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DRYING SPEED OF COFFEE BEANS IN A ZENITHAL SOLAR DRYER IN THE CAÑADA REGION, OAXACA, MEXICO

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Abstract:A zenithal type solar dryer was evaluated during two drying cycles: the first cycle was under a humid environmental condition (rainy and cloudy days), the second cycle under a dry condition (sunny and clear days). The temperature and humidity of the air inside and outside the solar dryer were compared by recording these parameters every 20 minutes to determine the influence of these conditions on the coffee bean drying process. The results indicated that the maximum temperature difference between the inside and outside of the dryer was 17.7 °C (humid cycle) and 18.0 °C (dry cycle). Temperatures of up to 48.5 °C were recorded in the humid cycle and 47.4 °C in the dry cycle, which can be dangerous for the coffee beans, since, when exceeding 45°C, they can damage the embryo causing undesirable flavors in the organoleptic analysis. Based on the bean drying curves, the solar dryer evaluated does not accelerate the drying process, but it favors a loss of humidity at a homogeneous rate in comparison with traditional drying, which presents strong fluctuations in the humidity of the bean.
Keywords: Temperature, air humidity, grain moisture.

INTRODUCTION

Coffee growing in Mexico is one of the most important activities in the agricultural sector, especially in rural communities. Production areas are concentrated in 12 states, mainly in small production units in mountainous areas, with the states of Chiapas, Veracruz, Oaxaca and Puebla accounting for 84.6% of the area planted and 88.6% of the production volume in 2023 (SIAP, 2024).

One of the little studied technological components in coffee production is the post-harvest process, specifically the drying of the bean, which has the purpose of reducing the moisture content of washed coffee (varies from 48 to 56% in the humid phase) to a range that oscillates between 10 and 12% moisture. Drying is a process by which the bean is dehydrated to prevent its deterioration and, therefore, preserve its quality during storage, this stage is critical and requires control, as it is decisive for the organoleptic quality of the beverage due to its direct impact on sensory quality (Ventura *et al.*, 2019). Coffee drying depends, among other factors, on the prevailing environmental conditions during the process (Prada *et al.*, 2019). In tropical climates, due to constant rainfall, it deteriorates up to 50% during the harvest season (Guevara *et al.*, 2019).

One of the alternatives for coffee drying is to use solar energy, through the use of solar dryers (Hii *et al.*, 2019; Yoo *et al.*, 2017). These are facilities that require little investment capital and low maintenance costs, easy construction and any material available in the construction area can be used, with tendency of the designs to simplicity, due to the fact that there is no significant difference in the results obtained with the initial designs compared to the most current and sophisticated designs (Sharma *et al.*, 2018; Belessiotis and Delyannis, 2011).

On the other hand, the performance of a solar dryer depends on climatic conditions such as ambient temperature and solar radiation (Jambhulkar *et al.*, 2017; Sandali *et al.*, 2019). To characterize the behavior of a solar dryer, one of the most important parameters is the temperature generated inside, given its importance for the development of the parchment coffee drying process (Parra *et al.*, 2008). Temperatures inside the dryer should not reach temperatures above 45 °C, while in traditional drying they should not dry at more than 40 °C (Puerta, 2008). Air temperature during coffee drying is one of the critical variables to control, since a decrease in the water potential of coffee seeds during drying produces massive stress responses that are associated, in the initial stages of drying, with germination processes and, as water is reduced, with drought stress in embryo and endosperm tissues (Kramer *et al.*, 2010). Also, temperature must be maintained at a constant level during certain periods of drying, and temperature also affects relative humidity, since the higher the temperature, the higher the water vapor saturation pressure, and therefore, the greater the margin of water uptake into the grain (Guevara *et al.*, 2019).

Another important parameter that characterizes the behavior of the dryer is the ratio between the internal and external relative humidity of the dryer. The internal relative humidity has a behavior that depends on the stage of the drying process. In the early stages of the drying process, the internal relative humidity increases because the product releases the greatest amount of water vapor (Chaverri and Moya, 2008). Air speed is another fundamental factor in the drying process, whose function is to transmit heat to the grain for evaporation of the water contained in it. This means that the higher the speed, the greater the air renewal and the faster the transport of evaporated water (Quintanar and Roa, 2017).

The objective of the study was to evaluate the drying rate of coffee beans inside and outside a zenith solar dryer under two different environmental conditions in the La Cañada region of Oaxaca.

