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Thermal performance assessment of an indirect solar dryer: A case study of Bananas

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ABSTRACT

This study presents a design for an absorber used in a solar air collector for an indirect solar dryer. The absorber comprises two aluminium plates corrugated and joined together to form parallel cylinders, enabling airflow within the collector. This research aims to experimentally examine the drying process of two types of bananas, one from Morocco and the other from abroad, using the designed solar air collector. Additionally, the study aims to investigate the peculiarities of the drying process and the performance of the solar dryer employed. The experiments were conducted by subjecting the bananas to the designed solar air collector, and the evolution of drying was monitored. The initial mass of the bananas used was 631.6 g for the Moroccan banana and 713.6 g for the Export banana. After the drying process, the mass of the Moroccan banana reduced to 77.5 g, while the Export banana reduced to 137.3 g, indicating significant moisture removal. The percentage of the amount of water extracted (Q) from the bananas was found to be 87.7% for the Moroccan banana and 80.8% for the Export banana. These results demonstrate the effectiveness of the corrugated aluminium plate absorber in facilitating the drying process in the solar air collector. The significant reduction in the mass of the bananas and the high percentage of water extraction highlight the efficiency of the solar dryer in removing moisture from the agricultural produce. The findings of this study contribute to the understanding of the drying process of bananas and offer valuable insights for the design and optimization of solar drying systems for agricultural applications.

Keywords: indirect solar dryer, solar collector, banana, global irradiance

INTRODUCTION

The increase in prices and the shortage of fuels have prompted extensive studies and research on the use of solar energy as an alternative energy source, particularly in developing countries **[1]**, **[2]**, **[3]**. Solar drying, a widely adopted solar energy system, has been recognized as an effective method for food preservation. Drying fruits and vegetables is an energy-intensive process in the food processing industry and serves as a valuable means to reduce post-harvest losses. Solar drying of crops, fruits, and vegetables has been practiced worldwide for centuries, utilizing the sun's energy in the open air. It has been historically employed for drying grains, meats, and other agricultural products for consumption **[4]**, **[5]**, **[6]**.

The traditional method of drying fruits and vegetables in the sun, without technical aids, continues to be the predominant practice for much of the world's supply. However, large-scale production limits the use of normal outdoor sun drying. This traditional approach suffers from various issues. Among them are the lack of proper control over the drying process, uncertainties caused by weather conditions, high labor costs, the need for extensive space, and the risk of infestation by insects and other foreign bodies. As a result, solutions involving solar energy have been developed, including the use of collection devices or solar dryers **[7]**, **[8]**.

The utilization of a well-designed solar dryer can help mitigate the disadvantages associated with open sun drying and lead to enhanced quality of the final dried product. Numerous scientists have conducted studies on the modeling of solar drying for agricultural products. Additionally, simulation studies have been carried out on solar dryers, both direct and indirect, and the behavior of various vegetables and fruits, focusing on their drying kinetics

[9]. By harnessing free, renewable, and non-polluting energy from the sun, the adoption of solar dryers in developing countries has the potential to reduce crop losses and significantly enhance the quality of the dried product compared to traditional drying methods.

In recent years, significant efforts have been made to develop solar drying systems, particularly for the preservation of agricultural products. The design of solar drying systems needs to be tailored to meet specific drying requirements and accommodate different types of crops. In a study focusing on apricots, researchers presented a mathematical model for a thin-layer solar drying process. They utilized a cabinet solar dryer with a forced convection system operating in mixed and indirect modes **[10]**. The findings revealed variations in the drying rate of apricot samples based on the solar drying technique employed and the drying air's temperature and airflow velocity. Notably, apricots exhibited faster drying rates when subjected to mixed-mode solar drying compared to indirect solar drying.

Pruengam et al. **[11]** developed a solar collector dryer that can be positioned on both sides of a drying chamber. Their study involved drying bananas in the dryer for 5 days, reducing the original moisture content from 68.5% to 17.4%. In comparison, the open sun drying method reduced the moisture content to 27.3%. The solar collector dryer reduced moisture content for bananas by a factor of 1.3-1.5 when compared to sun drying.

In another study, Essalhi **[12]** presented an innovative absorber design for a solar air collector used in an indirect solar dryer. The absorber consisted of two corrugated aluminium plates. The data obtained from the study revealed that after 24 hours of drying pears, the sample's mass decreased from 997.3 g to 135.1 g. The average thermal efficiency of the drying chamber was observed to be 11.1%.

In this paper, our experimental study aims to investigate the drying characteristics of two different banana types **[13]**, **[14]**. By examining the drying evolution of these different banana types , we aim to identify any drying anomalies and potential limitations of the dryer system specific to this agricultural product. Through this research, we aim to gain insights into the optimal drying conditions and potential improvements that can be made to enhance the drying process for these two different banana types. The findings from this study will contribute to a better understanding of banana drying and provide valuable information, including global solar irradiation **[15]**, for developing more efficient and effective drying techniques in the future.

Scientific Hypothesis

By implementing a well-designed indirect air solar dryer and following the recommended temperature range provided by the manufacturer, we have expected that the drying process for agricultural products, specifically sweetened bananas, will be more efficient and effective. Furthermore, by incorporating pre-treatments to eliminate obstacles that hinder drying kinetics and incorporating a heat storage mechanism to retain generated heat during nighttime, we expect to observe improved drying outcomes regarding optimal nutritional and aesthetic qualities within the designated drying time.

