



Evaluation of The Thermal Performance of An Indirect Solar Dryer With a Glazed Collector Equipped with Three Parabolic Trough Reflectors for Drying Agri-Food Products

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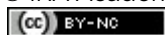
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ABSTRACT

In a context of growing development of indirect solar drying technologies using flat-plate collectors, this study focuses on an innovative solar dryer operating by natural convection. The device, designed in Ouagadougou for drying agri-food products and tested with plantain bananas, integrates parabolic trough reflectors into the collector, topped with a drying chamber and a mobile support. Two types of banana cutting were tested. During the tests, changes in sunlight, temperatures and humidity of the drying air, product moisture content, and drying speed were monitored throughout the drying time. Experimental results indicate an average efficiency of 73% for the thermal collector and an overall efficiency of 23.4% for the dryer, thus demonstrating the benefits of integrating reflectors to improve solar drying performance.

Keywords: Parabolic trough, glazing, drying, temperature, efficiency.

1. Introduction

In sub-Saharan Africa, most farmers suffer significant post-harvest losses due to the lack of effective preservation methods. Traditional drying, which involves exposing agricultural produce to the sun on mats or loincloths, remains the most common method. However, this rudimentary practice has several drawbacks: direct exposure to sunlight degrades nutrients, contamination by dust or insects, and poor control over drying conditions. To address these limitations, scientific research has led to the development of more efficient drying technologies, including solar dryers. These devices use solar energy as a heat source to gently dehydrate agricultural products, thereby extending their shelf life while preserving their nutritional quality. Burkina Faso, located in the Sahel region, benefits from one of the highest solar potentials in the world, with an average irradiation of 5.5 kWh/m² per day. This favorable climatic context makes the development of solar drying technologies particularly relevant. Several types of dryers can be distinguished according to their operating principle: direct, indirect, hybrid and mixed (Dianda et al., 2022). Among them, indirect solar drying stands out for its ability to offer better control of thermal parameters, thus ensuring better preservation of the quality of food products (Prakash et al., 2020). Several studies have confirmed the interest of this technology. Among these works are those of Ankit et al. (2025). They dried curry leaves using an indirect solar dryer. The dryer showed a temperature increase of 18.9 °C compared to ambient air under solar radiation of 750 W/m². Mohamad (2025), studied the drying kinetics of lemon slices in an indirect solar dryer with forced convection. The research results showed that the final water content of lemon slices was 14.61%. Shazzad et al. (2025) designed, fabricated and evaluated the performance of an indirect vegetable dryer. It was found that the air temperature in the drying chamber reached 51–57 °C at an ambient temperature of 29–35 °C. Pakouzou et al. (2017) investigated the integration of a thermal receiver in the caustic zone of a parabolic trough concentrator to maximize its efficiency. Thierry et al. (2021) tested an indirect solar dryer equipped with hemispherical concentrators for drying mangoes and ginger. The dryer had temperatures between 57 and 67 °C and the drying of the produce lasted approximately 8 hours. Germain et al. (2017) studied, by modeling and experimentation, the natural convection of air in a vertical tower-shaped solar dryer. Dianda et al. (2022), for their part, analyzed the performance of an indirect solar dryer equipped with an external collector for drying papaya. These studies reflect not only the diversity of approaches but also the continuous improvement

of indirect solar dryer performance, adapted to the climatic and agricultural realities of tropical and Sahelian regions.

In this dynamic of continuous improvement of solar dryer performance, this work aims to propose an innovative technological solution. Its objective is, on the one hand, to design an indirect solar dryer with natural air circulation, incorporating parabolic trough reflectors, and on the other hand, to conduct an experimental study to evaluate its thermal performance and efficiency under real-world operating conditions.

2. Materials and methods

2.1 The solar dryer

The drying device that we are thermally evaluating is an indirect solar dryer with parabolic trough reflectors and operating in natural convection as shown in Figure 1. It is essentially made up of three parts: a thermal collector, a drying chamber and a mobile support comprising the two previous elements. These three elements are all made up of multiple clearly distinct parts.

-The thermal sensor

The thermal collector consists of three parabolic cylindrical reflectors made of aluminum foil, joined together. Each reflector reflects direct solar radiation onto a 1 m galvanized tube painted in matte black, which acts as an absorber. The reflector has an opening diameter of 0.18 m, the receiver diameter of 0.06 m. The concentration rate is 9. A clear glass 1 m long, 0.6 m wide and 5 mm thick covers the collector. It creates the greenhouse effect within the collector.

- The drying chamber

The drying chamber is made from lightweight square tubes with a cross-section of 20mm × 16mm, and benefits from thermal insulation made of 20mm thick polystyrene. The exterior faces are clad in black sheet metal, while the interior surfaces are made of aluminum-zinc, ensuring better resistance to corrosion and optimized thermal reflection. The structure includes three functional levels:

- **First level (lower storage):** Located at the base of the enclosure, this compartment measures 0.6m in length, 0.3m in width and 0.3m in height. It is intended for the storage of materials or dried products.
- **Second level (drying area) :** Located above the first, this level constitutes the main space for dehydrating the products. It has dimensions of 0.6m (length) × 0.4m (width) × 0.7m (height). The products to be dried are placed on stainless steel racks, designed from grids framed by 20mm × 16mm square tubes, in order to prevent any contamination by corrosion.
- **Third level (exhaust chimney) :** Located in the upper part, this compartment acts like a chimney, facilitating the natural evacuation of humidity to the outside thanks to the thermal draft effect.

