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Research article

Minimizing post-harvest waste of mango in rural Mozambique—The effect of different solar setups in mango drying

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Abstract: Four solar dryers were tested for dehydrating mango slices. The design of the dryers included setups allowing direct exposure of the fruit to the sun, with fans (DF) or without fans (DnoF), as well as setups that provided shade to the fruits, with fans (IF) and without fans (InoF). Mango slices dried in the open sun (OS) were used as a control. Parameters measured included air temperature, humidity, fruit weight loss, and dried mango analysis for water content, water activity, and microbial count. The setups DF and IF dried the mango slices approximately 40 hours faster than OS, while DnoF took approximately 74 hours and did not dry the mango to the microbial-safety zone of 0.6 of water activity. Microbiological analysis (Enterobacteriaceae, lactic acid bacteria, mould, and yeast) showed no significant differences except for total aerobic plate count, which, despite the difference, its values remained under the safe consumption limit of 4 CFU/g. The economic evaluation suggests a potential revenue of 980 USD for smallholder farmers in Mozambique using DF and IF setups from the first year. This study advocates for solar dryers to reduce post-harvest losses and increase income in rural Mozambique.

Keywords: drying; drying flux; economic evaluation; mango; solar drying setups

1. Introduction

In Africa, where agriculture is dominated by smallholder farmers, post-harvest processing and preservation are mainly used for food categories considered staple foods, such as cereals, legumes, grains, cassava, and horticultural products like peppers and onions [1]. Consequently, most fruits and vegetables are consumed and commercialized in their fresh form [2]. This situation is also observed in Mozambique, where a large proportion of fruit and vegetables goes to waste at the peak of the harvest season [3–5]. As an example, Mozambique produces a substantial amount of mango. The FAO statistics point to an annual production of approximately six tons per hectare per year https://www.fao.org/faostat/en/#data/QCL [6]. However, approximately 30% of it is lost due to the underdeveloped preservation industry and less developed processing units. In Tanzania, these losses can be up to 60% [7]. Nevertheless, fruit and vegetable products are rich in minerals and vitamins and are necessary for year-round consumption to maintain a healthy diet [8].

There are certain challenges in preserving fruits in rural Africa, such as the fruits' high-water content and the climate, characterized by high temperatures and humidity, which promotes fast spoilage. In addition, in some rural areas, electricity is not available. This situation presents a challenge since electricity is necessary for many of the methods used in fruit preservation.

Numerous efforts have been made to find solutions for the preservation of fruit and vegetables that would be feasible to implement for the farmers in low-income countries. One of these efforts was the development of solar drying technology to preserve fruits [9–11]. To address food waste, smallholder farmers in rural areas have been encouraged to preserve fruits and vegetables. This practice allows them to extend the availability of these products beyond the harvest season and increase their income by selling the dried fruits in markets [11]. The most common technology for drying agricultural products in Africa is the exposure to direct sunlight, but this is done without strict hygienic precautions. The farmers are familiar with this simple drying technology, but it is only used for staple foods such as legumes, grains, cassava, and rice [12], all of which are cooked before consumption. One of the applications of dried fruits is ready-to-eat products, which means that the drying procedure must be hygienic to avoid contamination from pathogenic microorganisms [13]. Furthermore, the dryer being used must be simple to construct and provide significant advantages in terms of construction cost and long-term benefits. It must be effective in drying and financially viable for deployment in rural regions of a low-income country.

Solar collectors have been developed and introduced as a solution for fruit drying. Earlier projects attempted to distribute solar dryer designs among smallholder farmers to dry mango and other agricultural products in Mozambique, thus reducing post-harvest losses. The proposed model was a direct active solar dryer, using direct ventilation in a drying box, where photovoltaic (PV) panels were used to supply electricity to the fans [11,14]. This type of solar dryer can be used in rural areas without the prerequisite of electricity. However, direct solar drying of fruits and vegetables can degrade some nutrients and affect the color of the dried product due to the high temperature [15,16]. Therefore, it is important to perform drying without direct exposure to sunlight. In this study, we assessed whether direct or indirect solar dryers, with or without a fan, could produce different temperature profiles, which also has the potential to affect the microbiological load of the dried goods [17].

The aim of this study was to identify the most efficient solar dryer and assess the economic feasibility of the implementation of the technology in the rural area of Mozambique.

2. Materials and methods

2.1. Raw material handling and characterization

Mangoes (*Mangifera indica*) (11.0 ± 1.0 cm in length and 6.5 ± 0.5 cm in width) were purchased from a local market in Maputo, Mozambique. The chosen mangoes were red and slightly soft at a finger pressing. The market is situated approximately 26 km from the processing location. The purchased mangoes were placed in Styrofoam boxes with not more than 3 layers in each box, placed inside a car, and transported immediately after purchase. The drying started approximately 5 h later. The soluble solids content and pH of the fruits were analyzed with a digital refractometer (Model HI 96801, ±0.2 °Bx/±0.3 °C, Hanna Instruments, USA) and a portable pH meter (SCHOTT HandyLab 1, accuracy ±0.01 pH units, Schott Glaswerke, Germany), respectively.