MATERIAL AND METHODOLOGY

Samples

We have selected bananas as our chosen "wet product" for the study. Bananas hold significant importance as a food source for various reasons. They are rich in dietary fiber, which promotes digestive health and helps reduce the risk of certain diseases. Additionally, bananas are packed with essential vitamins and minerals such as vitamin C, vitamin B6, and potassium, crucial for maintaining overall bodily functions. Their carbohydrates provide quick energy, making them popular among athletes and active individuals. Moreover, bananas are readily available throughout the year, making them an ideal fruit for drying **[16]**, **[17]**. As depicted in Table 1, they possess substantial nutritional value. With the increasing demand for dried banana products **[18]**, exploring their drying characteristics becomes crucial.

Chemicals

The experiment involves treating the samples with a highly acidic solution of lemon juice, with a pH level ranging from 2 to 3 on the pH scale. This solution exhibits a significantly higher acidity level than water, with lemon juice being nearly 100,000 times more acidic than water. It is important to note that only the exported banana variety underwent the preliminary treatment with lemon juice before the subsequent analysis. A comparative analysis was conducted between the treated exported bananas and the unprocessed Moroccan banana variety.

Animals, Plants and Biological Materials

This study used two types of banana (exported and Moroccan) as they are considered a plant-based food.

Table 1 Nutritional value per 100 g of banana.

Banana nutritional value per 100 g of raw banana			
Water	Total Ash	Fibres	Energetic value
74.9 g	0.8 g	2.6 g	89 kcal
Proteins	Lipids	Carbohydrates	Simple sugars
1.1 g	0.3 g	22.8 g	12.2 g
Trace elements			
Potassium	Magnesium	Phosphor	Calcium
358 mg	27 mg	22 mg	5 mg
Sodium	Copper	Iron	Zinc
1 mg	78 µg	26 µg	25 µg
Vitamins			
Vitamin C	Vitamin B1	Vitamin B2	Vitamin B3
8.7 mg	31 µg	73 µg	665 µg
Vitamin B5	Vitamin B6	Vitamin B9	Vitamin B1
334 µg	376 µg	0 µg	0µg
Vitamin A	Vitamin K		
64 µg	0.5 µg		
Fatty acids			
Saturated	Monounsaturated	Polyunsaturated	Cholesterol
112 mg	32 mg	73 mg	0 mg

Note: Data processed from **[19]**.

Instruments

The solar dryer: This solar air dryer (Figure 1, Table 2) was constructed step by step at the Laboratory of Solar Energies and the Environment at the University of Mohammed V. The project is supported by The Institute for Solar Energy and New Energies Research (IRESEN) (https://iresen.org/amelioration-du-fonctionnement-des-sechoirs-solaires/). All equipment is placed on the roof of the annex where orange trees are located in Rabat, Morocco (34° 1' 15.1752" N and 6° 50' 29.9400" W), facing south at an angle of 34 degrees to maximize solar radiation absorption for our drying experiment **[20]**. The primary objective of this study was to develop and construct an air-type solar collector with an improved cost/performance ratio, specifically designed for solar drying of agricultural products.

Figure 1 The indirect air solar dryer used (34° 1' 15.1752" N and 6° 50' 29.9400" W).

The solar collector: The solar collector used in this study follows a simple and conventional design. It comprises an insulating "cork" on the lower face, a black aluminium absorber with cylindrical cavities, and a standard glass cover on the upper face. The collector functions by allowing fresh air to enter through an opening at the bottom and flow through the 7 cavities of the absorber. This design has been analyzed in a study by **[12]** to assess its impact on the performance of the solar collector. The review concludes that optimizing these parameters can significantly enhance the thermal efficiency of the collector.

Table 2 Solar collector dimensions.

Collector length (cm)	Collector width (cm)	Collector thickness (cm)	Opening diameter (cm)	Cavity diameter (cm)
114	99.5	16	15	9

