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Experimental Study of a Direct Solar Dryer with an Automatic Temperature Control System

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ABSTRACT

Preventing post-harvest losses is an imperative for human populations. Drying is one of the various conservation techniques. This is an operation that requires a fair amount of energy, hence the need to use available renewable energies such as the sun. For countries with a lot of sunshine, solar dryers are an asset for preserving agriculture products. However, the dryers traditionally used do not perform satisfactorily, hence the need to develop 'modern' dryers. The present work concerns the design and study of a direct solar dryer whose internal temperature can be regulated. The experimental study consisted of monitoring the temperature of the drying air in the dryer at no load and under load, monitoring the moisture content of the products being dried and determining the dryer's output. The products to be dried were okra and tomatoes. The results of the no- load test showed that the air can reach a temperature of 84°C in the dryer. During drying, the average temperatures recorded in the dryer were around 58°C and 56°C for okra and tomatoes respectively. The drying kinetics showed only one phase, the decreasing phase. The average thermal efficiency of the dryer is 22%. The results obtained are appreciable.

Key words: direct solar dryer, temperature, regulation, drying kinetics, efficiency

1. INTRODUCTION

Drying was an ancient technique, traditionally practiced by exposing the products to be dried directly to dry air [1,2] and sunlight [3], usually in unenclosed environments. This was not without consequences. Direct exposure of the product to be dried in the sun results in a loss of nutritional value, as temperature has a significant influence on the final dry product. In addition, there is a deterioration in hygiene, which can lead to health problems if the product is exposed to open air and aerosols such as dust particles. Electric dryers offer good yields in terms of dried products, but their use is limited due to their high cost for rural populations with low economic incomes and the unavailability of electricity in many rural areas. Numerous advantages, such as lower drying costs and significant savings compared with electric dryers, make solar dryers a better alternative for drying [4]. The literature reveals the existence of several types of solar dryer with natural or forced air circulation. Several aspects of these dryers have already been studied in the literature [5-10]. Natural convection dryers rely on the natural circulation of air to promote the drying process. They are used for small applications and are generally simple to design. In a study of tomato, maize and mango drying using a low-cost natural convection solar tunnel dryer, Uwa Ujunwa R et al [11] showed that there is an exponential relationship between temperature and drying time.

The efficiency of natural convection solar dryers fueled by optimally selected biomass has been demonstrated by A. Deb et al. in their work [12]. Prakash and Kamatchi [13] have shown that a mixed-mode natural convection solar dryer combining a normal flat plate collector, integrated fins and a latent heat storage system performs well. Hadibi et al [14] used oven drying methods such as basic solar drying, solar-geothermal drying, solar convection drying and the combination of convection and geothermal drying to determine the most suitable method for drying tomato paste. After comparing the effects of these drying methods on exergy efficiency, economic issues and quality, geothermal energy combined with convection was judged to be the most suitable method. Thermal storage integrated with solar dryers is a subject that has given rise to a great deal of research work, such as that by Tera et al [15], who developed a heat storage system coupled to an indirect forced convection solar dryer used for drying tomatoes. The results obtained, in particular the overall average yield and drying time for tomatoes, bear witness to the system's relevance. Researchers are still looking to improve solar drying systems in order to reduce drying time and obtain better quality dried products. This is the purpose of this study. The main objective of this study is the development and experiment study of the thermal performance of a direct solar dryer. The dryer is equipped with an automatic temperature control system in the drying room.

2. MATERIALS AND METHODS

2.1. Material

2.1.1. Solar dryer

The solar dryer produced and studied is composed of two main parts, namely the drying enclosure and the temperature control system.

Figure 1 shows the diagram of the dryer.

