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Realization and Experimental Study of a Forced Convection Solar Dryer

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Post-harvest losses represent a significant cause of food insecurity worldwide. These losses not only affect the availability of food, but they also impact the economic stability of farmers and communities dependent on these crops. Food drying presents itself as a viable solution to reduce these post-harvest losses and ensure greater availability of food for human consumption. It is in this context that our work on the creation of an indirect solar dryer with forced convection, integrating an automatic temperature control system, takes place. This study consisted of creating a prototype and subsequently carrying out drying experiments on onions in order to evaluate the performance of the device. Our experiments took place from October 25 to October 29, 2023 at Joseph KI-ZERBO University. After 8 hours of drying, only 12% of the initial mass of the onions remained. The solar thermal collector presented an efficiency of 62%. And a drying efficiency, estimated at 17% with an average sunshine of 600W/m^2.

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1. INTRODUCTION

The processing and preservation of food products constitutes an important issue, especially in countries where food self-sufficiency is not always guaranteed. It is therefore important after each harvest to ensure the proper conservation of products in order to ensure a stable supply of food even when fresh products are not available. Conservation also helps reduce post-harvest losses and wastage of surplus crops. By preserving food for periods of shortage, it promotes food self-sufficiency and contributes to the well-being of communities. Reducing post-harvest losses allows producers to improve their income, lower costs and preserve the environment [1]. Today there are several means and techniques of preservation such as refrigeration, freezing, pasteurization, drying, etc. Drying has long been used over the centuries in different societies around the world as a technique for preserving products. The advent of progress through the consideration of hygiene and the speed of responding to requests for dried products have led to the development of several drying methods[2]. Drying food products corresponds to a reduction in the water content inside the product. But the use of fossil fuels for drying poses a major problem of cost and environmental protection. Thus, it is important to use renewable energies such as solar energy [3-5].

Burkina Faso has a significant solar resource. Its average daily sunshine is around 5.5 kWh/m²/d. There is therefore considerable interest in the scientific study of solar dryers. Solar drying is a conservation and recovery process which promotes the storage of food and which uses solar energy as a heating source, it constitutes a cost-effective means for the dehydration of agro-food products at low temperatures [6.7]. It is an efficient, sustainable and environmentally friendly technology. For this purpose, there are several types of solar dryers. Depending on the mode of their operation, we distinguish: Direct wage dryers, indirect solar dryers, hybrid wage dryers, mixed wage dryers [8].

Indirect solar drying offers a superior solution by enabling controlled drying processes that preserve the quality and nutritional content of products [9,10].

In drying industries, an improvement in energy efficiency of 1% leads to profit growth of up to 10% [11]. For the same final humidity, the relative thicknesses of the products are not constant [12]. An increase in drying air temperature leads to a reduction in drying time [13].

The literature actually tells us that the indirect solar dryer has better performance compared to the direct dryer. This is how a lot of work has been carried out on this type of dryer, some of which we cite.

Boulemtafes and D. Semmar, [14] in 1999 already designed an indirect dryer and tested its performance through drying experiments. Djamel Mennouche [15] using an indirect solar dryer effectively dried mint and was able to conclude that the drying presented a single phase. Benseddik Abdellouahab[16] carried out and numerically studied the drying of figs in an indirect solar dryer in forced convection. Dianda et al [8] studied the performance of an indirect solar dryer with a collector fitted elsewhere in drying papaya. Thierry et al [17] studied the performance of an indirect solar collector dryer equipped with hemispherical concentrators by drying mango and ginger.

The present work contributes to the improvement of this type of dryer with new technology. Firstly, it is a question of creating an indirect solar dryer, with forced air circulation and having an automatic temperature control system in order to allow the drying of a wide range of products while respecting the temperature intervals. required to retain the maximum of their nutritional values. Secondly, an experimental study is carried out to determine the performance of the dryer produced.

2. MATERIALS AND METHODS

2.1 The Dryer

- **The solar collector**

The collector is fixed above the drying box. A frame inclined on both sides carries clear glass glazing on each slope with dimensions: 1mx 0.3m x 0.005m. This double slope offers better capture of solar rays throughout the day. Below the glazing is the absorber which is a sheet of iron (7 mm) painted black. This absorber is above the drying box. The entire dryer rests on a 20 mm square tube support with a height of 0.6 m.