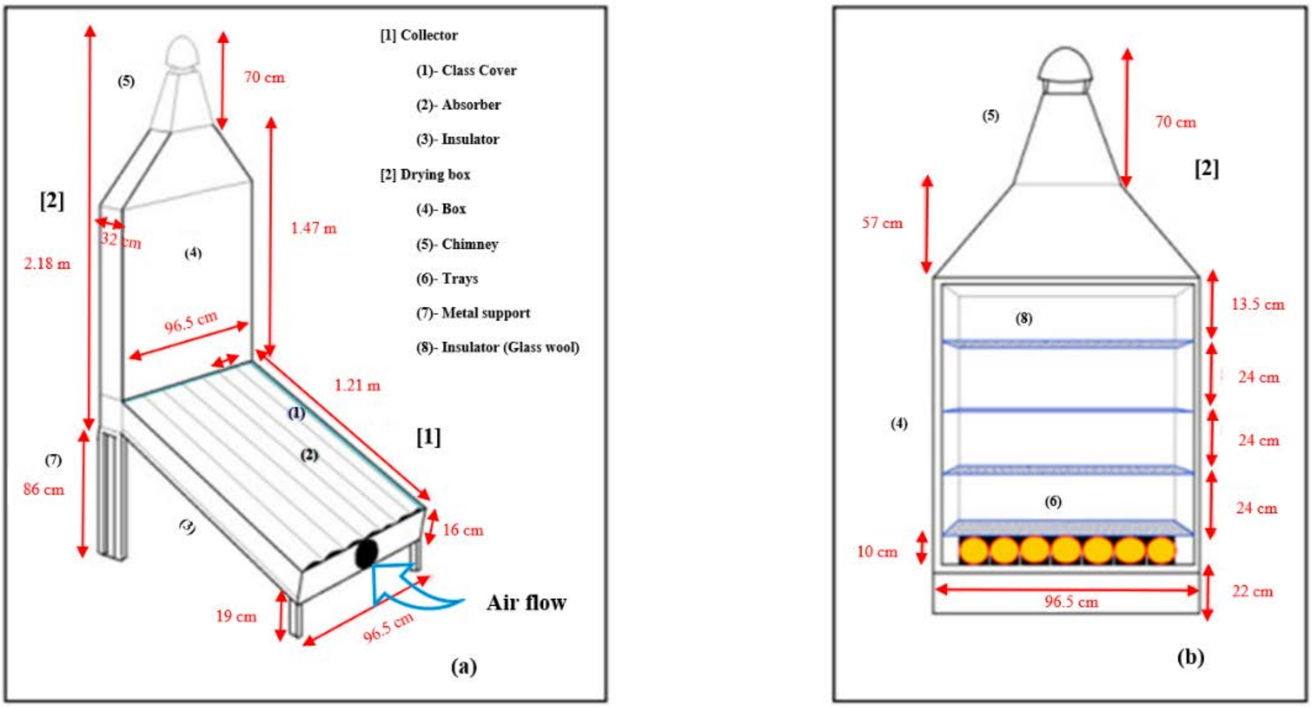

Figure 2 (a) Schematic diagram of the drying system, (b) drying chamber **[12]**.

Drying chamber: The chamber is a parallelepiped-shaped enclosure supported by an iron frame constructed from a durable wood material called "Tréspa." This specialized wood is designed to provide both structural stability and insulation properties. Inside the chamber are four aluminium trays with perforations that allow the drying air to circulate and transfer heat to the bananas. The chamber is equipped with a double-leaf door to facilitate the loading and unloading of the bananas. A chimney is installed at the top of the chamber to release the moist air. For the distribution of the product, only the first three shelves were utilized (Table 3, Figure 2).
The drying box utilized in our study has a capacity of up to 10 kg of bananas, determined by the airflow rate. It is crucial to maintain an optimal airflow in a solar dryer to effectively remove moisture from the product without causing any damage to the fruit. The solar collector's dimensions also constrain the drying chamber's size. In our analysis, we consider the inclusion of the 4th tray within the drying box, as illustrated in (Figure 3).

Table 3 Drying chamber dimensions.

Box length (cm)	Box width (cm)	Box thickness (cm)	Dimension of the 1st tray			Dimension of the 2nd and 3rd tray			Chimney length (cm)
			Length (cm)	Width (cm)	Thickness (cm)	Length (cm)	Width (cm)	Thickness (cm)	
114	96.5	32.5	93.5	9.5	0.2	93.5	28.5	0.2	113

Figure 3 The drying box was used.

Laboratory Methods

The study was conducted in Rabat, the capital of Morocco, utilizing the previously demonstrated indirect air solar dryer. Rabat experiences a warm and temperate climate, characterized by most rainfall occurring during winter and relatively low rainfall during summer. According to the Köppen-Geiger climate classification, Rabat falls under the *Csa* category **[21]**.

In this study, we also investigated integrating a computer system for data management and storage throughout the drying process, along with using thermocouples to facilitate communication between the computer and the solar dryer. For an indirect solar dryer, it is crucial to consider background meteorological measurements to understand the ambient weather conditions that may influence the dryer's performance. These measurements include temperature, relative humidity, solar radiation, wind speed, and rainfall. Campbell Scientific sensors and CR1000 data loggers were deployed at the solar dryer site to capture these measurements. A computer assembly consisting of a junction box connected to an acquisition box was utilized to collect data hourly, with a computer designated for data storage.

Figure 4a displays the eight T-type thermocouples that constitute the assembly. Each thermocouple is individually connected to the solar dryer elements to measure their temperatures. A junction box (depicted in Figure 4a) consolidates the T-type thermocouples. T-type thermocouples consist of two distinct metal wires: copper (positive) and constantan (a copper-nickel alloy, negative). This type of thermocouple is particularly suitable for low-temperature applications, with a temperature range of -200 °C to 350 °C. The junction box collects temperature readings from all the elements of the dryer and routes them to the acquisition system.

The acquisition system (shown in Figure 4b) serves as the interface between the computer and the junction box. It includes an electronic card and computer software. The laboratory system incorporates a memory module from Campbell Scientific CR10X-2M (up to 1,000,000 data points). All measuring instruments and thermocouples are connected to this acquisition system. The system is controlled by a computer using a data acquisition program. However, there are drawbacks to this procedure: during the assembly of the thermocouples with these wires, some temperature is lost, leading to inaccurate numerical values.

This temperature is used with the temperature of the acquisition box called the reference temperature T_f. The real temperature is given by equation (1):

$$T_r = T - T_b + T_f \quad (1)$$

Where:
T_r – Actual temperature of an element of the dryer ; T – Temperature displayed in the program; T_f – Reference temperature; T_b – Junction box temperature.

Table 4 shows the real location of each thermocouple in the acquisition system.

Table 4 Location of each thermocouple.