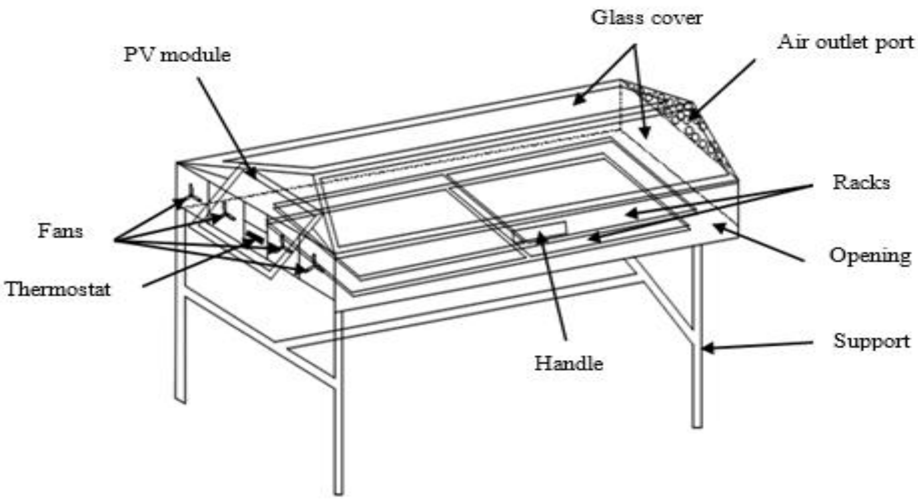

Figure 1: Diagram of the solar dryer

- **The drying chamber:** it has the shape of a parallelepiped. It measures 1.5 m long, 0.6 m wide and 1 m high. Polystyrene is used on the interior walls for thermal insulation purposes. The interior is covered with aluminum sheeting for protection against corrosion and contains two racks 1.30 m long and 0.55 m wide for holding the products to be dried. The roof is composed of two opposing glazing slopes to facilitate the dynamics of air masses and optimize the capture of solar radiation. Ventilation holes are made on the side walls to allow air renewal.

Figure 2 shows in real view the details of the drying enclosure and the racks placed there.

Figure 2: Details of the drying enclosure of the direct solar dryer

- **Temperature control system:** during periods of strong sunshine, a large increase in temperature is often observed in the drying chamber, which can affect the quality of the products to be dried. During this critical phase, an electronic thermostat is used to activate and deactivate the operation of the fans, in order to lower the temperature to the set temperature. These elements are powered by a photovoltaic solar module whose necessary power is pre-calculated. The temperature control system allows the products to be dried while respecting the temperature conditions and retaining the maximum nutritional value of these products.

The direct solar dryer with automatic temperature control uses the sun as an energy source. During the experiment, it is placed so that the photovoltaic solar module faces south so that one slope of the transparent cover receives a large portion of the solar radiation in the morning and the other slope in the evening to promote the greenhouse effect.

2.1.2. Measuring equipment

The experimental study was carried out with the measuring equipment composed of:

- ❖ a GRAPHTEC midi LOGGER GL220 temperature data logger. It has 10 inputs to which thermocouples are attached.
- ❖ thermocouples intended for temperature measurement,
- ❖ an electronic scale for measuring the mass of the products subjected to drying,
- ❖ a solarimeter with a sensitivity of 72 mV/1000 W/m² for measuring sunlight.

2.2. Method

2.2.1 Experimental protocol

The products undergoing drying are tomatoes and onions. The selected products are firm and not overripe. They are washed, cut, drained, and weighed before being introduced into the dryer. The product's mass is regularly monitored before determining changes in its water content. The drying process is stopped when the product's mass becomes practically constant. During the tests, the sunlight and air temperatures at the inlet, inside and outlet of the dryer were monitored. The okra slices were cut to thicknesses greater than the tomato

2.2.2. Mathematical expressions

The water content on a dry basis over time is determined by the following relationship:

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

With X(t): water content of the product at time t, m(t): mass of the product at time t, Xo:

initial water content of the product on a dry basis and mo: initial mass of the product.
The dryer efficiency is calculated by equation 2

$$\eta = \frac{m_w \times L_v}{N \times I_r \times S} \qquad (2)$$

m_w ; L_v ; N and S are respectively the mass of water evaporated during the total drying time, the latent heat of vaporization, the drying time and the surface area exposed to solar radiation.

3. RESULTS AND DISCUSSION

The experiments are conducted empty and loaded

3.1. No-load tests

The no-load tests of the dryer were carried out on February 7, 2025, the temporal evolution of the sunshine being shown in Figure 3.

