Thermal analysis and validation of a geodesic dome dryer for Capsicum baccatum

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Abstract

Today, Peru is among the first countries with the largest non-conventional agroexports worldwide. One of the most representative products is the Capsicum baccatum, which is mostly exported as frozen, pasta and sauces because the traditional process used for drying is not optimal. Given this, a geodesic dome type dehydrator, that uses solar thermal energy, was developed to contribute to the process of drying a variety of Capsicum baccatum. This research has been developed in the project "Design and development of a portable dehydrator for the transformation and conservation of pickled chili in Mórrope Lambayeque using renewable energies", which has the sponsorship of the National Program of Agricultural Innovation (PNIA) of the Ministry of Agriculture of Peru, the World Bank and the Inter-American Development Bank. The results using the dome dryer are a temperature of around 43° C has been obtained for a day with global irradiance at midday of 780 W m^{-2} and an air flow velocity of 1.1 m s^{-1}; in addition, for a load of 50 kg of chili the dome is able to reduce its moisture content from 89.5% to 15% in 20 days

Keywords: geodesic dome, Capsicum baccatum, solar thermal energy, drying, dehydration, ají escabeche, productive uses

1. Introduction

Peru is the fourth exporter of chili (genus Capsicum) in the world, among them, the *ají escabeche* or Capsicum baccatum is being increasingly valued especially due to the gastronomic boom nationally and internationally. The product that is exported dehydrated presents limitations due to a rudimentary drying process used. After harvest, the product is spread on the ground to be dehydrated by the sun. As a result, the product ends up contaminated, rotten or with other problems, reaching losses of up to 50% of the initial production. It should be noted that the project also seeks to maintain the carotenoids, organic pigments, which give the characteristic color to the chilies. The general consensus is that there is sufficient evidence to support increased consumption of carotenoid-rich food (Rodriguez-Amaya, 2018) since many health benefits has been attributed to carotenoids: eye health, brain-cognitive function, heart health, cancer prevention, skin-UV protection, fertility, immune modulation (Eggersdorfer and Wyss, 2018). Therefore it is important to optimize heating treatments to minimize carotenoids loss. Saini et al. (2014), assessed different types of drying processes for M.oleifera fresh leaves, finding that drying at 50°C in cabinet trays had the best performance preserving carotenoids and Direct solar drying (exposed to the sun) was the worst. Fratianni et al. (2018), evaluated 3 different temperatures for drying goji berries (50, 60, 70°C) finding no significant difference in carotenoids loss. Multari et al. (2018), found that 60°C was the best drying temperature for carotenoids contents in quinoa seeds. Considering this problem and that the level of global irradiance in Lambayeque is around 5 kW h m^{-2}, according to the Solar Atlas of Peru, it was proposed to optimize the drying process based on solar thermal energy in order to be used for the product transformation. The research has been developed in the project "Design and development of a portable dehydrator for the transformation and conservation of chili in Mórrope Lambayeque using renewable energies" for which it was considered to develop a geodesic dome dryer coupled to a thermal storage system that allow to standardize the parameters for optimal drying. The geodesic dome has been built and installed for tests in Cieneguilla, Lima, Peru with coordinates 12°04'10.0"S 76°45'15.5"W.

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The following images, in figure 1, show the transition in the appearance of chilies through the drying process.

Fig. 1:. Left: Photograph of Capsicum Baccatum. Fresh, dried into the dome and dried outdoors. Right: Fresh chili pepper.

2. Methodology

Based on the research of "Analysis of a geodesic dome solar fruit dryer" (Goswami, 2007) and considering the structural and homogeneity of temperatures advantages, a geodesic dome type dryer was developed consisting of a single dome and wind extractor. The dryer was designed to extract the moisture content from 90% to around 15% of chili. For this, a geodesic dome type dryer of 5 meters in diameter and 3 meters high was developed to obtain a homogeneous drying of the product. The dome was built with accessible materials in areas of agricultural activities. Polyvinyl chloride (PVC) tubes were used for the structure, a layer of Linear low-density polyethylene (LLDPE) was made using the heat-sealing process and a common plastic was placed on the floor.