Thermocouple	Location
T1	Collector input (At collector level)
T2	On the absorber (At collector level)
T3	Collector outlet (the inlet of the drying box)
T4	The 1st tray (At the level of the drying box)
T5	The 2nd tray (At the level of the drying box)
T6	The 3rd tray (At the level of the drying box)

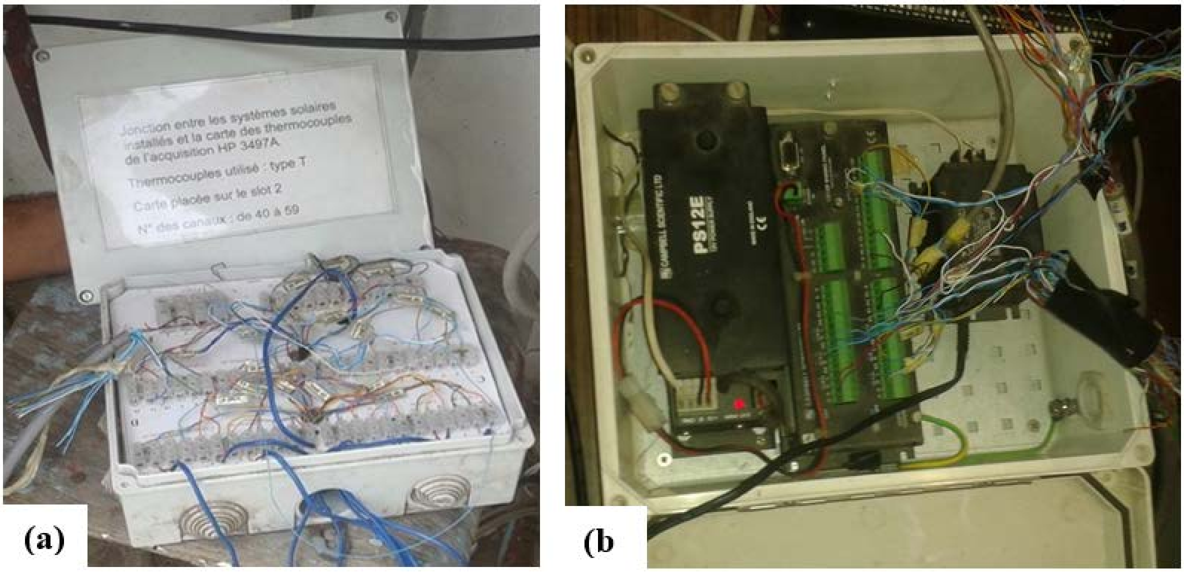

Figure 4 The junction (a) and acquisition box (CR10X) (b).

Description of the Experiment

Sample preparation: The bananas used in the study were purchased on May 1, 2018. They were measured to be between 10 and 13 centimetres in length and 2 to 2.5 centimetres in diameter. Prior to the experiment, the bananas were sliced into rounds with a thickness of 5 millimeters. After removing the waste, which weighed 468.5 g, from the initial mass of the bananas 1130.0 g, we were left with 661.6 g as the starting mass for the drying process.

On May 8, 2018, we introduced another variety of banana (exported banana) to the solar dryer, alongside the Moroccan banana. The Moroccan banana had a length ranging from 18 cm to 20 cm and a diameter ranging from 2.5 cm to 3 cm. For the exported bananas, we imported a total of 1240.0 g. After removing all the imperfect bunches, which weighed 526.4 g, we were left with 661.5 g as the starting mass for the drying process.

It is important to note that while this experiment is from an older timeframe, research on renewable energy and sustainable agriculture remains an ongoing and constantly evolving field. There is still a need for studies exploring the efficiency and effectiveness of solar drying technology. Furthermore, this research may have practical applications and implications for farmers, producers, and other stakeholders in the sustainable agriculture industry. This can be seen in recent publications such as **[22]** (published in 2022) and **[23]**, **[24]**.

To preserve the banana's color and prevent oxidation, we treated all export bananas with lemon juice before drying.

Number of samples analyzed: This study analysed two samples of bananas.

Number of repeated analyses: Data was collected for a duration of 30 days in this study.

Number of experiment replication: Each experiment was repeated 30 times in this study to obtain a single value.

Design of the experiment: The indirect solar dryer was assembled step-by-step within the University of Mohammed V laboratory, specifically in the laboratory of solar energies and the environment. The nutritional composition of the agricultural products, such as moisture, protein, fibers, ash, salt, as well as the content of vitamins, magnesium, calcium, water, and fat, was determined. Furthermore, the products were thoroughly cleaned, and the exported bananas were mixed with lemon juice before being placed inside the drying chamber. This step was taken to facilitate a comparison between the two products after the experiment.

Statistical Analysis

The data collected from the computer assembly features was analyzed using using Microsoft Excel and Python, a programming language commonly used for data analysis. The analysis included performing descriptive statistical analysis and calculating the Pearson correlation coefficient. Descriptive statistics provided measures such as mean, standard deviation, minimum, maximum, and quartiles, which helped in understanding the data's central tendencies, variability, and distribution. The Pearson correlation coefficient was used to assess the strength and direction of the linear relationship between variables, specifically between the temperature of the trays and the global solar irradiation. By analyzing Python, we leveraged its powerful libraries and functions for data manipulation, analysis, and visualization, allowing for a comprehensive examination of the data and accurate interpretation of the results.

RESULTS AND DISCUSSION

Experimental observation: We have two types of bananas: Banana 1 (Moroccan) and Banana 2 (export). The drying process took place from May 1 to May 28, 2018, with Banana 1 being placed in the dryer from May 1 to May 8, and Banana 2 being added from May 8 until May 28. The total drying period was thirty days. While the temperature varies from day to day on May 1 (the first day of drying), after a week of daily monitoring, we observe that banana 1 is still relatively in the same condition as when we first checked on it. Banana 1 has been slightly overripe, and its high humidity is readily apparent **[25]**; therefore, it was seen that its viscosity reduces during a sunny day around 2 p.m., indicating drying takes place; however, by 8 a.m., the banana had reverted to its initial state.