- **The drying box**

The drying box is the enclosure which must contain the products to be dried. It is important to ensure that it is well insulated to avoid heat loss. Our drying box is made of iron using 20 (mm) square tubes. It has a length of 1m, a width of 0.6m and a height of 0.16m. A layer of 2 cm polystyrene insulation on the side and bottom walls. The interior of the drying chamber is lined with aluminum sheet. Inside the drying box are placed two racks 1m long and 0.55m wide. A downward curved door allows for closure and prevents heat leakage. On this door where the fresh air enters are the 3 fans, the thermostat and the PV solar module. The air outlet is slightly raised upwards, which allows for a difference in level between the air inlet and outlet.

- **The forced convection and temperature control system**

To force air convection and ensure temperature control inside the dryer, we have three identical fans and a thermostat. This equipment operates using a PV module sized according to needs. The characteristics of this equipment are recorded in Table 1.

- **Operating principle of the dryer**

The forced convection solar dryer with automatic temperature control operates using solar thermal and photovoltaic energy. In fact, the solar collector with two slopes located above the drying box transforms the sun's rays into heat. The air entry into the dryer is forced by a fan (which in principle improves the drying process) powered by PV energy. Once this air is in the dryer, it heats up by recovering heat from the absorber (which is the upper part of the drying box). This hot air draws moisture from the products and then escapes through the upper opening of the dryer.

To control the temperature inside the dryer, we have a thermostat equipped with a probe that is placed inside the drying box. The other two fans are connected to the thermostat. Depending on the need, we adjust the minimum and/or maximum temperature to be inside the dryer. Once the desired temperature is reached, the thermostat closes or opens the electrical circuit to turn two fans on or off. This automatic temperature control allows various products to be dried while maintaining the temperature range required to preserve their nutritional or organoleptic properties as much as possible.

2.2 The Devices Used

To carry out our experiments, we used the following devices:

- a GRAPHTEC brand data logger model midi LOGGER GL 220 equipped with 10 thermocouples to record and record temperature values,
- an SR03 type pyranometer, Sensitivity 9.58 µV (W/m2) to measure solar lux,
- a hot wire anemometer to record the air speed values,
- and a PCE-BH 6000 brand electronic scale to measure the mass of the product during drying. Fig. 2 shows these different measuring devices.

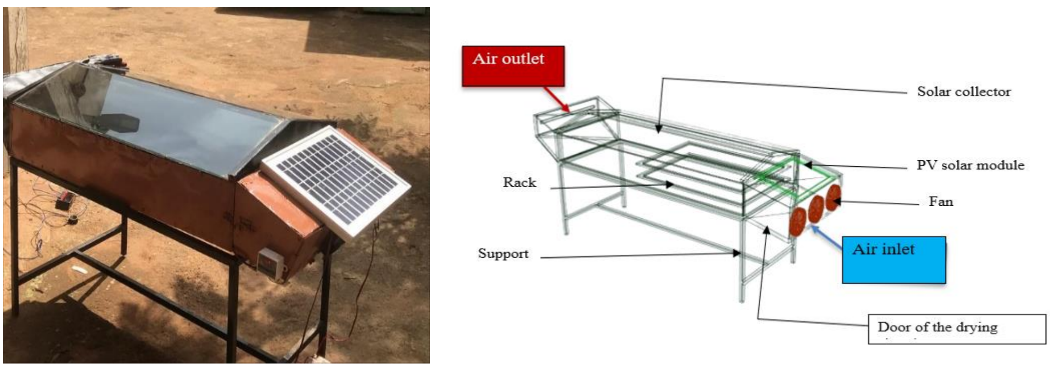

Fig. 1. Forced convection solar dryer

Table 1. Characteristics of the electrical devices used

Devices	Number	Voltage	Power	Operating time	Energy
Fan	03	12V (DC)	1,80 W	08h	43,20 Wh
Thermostat	01	12V (DC)	0,02 W	08h	0,16 Wh
PV Module	01	12V (DC)	10Wc	08h	