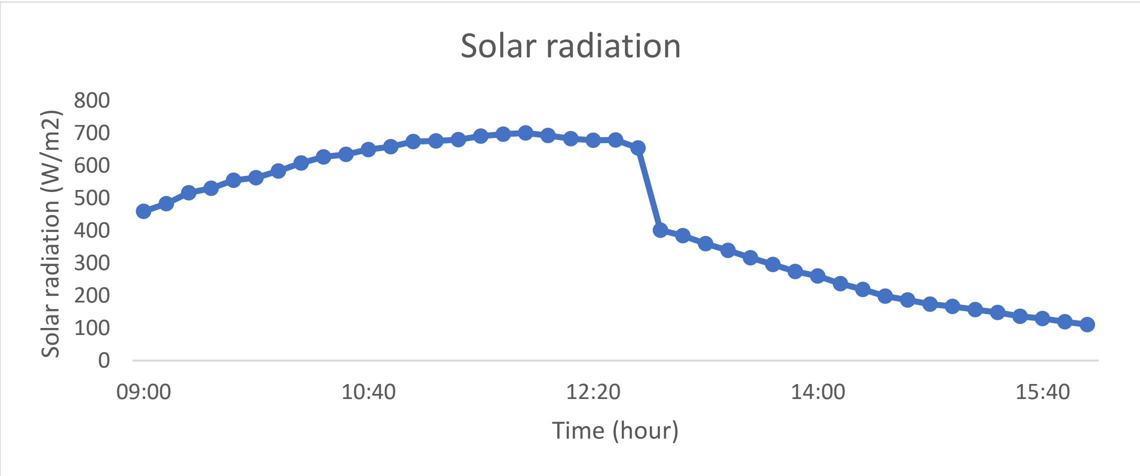

Figure 3: Temporal variation of solar irradiation on February 7, 2025

Overall, we observed an increase in solar radiation until reaching its maximum of approximately 700 W/m², recorded around 12 p.m. Subsequently, we observed a rapid drop from 700 W/m² to 401.2 W/m², followed by a gradual decrease until the end of the test. These three sequences can be justified respectively by a clear sky followed by a cloudy period between 12 p.m. and 1 p.m. and a partially cloudy sky until the end of the day. The average sunshine recorded on this day was approximately 441.5 W/ m².
Figure 4 shows the variations in air temperature at the inlet and outlet of the dryer as a function of time. In this experiment the temperature control system is not used.

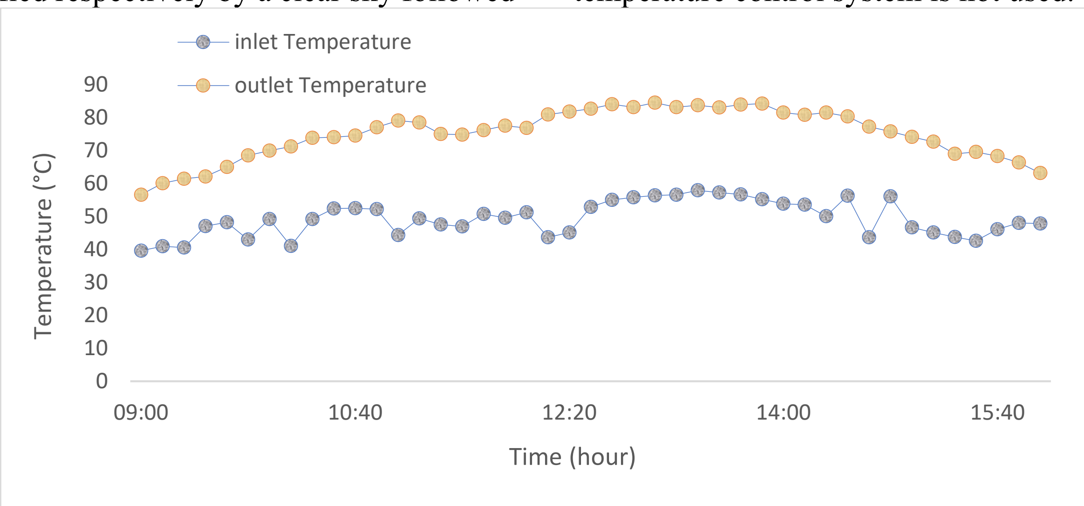

Figure 4: Variation of air temperature at the inlet and outlet of the solar thermal collector

A difference in air temperature is observed between the inlet and outlet of the sensor. The air temperature at the inlet varies little, with some fluctuations over time, but remains low compared to the air temperature at the outlet. This temperature difference is explained by the fact that the incoming air receives a large amount of heat thanks to the greenhouse effect, which contributes to increasing its temperature compared to the temperature at the inlet. The maximum and average air temperatures obtained at the inlet are 57.9 °C and 49.34 °C respectively. At the outlet of the sensor, 84.5 °C and 75.05 °C are recorded as maximum and average temperatures.