Statistical results of clear sky day and partially overcast day: Tables 5, 6 and 7 provides a descriptive statistical analysis of the data for the clear sky day and partially overcast day (6 and 5 May 2018 respectively), offering insights into the temperature variables (T4r°C, T5r°C, T6r°C) and irradiation levels. The statistics reveal important information about the dataset, such as the average values, standard deviations, minimum and maximum values, and quartiles. These measures help us understand the typical range, variability, and central tendency of the temperature and irradiation data. Moving to Table 6-8, it presents the correlation coefficients between the temperature variables and irradiation. The correlation coefficients quantify the strength and direction of the linear relationship between these variables. This analysis shows high positive correlations among the temperature variables, indicating that they are closely related and change together. Additionally, a strong positive correlation between temperature and irradiation suggests that irradiation levels also tend to increase as temperature increases. These correlation coefficients provide valuable insights into the relationships between the variables and help us understand the interconnected nature of temperature and irradiation. Figure 5 shows the map of the Pearson correlation of a clear sky day and a partially overcast day.

Table 5 Descriptive statistics of clear sky day (6 May 2018).

	T4r °C	T5r °C	T6r °C	Irradiation W/m^2
count	23.00	23.00	23.00	23.00
mean	24.18	23.45	24.18	344.23
std	12.78	11.78	12.78	376.39
min	10.56	10.54	10.56	0.20
25%	12.45	12.33	12.45	0.39
50%	18.82	18.96	18.82	167.70
75%	35.445	33.30	35.44	704.30
max	44.74	42.280	44.74	951.00

Table 6 Pearson correlation analysis results of clear sky day (6 May 2018).

	T4r°C	T5r°C	T6r°C	Irradiation W/m^2
T4r°C	1.00	0.99	1.00	0.96
T5r°C	0.99	1.00	0.99	0.96
T6r°C	1.00	0.99	1.00	0.96
Irradiation	0.96	0.96	0.96	1.00

Table 7 Descriptive statistics of partially overcast day (5 May 2018).

	T4r°C	T5r°C	T6r°C	Irradiation W/m^2
count	23.00	23.00	23.00	23.00
mean	22.10	21.71	21.01	170.64
std	6.47	6.04	5.26	219.33
min	15.99	15.90	15.75	0.30
25%	17.33	17.30	17.26	0.41
50%	19.02	18.61	18.15	71.60
75%	25.56	25.00	24.05	312.55
max	34.04	33.14	31.25	614.60

Table 8 Pearson correlation analysis results of partially overcast day (5 May 2018).

	T4r°C	T5r°C	T6r°C	Irradiation W/m^2
T4r°C	1.00	0.99	0.99	0.97
T5r°C	0.99	1.00	0.99	0.96
T6r°C	0.99	0.99	1.00	0.95
Irradiation W/m^2	0.97	0.96	0.95	1.00

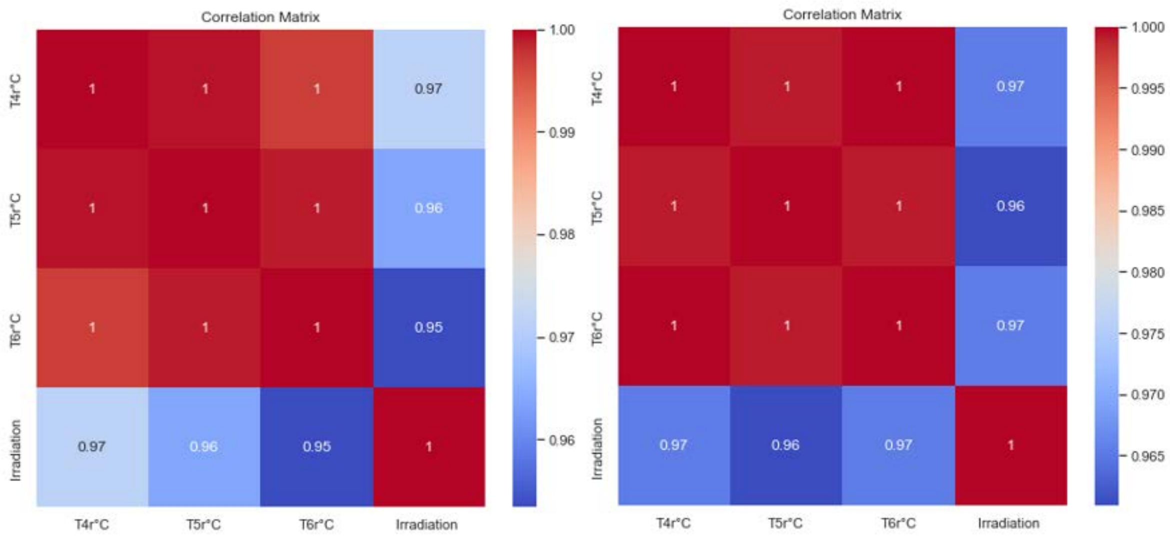

Figure 5 Correlation map of clear sky day and partially overcast day.

