Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 02 February-2025, Page No.- 3846-3850

DOI: 10.47191/etj/v10i02.13, I.F. – 8.482

Drying Performance of Integrating Mesh Wire as Drying Space into the Inflatable Solar Dryer for Drying Coffee

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ABSTRACT: The drying performance of coffee laid in a mesh wire that serves as a drying space in an inflatable solar dryer (ISD) was evaluated and compared to open sun drying (OSD) and ISD without mesh wire drying space in the Philippines. Condensation was observed in ISD due to the moisture content of the crops and solar radiation, which affected the drying time. Thus, mesh wire was introduced to reduce moisture buildup inside the ISD. The drying time was determined upon reaching the ideal moisture content of 12% for coffee.

The dryer was composed of a solar-powered fan, a solar air heater, and an inflatable solar dryer with mesh as a drying space. Three batches of 16.3 kg of fresh coffee were dried in each dryer. The temperature inside the ISD was measured using a data logger humidity and temperature sensor, and the coffee's weight was determined using a digital weighing scale.

The experiment trial demonstrates that an ISD with a mesh wire dramatically reduces drying time and prevents mass losses. Besides, product quality improved significantly because mesh wire aids in straining unwanted particles from the crops. The coffee is completely protected from rain, dust, insects, and animals during drying, resulting in high-quality products. The material costs associated with adding mesh wire into the ISD are insignificant when compared to the additional earnings generated by reduced mass losses and fastest drying time. Due to the solar-powered fan, the dryer can easily be operated by farmers and is reliable even when off-grid.

KEYWORDS: Mesh wire; solar-powered fan; inflatable solar dryer; solar air heater; coffee.

1 INTRODUCTION

Open sun drying (OSD) is the most common method of preserving agricultural products in developing countries such as the Philippines. Due to a lack of drying technologies, farmers tend to dry their crops in open areas like roads and pathways where solar radiation can directly hit the crops. Moreover, drying in open areas exposes the crops to the sun, wind, and motorists or vehicles that may run over and destroy the crops. Significant losses could happen during OSD due to various factors, including rain, mice, birds, insects, and rain. Additionally, over-drying, dust spills, and insect damage are characteristic of OSD. The products concerned are sold at lower prices or are not marketable at all even to local dealers because of the deterioration in product quality.

One issue the Philippines is currently dealing is the large number of imported crops required to ensure the population's food supply. Thus, there is an urgent need to develop sufficient drying technology to improve crops' quality that could add to the country's food supply. Nonetheless, studies have shown that even the simplest and most essential oil or gas-fired mechanical dryer and an electricity-connected dryer cannot be used on small-scale farms because they are too expensive. Solar dryers appear to be a promising way to overcome existing drying technology problems since the available solar irradiance is sufficient to support the heat demands of small drying systems.

Different kinds of small-scale solar dryers have been used for decades in developing countries like the Philippines. One of those successful dryers tested in the country was the ISD using rice as a commodity [1]. The ISD was proven effective for drying rice compared to OSD and was more affordable than mechanical dryers. However, during drying, the ISD has drawbacks in terms of condensation. Higher mixing frequencies were used as a preventative measure to avoid condensation when hot, humid air entered the still-cold bottom layer drying area and to move the heated top layer to the bottom. The previous study introduced a roller bar which was used to easily mixed the crops inside the ISD to prevent too much condensation and was seen effective. Unfortunately, adopting the roller bars in sandy areas and uneven or rough drying spaces was challenging in Burkina Faso[3]. Thus, this study focused on materials that could eliminate too much condensation during drying coffee without utilizing the roller bar. This study integrated a mesh wire which served as a drying space inside the ISD and compared its performance in terms of drying time and final crop weight to that of ISD without mesh wire and OSD.

2 MATERIALS AND METHODS

2.1. ISD with and without mesh wire

Unlike the earlier study in ISD, which barely laid the crops in the polyvinyl chloride (PVC) film, this research employed an elevated mesh wire inside the ISD chamber to improve the airflow of the moisture inside the dryer and to allow double passes of hot air into the top and bottom parts of coffee. Similar to the investigation by [1, 2, 3], this study evaluates the ISD as well without using mesh wire and by barely placing the crops in PVC.

The mesh wire drying area was constructed out of two by two (2x2) coconut wood that was 1.5 meters wide and 2.5 meters long. The rectangle-shaped wood frames were a platform for installing the 15 x 15 cm mesh wire within the ISD. Figure 1 shows the drying setup in ISD without mesh wire and OSD, while Fig. 2 shows the drying of coffee in ISD with mesh wire.