MATERIALS AND METHODS

The present project was carried out in the municipality of Santa Cruz Acatepec, belonging to the district of Huautla de Jiménez, located in the region of La Cañada, in the state of Oaxaca, at the geographical coordinates Latitude: 18° 9' 44" North, Longitude: 96° 52' 36" West, with an altitude of 1 617 masl, the average annual rainfall is 2300.However, during the harvest season (January to April) there is an average monthly rainfall of around 38.6 mm, with an average of 12.1 cloudy days per month during this period (CONAGUA, 2022).

The zenith type solar dryer was built with a wood base and lined with 720 caliber greenhouse plastic with UV ray treatment (Fig. 1), it has an area of 30 m^2 (7.5 m x 4 m) and three drying levels (12 screens per level) with a total of 36 screens of 1 m^2 each. Two drying cycles were evaluated; the first one was from February 24 to March 6 under a humid condition (rainy and cloudy days) and the second one from March 23 to 27 under a dry condition (sunny and clear days). To obtain results of the environmental conditions (temperature and relative humidity) inside and outside the dryer, Dataloggers model RC-4HC of the Elitech brand, programmed to collect data every 20 min, were installed at a height of 1.80 m, both inside and outside the dryer. To generate the coffee bean drying curve, a Draminski model TwistGrain pro bean and seed moisture meter was used, recording the bean moisture percentage three times a day (morning, afternoon and evening), until a moisture content of 10 to 12% was reached (optimum moisture for storage).

Figure 1. Zenith type solar dryer for coffee drying, used in the study.

Three sieves were monitored inside the solar dryer (random samples), with a coffee layer thickness of less than 3 cm, as well as the traditional drying in full sun on palm mats, in order to compare both drying methods and to analyze the drying time.

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RESULTS AND DISCUSSION

Based on the data recorded by the Dataloggers, the maximum, minimum and average air temperature and humidity averages were calculated in the wet and dry cycles, to differentiate the behavior of the two different environmental conditions, resulting in an average temperature difference of 6.0°C in the wet condition in the solar dryer compared to the outside and 4.3°C in the dry condition. The average humidity in the air showed the opposite behavior to that of the temperature, since there were higher percentages of humidity outside than inside the solar dryer, as described in Table 1.

Maximum temperatures inside the dryer exceeded the recommended threshold of 45°C in cycle 2 (dry condition), which may contribute to quality loss (Puerta, 2008). All days showed a common temperature fluctuation between daytime and nighttime conditions, where peaks represent daytime air temperatures and "valleys" represent nighttime air temperatures (Figure 2). These results are congruent with those reported by Quintanar and Garcia (2023), who mention that the temperature inside the dryer is always higher than the ambient temperature. However, the temperature profile is not constant during the hours of the same day, nor during the days of the drying process (Figure 2).

The average initial moisture content of the wet parchment coffee samples was approximately 55%. However, the monitoring of the percentage of moisture in the bean began when its moisture content was approximately 35%, which is the value when the hygrometer began to detect changes in the moisture content of the bean. In the first cycle under conditions of rain and high cloud cover, the optimum grain moisture (10% to 12%) was reached in a period of 10.5 days in the solar dryer, compared to traditional drying, which reached its moisture content in only 8.5 days. The behavior of the fluctuations in the first four days was similar both inside and outside; from the fifth day on, there began to be a difference in the absorption and release of moisture in the grain, between the outside and inside; inside the solar dryer, drying was slower, as shown in Figure 3.

In the second drying cycle (dry condition), even when temperatures higher than the ambient temperature (outside the solar dryer) were generated, the grain drying was not accelerated, having a similar behavior to Cycle 1 in humid conditions, which shows that the dryer slows down the drying speed and generates a less aggressive curve in the grain drying (Figure 4).