The soluble solids were measured by placing approximately 150 µL of mango juice in the refractometer with a Pasteur pipette and reading the values. This procedure was done in triplicate. The equipment was calibrated with deionized water before the measurements were taken [18].

The pH of the fruits was measured by placing the mango juice in the pH meter and reading its value. This measurement was made in triplicate. The pH meter was calibrated with standard solutions of pH 7 and pH 4 before measurement [19].

2.2. Sample preparation

Experiments were conducted under typical outdoor conditions in Mozambique at the University Eduardo Mondlane in Maputo (latitude 25º57'06''S, longitude 32º36'11''E, elevation 43 m), for three days. On the first day of the experiments, the samples were prepared according to the procedure shown in Figure 1. Prior to the drying experiments, all the equipment that the fruit was exposed to was sterilized with boiling water. Additionally, all participants were required to wash their hands with soap and water and then sanitize their hands with 70% alcohol gel before starting the preparations. The mangoes were washed with clean water and peeled by hand. After peeling, the mangoes were cut into 0.5 ± 0.1-cm-thick slices using a sharp stainless-steel knife.

Before the samples were placed to dry in the solar dryers and in the open sun (OS), a digital scale (Model Lola/KE 1301, ADE, Germany) was used to monitor the weight of the samples. Both the scale and the person's hands weighing the slices were disinfected with ethanol between the mass measurements to avoid cross-contamination between samples.

2.3. Solar drying

In this study, five solar drying setups were investigated (Figure 1): direct solar exposure with fan (DF), indirect solar exposure (shade solar drying) with fan (IF), direct solar exposure without fan (DnoF), indirect solar exposure without fan (InoF), and open sun (OS). The samples that were dried using OS were considered control samples. The number of samples used to determine drying flux (D), and to assess the microbiological quality (M) for each solar drying setup are reported in Figure 1.

The design for the solar dryers was modified from a design that has been previously reported [9, 11]. In the current study, the frame for the forced convection dryers (DF and IF) was made entirely of wood. The choice of wooden material was made because wood is locally available and easily accessible.

Despite its biodegradability, which needs periodic replacement, its use remains economical compared to metal, in addition to wood's advantage of having low thermal conductivity [20–22]. To create both direct and indirect solar drying conditions within the same solar dryer (Figure 2A), a wooden board was placed over one-half of the solar collector. This setup ensured that mango slices directly exposed to the sun underwent direct solar drying, while those positioned under the wooden board, shielded from direct sunlight, experienced indirect solar drying. Fans were used to create a forced convection. This dryer was connected to a solar panel. Since the optimal tilt angle for a solar panel is close to 0° in this region of Mozambique during the month of December [21], the photovoltaic cell was tilted at an angle of 6°–7°. The small tilt angle was chosen to allow potential rain to drain off from the panel.

For the setups with natural convection (DnoF and InoF), a solar dryer with two corrugated metal sheets was used instead of wood and no fans were used. The setup with direct sunlight exposure (DnoF) and the setup with indirect sunlight exposure (InoF) (Figure 2B) were created by placing a wooden board to cover half of the dryer, allowing the formation of two separated zones (DnoF and InoF) within the same dryer. However, the samples in the InoF setup started developing mold during the drying procedure, and therefore, it was discontinued during the study. All the drying chamber covers were not perfectly sealed, so it allowed air exchange with the outside environment by natural convection and forced convection provided by the fans.

The OS setup (Figure 2C), used as a control, consisted of mango slices loaded on a net rack and directly exposed to sunlight in the open space.