It was used a datalogger specially designed to measure temperature and relative humidity in 11 different points distributed inside the dome. According to the figures 2 and 3, the elements with a *DHT#* nomenclature were the sensors that measured temperature and relative humidity and were located on the floor, on the top and on the sides inside the dome; whereas those with a *B#* nomenclature only measured the temperature which were on the trays. These measurements were taken every minute.

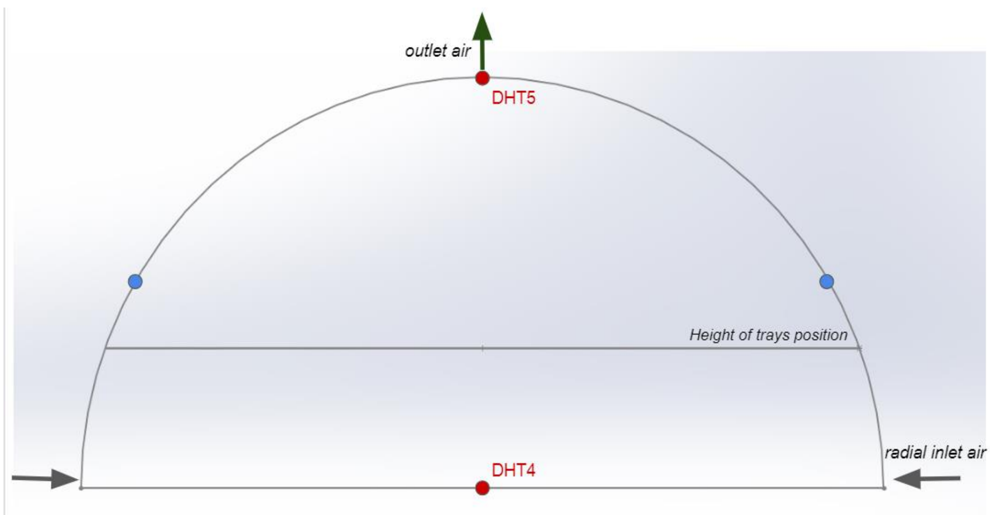

Fig. 2: Side view of a schematic diagram of a geodesic dome solar dryer. Distribution of the sensors which measures temperature and humidity.

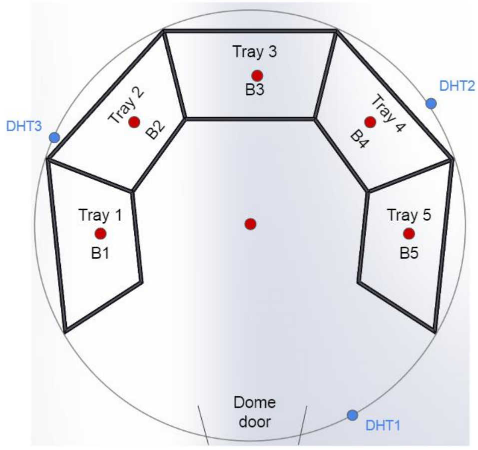

Fig. 3: Top view of a schematic diagram of a geodesic dome solar dryer. Distribution of the sensors that measures temperature and humidity.

Outside, weather conditions were measured with a Davis Portable Weather Station (figure 4) in which temperature, relative humidity, radiation and precipitation measurements were taken every 10 minutes to transmit them to a remote console.

Fig. 4: Left: Photographs of weather station DAVIS. Right: Panoramic view of the dome.

3. Results and discussion

Then, the graphs of the behavior of the dome's temperature and humidity during the month of August are presented for a solar energy average of 4.3 kW h per day. In the first graph you can see the cover's average temperature calculated with the average of DHT1, DHT2, DHT3, the floor center's temperature measuring in the point DHT4, the outlet temperature measuring in the point DHT5 and the inlet temperature using the ambient temperature of the Weather Station.