Figure 5 shows the evolution of the temperature in the drying cage of the racks log during the day of February 7, 2025 without the temperature regulation system.

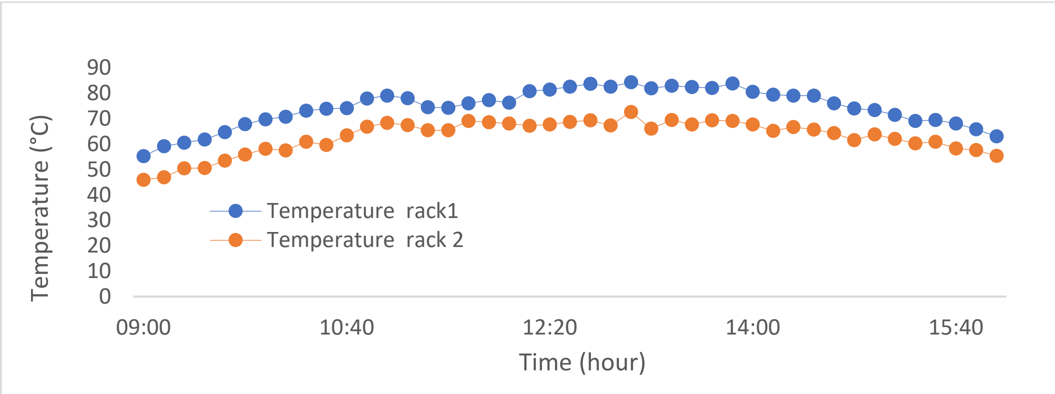

Figure 5: Evolution of air temperature at the level of the racks

The temperature on both racks has approximately the same characteristics throughout the day. The temperature of rack 1 is higher than that of rack 2. This is explained by the fact that rack 1 is the one closest to the glazing where the solar rays arrive. Since the temperature control system has not been activated, we observe a large rise in temperature especially at rack 1 where the maximum temperature is 84°C around 1 p.m. and 73°C on rack 2 at the same time. We also observe that the decrease in solar radiation does not significantly impact the temperature of the racks. This allows us to say that the dryer studied has good thermal inertia. On average, the air temperature at rack 1 is 74.46°C and 62.94°C for rack 2. The temperature difference observed on the two racks is higher than that observed by Dianda et al. [16] with an indirect solar dryer. This unfortunately indicates poor air circulation in the dryer.

Figure 6 shows the effect of the temperature control system on the operation of the direct solar dryer.