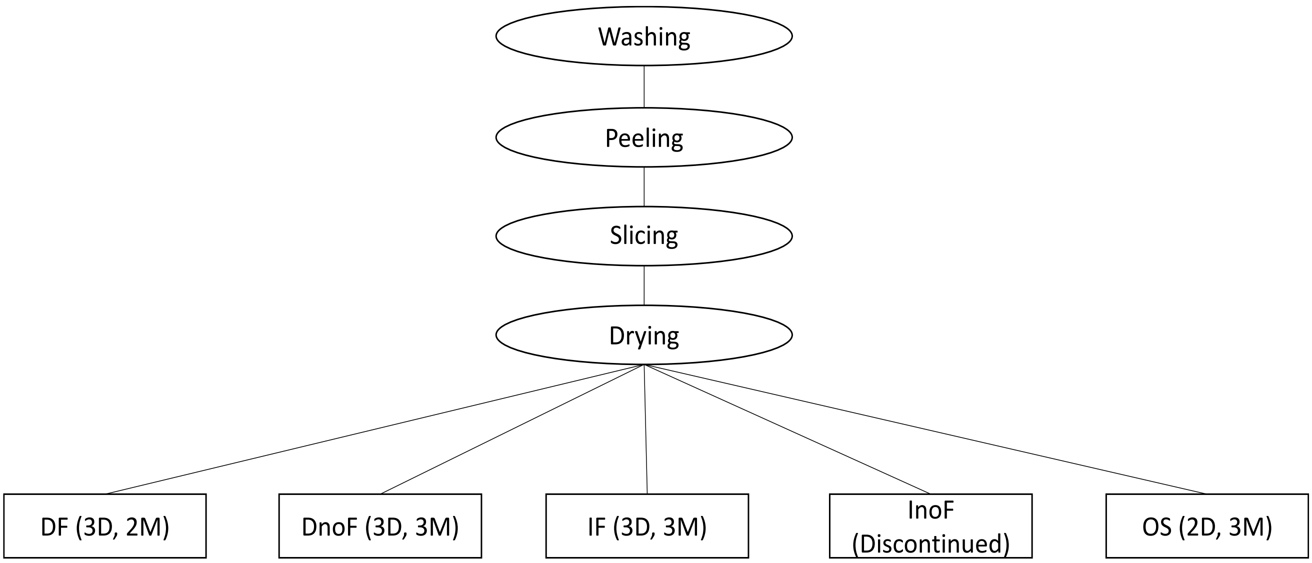

Figure 1. Processing steps prior to the test of the different solar dryer setups. In this experiment, mango slices were dried in five different solar drying setups: DF = direct with fan, DnoF = direct no fan, IF = indirect with fan, InoF = indirect no fan, and OS = open sun. The numbers in brackets report the number of samples used to determine the average drying flux (D) and to assess the microbiological quality (M).