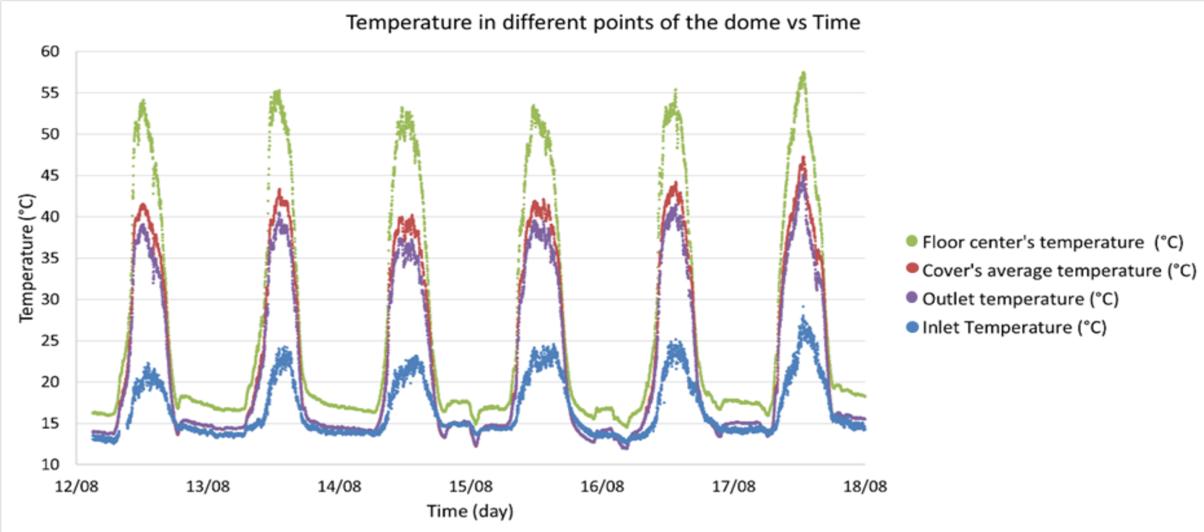

Fig. 5: Temperature in different points of the dome vs. Time.

It can be seen in the graph (figure 5), that the maximum difference temperature between floor and inlet temperature is around 31°C during the day and 2.8 °C in the night . The floor of the dome has been covered with a thick black plastic.

Floor temperature rises very quickly up to a maximum of 55°C in the mornings and decreases up to a minimum of 16.5°C even with an ambient temperature of 13°C.

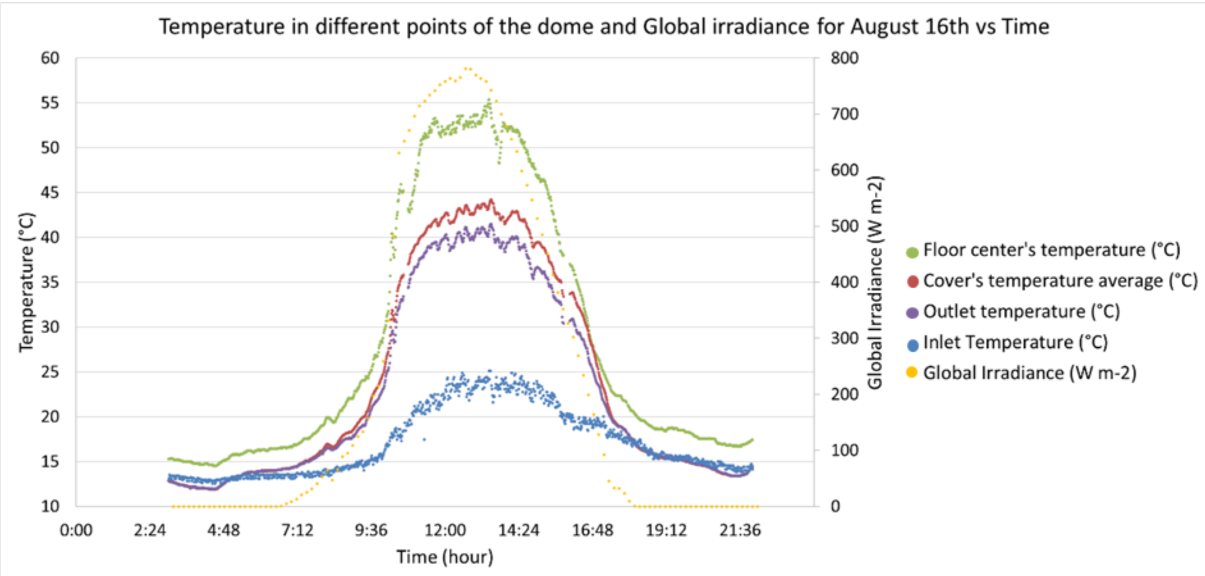

Fig. 6: Graphing of temperatures in different points of the dome on an average day of August 2018.