The sensor and the drying chamber are supported by a metal bracket. It is equipped with wheels for easy mobility.

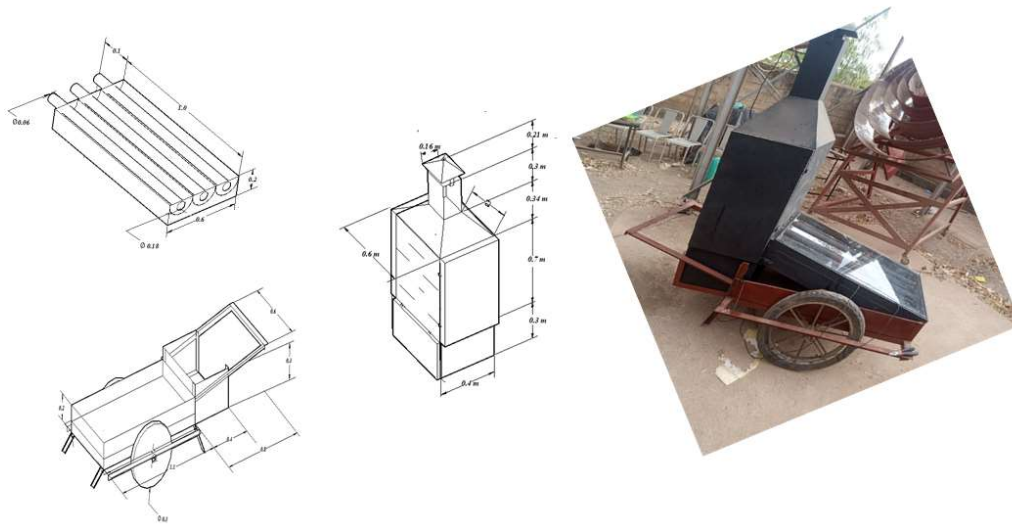


Figure 1: The main parts of the indirect solar dryer with parabolic trough reflectors

2.2 Measuring devices

The results are obtained using certain devices that we list below:

- A data logger designed by GRAPHETEC Corporation, branded midi logger GL220. It is equipped with 10 inputs where K-type thermocouples are connected for temperature measurements. It operates with an error margin of $\pm 0.05\%$ of the measured value and is used for temperatures between -100°C and 1370°C .
- A Hukseflux Thermal sensor SR03 solarimeter with a sensitivity of $9.58 \mu\text{V (W/m}^2\text{)}$ was used to measure the sunlight. This device is equipped with a transparent ball-shaped sensor for receiving solar radiation.
- A Memmert UN 55-53L oven with a temperature range of $+20^{\circ}\text{C}$ to 300°C , a volume of 3 liters and a margin of error of $\pm 0.5^{\circ}\text{C}$ was used to determine the initial water content of the plantain banana.
- A Citizen type electronic scale supporting a maximum mass of 210 g with an accuracy of 0.001 g was used to weigh the mass of the plantain banana before and after being placed in the oven.
- An electronic balance PCE-BS 6000 capable of supporting a mass of 6g and precision 1 gram was used for weighing the mass of the plantain banana during its drying.
- A UNI-T UT330C hygrometer, which can be manually activated and deactivated using a button, was used to monitor the humidity of the drying air.
- Utensils consisting of casserole dishes, knives, peeler and several used cloths served as support tools.



Figure 2: Images of measuring instruments (a: data logger, b: pyranometer, c: oven, d: balance, e: hygrometer, f: utensils)

2.3 Plantain banana

The plantain banana is a hybrid species belonging to the Musaceae family. Like the dessert banana, it is part of the *Musa paradisiaca* subgroup, resulting from the cross between *Musa acuminata* and *Musa balbisiana*. This fruit, eaten primarily as a starchy food, has different names depending on the geographical region. Compared to the dessert banana, the plantain banana is generally larger and longer, with flesh that is sometimes slightly pink. It is also slightly less sweet but much richer in starch, which gives it a firmer texture and good cooking properties. Its skin is often more greenish. In sub-Saharan Africa, the plantain banana is most often eaten ripe, boiled, grilled, or fried. When cooked before reaching full maturity, it has a firmer, less sweet texture, similar to that of floury tubers

2.4 Experimental protocol

The plantain banana used for drying was washed, peeled, cut into longitudinal slices and rounds, drained and then weighed to determine the initial mass. A portion of the banana was placed in the oven to determine the initial water content. The product subjected to drying was weighed regularly to monitor its mass. The different

temperatures at the sensor and in the dryer were recorded using thermocouples connected to a data logger. The sunshine on the site and the humidity of the drying air were also monitored.

2.5 Mathematical approaches

- Moisture content

The water content over time is determined by the following relationship:

$$X(t) = \frac{m(t)(X_o + 1) - m_o}{m_o} \quad (1)$$

With X(t): the water content at time t or spontaneous, m(t): the mass of the product at time t, X_o: the initial water content; m_o: initial mass of the product to be dried.