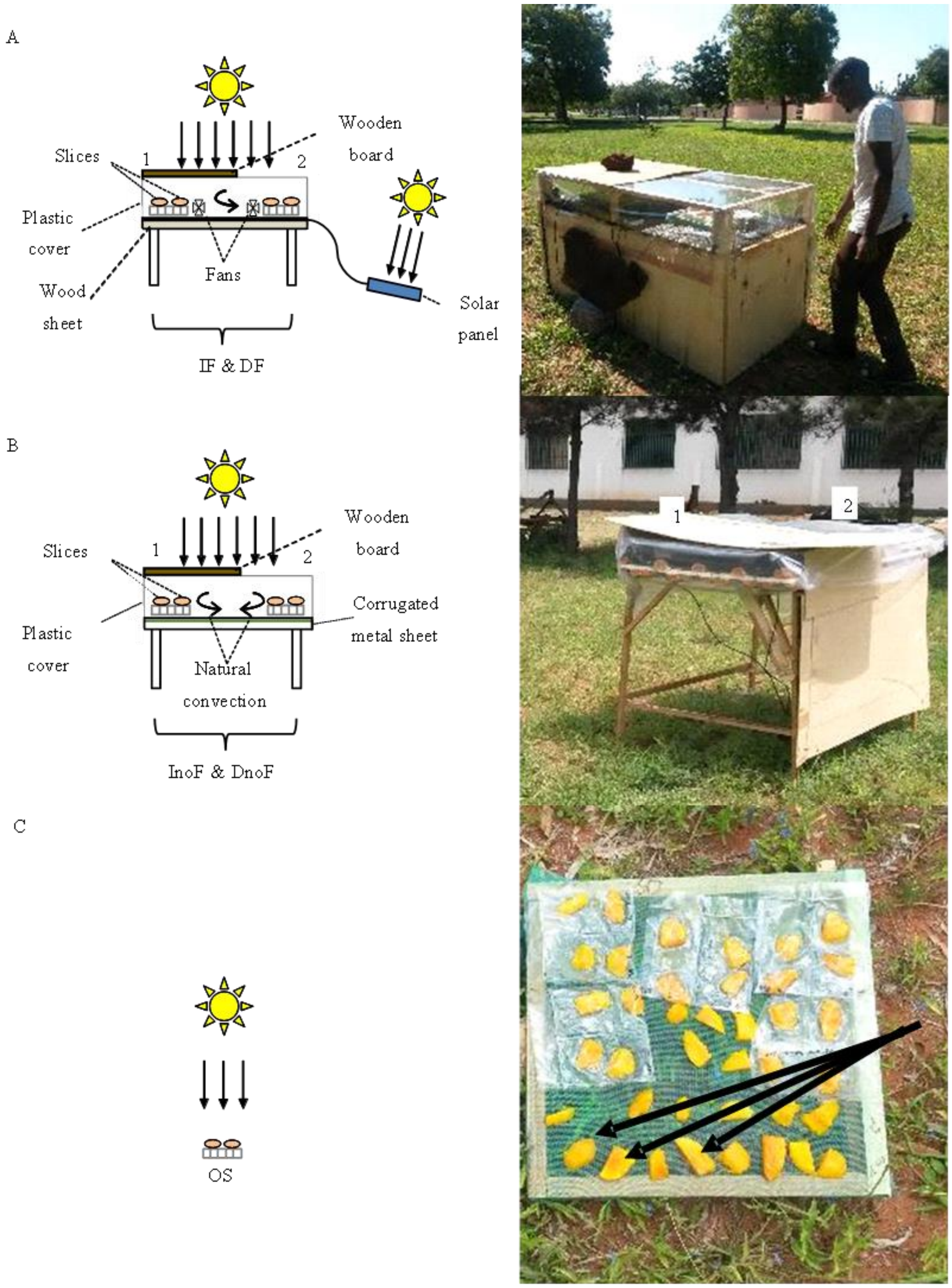

Figure 2. Solar dryer systems tested for the drying of mango slices. (A) Hybrid solar drying setup where half uses indirect exposure (shade) with fan (IF), and the other half uses direct exposure to the sun with a fan (DF) for drying with forced convection. (B) Hybrid solar drying setup where half uses indirect exposure (shade) without fan (InoF), and the other half uses direct exposure to the sun without a fan (DnoF) for drying with natural convection. (C) Samples are exposed to the open sun (OS) as a control. The arrows in picture C indicate the samples used for the OS.

For drying, the mango slices were positioned horizontally on racks made from wood and a plastic netting material. The racks were placed on top of the black surface of the collector, allowing both sides of the slices to be exposed to air during the drying. The outer dimensions of the rack were 0.50 m × 0.45 m, and the size of the netting was 0.45 m × 0.40 m. The load density per tray was 2 ± 0.5 kg/m^2.

Throughout the experiment, the samples were weighed twice a day, at 8:30 am and 5:00 pm, and drying continued until the product reached a final water activity of 0.6 or lower. The endpoint of water activity of 0.6 was chosen since most microorganisms cannot grow at water activities less than 0.6 [23,24].

Samples that required a longer drying period than one day were stored in a shed on their respective drying racks between 5:00 pm and 8:30 am. Each morning, the samples were also flipped to allow both sides of the samples to receive sun exposure. Dried samples were vacuum sealed in airtight plastic bags and stored at ambient conditions until further analysis.

Throughout the study and during drying, the temperature and relative humidity of the ambient air and inside the solar dryers were continuously recorded with temperature and relative humidity probes (Testo, Hampshire, United Kingdom). A hot-wire anemometer (Testo, Hampshire, United Kingdom) was also installed inside the solar dryer setups with fans (DF and IF) to record the air velocity produced by the fans. During the night, temperature and relative humidity were recorded inside the shed with two portable USB probes (Standard ST-171 Data Logger, ± 1.0 °C, ± 3.0% RH, Clas Ohlson, Insjön, Sweden).

2.4. Calculations and analyses

2.4.1. Sun exposure

The sun exposure was recorded for each sample based on the number of hours the samples were exposed to sunlight during the drying process.

2.4.2. Average drying flux and drying curves

The average drying flux ($kgm^{-2}h^{-1}$) is defined as the rate of mass loss through a specified surface area between two time points in an experiment (Equation 1).

$$\text{Average drying flux} = \frac{(m_{t_1} - m_{t_2})}{A \cdot (t_2 - t_1)} \quad (1)$$

where *m* is the mass of the sample (kg) at a specific time, *A* is the effective surface area of the sample (m^2), *t* is the time of the respective measurements (h), and 1 and 2 represent two different time points.

To determine the effective surface area, measurements of the mass and the thickness of each mango piece were used. For determination of the mango density, fruits were weighed and submerged in 1 L of water. The volume of water displaced by the mango was measured, and the weight of the mango was divided by this volume. The calculated density of the mango was found to be 1.0 ± 0 kg/cm^3. The values of weight and density were used to determine the volume (m^3) of each slice, which was then utilized to calculate the effective surface area of each slice. Once the effective surface area was determined, it was used to calculate the drying flux (Equation 1), representing the velocity of water loss occurring during drying until the endpoint of a target water activity of 0.6.

The drying curves illustrate the water removed from the mango during a specific length of time, where the time corresponds to the actual sun exposure time. To plot the drying curves, the initial moisture content of the fruit (84.3 ± 2.0% w.b) was determined using the AOAC method [25]. Samples were placed in metal crucibles and placed in an oven (Memmert GmbH D-91126 Schwabach FRG, Germany) at 105 °C until constant weight was achieved.

2.4.3. Water activity

The water activity was measured with an AquaLab Series 3TE water activity meter (accuracy ± 0.003, Decagon Devices, Inc., Pullman, Washington, USA). Standard salt solutions (13.41 mol/kg LiCl: a_w = 0.245, 8.57 mol/kg LiCl: a_w = 0.496, 6.0 mol/kg NaCl: a_w = 0.760 at 20.0 °C) and deionized water were used to verify correct calibration. The measurements were carried out at a temperature of 20.2 °C ± 0.1 °C.

2.4.4. Microbiological analysis: Viable count

To assess the microbial content of the dried mango slices, a viable count analysis was conducted eight months after the field study by Eurofins Steins Laboratorium A/S (Vejen, Denmark). Prior to analysis, samples were stored in airtight bags protected from light at an average temperature of 19.5 °C and relative humidity of 29.7%.