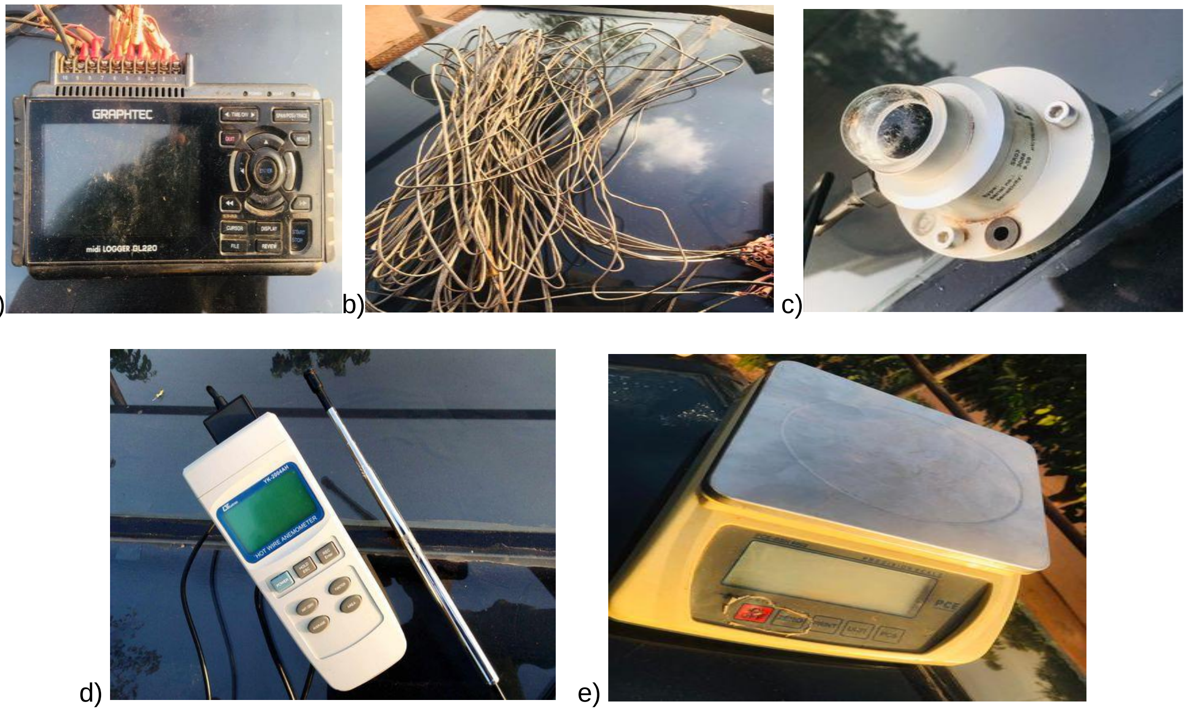

Fig. 2. Datalogger (a), thermocouples (b), pyranometer (c)anemometer (d), electronic scale (e)

2.3 Mathematical Approach

➢ **Water Content**

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

$$X(t) = \frac{m(t)(X_0+1)-m_0}{m_0} \quad (8)$$

With X(t): water content of the product at time (t), m(t): mass of the product at time (t) in kg, Xo: water content of the product on a dry basis and mo: initial mass of the product (kg).

➢ **Dryer Efficiency**

The efficiency of the dryer is determined by the following relationship :

$$\eta = \frac{m_e \times L_V}{N \times G \times S} \quad (9)$$

With η: dryer efficiency, me: mass of water extracted (kg), Lv: latent heat of vaporization of water (J/kg), N: Drying time, G: Average solar irradiation (W/m^2) and S: collector surface (m^2).

➢ **Average Air Flow**

The average air flow D (m3 /s) at the inlet of the dryer is calculated as follows:

$$D = V \times S = V \times \pi \times R^2 \quad (10)$$

With V: air speed at the dryer inlet (m/s), S: air inlet section (fan surface) in m2 and R: fan radius (m).

➢ **Collector Performance**

The efficiency of the collector ηc is determined by the following relationship: [18]

$$\eta_c = F_R \alpha \tau - F_R U_L \frac{(T_s - T_e)}{I_t} \quad (11)$$

$F_R \alpha \tau$: Optical efficiency, $F_R U_L$: Overall heat loss coefficient. I_t : Incident solar irradiation of the collector in (W/m^2), Ts : Air temperature at collector outlet (°C), Te : Air temperature at collector inlet (°C).