- Dryer efficiency

The collector efficiency is evaluated as follows from the equation (2)

$$\eta = \frac{m_v L_v}{t G_s A} \quad (2)$$

With η : the dryer's efficiency , m_v : mass of water evaporated during the total drying time; L_v : latent heat of vaporization; G_s : average daily solar radiation on the dryer surface; A : area of the absorber exposed to solar radiation ; t : drying time in seconds.

- Collector performance

The collector efficiency is determined by the following relationship

$$\eta_c = \frac{S_{col} F_R [(\alpha \tau I_t - U_L (T_e - T_a))]}{I_r(t) S_{col}} = F_R \left(\alpha \tau - U_L \left(\frac{T_e - T_a}{I_t} \right) \right) \quad (3)$$

With FR: Form factor, UL: Total thermal conductance of losses, It: Incident solar irradiation of the collector, Te: Air temperature measured at the collector inlet, Ta: Ambient air temperature.

Furthermore, using the French standard NF P50-501, the efficiency can then be expressed in the following form:

$$\eta_c = B - K T^* \quad (4)$$

With B: Optical factor of the sensor, K: Total thermal conductance of losses and T* which represents the ratio $\frac{T_p - T_a}{G_{st}}$ where Tp is the sensor temperature, Ta is the ambient temperature and Gst is the global insolation

3. Results and discussion

3.1 Temperature, sunshine and relative humidity

We monitored the evolution of sunshine, air temperature at the inlet and outlet of the sensor over time.

- Sunshine depending on the weather

Figure 3 illustrates the evolution of sunshine as a function of time during the day of May 28, 2023.

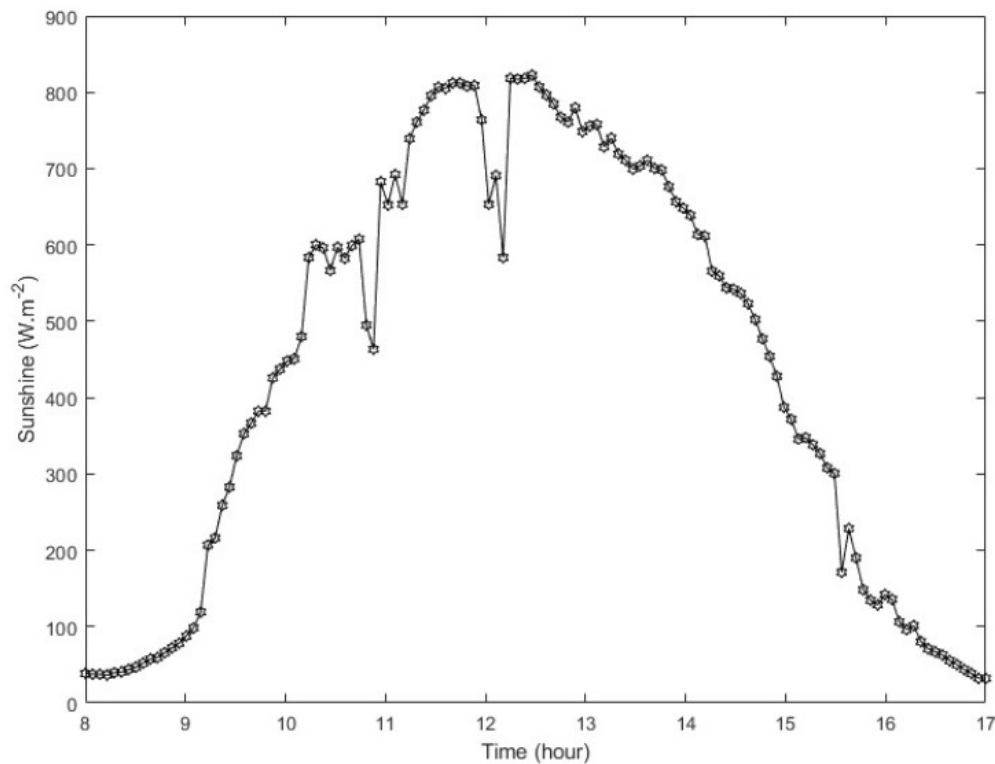


Figure 3: Evolution of sunshine over time

The overall sunshine profile shows a typical bell-shaped curve, characteristic of a sunny day, with a maximum intensity reaching around 850W/m² around 12:00. However, significant fluctuations are observed, deviating from this ideal profile. Two marked drops in solar flux appear: the first between 10:30 and 11:20, and the second between 12:30 and 13:00. These sudden variations are most likely due to temporary cloudy periods, which reduce the intensity of direct sunlight received by the sensor. Indeed, the presence of clouds can cause occasional and sometimes significant drops in incident radiation, as this experimental curve clearly shows.

- Drying air temperature at the inlet and outlet of the collector and solar flux

Figure 4 illustrates the evolution of the air temperatures at the inlet and outlet of the solar collector, as well as that of the direct solar flux, during two consecutive days of plantain drying.