Following standard Eurofins protocols, each sample was diluted with a Maximum Recovery Diluent (MRD) and plated in duplicate on four different types of media. Tryptic Soy Agar (TSA) targeted total aerobic bacteria, while Malt Extract Agar (MEA) identified yeast and mold. Lactic acid bacteria were counted using De Man Rogosa and Sharpe agar with added amphotericin B (MRSaB), and Violet Red Bile Dextrose (VRBD) agar specifically detected Enterobacteriaceae. Incubation conditions varied by media: TSA at 30 °C for 72 hours (±6 hours), MEA at 25 °C for 120 hours (±6 hours), MRSaB at 25 °C for 120 hours (±6 hours), and VRBD at 37 °C for 24 hours (±2 hours).

Following ISO 14461-2:2005 (ISO 2005) guidelines [26], plate counts were calculated by averaging duplicates if they exhibited acceptable statistical homogeneity. Refer to Figure 1 for details on the number of samples analyzed per pre-treatment and solar drying setup. For example, "3M" in Figure 1 indicates three separate samples were analyzed from a particular drying configuration. Since Eurofins prepared duplicates, a total of six plates per media type were used for that specific setup.

2.4.5. Statistical analysis

Statistical significance between treatments was tested by means of one-way ANOVA ($p < 0.05$) using the SPSS software v. 28 (IBM, United States of America). Tukey's confidence intervals were used to evaluate the true difference in treatment means. Plate counts reported as < 1.0 Log CFU/g or > 3.2 Log CFU/g were assumed to be 1.0 Log CFU/g and 3.2 Log CFU/g in the statistical analysis, respectively.

2.5. Economic evaluation

All materials used to build the solar dryer, along with their respective prices as purchased in Maputo province, were recorded. Additionally, labor costs associated with the construction and operation of the dryers were used to determine the total building cost of the solar dryers.

To determine the selling price, we utilized the average price of dried mango in the most prevalent markets within the region, including Maputo International Trade Fair (FACIM) and various South African stores such as Clicks, Woolworths, and Pick'n Pay. Subsequently, this price was multiplied by the anticipated quantity of dried mango that could be produced from the fresh mango currently going to waste on the farms. This unused fresh mango could instead be dried during the harvesting season. The resultant figure was then employed to calculate the financial benefits.

The cost-benefit analysis incorporated labor costs and the calculated financial benefits. We determined the quantity of dried mango that would need to be sold within a specific timeframe to offset the expenses associated with acquiring a solar dryer and to initiate profit generation.

3. Results and discussion

3.1. Drying conditions in the drying setups

The fresh mangoes had a soluble solids content of 16.2 ± 0.3% wet basis and a pH of 4.4 ± 0.4. Figure 3 shows the registered temperature, solar radiation, and relative humidity in the different solar setups over three days of drying.

In the Indirect Fan (IF) setup, the wooden board used to block direct exposure of the samples from sunlight slightly influenced the amount of heat available for drying, reducing the temperature and increasing the relative humidity in comparison with the section of the hybrid dryer that is directly exposed to sunlight (DF). This difference was higher during the second day of drying, where lower values of solar radiation were recorded.

In the solar DF setup (which registered the second-highest temperature), a convective air circulation promoted distribution of the heated air [27], allowing the goods to dry faster and more evenly. This result was also observed by Phinney et al. (2015) in their experiments with solar drying of tangerine puree [28]. A higher temperature and lower relative humidity were registered in the solar DnoF setup. The absence of forced air circulation reduced temperature losses because there was not much air escaping from the dryer, thereby promoting a significant increase in temperature. When IF and OS are compared, the IF captured heated air in the dryer, which was reflected in a lower relative humidity value and higher temperature.

The solar setups with temporarily locked air registered higher temperature values than the solar OS setup, where there was a constant natural ambient temperature air circulation during the drying process, as the samples were exposed to the sunlight in the open air. As expected, the presence of fans promoted a uniform air distribution and lowered the registered temperature while increasing the relative humidity.