Experimental results: The following method is proposed for studying the drying process's evolution: we measured the drying process's temperature evolution over two days, one sunny and the other partially covered, for each period ([1 May-8 May] and [8 May-28 May]), which will allow us to determine our dryer's behaviour and combine the result with the experimental drying result to determine the factors governing the drying process **[26]**. For banana 1 (Moroccan banana): we selected May 5 as a partly cloudy day **[27]**, and May 6 as a sunny day **[28]** over this time frame (May 1-May 8). The selected days during the drying period were chosen to represent average weather conditions, with a mix of sunny and partially cloudy days. Evaluating the thermal performance of an indirect solar dryer for bananas involves assessing its ability to effectively utilize solar energy for heat generation and moisture removal **[29]**. This process is closely linked to meteorology, as it relies on factors such as sunlight intensity, temperature, humidity, and wind speed **[30]**. In this study, ERA5 hourly fractional cloud cover data **[31]** was utilized to identify clear-sky days in the study area, following the approach validated by recent studies in South Africa by Mabasa et al. **[32]** and in Morocco by Mendyl et al. **[15]**. Evaluating the solar energy resource available at the desired location is crucial before implementing solar energy technologies for photovoltaic (PV) or thermal applications. This assessment helps determine the feasibility and suitability of solar energy as a renewable energy source for that specific location **[33]**, **[34]**. The pvlib python library **[35]**, **[36]** can be utilized to configure solar models and assess the hourly global horizontal irradiance (GHI) for the study location prior to the start of the experiment.Figures 6 and 7 depict the 24-hour temperature evolution in the 3- trays dryer on a sunny and partly sunny day, respectively.

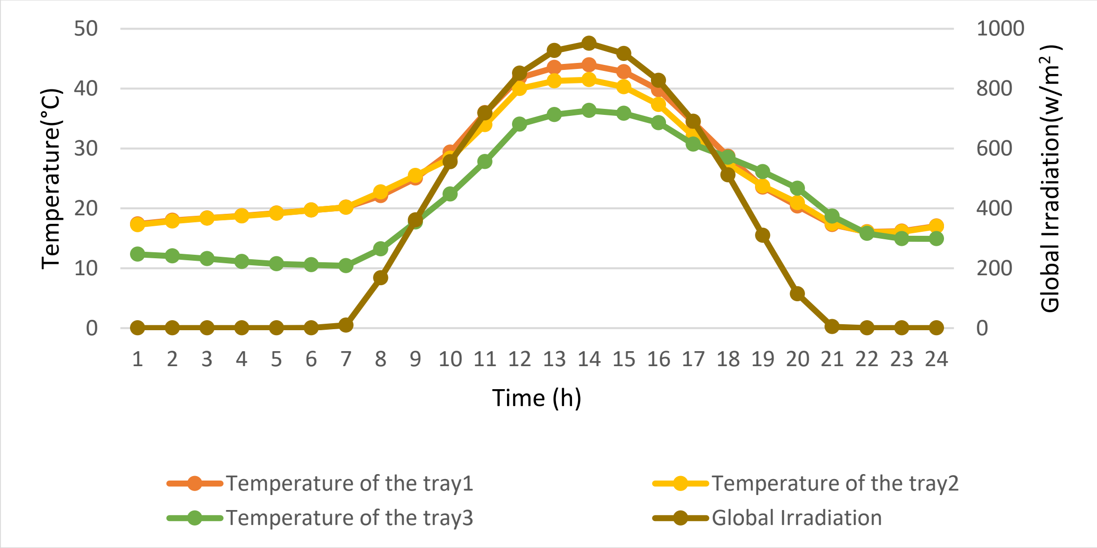

Figure 6 Temperature and global Irradiation evolution during clear sky day(W/m^2).

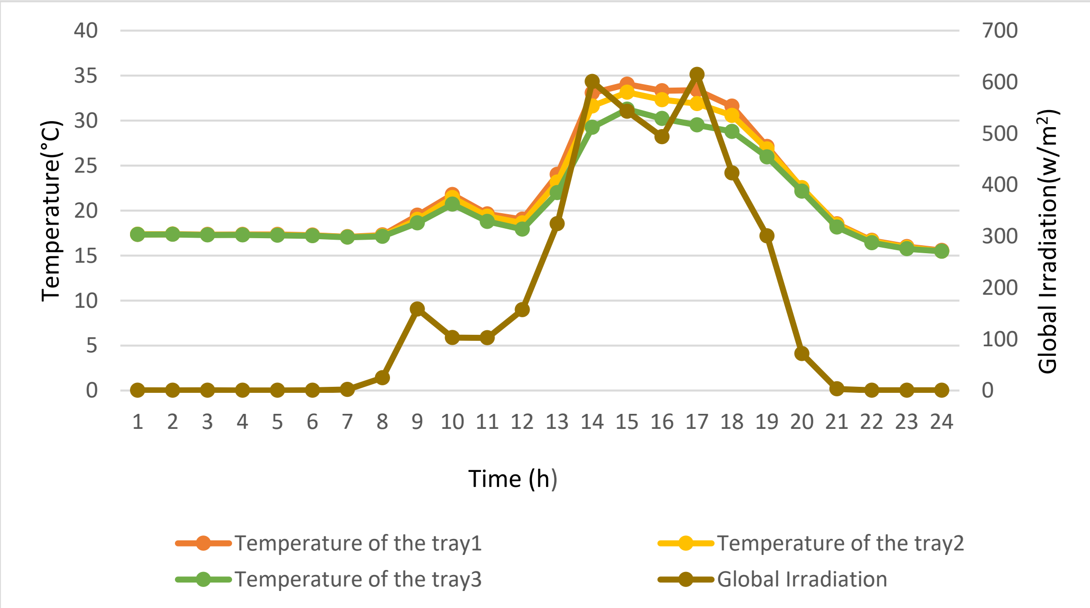

Figure 7 Temperature and global Irradiation evolution during partially overcast day(W/m^2).