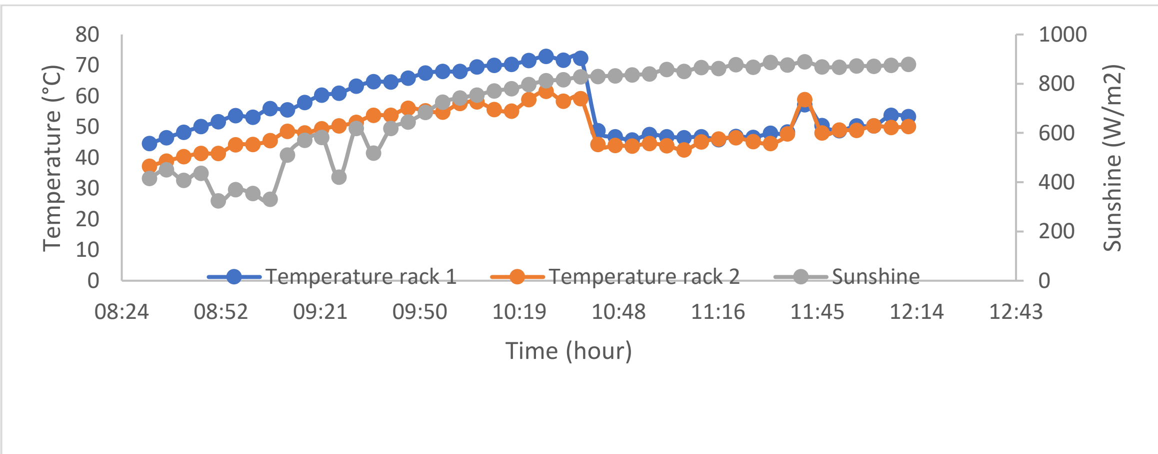

Figure 6: Influence of the temperature control system on drying

The experiment was carried out on February 8, 2025. The maximum desired temperature in the dryer is 70 °C. It is also observed that the temperature of rack 1 is higher than that of rack 2. The temperature of rack 1 having reached 70 °C, the control system started and a drop in temperature is observed. The temperature drops to about 46 °C. The temperature of rack 2 following the same dynamics going from lower values to values almost equal to those of the upper rack. These observations clearly highlight the importance of the temperature control system during the drying process. Despite the continuous increase in sunshine, our temperatures remained below the defined thresholds. This constant is also made by Dianda et al. [16].

3.2. Load tests

The experiments took place between October 21, 2024 and October 25, 2024.

Figure 7 shows the variations in okra temperature on the two drying racks and in sunlight on October 21, 2024.

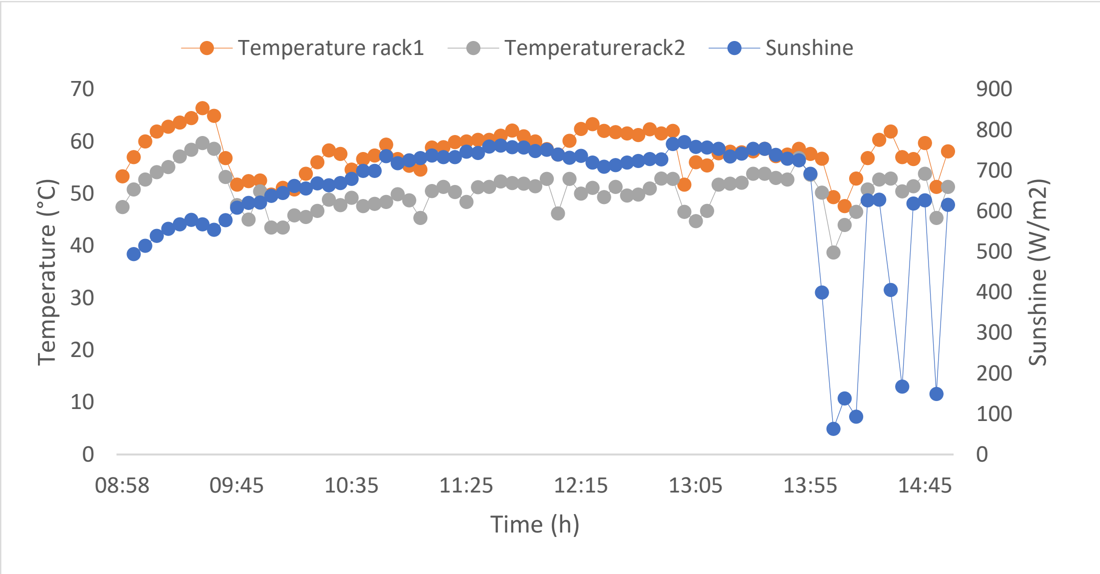

Figure 7: Temporal evolution of the temperature of okra on the drying racks

On this day, there was little sunshine at the beginning of the day. It then gradually increased over time until around 2 p.m. when a cloudy period was observed. This cloudy period caused large fluctuations until late evening with low values. The temperatures of the two racks had the same appearance over time. A rapid increase in temperature was observed on the racks at the beginning of drying. The temperature on rack 1 quickly reached the set temperature of 65°C, which activated the control system to lower the temperature. Some fluctuations were observed on the curves due to fluctuations in solar radiation. The temperatures remained practically constant throughout the drying process. Rack 1 had a maximum temperature of around 65°C (set temperature) while rack 2 had a maximum temperature of around 60°C. Since rack 1 is closest to the glass, its temperature is therefore higher than that of rack 2. This is explained by the fact that when the glass creates the greenhouse effect inside the drying cage, part of the heat produced is first recovered by rack 1 to evaporate the water from the products before passing to rack 2.

The variations in tomato temperature on the racks are shown in Figure 8.