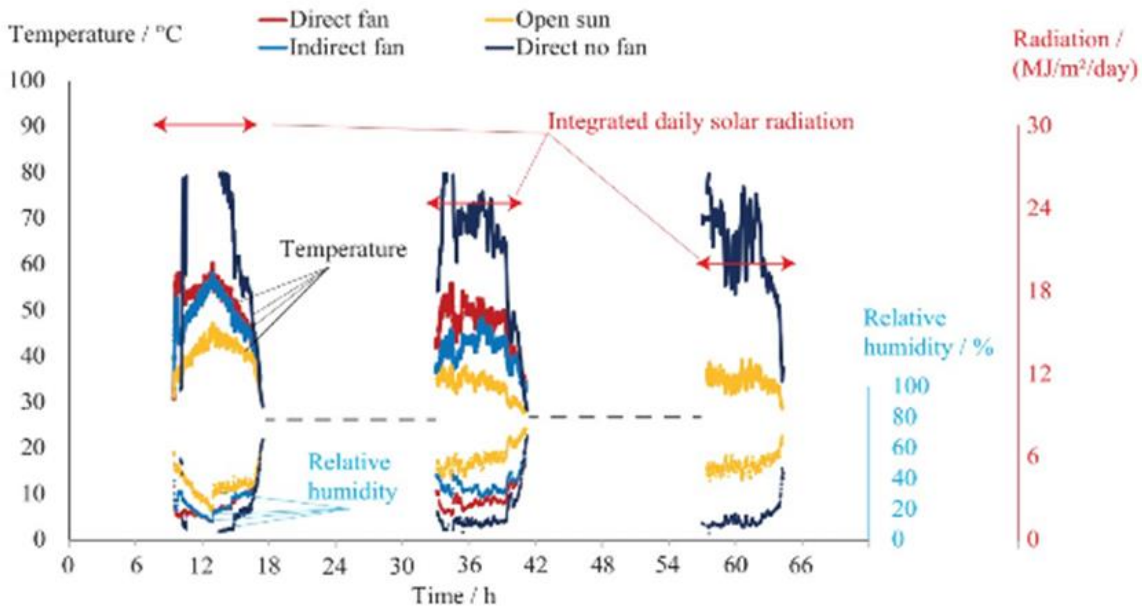

Figure 3. The temperature, solar radiation, and relative humidity registered in the solar setups DF, DnoF, IF, and OS during the drying of mango slices over three days. As the temperature varies only slightly overnight, the storage temperature is presented as the nightly average (horizontal dashed line).

3.2. Drying time and solar setup performance

Figure 4 reports the drying curves obtained for the mango samples on each of the studied solar drying setups. The most efficient setup was the hybrid solar drying with IF and DF, which produced a dried product with a water activity less than 0.6 after 23 h and 25 h of sun exposure, respectively. Because of the design of the hybrid dryer, the IF dryer may have benefited from the solar radiation on the DF dryer, as both had fans that blew the air.

The slowest dryer setup was the DnoF. The mango samples in this dryer did not reach the water activity safety zone for stability and consumption ($a_w < 0.6$). This result shows that the drying setup DnoF is not suitable for dehydrating the fruit. Although the DnoF setup does get direct sun exposure, which could imply a faster drying process, the absence of fans that can blow the heated air around the slices slows the rate at which water can be removed from the surface of the fruit.

The increase in moisture content on the third day of the experiment was likely due to the setup. With the absence of fans, the local relative humidity near the mango slices might have been higher than the water activity at the surface of the mango slices. As a result, water would transfer from the air to the mango slices.

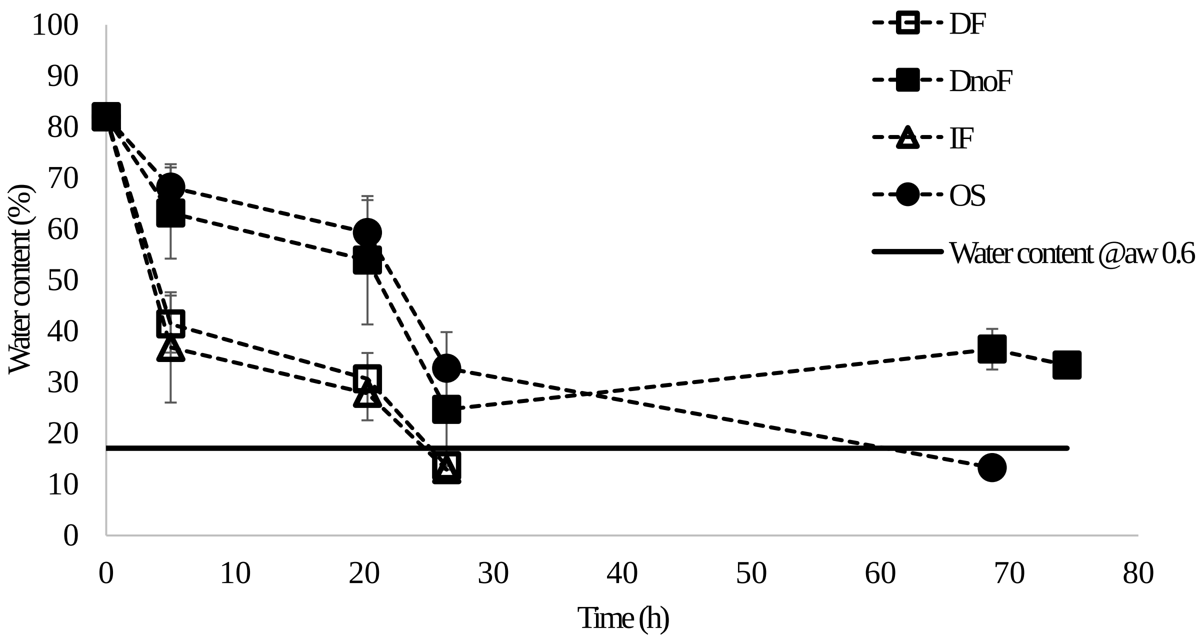

Figure 4. Drying performance of mango slices in different solar drying setups, DF, DnoF, IF, and OS, as described in the Materials and Methods section. The curves represent the overall drying time, including day and night periods. The horizontal line represents a threshold where the product reached a water activity of 0.6.