The curves generated in Excel and the experimental results demonstrate that global irradiation on partially cloudy days fluctuates significantly but does not exceed 600 W/m^2 for extended periods. On sunny days, global irradiation can reach 950 W/m^2 and remain above 700 W/m^2 for approximately 5 hours. This disparity has a noticeable impact on the trays, as observed by the temperature of the first tray reaching 45 °C around 3 p.m. on sunny days, while staying below 25 °C on partially cloudy days. Throughout the experiment, the temperature of the lower tray (tray 1) consistently exceeds that of the upper tray (tray 2). This temperature difference arises from the airflow path in the indirect solar dryer, where the air initially contacts the lower tray, providing heat and absorbing moisture, as noted by the authors **[37]**.

These data will assist us figure out what's going on with our dehydration **[38]** due to the drying temperature, which does not reach 45 °C even under ideal conditions within the chamber, and the initially ripe stage of banana 1, the drying process took a very lengthy time (May 1-May 8). This product is best dried between 50 °C and 70 °C. The study carried by **[39]** concluded that a higher temperature (80 °C) was ideal for producing dried bananas, as it had the highest global desirability value.

Banana 2 (export bananas): We picked "May 16" as the sunny day for this time frame (May 8-May 28). We choose these days because, on average, they were sunny and bright with consistent daily irradiation, ideal for drying.

The water content of 2 products: The quantity of water extracted from each banana was determined by measuring its mass again after a month (Moroccan and exported bananas) and comparing it to its initial mass (Table 5).

Table 9 The amount of water extracted from each banana type

	Banana from Morocco	Export banana
The initial mass (Q_i) to be dried (g)	631.6	713.6
The final mass (Q_f) of the dried banana (g)	77.5	137.3
The amount of water extracted from the banana (g)	554.1	576.3
The percentage of the amount of water extracted (Q) in %	87.7	80.8

The percentage of the amount of water is calculated by equation 2 according to the American Society of Agricultural and Biological Engineers Standards (ASABE) **[40]**.

$$Q = \left(\frac{Q_i - Q_f}{Q_i}\right) \times 100 \quad (2)$$

These findings reveal that the water content of each product is high, with only a slight variation between the two bananas. The longer a banana from Morocco is allowed to dry, the more moisture can be removed from it. The authors of **[41]** found that during a continuous 8-hour drying process of banana slices, it was noted that the greatest decrease in both weight and moisture content occurred in the lower tray at a higher air mass flow rate. Specifically, the weight of the banana slices reduced from 150 grams to 48 grams, while the moisture content decreased from 78% to 28.1%. These observations were made without any interruptions in the drying process.

The effect of the treatment: We found a significant distinction between Moroccan and exported bananas at the end of drying process. In fact, unlike untreated bananas, those that were treated with lemon juice did not become entirely black. Since the export bananas have preserved a fairly large size compared to Moroccan bananas, the diameter of the bananas played a role as crucial as that of the treatment, especially at the aesthetic level. The study's findings **[42]** indicate that using pre-treatment methods such as freezing and combined blanching and freezing can significantly increase the drying rate of bananas and reduce the drying time. This may offer a cost-effective solution to enhance the efficiency of the drying process. However, it should be noted that the pre-treatment methods that yielded the most notable improvement in drying performance also significantly reduced the quality of the final product.

The smaller banana in Figure 7 is the Moroccan type, whereas the larger banana is the export variety.
The size of each banana in the initial state:

- Export banana Type 1 (diameter [2.5 cm-3cm]).
- Moroccan banana Type 2 (diameter [2 cm-2.5 cm]).