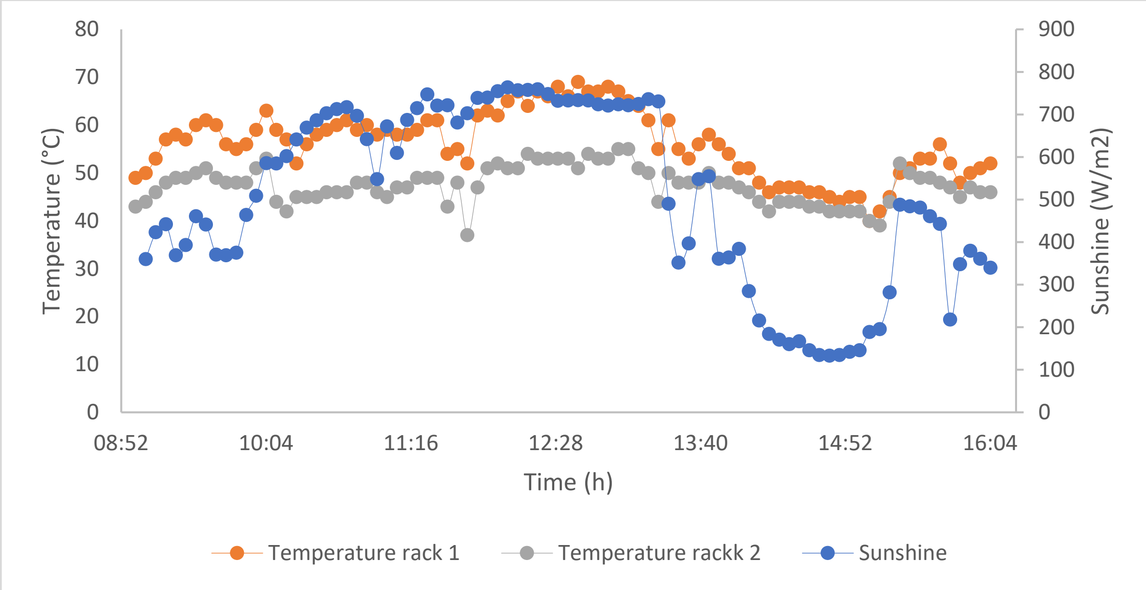

Figure 8: Evolution of the temperature of the tomato on the racks on October 25, 2024

For this experiment, the set temperature is 70°C. The temperatures of the two racks have a similar appearance throughout the day. Rack 1 reaches a maximum temperature of approximately 69°C around 1 p.m. and rack 2 a maximum temperature of approximately 55°C. Since the set temperature was not actually reached, the temperature control system did not activate. We also note that the temperature of the two racks changes according to variations in sunlight, but the temperature of rack 1 is frequently higher than that of rack 2 because of its position. Solar radiation increases slowly during the day. It reaches its maximum around 12 p.m. before falling due to cloud disturbances. Overall, temperatures remain high between 11 a.m. and 2 p.m., which allows for optimal drying.

Figures 9 and 10 show the drying kinetics of okra and tomato respectively during their drying.