As is to be expected, it can be seen in the figure 6 that the increase of temperature in all the points is proportional to the irradiation during the day. Outlet air temperature of the dome is almost the same than in the dome cover, with a slight difference of 3°C in the peak hour at 1:00 pm.

It is worth mentioning that the temperature at dome exit (35°C to 40°C in four hours of sun) does not affect the properties of the chili owing to the maximum temperature allowed to a good drying, that is 60°C. Despite the above, the exit temperature can be modified by 3 ways:

- Increasing the input area of the air.

- Increasing the airflow of the extractor.
- Increasing the amount of product.

All these variables are currently being worked and can be grounds for future documents.

For the following graphs (figures 7 and 8), it was measured the average temperature using DHT 1 to DHT 5 and B1 to B2, the average of relative humidity (%) using DHT 1 to DHT 5, and the Inlet temperature using the ambient temperature of the Weather Station.

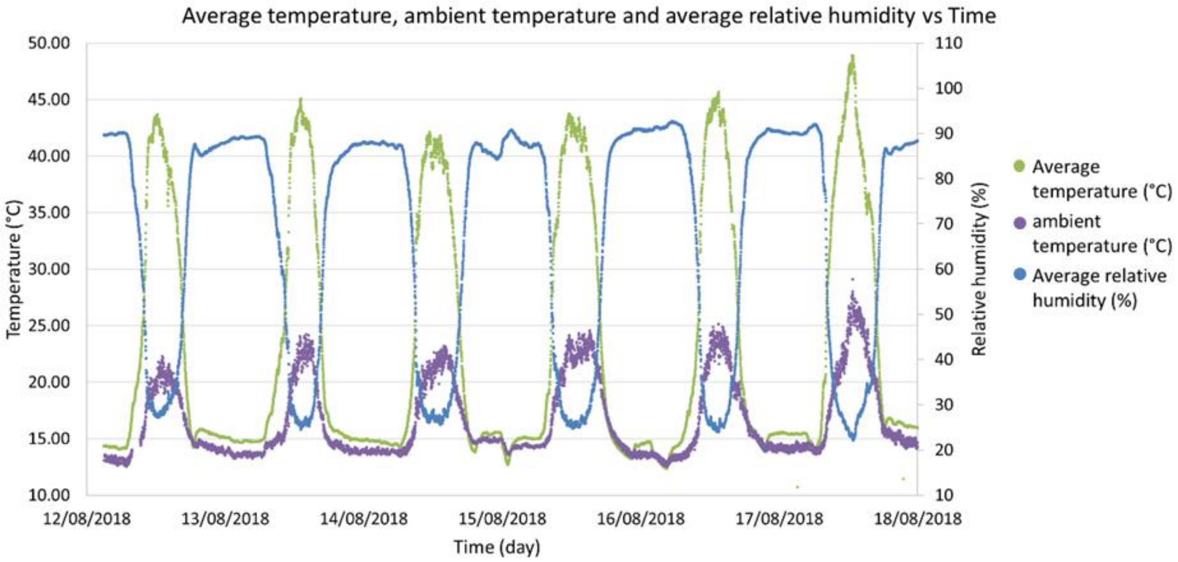

Fig. 7: Diagram model of the temperature and relative humidity on several days of the week.

It can be observed, in the previous graph, the uniformity of the measurements over time, which lead us to predict a steady and uniform dome behavior to drying process with better precision.