Figure 1. Drying in ISD without mesh wire and OSD

Figure 2. ISD with mesh wire

The ISD was based on the study made by [1], based initially on the solar tunnel dryer by [2]. The dryer is still collapsible, just like Salvatierra-Rojas' study, and was positioned on the ground. The ISD was composed of 150 m UV-transparent polyethylene (PE) film attached and sewed by a heavy-duty zipper to a 0.52 mm reinforced black polyvinyl chloride (PVC) film. For the dryer to bubble, the air is blown into the tunnel by one 220 V solar-powered fan and then ejected through vents on the opposite side. Renewable energy was used in this study because of the Salvatierra-Rojas study's conclusions, which suggested additional work should focus on integrating ventilators powered by solar energy, allowing for off-grid usage. The trial drying surface in the chamber is 1.5 meters wide by 2.5 meters long. Inflation effectively stabilizes the tunnel without the requirement for structural support because of the air pressure the fan creates.

The crops were then spread at the height of 20 mm on the mesh wire drying space and mixed with a rake to prevent overheating due to direct sunlight on the upper layer.

2.2. Solar Air Heater (SAH)

To raise the temperature of the air as it enters the ISD, a solar air heater was used in the study. Three 390 ml steel cans were perforated on both ends and used to construct the solar air heater. The 78 pieces of cans were organized in two layers. The first layer was set up vertically in seven groups; the second layer, however, was set up in five groups. For the second layer, there were spaces between the cans to let air flow inside the SAH. The SAH's structure had dimensions of 0.905 meters long, 0.6 meters wide, and 0.2 meters high and was framed using a 5mm plyboard. The device has black paint that serves as a coating and helps improve thermal performance. To minimize the steel cans' ability to collect radiative and convective heat, the SAH's top cover and glazing system was composed of 5 mm transparent glass. The SAH has four sturdy caster wheels at the bottom, making it movable and easy to transfer. To connect the SAH, fan, and ISD, a two-layer layout made of insulator foam and black polyvinyl chloride (PVC) film was sewn together. The sides were then connected using magic tape. Complete set-up of the dryer was shown in Fig. 3.

Figure 3. The ISD, SAH, and Solar powered fan

2.3. Experimental Trial

The dryer was used in the Sultan Kudarat province of the Philippines (6.5069° N, 124.4198° E) and was positioned in the center of an empty paddy field. An ISD without mesh wire was tested alongside the OSD, while the ISD with mesh wire was conducted after testing the ISD without mesh wire. In each experimental study, three batches of 16.3 kg. Robusta coffee was dried the day after it was harvested. Fresh coffee was weighed at the start of the drying experiment and determined its initial moisture content. After being set aside overnight or during periods of heavy rain, the crops were weighed again and determined their moisture content to note how much had changed throughout the day's drying process. The experimental trial lasted 10 hours every day, starting at 7 in the morning and ending at 5 in the afternoon, until the ideal moisture content of coffee was attained.

In ISD without mesh wire, the crops were laid on a divided three parts of black polyvinyl chloride (PVC). After the crop was spread out, the dryer was zipped, and the digital moisture content meter was placed on the SAH, middle in the fan and top of the crop inside the ISD. The solar-powered fan was then turned on to create a bubble and to allow the continuous flow of air until 5 in the afternoon. Every hour, the crops were mixed manually with a rake. The same drying process was followed using ISD with mesh wire; the only difference is that the crop was laid on the constructed mesh wire inside the ISD.

The OSD was used as a control strategy during the experiment. In OSD, the sample crops were arranged with a bulk height of 20 mm (the same with ISD with and without mesh wire) on a black polyvinyl chloride (PVC) film next to the ISD. The crops in both dryers were raked simultaneously. The crops were left aside overnight or during periods of heavy rain, just like with the ISD, and dried the following day until the ideal moisture level for each crop was obtained.

2.4. Instruments used in the study

Four essential tools were applied to assess the study's objective. The initial and final weights of the crops were measured using a digital weighing scale with a 25 kg capacity. While the moisture content of the crops was ascertained using a digital moisture content meter (AR991 KERRO Smart Sensor Digital Grain Moisture Meter). The study continuously dried the coffee until the ideal moisture content of 12% was reached. To measure the temperature and relative humidity of the ISD, a self-logging humidity and temperature sensor (BSIDE Mini USB Humidity Temperature Data Recording Logger) was put on the inlet, mid (in the fan, where the wind is pushed), and ISD chamber and the data was automatically created and exported with 10 seconds interval when the device was connected to a computer.