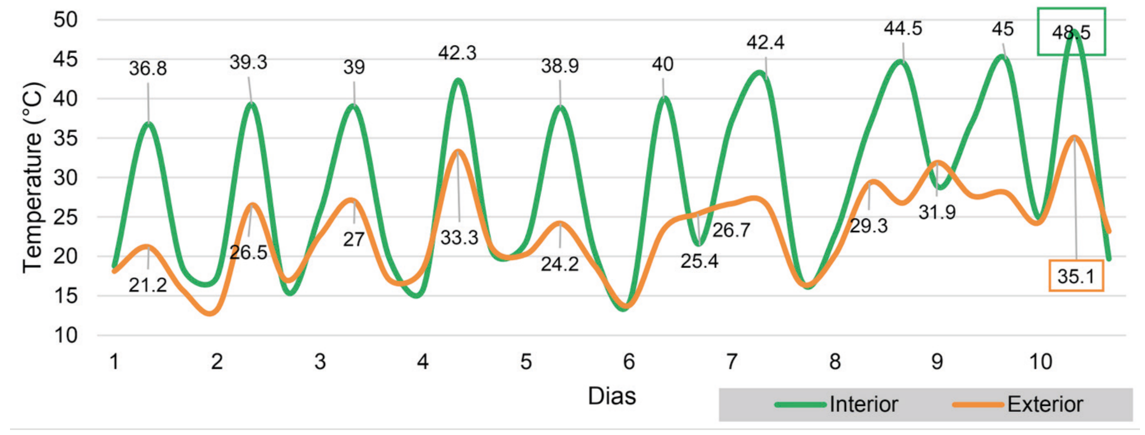
A common relationship in the data for all days in both cycles was that of high daytime temperatures corresponding to low relative humidity fluctuating with low nighttime temperatures and high relative humidity in the absence of the sun. These conditions in the drying environment generated a similar behavior in the drying rate during the first three days both inside and outside the dryer in both cycles.

On the other hand, the higher the air temperature, the greater the air's ability to hold moisture, which reduces relative humidity. As temperatures drop, the air can retain less moisture and saturated air reaching the dew point temperature, allowing condensation to form. This allows the coffee to equilibrate with the surrounding humid air, generating a resting condition. This has an impact on the rate of drying of the beans, which began to occur on the fourth day, increasing as soon as the temperature inside the dryer began to increase and stopping when the temperature dropped and the relative humidity inside the dryer increased, which is in accordance with what was reported by Sihombing *et al.* (2024), who mention that with an increase in temperature, the drying rate is higher, so

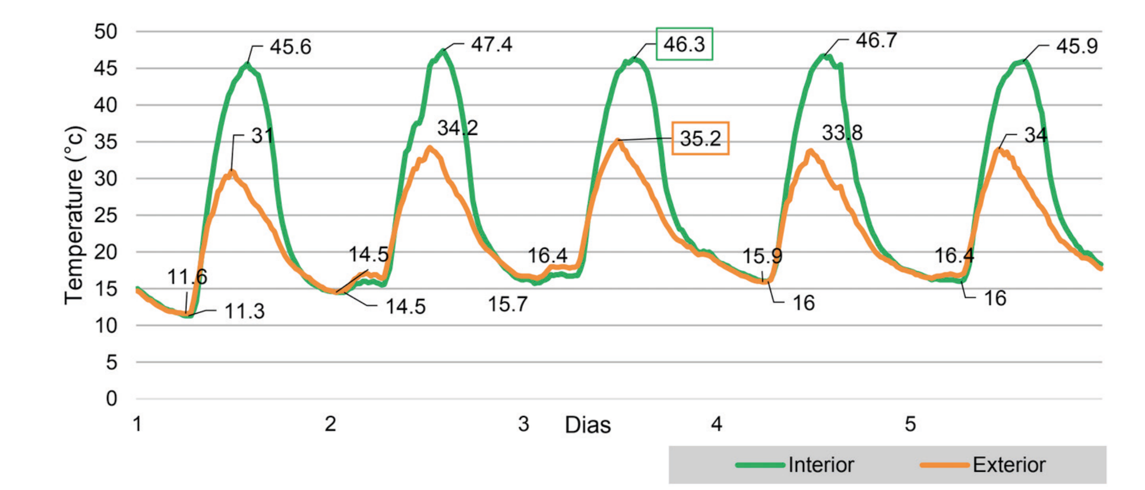
Variable		Cycle 1 (wet condition)			Cycle 2 (dry condition)		
		Dryer	Exterior	Difference	Dryer	Exterior	Difference
Temperature (°C)	Average	29.1	23.1	6.0	26.5	22.2	4.3
	Maximum	41.6	28.0	13.6	46.3	33.6	12.7
	Minimum	19.3	18.5	0.8	14.7	15	0.3
Air humidity (%)	Average	45.2	50.9	5.7	56.3	64.2	7.9
	Maximum	64.5	65.7	1.2	80.2	84.6	4.4
	Minimum	25.6	38.6	13.0	24.9	34.2	9.3

Table 1. Average air temperature and humidity inside and outside a solar dryer during two environmental drying conditions.

Source: Own elaboration.



a. Wet environmental condition



b. Dry environmental condition

Temperature conditions inside and outside a solar coffee dryer, for two environmental conditions.