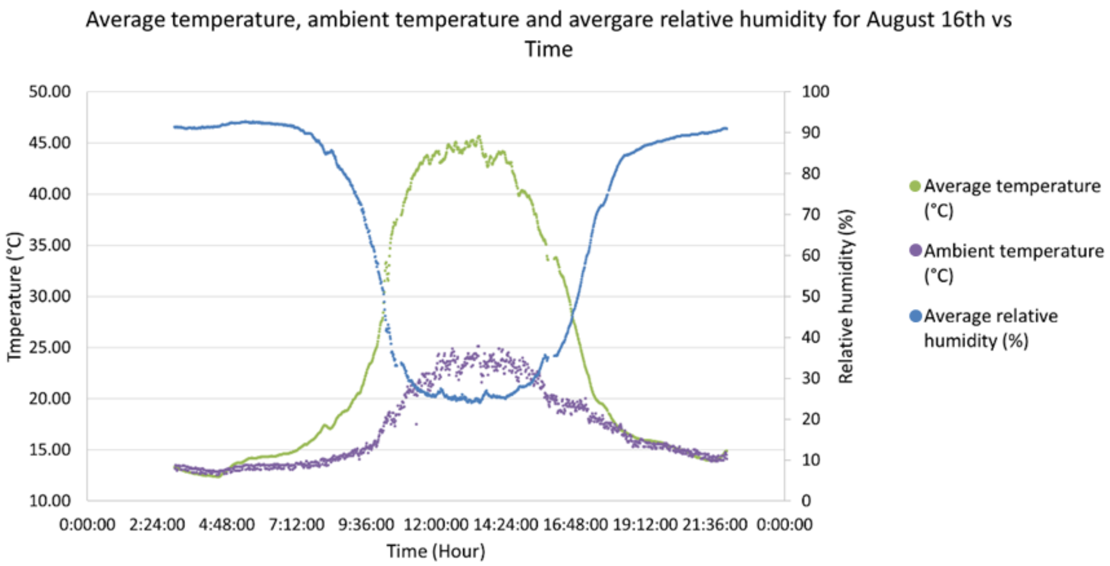

Fig. 8: Air behavior. Temperature and relative humidity inside the dome on an average day with respect to the environment.

In the figure 8, it can be observed how the dome affects the inside temperature and relative humidity, reaching a maximum of 45°C and a 25% of relative humidity.

3.1 Chili behavior

The tests were done with 50 kg of fresh chili. Each tray contains 10 kg of chili. The methodology used to measure the loss of moisture content was through the weight control of a sample of 5 chilies per tray. For which an electronic scale with resolution of 1 g inside the dome was used. Three times a day we proceeded to weigh the samples.

Fig. 9: From left to right. Photographs of the chili in sacks and their distributions inside the dome.

Figure 9 shows the distribution of peppers in the 5 trays inside the dome. The trays were constructed of steel and with a metal mesh with plastic coating.

By making use of the sensors B1- B5 located in tray 1- tray 5, we can show the homogeneity of the tray temperatures.

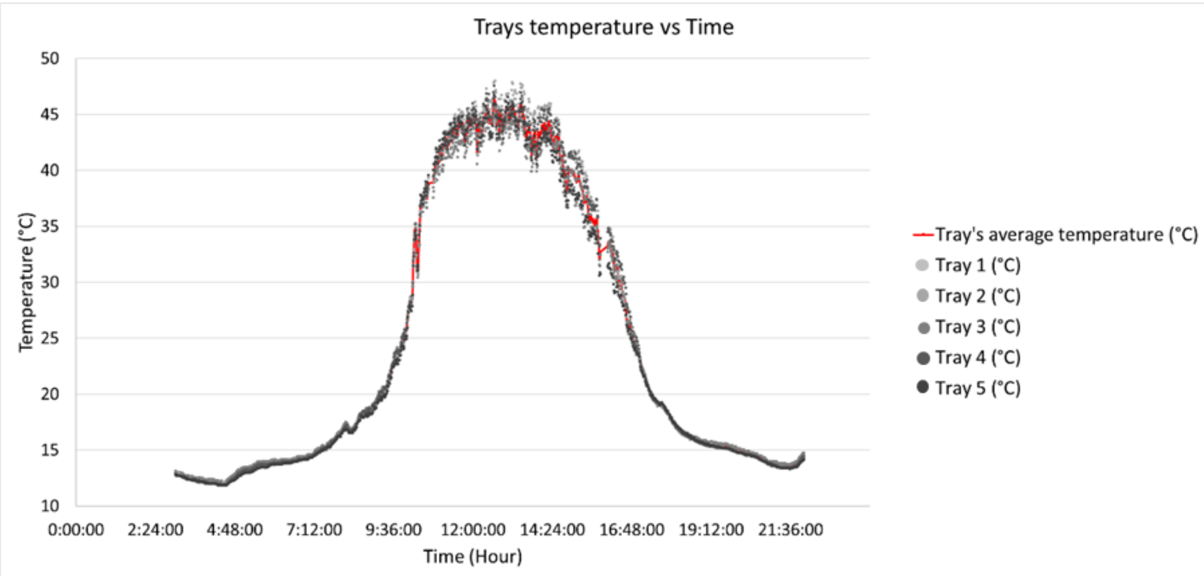

Fig. 10: Temperature in the five trays at a height of one meter above ground level.