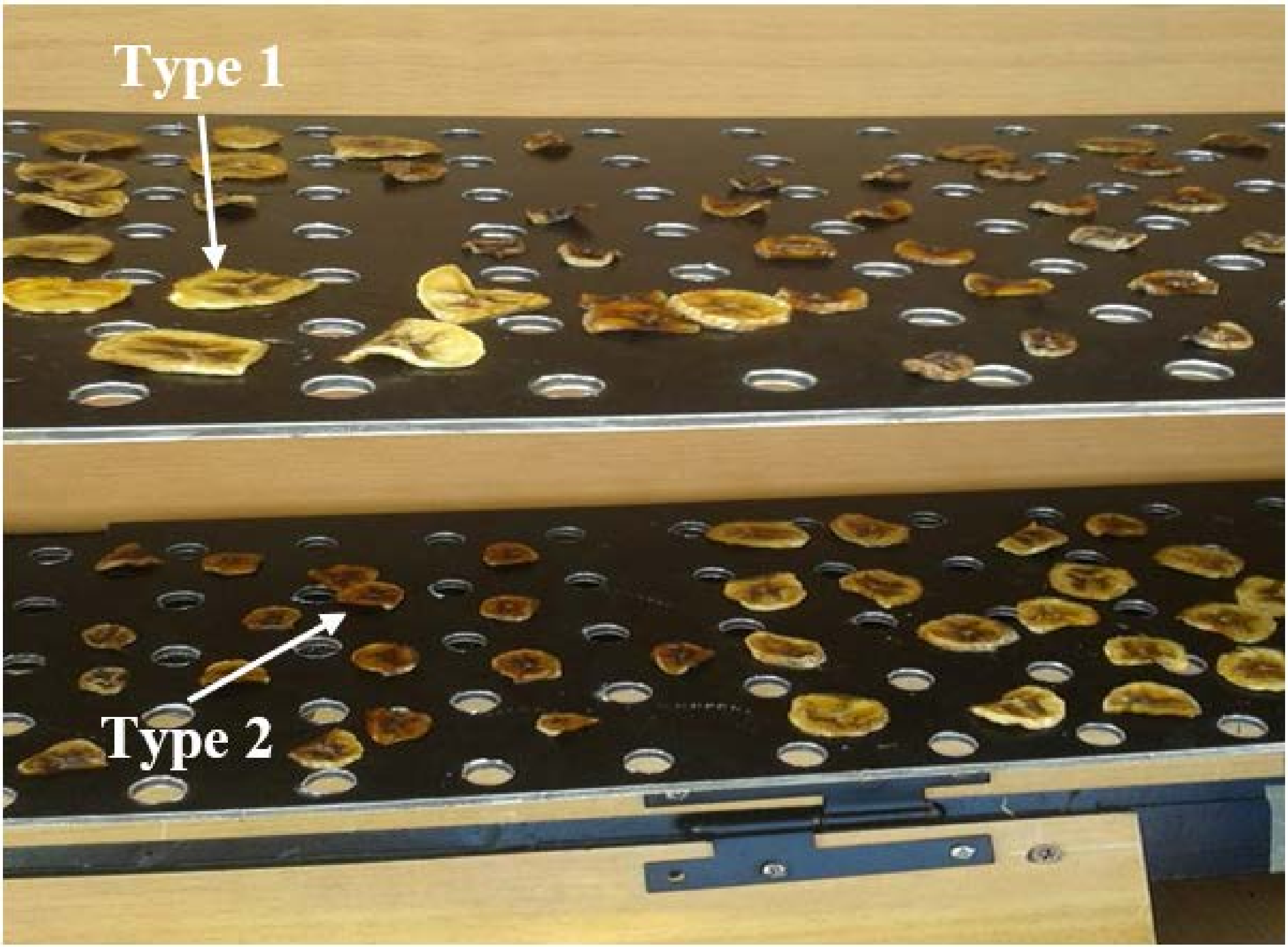

Figure 8 Real image of the two types of bananas placed on the trays in the dryer at the end of drying process.

Problems and Recommendations: One of the biggest issues we had was a dip in temperature during the night caused by the humid air entering via the cavities. Humidity in the drying chamber has increased due to the infiltration of outside air, so the product must spend more time drying. This study by **[43]** examined the impact of changing ambient conditions on the solar drying of mint leaves using two methods under specific dry climate conditions. The study observed how changes in air relative humidity affected product rehydration during the drying process.

Due to the fluctuating weather conditions during the day, we can also say that the drying temperature was unfavourable. It should be remembered that a drying time of 144 hours and a temperature range of 60 °C to 80 °C (without ventilation) is ideal for drying bananas (6 days). This is accomplished by putting the day's production of heat into a storage system so that it can be used to warm the product overnight. This study **[44]** investigated the impact of various variables on the convective drying behavior of bananas, including cultivar, shape, blanching, and heated air conditions (temperatures of 50 °C and 70 °C and velocities of 0.14 and 0.42 m/s). The study used mathematical modelling to analyze the drying process and dehydrated the bananas in a tray dryer, monitoring their weight at set intervals. In **[45]** A drying temperature of 55 °C was found to give superior quality OD banana slices in terms of reduced bulk, improved flavour, decreased aw (<0.60), and reduced dehydration time and energy using HHP as a pretreatment.

Drying viscosity is another issue we've noticed. During the drying process, it was observed that the banana's viscosity increases mostly in the morning and decreases in the afternoon **[46]**. Additionally, we find that the products' viscosity is still noticeable even after drying has reached its final stages.

This difference in viscosity results from the fact that sugar **[47]** adheres to pores when water migrates towards them, creating an appearance of viscosity on the product and slowing down drying kinetics.

It's important to note that products placed on the second and third trays in a drying chamber don't dry as quickly as those on the first try. This is because the products in the first tray are dried by air entering at a specific temperature. Since the humidity in the drying chamber rises as water vapor is taken from the product **[48]**, the process continues to the second and third tray , although at a lower temperature. Because of this, and as evidenced by the daily curves sketched earlier, there is a substantial temperature difference between the trays when the product is present.

It is recommended that the following steps be taken to address these issues when drying bananas:

- Never dry ripe bananas, and install a heat storage system during the day to compensate for the dryer's temperature dropping at night.
- Use a treatment to lower the quantity of sugar in the banana for sweet products, such as sodium or sodium metabisulphite, to eliminate the crusting problem. The study by **[49]** found that the bananas lost sugar during the ultrasonic treatment, so the ultrasonic pre-treatment can be an interesting process to produce dried fruits with low sugar content.
- Close the compressor outlet at night to prevent ambient air from entering the drying box.

CONCLUSION

Through the drying process of bananas, we had the opportunity to observe the behavior of an indirect air solar dryer. During this process, we noticed a significant reduction in the weight of banana slices, decreasing from 150 grams to 48 grams. Additionally, the moisture content of the slices decreased from 78% to 28.1%. These valuable insights allowed us to evaluate the dryer's effectiveness and identify areas requiring enhanced performance improvement. Consequently, we gained a deeper understanding of the significance of certain elements involved in the drying process.:

- When drying a product, it's important to stay within the range of temperatures recommended by the manufacturer.
- Heat loss can be prevented by using an effective and well-made dryer.
- Agricultural products, especially those that have been sweetened, need to undergo treatment to eliminate all the obstacles that slow down the drying kinetics.
- As the temperature drops at night, the dryer needs a way to store the heat it generates during the day.

All of the recommendations are necessary prerequisites for drying food to the appropriate standards and in the allotted time for the product to be presented in optimal nutritional and aesthetic form. However the analysis of the moisture content is crucial in understanding the effectiveness of the drying process and identifying areas that require improvement for a more efficient dryer.

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