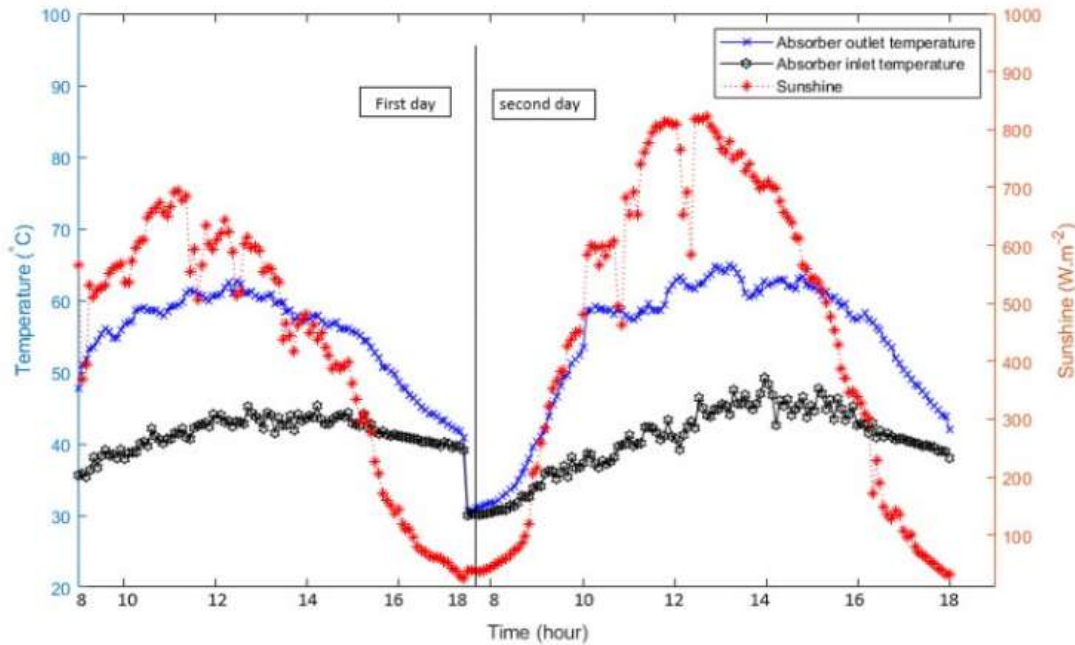


Figure 4 : Variations in sunshine, air temperature at the inlet and outlet of the collector as a function of time during plantain drying (27-28/05/2023)

The temperature profiles show similar trends for both days, closely following the variation in sunshine. Temperatures gradually increase in the morning, reach a peak around 12:00, and then gradually decrease until the end of drying. More specifically, the air temperature at the collector inlet remains close to ambient temperature, with slight variations throughout the day. In contrast, the air temperature at the collector outlet rises significantly, reaching maximum values of approximately 60°C on the first day and 65°C on the second day, reflecting good capture and conversion of solar energy without the collector. This difference in performance is explained by more favorable sunshine on the second day, as evidenced by the higher and more constant solar flux curve. These results confirm the collector's effectiveness in significantly raising the drying air temperature, an essential parameter for the proper operation of an indirect solar drying system.

- Product drying air temperatures

Figure 5 shows the temperature evolution profiles of the drying air and the product (plantain banana) over two consecutive days of drying.

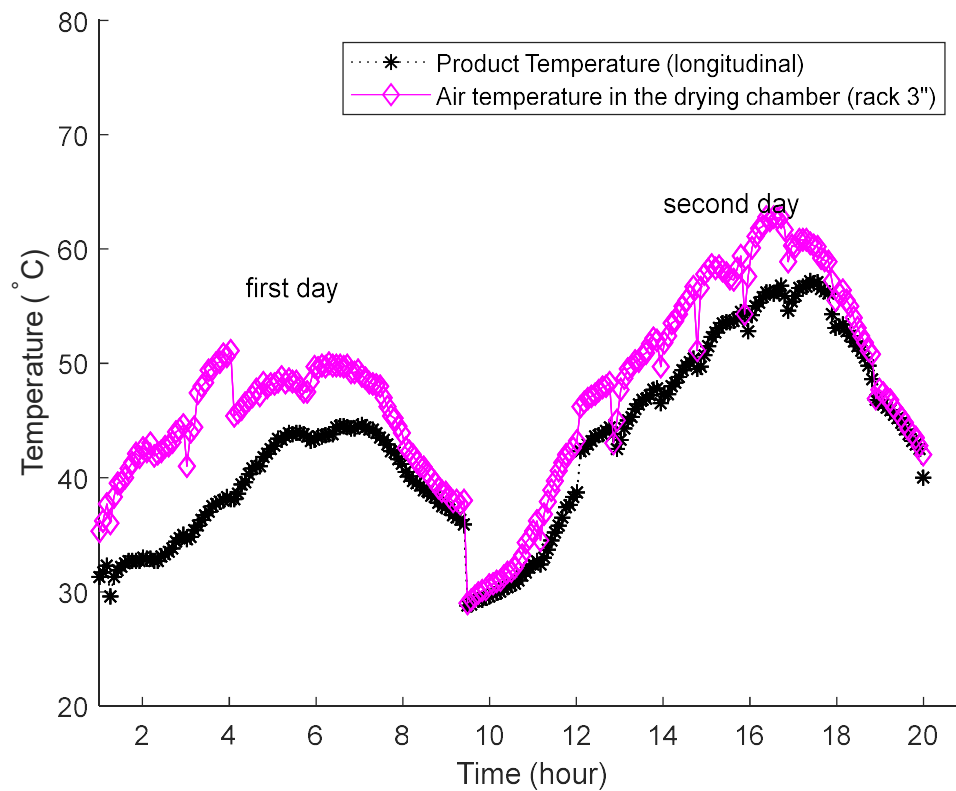


Figure 5 : Variations in air and product temperature in the drying chamber over time