In figure 10 is appreciated the uniformity in the measurements of the temperatures in the five trays distributed inside the dome. It was calculated an average standard deviation per day using temperatures of 0.368.

The loss of moisture content during the 20 days of the test can be observed in the figure 11.

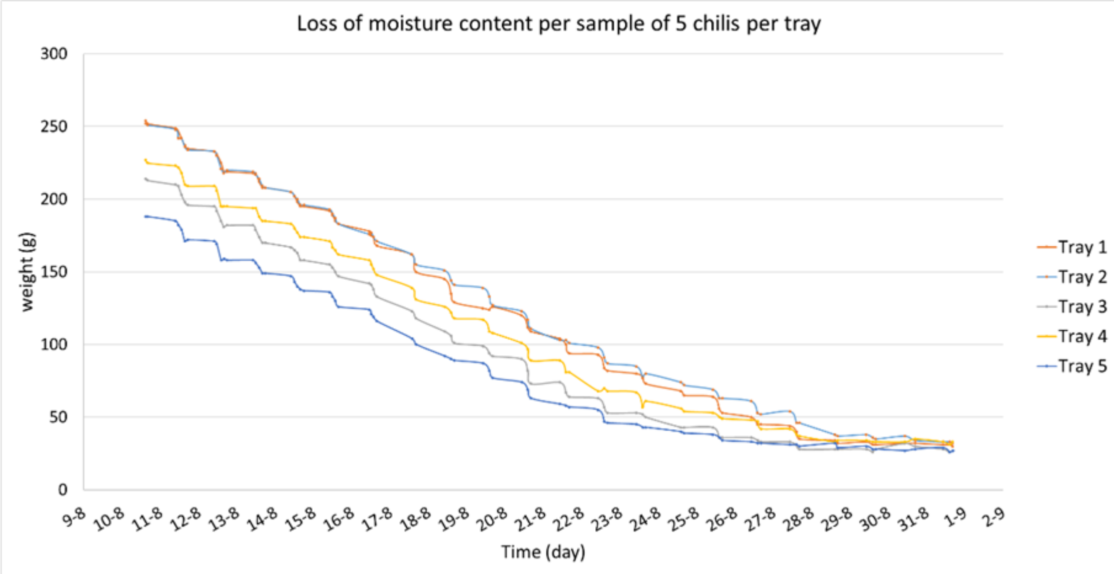

Fig. 11: Loss of weight per sample of 5 chilies per day.

The samples of tray 1, tray 2, tray 3, tray 4 and tray 5 had an initial weight of 254, 252, 214, 227 and 188 grams respectively. After 20 days of drying with an average daily radiation of 4.3 kW-h m^{-2}, a final weight of 30, 31, 26, 29 and 24 grams respectively was obtained.

