This study does not involve any experiments on humans or animals. Hence, ethical approval was not required.

Informed consent

Not applicable.

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Conflict of Interest

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and materials availability

Data that support the findings of this study are embedded within the manuscript.

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