2.4 The Onion

The dried product for the experimental phase is the onion. Onion production worldwide is around 18,859,001 tonnes, a significant part of which (508,740 tonnes) comes from West Africa. However, the losses recorded during conservation, despite the different methods used, reach 22% [19]. Dried onion is increasingly integrating into eating habits and has become a standard ingredient used as an aromatic additive in several agro-industrial products such as sauces, soups, sausages, meats, fries, biscuits, etc.

3. RESULTS AND DISCUSSION

3.1 No-Load Tests

We carried out tests without loads in the dryer during the day of October 25, 2023. During these tests we monitored the sunshine, the speed of the air at the entrance to the dryer, the temperature of the air in the collector and in the drying box. The results obtained are presented and discussed.

Fig. 3 shows the sunshine evolution curve.

We generally see that sunshine increases considerably in the morning and reaches a maximum value of around 1000 W/m2 before decreasing. However, cloud disturbances occurred, causing sawtooth variations in the solar flux. The average irradiation value on this day is approximately 703 W/m2.

Fig. 4 shows the evolution of the air temperature at the collector level.

All these curves look practically the same. The air temperature at the collector inlet varies slightly and is approximately equal to the ambient temperature. However, the air temperature at the outlet is significantly higher than that at the inlet. This is proof that the air receives heat and its temperature increases. We sometimes notice a drop in the air temperature at the outlet which is due to the reduction in sunshine; the heating of the air is therefore linked to sunshine. The maximum air temperature recorded at the outlet is 69.5°C. The average air temperatures at the inlet and outlet of the collector are 37.83°C and 60.58°C respectively.

Fig. 5 represents the evolution of the temperature in the drying box.

The temperatures on the two racks show the same trends. Even if at times the temperature of the two racks seems to be identical, we notice that rack 2 has a slightly higher temperature than rack 1. In fact, rack 2 is the one closest to the absorber, which justifies its temperature higher than that of rack 1.