2.5. Statistical tools used in the study

One-way analysis of variance (ANOVA) determines whether there is statistical evidence that the linked data means are statistically substantially different by comparing the means of two or more independent groups. The samples of data were from the means of ISD with and without mesh wire and OSD. Case study 2.1 uses equation 1.22 to solve for the one-way analysis of variance.

Equation 1

$$F = \frac{MSB}{MSW}$$

Where F means the coefficient of ANOVA, MSB as the mean sum of squares between the groups, and MSW as the mean sum of squares within groups.

3 RESULTS AND DISCUSSION

3.1. Temperature and relative humidity

The temperature of both ISD with and without mesh wire was measured using a digital moisture content meter placed at three distinct places in the dryer. The first moisture meter

(TH1), which also measures the surrounding air, was installed at the SAH's air inlet. At the same time, the second (TH2) and third (TH3) moisture meters were positioned in the middle where the fan is located and in the ISD, respectively. In ISD, the temperature of both with and without mesh wire was more significant than in OSD. The three digital moisture content meter temperatures of ISD with mesh wire from SAH, middle, and varied from 31 to 46ºC, 31 to 51 ºC, and 31 to 70 ºC, respectively, the same in ISD without mesh wire. The highest ISD's temperature varied between 31 and 70 ºC, more than 30 ºC difference from ambient air.

The temperature gradually increased between the SAH air inlet and the fan. However, from the fan to ISD had the most remarkable temperature rise. The day's peak temperature occurred, between 11 in the morning and 2 in the afternoon. Though it progressively began to drop until it reached the ambient temperature after sunset. The same scenario was observed in drying using ISD with mesh wire.

3.2. The initial and final weight of ISD with and without mesh wire compared to OSD

Coffee weight differences and its relationship to time are depicted in Table 1 and Fig. 4. The table demonstrates a statistically significant difference between OSD and ISD with mesh wire. However, comparison among other dryers did not differ significantly from one another. Following the trial, it was discovered that there was a weight difference of 0.6 kg between ISD with mesh and ISD without mesh wire, 0.5 kg difference between ISD without mesh wire and OSD, and 1.1 kg difference between ISD with mesh wire and OSD. Figure 4 shows how the crops' weight reduces over time as it dries out. This suggests that the ISD with mesh wire is preferred compared to others in terms of the shortest time required to obtain ideal moisture.

Table 1. Coffee weight result in ANOVA

Source	*df*	*SS*	*MS*	*F*	*P*
Groups (between groups)	2	0.20	0.10	10.11	0.012
Error (within groups)	6	0.06	0.01		
Total	8	0.26	0.03		

Dryer	Mean	SD	DMRT
ISD with mesh wire	7.73	0.12	a
ISD without mesh wire	7.56	0.06	ab
OSD	7.36	0.12	b