3.3. Drying flux

The drying flux of the DnoF setup was not considered in this comparison, as the drying was not completed. The mass and surface area of the slices used in this study are provided in Table 1. The drying flux did not vary significantly among the solar setups DF and IF. The solar setup OS registered the lowest statistically significant drying flux. As expected, the solar setups equipped with fans exhibited the highest drying flux values and the shortest drying process times.

The measured final water activity showed no statistical differences in the setups DF, IF, and OS, as the samples had a quite similar water activity (approximately 0.50). However, the setup DnoF did not reach the safe zone in terms of water activity and registered an average value of 0.68, and this value was significantly higher than the safe zone value of 0.60. The presence of a fan in the design of some of the dryers accelerated the drying process and helped reaching the right level of drying. This was also found in a study about mango drying, where efficient air circulation ensured that hot air flowed uniformly over the drying material, increasing the drying rate of the product and reducing the time needed to reach the desired moisture level [29,30].

Table 1. Mass, surface area, and drying flux (the time to reach an aw of 0.6) of mango slices placed in different solar drying setups. Reported are the average and standard error of three samples.

Solar drying setup	Mass 10^{-3} (kg)	Surface area $\cdot 10^{-4}$ (m^2)	Drying flux $\cdot 10^{-3}$ (kg/m^2s)*	Final water activity (aw)*
DF	5.0 ± 0.9	0.96 ± 0.2	1.8 ± 0.1^{a}	0.49 ± 0.0^{a}
IF	3.5 ± 0.4	0.71 ± 0.1	1.9 ± 0.1^{a}	0.48 ± 0.0^{a}
DnoF	6.2 ± 1.2	1.2 ± 0.2	1.5 ± 0.1^{ab}**	0.68 ± 0.0^{b}*
OS	7.3 ± 1.0	1.4 ± 0.2	1.02 ± 0.1^{b}	0.49 ± 0.0^{a}

*Different superscript letters in the same column indicate significant differences ($p < 0.05$). **The drying flux of these samples was slow in comparison with the other solar setups. The drying of these samples was incomplete, as the water activity of 0.6 was not achieved.

3.4. Microbial load

The microbiological load of the mango slices dried in the different solar drying setups (DF, DnoF, IF, and OS) was analyzed. The growth of *Enterobacteriaceae*, lactic acid bacteria, molds, and yeast was less than the detection limit of 1.2 CFU/g set by the NSW Food Authority (Table 2). When looking at the total aerobic bacteria, significant differences were observed between DnoF (2.9 ± 0.2 CFU/g) and IF (3.7 ± 0.1 CFU/g), with IF registering the highest value ($p < 0.05$, Table 2). However, the microbial counts were still in the acceptable range of less than 4 CFU/g, and the mango slices could therefore be considered safe to consume from a microbiological perspective [31].

Most bacteria have their optimum growth at temperatures between 40 °C and 45 °C [32,33]. Above 45 °C most bacteria cannot grow because it is too hot. When analyzing the registered temperatures in the dryers (Figure 3) and in the solar setup OS, it was observed that the temperature varied from 26.7 °C to 60.1 °C in the DF, from 26.7 °C to 80 °C in the DnoF, from 26.7 °C to 58 °C in the IF, and from 26.7 °C to 47.3 °C in the solar setup OS. The reason for the limited amount of microbial growth in the dried mango slices, independent of the drying setup, could be attributed to a combination of factors including direct sun exposure, meticulous sample preparation, and the temperature inside the dryers that was high enough to prevent such growth.

Table 2. Microbial counts on mango slices dried in different solar setups. Different superscripts indicate a significant difference ($p < 0.05$) in the same row.

Microbial Analysis	Different solar setups ($n = 3$)			
(Log CFU/g)	DF	DnoF	IF	OS
Enterobacteriaceae plate count	<1.2	<1.2	<1.2	<1.2
Lactic acid bacteria plate count	<1.2	<1.2	<1.2	<1.2
Total aerobic plate count	3.5 ± 0.0^{ab}	2.9 ± 0.2^{a}	3.7 ± 0.1^{b}	3.4 ± 0.1^{ab}
Mold plate count	<1.2	<1.2	<1.2	<1.2
Yeast plate count	<1.2	<1.2	<1.2	<1.2

3.5. Economic evaluation

The price of the material and the labor cost to build the dryers are listed in Table 3. In this economic evaluation, it is considered that IF and DF are separate units and not a hybrid system. The estimated building cost of the IF dryer was approximately 401 USD. To estimate the cost for the DF solar dryer, the cost of 1 unit of Unitex wood sheet was subtracted from the cost of the IF dryer, resulting on a cost of approximately 379 USD.

Table 3. List of building materials and costs for DF or IF solar dryers. Costs are given in Meticals and US Dollars.