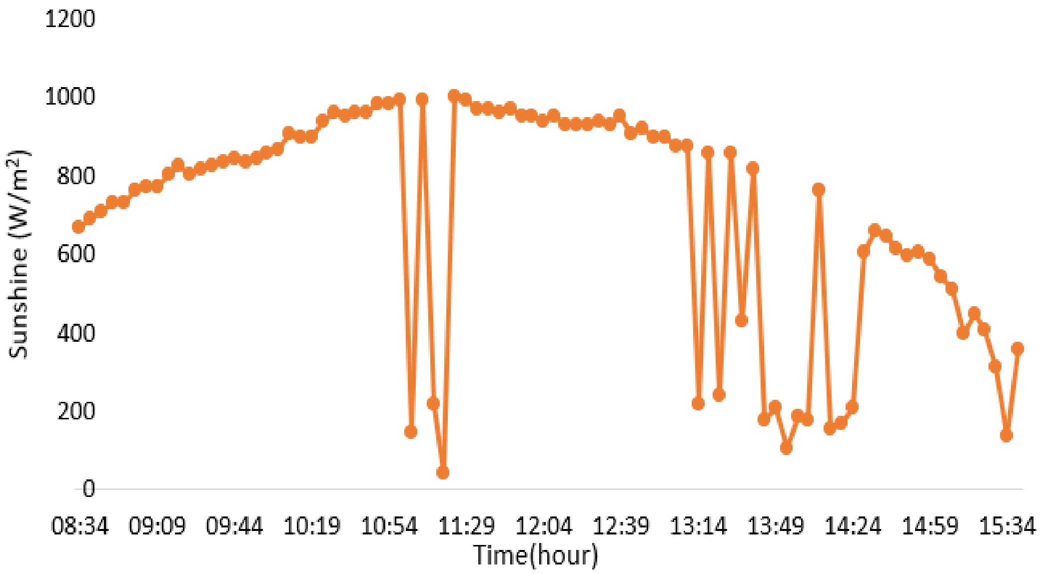

Fig. 3. Evolution of sunshine

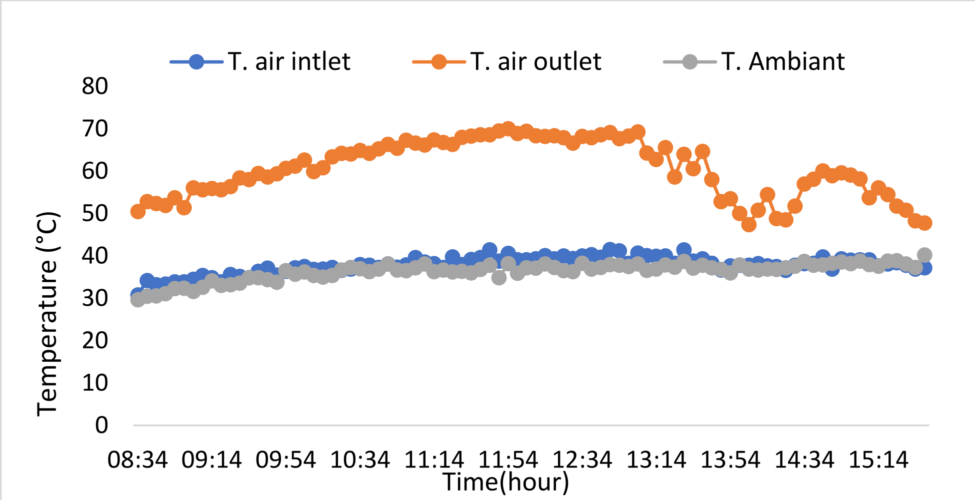

Fig. 4. Evolution of the temperature in the collector

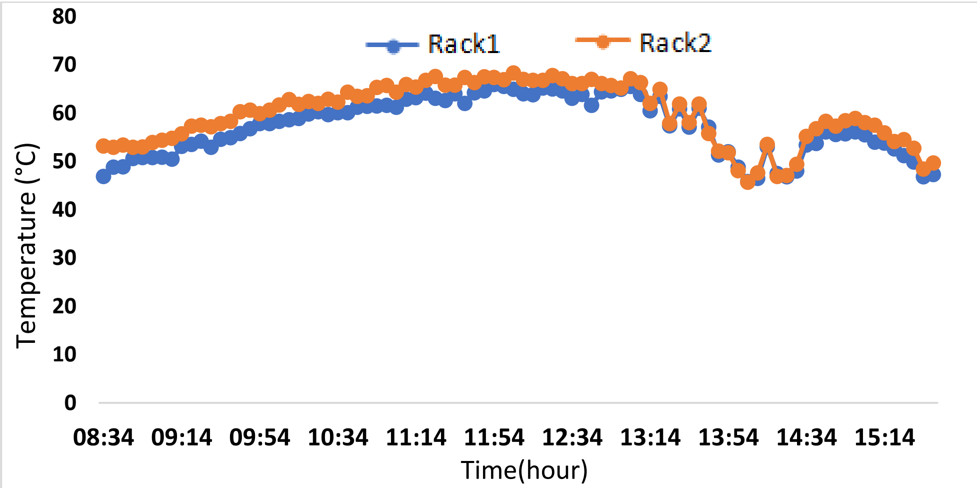

Fig. 5. Evolution of the temperature in the drying box

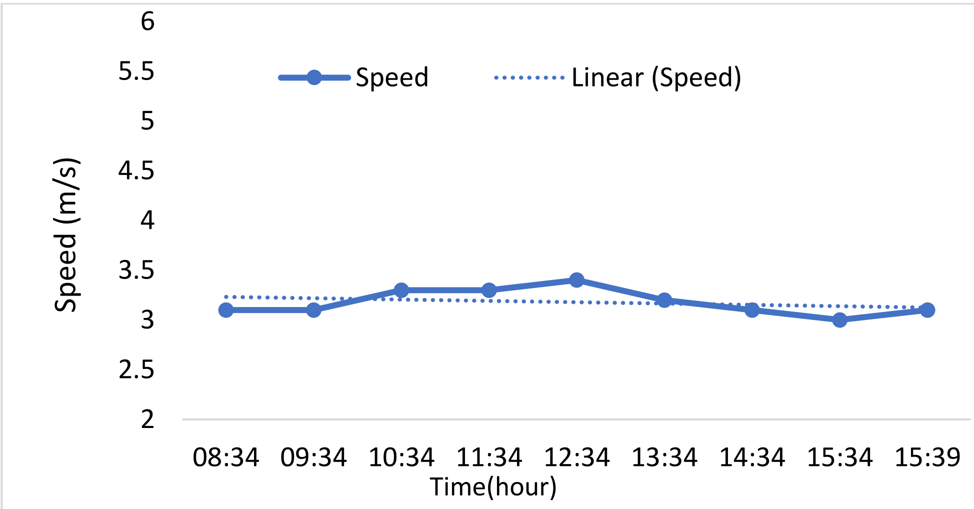

Fig. 6. Air speed at dryer inlet

Fig. 6 represents the evolution of the air speed at the inlet of the dryer.

The speed measured here is that of the air propelled by the fan at the inlet of the dryer. We observe that the speed curve varies little during the day. This means that the fan brings in air almost constantly. The average measured speed is approximately 3.1 m/s.

The calculated air flow rate D at the dryer inlet is: D= 0.029 m3/s. The efficiency of the collector ɳc is: ɳ_c= 0.62 or 62%.

3.2 Load Testing

In order to determine the actual performance of the dryer, we carried out onion drying tests between October 26 and 28, 2023.

➢ **Temperature and sunshine**

Thanks to the data logger and the pyranometer respectively we followed the evolution of the temperature of the drying air on the racks and the sunshine received on the drying site.

Fig. 7 represents the evolution of sunshine and air temperature on the racks.

The day was slightly sunny and punctuated by cloudy periods. This can be seen by the low level of sunshine from 11:30 a.m. onwards. As for the temperatures on the two racks, they have the same appearance and follow the sunshine. Around 11:48 a.m. the maximum temperatures on the racks were recorded. They are approximately 60°C for rack 2 and 56°C for rack 1. Rack 2 being closer to the absorber, has a temperature higher than that of rack 1. In fact, when the absorber heats up, it dissipates its heat in the drying box which is first received by rack 2. Some authors have obtained the same results [20-22].

This air loses part of the energy to evaporate the water from the products before passing to rack 1. The action of the fan promotes the passage of air over rack 1. The temperature difference on the racks under load is clearly visible compared to the empty test due to the fact that the air loses heat before passing over the next rack.

➢ **Drying kinetics**

During drying we followed the evolution of the mass by weighing and we calculated the content using the relation of equation 8. Drying is completed when the mass after two weighings remains practically unchanged. 1000g of onion is subjected to drying.

Fig. 8 shows the evolution of the water content of the onion on the racks during drying.