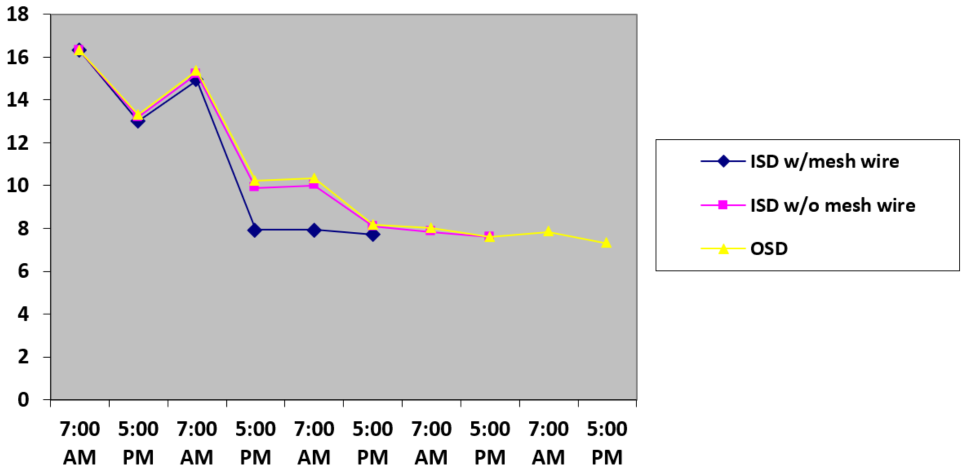

Figure 4. Weight of coffee in terms of time

3.3. The moisture content of ISD with and without mesh wire compared to OSD

Table II displays the crops' moisture content during ISD with and without mesh wire and OSD drying. Each experiment trial has the same initial moisture content. The ideal moisture content of 12% was attained by ISD with mesh wire in three days (27 hours), while ISD without mesh wire was in four days (38 hours) and OSD in five days (47 hours), from their uniform initial moisture content of 40.5%. Additionally, Fig. 5 illustrates how the moisture content of the coffee gradually decreases concerning the drying duration. As observed in the figure, remoistening occurs when the crops are taken out of the dryer at night, increasing the moisture content the following day compared to what was recorded before it was stored. However, once the desired moisture level is reached, remoistening is reduced to almost nothing.

Table II. The moisture content of coffee

Products	The final moisture content of coffee			
	Fresh coffee	*ISD with mesh wire*	*ISD without mesh wire*	*OSD*
Coffee	40.5%	12.00%	12.1%	12.1%

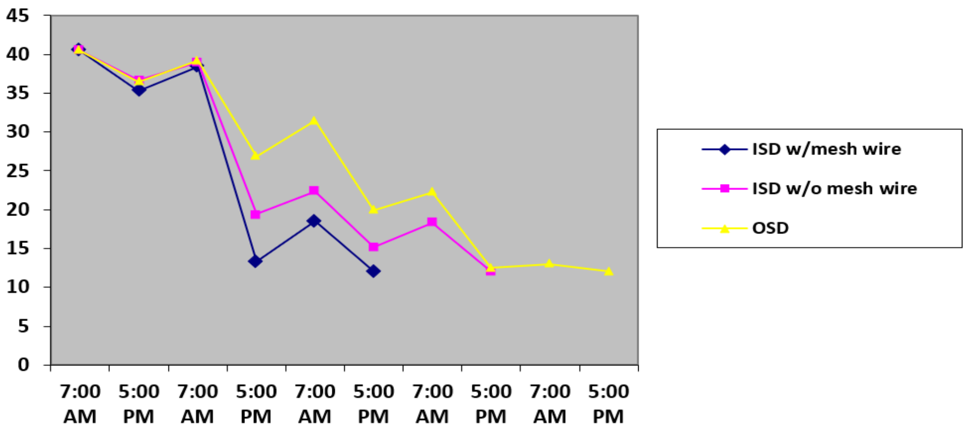

Figure 5. The moisture content of coffee in terms of time

3.4. Condensation occurrences and drying time

Condensation occurs when the surface temperature of the drier or the crops is lower than the moisture content of the drying air. Condensation in the ISD significantly affects the coffee's moisture content and drying duration. As observed in the ISD without mesh wire, there is a need to frequently mix the crop inside the dryer to remove the excess moisture on the bottom layer of the crop. However, in drying using the ISD with mesh wire, there is no moisture under the crops, because incoming air reaches and allows to dry even the crops at the bottom. Table III shows how long it took for each drier to attain the appropriate moisture level of 12 % that coffee requires to be considered dried.

Table III. Drying duration of coffee in three different drying procedure

Product	Moisture content	Total duration of drying		
	Final moisture content	***ISD with mesh wire***	***ISD without mesh wire***	***OSD***
Coffee	12.0%	27 hours	38 hours	hours

There is a difference of nine (9) hours between the OSD and the ISD without mesh wire, eleven (11) hours between the ISD without mesh wire and ISD with mesh wire and twenty (20) hours between the OSD and the ISD with mesh wire.

4. CONCLUSION

In the Philippines, the effectiveness of the ISD with mesh wire for drying coffee was evaluated and compared to ISD without mesh wire and OSD. The study measures the effectiveness of adding the mesh wire in the ISD and determines its final weight and drying duration results. The investigation found that only ISD with mesh wire and OSD have a significant difference in terms of the final weight of the coffee. However, in terms of drying duration, the results depict that the ISD with mesh wire was more effective in drying coffee. The 16.3 kg of coffee was easily dried and reached the desired moisture content of 12% using ISD with mesh wire in 27 hours, while the same amount of coffee was dried using ISD without mesh wire in 38 hours and 47 hours were spent to dry coffee in OSD. According to the data gathered during the experiment, the drying duration will significantly impact the crops' weight.

The device should be tested in large-scale drying to determine the actual capacity of the ISD with mesh wire. Moreover, further research should also consider evaluating the ISD with mesh wire using different crops.

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