Material	Quantity	Unit Price (Mtn)	Total Price (Mtn)	Total Price (USD)*
Unitex wood sheet (81 cm × 200 cm)	3	1368	4104	66.2
Wooden slat (3.8 cm × 3.8 cm × 600 cm)	8	336	2688	43.4
Shade net 80% (3m × 50m) (p/m) black color	5	718	3590	57.9
Mosquito net (120 cm × 300 cm)	5	82	410	6.6
Transparent plastic (m)	12	90	1080	17.4
Iron nail (2.5 cm)	1	175	175	2.8
Iron nail (7.5 cm)	1	175	175	2.8
Solar panel (100 W)	1	5000	5000	80.7
Wood glue (l)	0.1	340	34	0.6
Contact glue (l)	0.1	586	58.6	1.0
Fans (Fractal Design Silent Series R3 120 mm)	4**	578	2312	37.2
Parallel audio cable (2 mm × 1.5 mm Bicolor 1 m)	5	30	150	2.4
Stick tape	1	110	110	1.8
Labor/hour	20	250	5000	80.7
Total	-	9838	24886.9	401.4

* 62 Mtn = 1 USD. ** Each side of the solar dryer contains 2 fans.

To evaluate the cost-benefit of the implementation of the technology in the rural area of Mozambique, the following assumptions were made:

- In Mozambique, the highest mango production months, between December and January, also experience the highest post-harvest losses. Therefore, the drying period should also coincide with the highest production period.
- We assume 61 days as the period in which drying could be performed, with two days to complete one drying procedure using DF or IF (see Figure 3). This drying period also considers that, according to the Mozambican Meteorological Institute, there is an average of 12 days of rain during these months (average of the last 10 years). Holidays and Sundays are also considered. Therefore, a total of 45 days is considered to be used for dehydration during the season.
- The mango production per farmer is approximately 2000 kg per season. The estimated post-harvest mango losses per season are 30%, leaving 600 kg of mango available to dry in 45 days. Considering that the peel and the stone of the mango amounts for 33% of the total weight of the fruit, then the farmers have 402 kg of available fruit for drying during the season. However, the

402 kg of mango could be processed and dried in just 16 days using the solar dryer, considering that the capacity of the dryer is 50 kg.

- The raw material (mango) is free for the farmer. This is assumed because if not dried, the mango would be wasted.
- It is estimated that 90% of the initial moisture content of the mango is removed during drying.
- The price for 1 kg of dried mango already packed and distributed in the shops is around 20 USD. The price established for 1 kg of dried mango at the rural location will be 10 USD.

The result for the calculation of the profit for the farmers is reported in Table 4. Providing that the farmer can sell all their production, the total income for selling the dried mango is 980 USD per farmer for the first season. This income is enough to pay for the dryer construction in just one season of production. For a single farmer, the profitability in the following years should be higher than 601 USD (980 USD – 379 USD). If two farmers agree to share the investment cost, the dryer could be used to its full capacity in 45 days, resulting in an increase in profit for each farmer from 601 USD to approximately 791 USD (980 USD – 189.5 USD) in the first season (see Table 4). This profit could potentially be even higher in the subsequent seasons.

Table 4. Cost-benefit analysis of drying mango.

		Building cost (USD)	Drying period (days)	Production Volume				Income per season (USD)**	Profit for first season (USD) ****
				Total mango Production (kg)	Pulp to dry (kg)	Water to be removed (kg)*	Dried mango (kg)		
Solar dryer	DF	379	16	600	402	304	98	980	601
	IF	401	16	600	402	304	98	980	579
	DF***	189.5	16	600	402	304	98	980	791
	IF***	201	16	600	402	304	98	980	779

*Refers to 90% of the water in the mango. **Benefit is obtained by multiplying the dried mango (kg) by the selling price (10 USD per kg). ***Building cost divided by 2 farmers will be reduced by 189.5 USD (379 USD/2 = 189.5 USD). ****Profit per farmer will increase by at least 779 USD (980 USD – 201 USD).

4. Conclusions

The solar drying setups built for this study, designed in such a way that natural convection was obtained (DnoF and InoF), did not efficiently dry the mango slices. Therefore, fans need to be incorporated for forced convection. The presence of fans is particularly useful in removing excess humidity and speeding up the drying process. Fans are not an expensive addition to the drying designs and assure a safe product that can be produced in 2 days (DF and IF). The study indicates low bacterial growth for the analyzed species, mostly due to a combination of factors such as the direct sun exposure, a very hygienic sample preparation, and the inhibitory temperature. If implemented, this technology can be profitable for rural farmers in Mozambique, reducing post-harvest losses.

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Author contributions

PVS: Idea conception, funding acquisition, lab analysis, writing, editing; RP: Idea conception, funding acquisition, lab analysis, writing; KO: Funding acquisition, lab analysis, editing; LT: Idea conception, funding acquisition, writing, editing; MR: Idea conception, funding acquisition, editing; FGG: Idea conception, funding acquisition, editing; HD: Idea conception, funding acquisition, Lab analysis, writing, editing.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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