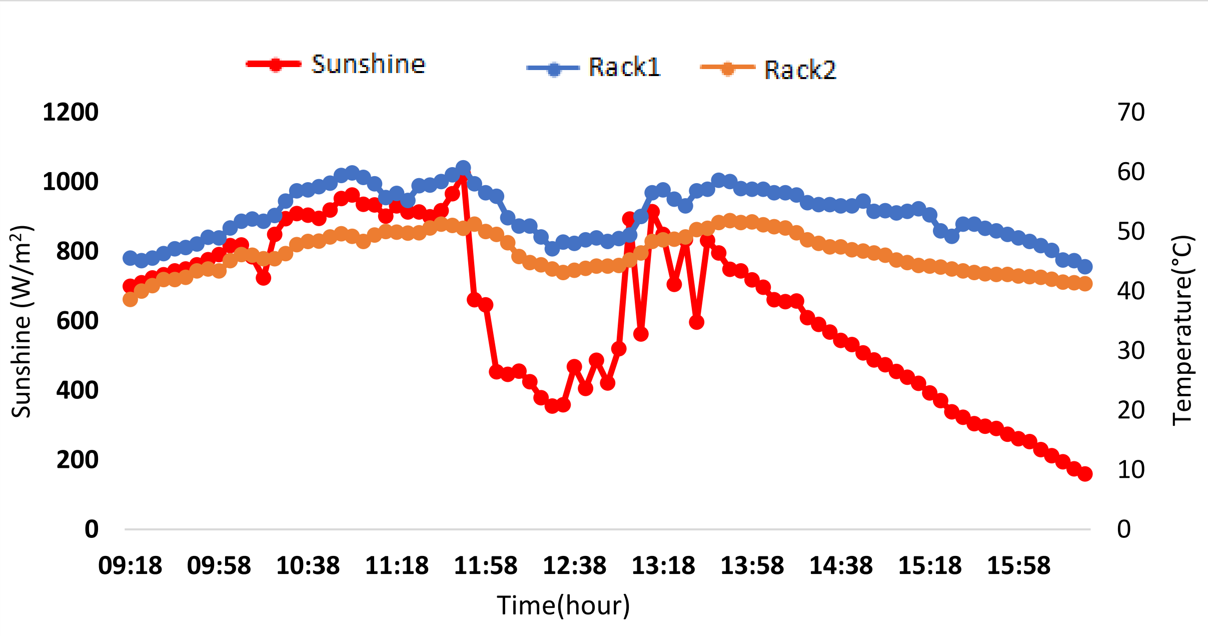

Fig. 71. Evolution of the temperature of the onion on the racks on October 26, 2023

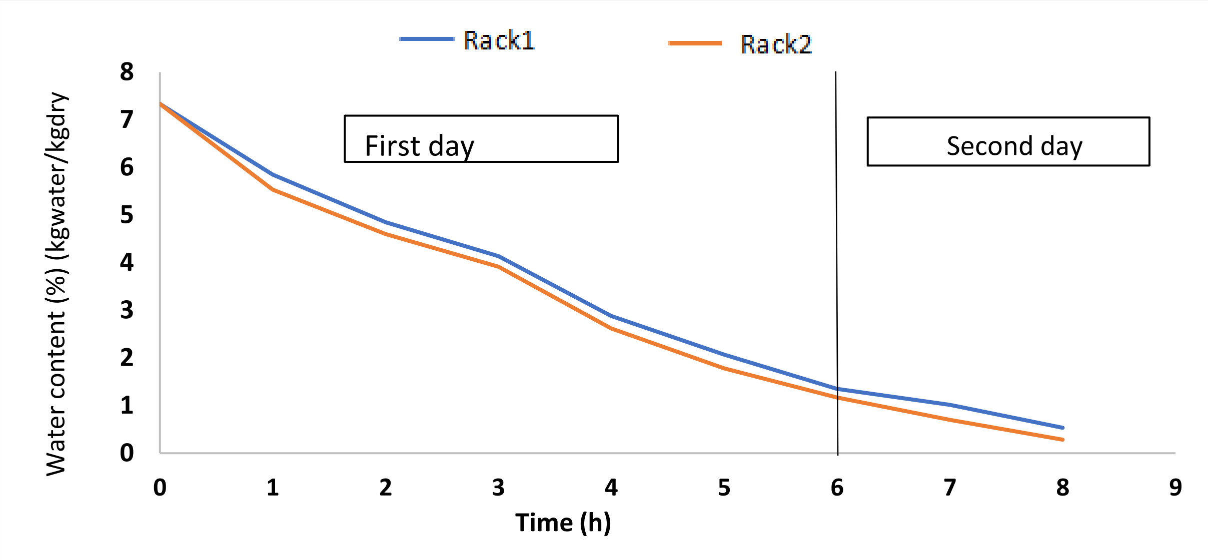

Fig. 8. Evolution of the water content of the onion during drying

The kinetics of onion drying only presents a decreasing phase, which is the case for most agri-food products [23-24]. The shape of the curves reveals that the water content decreases rapidly at the start of drying, then more and more slowly. Indeed, at the start of drying, the mechanism of movement of water by capillary action through the walls of the pores of the slices towards the surface takes place in an accelerated manner, thus reflecting a fairly rapid reduction in the water content in the product.

Drying lasted 8 hours with a final water content of around 12%. This final value of water content is consistent with literature data.

Fig. 9 and 10 show the onions before and after drying.

Fig. 9. Onion before drying

Fig. 10. Onion after drying

- **Dryer Efficiency**

The efficiency of the dryer calculated by the relation in equation 11 is worth $\eta = 0.17$ or an efficiency of 17%. This yield is quite average.