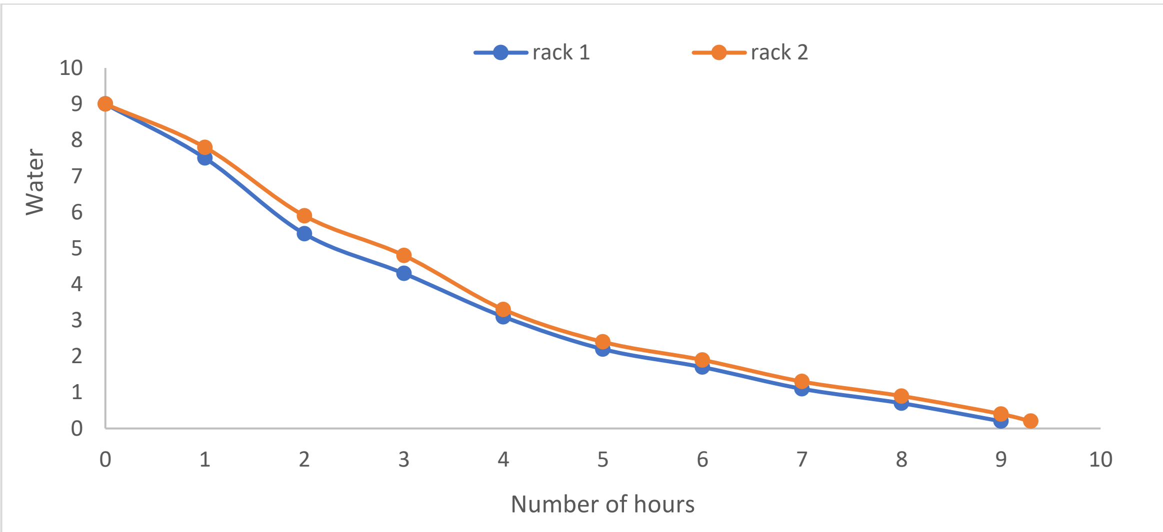

Figure 9: Curve of variation over time of okra water content

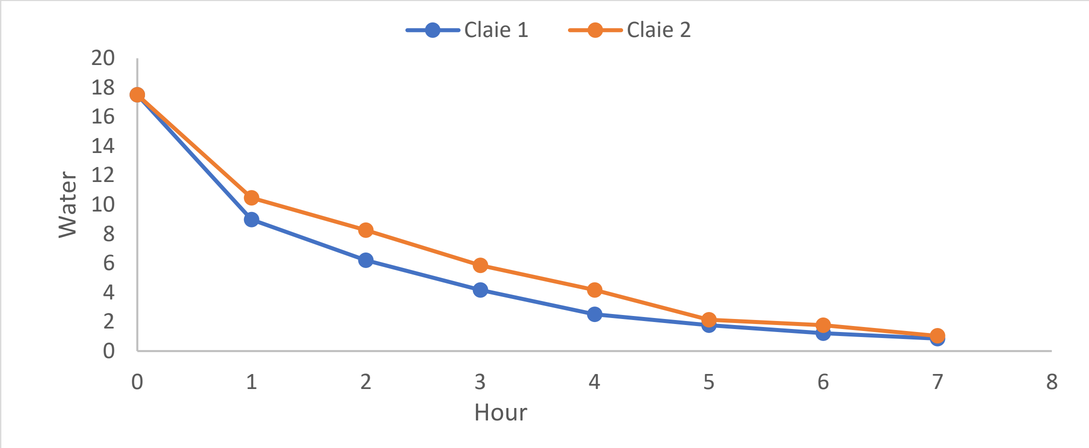

Figure 10: Curve of variation over time of water content in tomatoes

Okra drying curves show a decreasing phase.

The shape of the curves shows a rapid decrease in water content at the beginning of drying and then a slow decrease until the end. The steep slope at the beginning of drying shows that free water from the products on both racks is rapidly eliminated. However, after a few hours of drying, water loss slows down, beginning the transition to the elimination of bound water. It is also observed that the product on rack 2 has a higher water content than that on rack 1. This difference in water content is explained by the fact that the temperature on rack 1 is higher than that of rack 2. Similar observations are made by some authors in the literature [16-18].

The average temperatures during the drying of okra and tomato are approximately 58°C and 56°C respectively, although during the drying of tomatoes a temperature of 69°C was observed around 1 p.m. The drying of okra was carried out in nine (09) hours and that of the tomato in seven (07) hours despite the fact that the water content of the tomato is higher than that of the okra. This is explained by the fact that the okra slices have greater thicknesses than those of the tomato. Indeed, tomato slices with lower thicknesses carry out better thermal exchanges with hot air than the okra slices. The influence of thickness has been shown in the literature [19-22].

- **Thermal efficiency**

  The thermal efficiency of the dryer was evaluated by equation 2. Its average value is about 22%. This efficiency is much better than some dryers studied in the literature. Indeed, Lakshmi et al obtained an efficiency of 12% with their mixed solar dryer [23]. López-Vidaña Erick César et al., obtained an efficiency of 10.66% [24].

Figure 11 shows the images of the products before and after drying.

a) b)

c) d)

Figure11: Okra and tomato before and after drying (a: fresh okra, b: dried okra, c: fresh tomato, d: dried tomato)

4. CONCLUSION

A direct solar dryer was built and experimentally studied by drying okra and tomato. A temperature control system is attached to the dryer to regulate the internal temperature of the dryer. The tomato cut into thinner slices than the okra had a drying time of 7 hours compared to 9 hours for the okra. The drying kinetics present a single phase, namely the decreasing phase. The average temperatures during drying of okra and tomato are respectively approximately 58°C and 56°C. The average efficiency of the dryer is approximately 22%. The control system showed good temperature regulation in the dryer. In view of these results, the dryer produced is quite efficient.

Declaration by Authors

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Conflict of Interest: No conflicts of interest declared.

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