It is observed that the drying air temperature is significantly higher on the second day, which is attributable to the more favorable sunshine on this day. This improvement in air temperature is also reflected in the product temperature, which gradually increases from the first to the second day. The increase in product temperature can be explained mainly by the gradual decrease in its water content during drying. Indeed, the more the water in the product decreases, the more the heat heats the product. The maximum temperature reached by the product is approximately 55 °C on the second day. These results are in agreement with those obtained by Dianda et al. (2022), who also observed similar temperatures during natural convection drying. Furthermore, the temperatures measured here, between 45 °C and 65 °C, are considered appropriate and recommended for the drying of many agri-food products, ensuring a compromise between efficiency and preservation of nutritional quality.

- Drying air temperature and relative humidity

Figure 6 illustrates the simultaneous evolution of air temperature and relative humidity in the drying chamber, as a function of time, over two consecutive days of plantain drying.

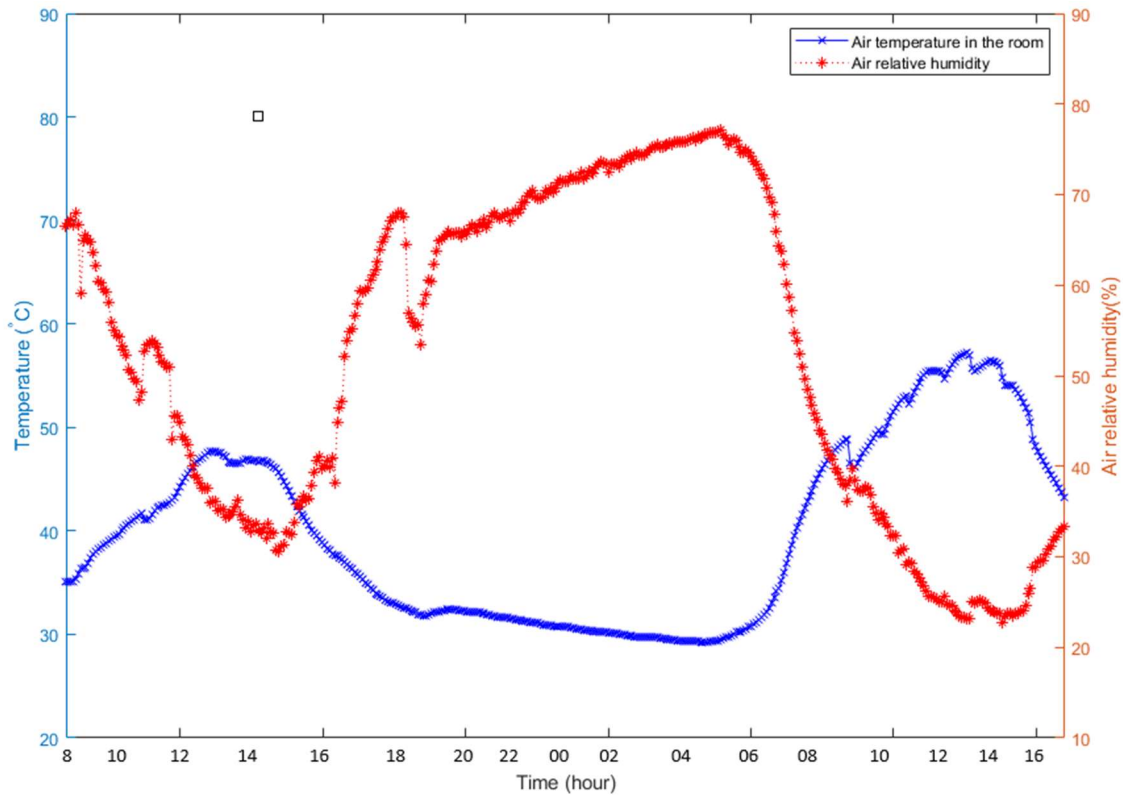


Figure 6 : Evolution of drying air temperature and relative humidity in the chamber during plantain drying

The two curves show inverse trends, meaning that as the air temperature increases, its relative humidity decreases, and vice versa. Over the two days, the air temperature in the chamber gradually increases from the morning, reaching a peak in the middle of the day, before slowly decreasing in the late afternoon. This trend is mainly due to the greenhouse effect produced by the drying chamber, which promotes an increase in the internal temperature. At the same time, the relative humidity decreases as the air warms up, reaching its minimum at the time of the thermal peak. This behavior is explained by the fact that the warmer the air, the better it evaporates the water particles it contains. This allows the warm air to more effectively evaporate the water from the products being dried.

A slight variation is observed from one day to the next. The maximum relative humidity tends to increase on the second day. This could be due to a partial accumulation of water vapor inside the enclosure, emitted by the products being dried, and insufficiently evacuated by natural ventilation.