- **Temperature Control System**

The temperature control system allows you to adjust the temperature inside the drying box to adapt it to the product to be dried. We tested its effectiveness by setting the maximum air temperature in the box at 60°C.

Fig. 11 illustrates the evolution of temperature and sunshine when the temperature control system is activated.

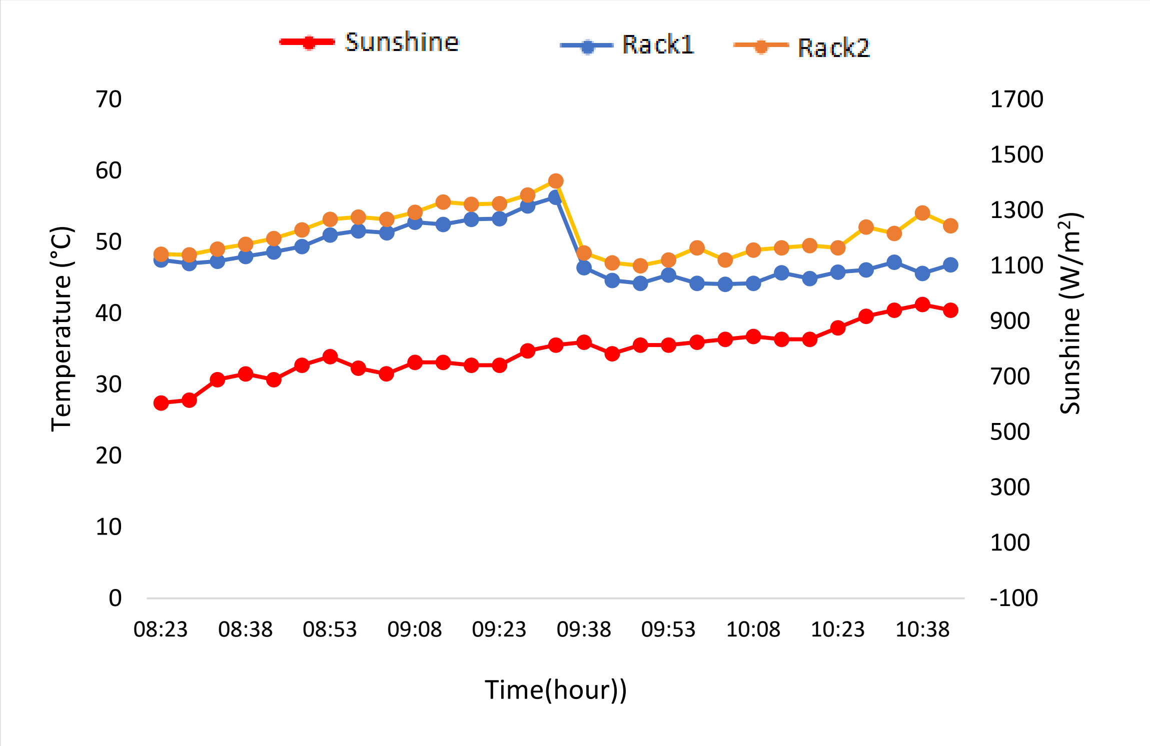

Fig. 11. Evolution of temperature and sunshine with the temperature control system

We observe that around 8 a.m. and 9:20 a.m., temperatures increase, as does the sunshine. However, from 9:23 a.m., a sudden drop in temperatures occurs, from around 60°C to 45°C. Temperatures remain relatively stable in the range of 45°C to 55°C while sunshine continues to increase. This observation clearly highlights the importance of our temperature control system during the drying process. In fact, we note that when the temperature reaches 60°C, which is the maximum temperature not to be exceeded, the system is automatically activated to lower this temperature. The system allows the temperature to decrease even though the sunshine continues to increase.

4. CONCLUSION

A new indirect solar dryer technology has been developed and tested. The tests were carried out empty, under load and with the temperature regulation device. The drying kinetics of the dried product, namely the onion, showed only the decay phase and a final content of 12%. The efficiencies of the collector and the dryer are 62% and 17% respectively. The temperature control system effectively controls the air temperature in the drying chamber. This system shows good performance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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