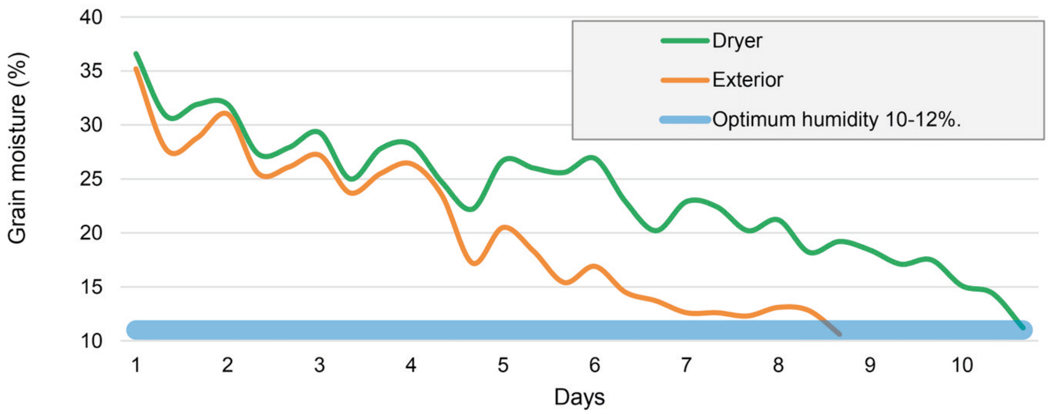


Figure 3. Drying curves in the open air and inside a solar dryer under an environmental condition of high relative humidity in the environment (rainy and cloudy days).

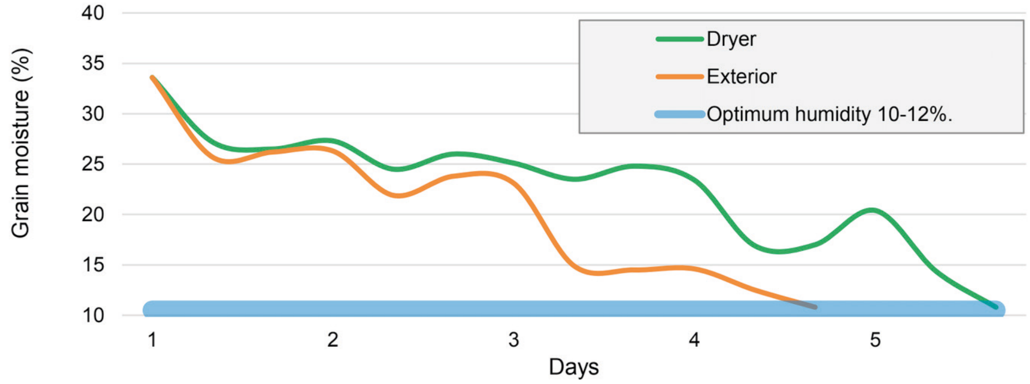


Figure 4. Drying curves in the open air and inside a solar dryer under an environmental condition of low relative humidity in the environment (sunny and clear days).

that the decrease in moisture content is faster and the drying time required is shorter. This occurs because as the drying process evolves, moisture gradients are formed inside the grains, and the moisture inside the grains is greater than the surface moisture. These gradients will be increasingly greater the drier the coffee beans are (Isquierdo *et al*., 2011). During resting, water migration occurs from inside the beans to the surface, increasing drying rates when the process resumes (Borém *et al*., 2018).

Another factor that directly impacts the drying rate and consequently the duration of drying time is the thickness of the exposed bean layer. It has been shown that distributing coffee in thin layers of 20 kg/m^2 , increases the drying rate and prevents fungal growth in dried coffee, compared to thicker layers (Kouadio *et al*. 2012; Menya and Komakech, 2013).

CONCLUSIONS

- The solar dryer inside generates higher temperatures and lower humidity percentages.
- The average temperature difference inside the solar dryer in wet conditions and in dry conditions is 2.6°C.
- The difference in humidity between wet and dry conditions is 11.1%, which is the opposite, since there are higher percentages of humidity on the outside than inside the dryer, which is an excellent structure for coffee producers.

- The maximum relative humidity difference between the inside of the dryer and the outside was 6.4% for the first cycle (wet condition) and 2.7% for the second cycle (dry condition).
- The solar dryer prolongs the drying time and speed, however, it generates a drying curve with smaller fluctuations between moisture absorption and release, which makes drying less aggressive (abrupt drying) compared to traditional drying, which presents strong fluctuations in grain moisture.

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