– Moisture content

Figure 7 shows the evolution of the water content of the product during drying.

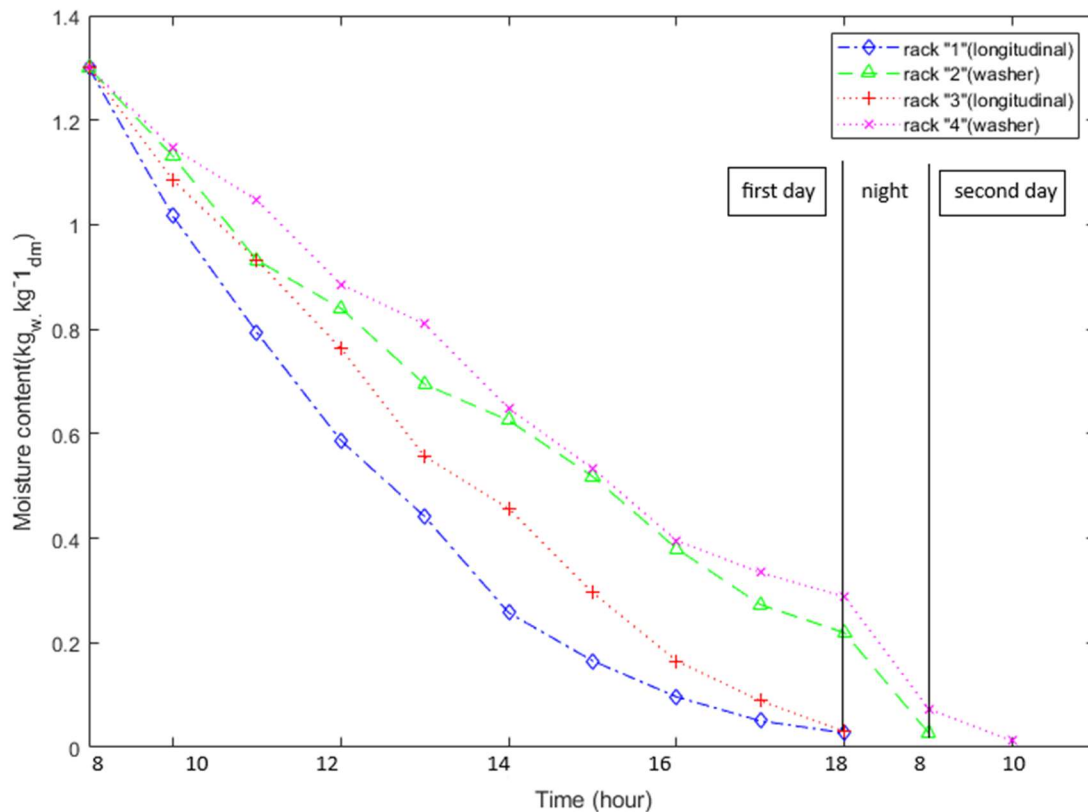


Figure 7 : Evolution of the water content of the banana depending on the cutting shape and the position of the rack during drying.

The moisture content curves show two major results:

✓ Position of the rack

The longitudinal cuts are on racks 1 and 3. The slice cuts are on racks 2 and 4. It can be seen that the drying kinetics decreases more quickly on the lower level racks for the same cut shape. This result is explained by the fact that the hot air passes from the lower level racks while rising. During its ascent it gives way and loses evaporative power. Similar results are obtained by Boureima et al. (2025), Boureima et al. (2024), Dianda et al. (2022), Arslan et al. (2023), Afolabi et al. (2014).

✓ Cutting shape

The analysis of the curves shows that longitudinally cut slices exhibit faster drying kinetics than round slices. This is due to the fact that longitudinally cut slices, due to a higher specific surface area, promote heat and mass transfer. Conversely, round slices, with a less favorable surface/volume ratio, exhibit slower drying. Pechaporn et al. (2017) obtained similar results with cassava chips.