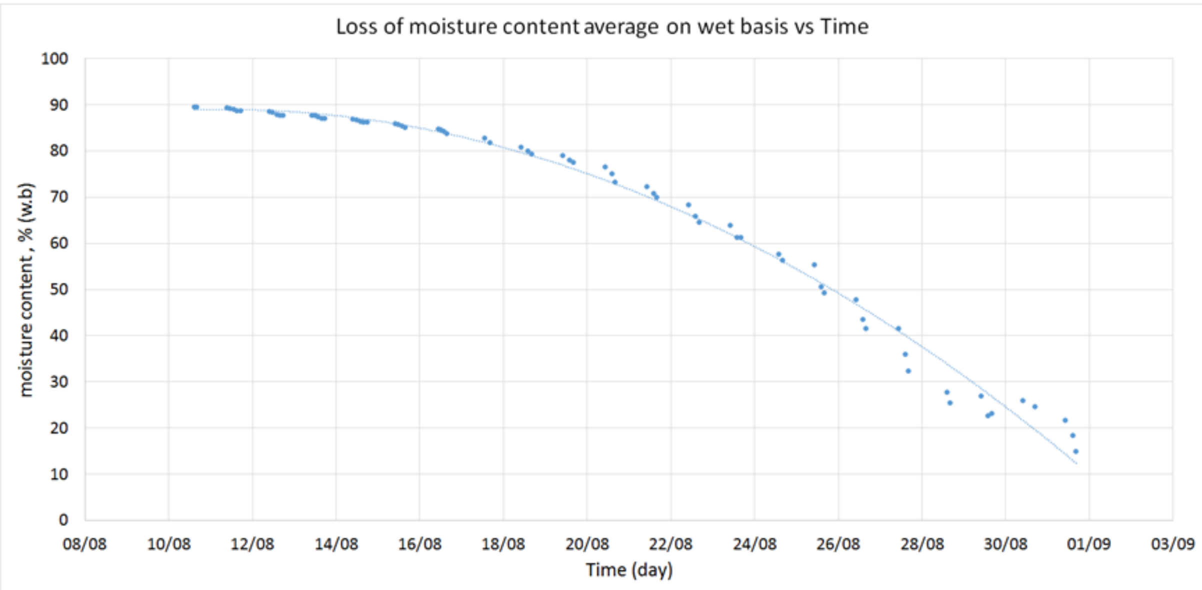

Fig 12: Loss of moisture content average on wet basis

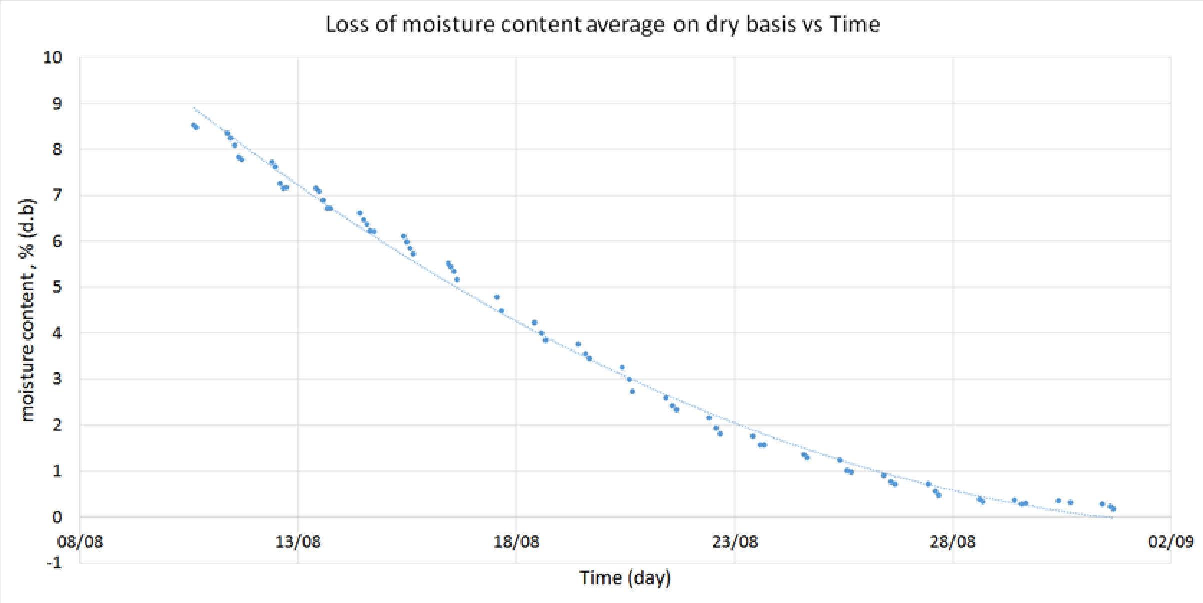

Fig 13: Loss of moisture content average on wet dry

As shown in figures 12 and 13, the moisture content on a dry basis reached its ideal weight of drying with a moisture content of 15% in 20 days.