- Drying rate

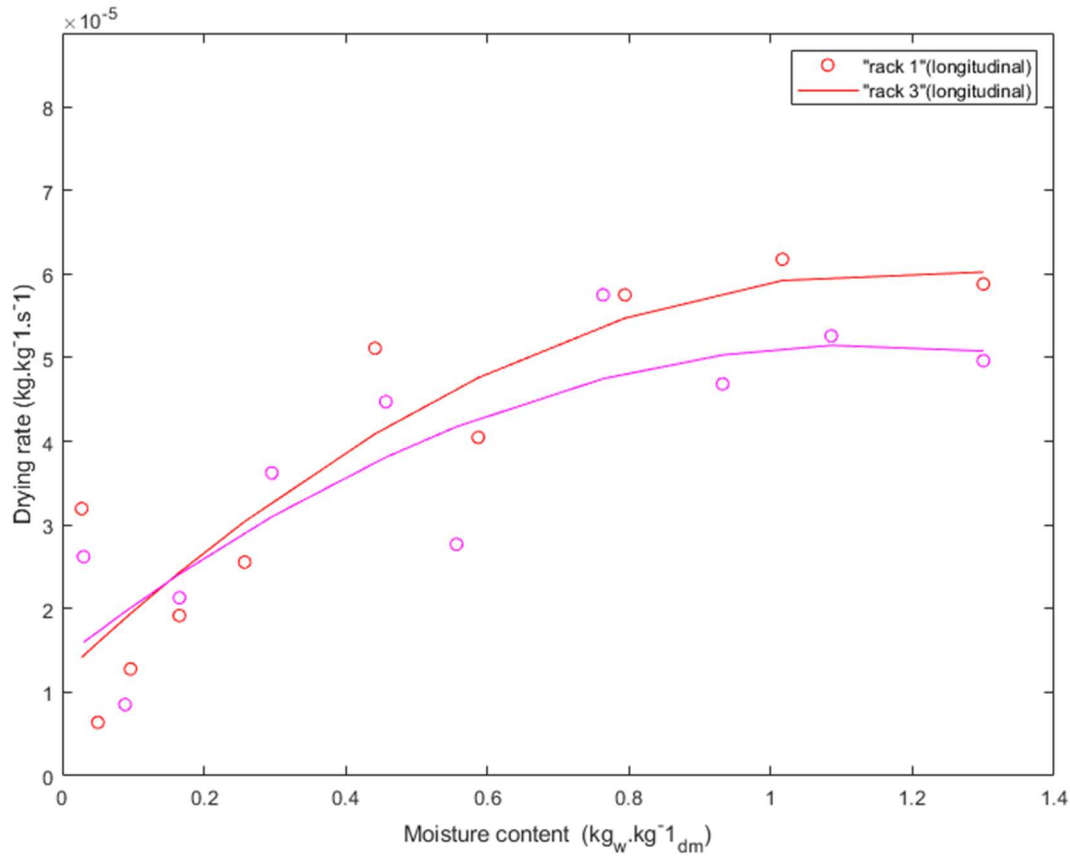


Figure 8 : Evolution of drying rate as a function of residual water content of plantain slices

The drying rates exhibit a single decreasing phase. The drying rate gradually decreases, reflecting a limitation of internal transfers: residual water is increasingly bound to the cellular structure, diffusion paths lengthen, and a surface crust can form. This phase is governed by internal diffusion mechanisms and becomes less efficient from an energy point of view. Comparison of the two racks shows similar behaviors in terms of drying profile, with similar maximum rates, around $6 \times 10^{-5} \text{ kg.kg}^{-1}.\text{s}^{-1}$. However, slight differences appear in the time course, due to factors such as heterogeneity of exposure to the air flow, variations in slice thickness, or differences in position in the dryer.

- Collector and dryer efficiency

Figure 9 illustrates the evolution of the thermal efficiency of the solar collector as a function of local time, for the day of May 28, 2023.

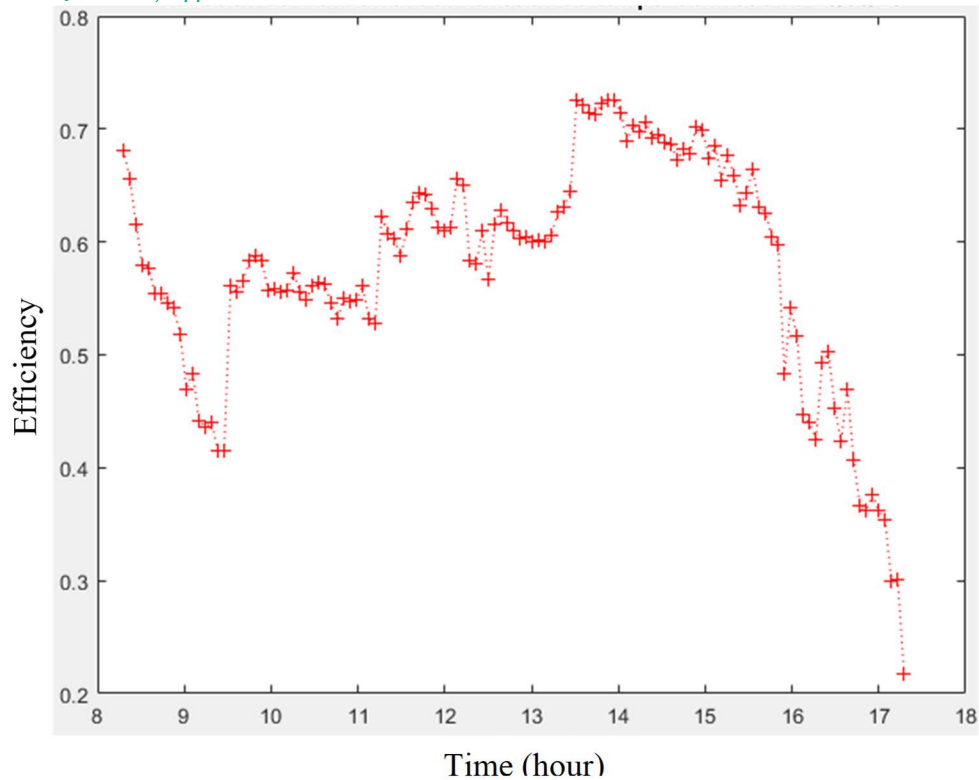


Figure 9 : Variation of the thermal efficiency of the sensor as a function of time

Three main phases can be distinguished on the collector's instantaneous thermal efficiency curve.

In the morning (8:00 to 9:30 a.m.), efficiency decreases very rapidly. The period from 9:30 a.m. to 2:00 p.m. corresponds to an optimal phase, where thermal efficiency reaches values between 60% and 72%. This peak efficiency is favored by maximum sunlight, a relatively stable operating temperature, and a good balance between energy input and heat transfer to the heat transfer fluid.

After 3:30 p.m, a gradual deterioration in efficiency is observed. This drop is attributed to the decrease in solar power, the accumulation of heat losses and the increase in the temperature gradient between the ambient air and the collector.

Figure 10 shows the thermal efficiency as a function of T^*

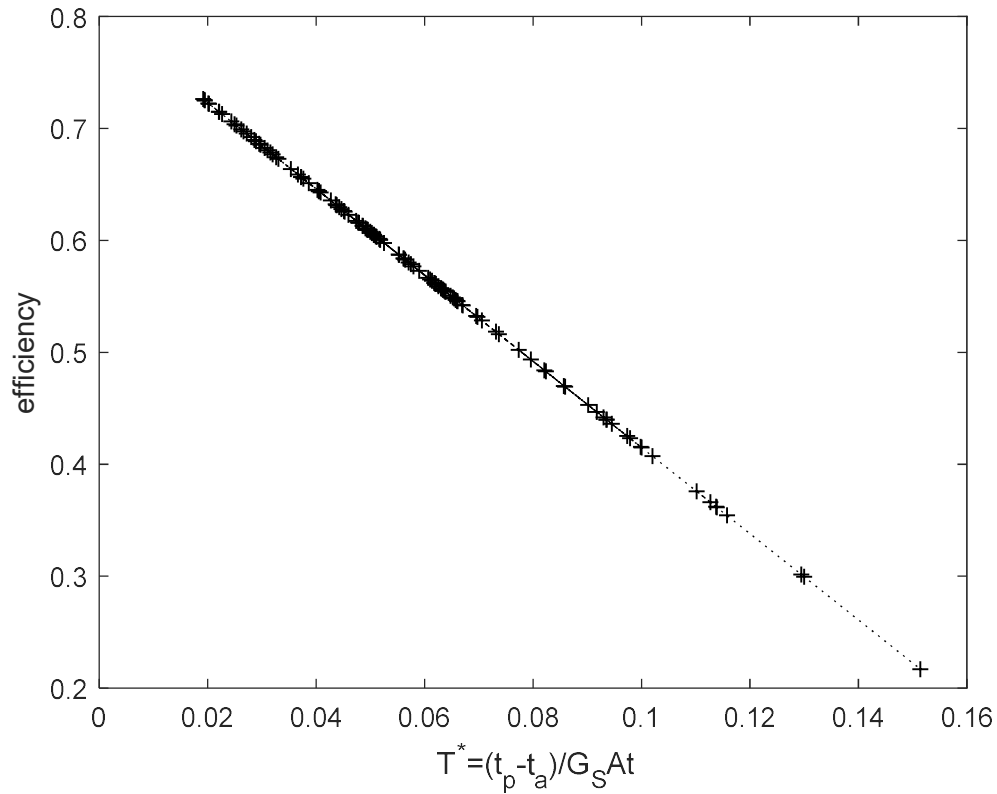


Figure 10 : Instantaneous efficiency of a solar collector as a function of the ratio T^*

The curve presented is a descending straight line, illustrating a gradual decrease in efficiency over time. Initially close to 72%, this efficiency gradually decreases, reflecting cumulative heat losses and reduced sunlight. The shape of the curve is perfectly consistent with that found by Boukaré et al. (2015), and the maximum efficiency values are also similar. Indeed, Boukaré et al. (2015) obtained a maximum efficiency of 74% for an air flow rate of 3 m/s using a finned flat-plate collector.

➤ **Dryer efficiency**

The dryer efficiency calculated using equation 2 is on average $\eta=23.4\%$.

Based on the literature results, we can confirm that this efficiency is good and reflects the quality of the dryer thanks to the improvement of its collector. Lakshmi et al. (2018) achieved an efficiency of 12% with a mixed solar dryer, while López et al. (2019), achieved an efficiency of 10.66%. Dianda et al. (2025) achieved an efficiency of 22% with a direct forced convection dryer.

4. Conclusion

This study evaluated the thermal performance of an indirect solar dryer equipped with parabolic trough reflectors, using plantain as the drying test product. Experimental results demonstrate the system's remarkable efficiency, with a collector thermal efficiency of up to 73% and an overall dryer efficiency of approximately 23.4%. These performance characteristics underscore the major benefits of integrating reflectors in optimizing solar drying, particularly in tropical regions where sunlight is abundant. The in-depth analysis revealed the decisive influence of product geometry on drying kinetics, with longitudinal slices dehydrating more quickly than round slices due to their larger specific surface area. Furthermore, variations in temperature and relative humidity within the drying chamber were correlated with fluctuations in sunlight, highlighting the importance of precisely controlling operating conditions to maximize process efficiency. Although these results are promising, several areas for improvement can be considered, including the integration of solar tracking devices to maximize energy capture, as well as the adoption of pretreatments aimed at accelerating the slowest drying phases. These adjustments could contribute to significantly increasing the overall efficiency of the system and extending its application to other agri-food products.

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