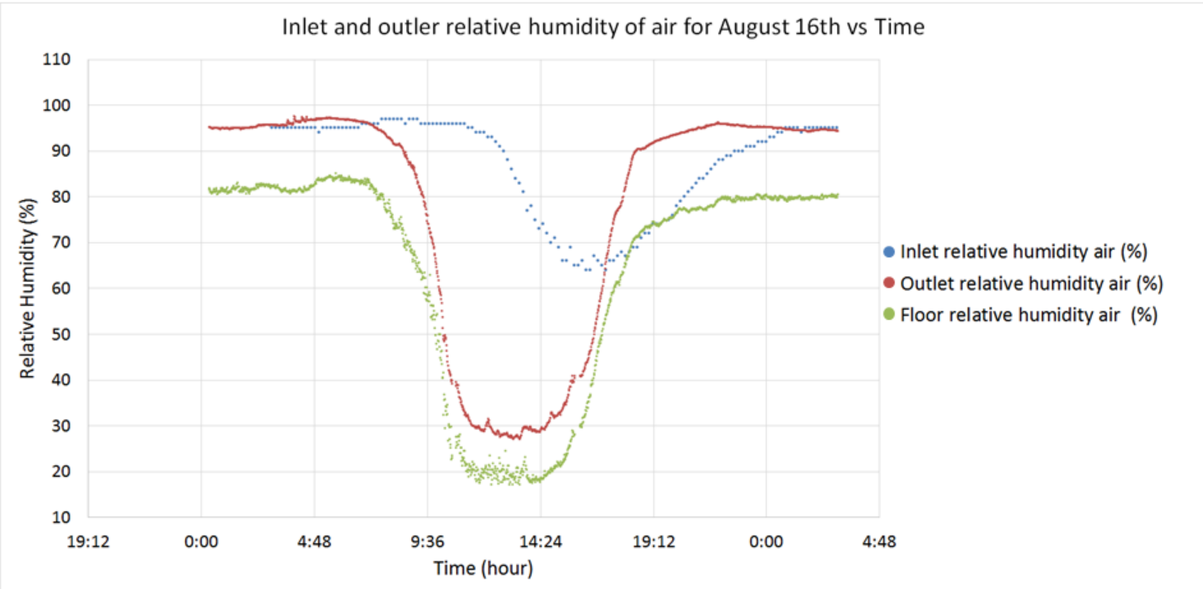

Fig.14: Inlet and outlet relative humidity vs. time in a specific day.

In figure 14, the differences in the percentage of relative humidity between the inlet and outlet air; the data was obtained from the DHT 5 sensor and the weather station. As it is revealed in the graph, a difference around 37% is observed in an average day. And, the differences in the percentage of relative humidity between the floor air and outlet air were 10%.

Fig.15. Color of the product dried

Finally, during the experimentation it was observed that the chili that had not been manipulated presented their characteristic color, while the chili peppers of sample showed a dark orange color.

4. Conclusions

The system shows that there is a maximum temperature reached per day corresponding to the maximum radiation delivered by the sun and the efficiency of the system based on the losses of the equipment itself.

A temperature of around 43° C has been obtained for a day with global irradiance at midday of 780 W m^{-2} and an air flow velocity of 1.1 m s^{-1}. The reached temperature allows carry out the process of drying the chili. In addition, for a load of 50 kg of chili the dome is able to reduce its percentage of humidity by 15% in 20 days

It can be concluded, the dome as a solar dryer for agricultural products can works efficiently for daily irradiations greater than 4 kW-h m^{-2}. That uniformity of the temperature makes the dome design affordable to any velocity and direction of outside wind, hence suitable for drying any other product.

More research is still necessary on the dome behavior in other places of higher and lowers daily irradiances than 4kWh m^{-2}. Additionally, it is needed to do more tests changing variables for different products like modifying the amount of product to dry for example. Furthermore, it is important to research about the behavior of the materials of the dome.

Nowadays, the *Grupo Rural de Apoyo al sector Rural* and the *Centro de Innovación Tecnológica de Industrias Alimentarias* continue working on the subject to achieve the optimal design of the dome, as well as attain the automatic functioning of all the processes.

Another application for this system is in the line of thermal comfort research for homes or others. Likewise, the system can be used for the replication of microclimates with an automated control.

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