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Evaluation of coffee drying in a zenith-type solar dryer in cañada region, Oaxaca

Evaluación del secado de café en un secador solar tipo cenital en la región cañada, Oaxaca

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Abstract

A zenith-type solar dryer was evaluated during two drying cycles: one under environmental conditions of rainy and cloudy days; and the other, under one of sunny and clear days. The air temperature and humidity were compared inside and outside the solar dryer by recording these parameters every 20 minutes. The results indicated that solar dryer increases temperature on average by 6.0 °C for wet condition and 4.3 °C for dry condition. The maximum temperature difference between interior and exterior of dryer was 17.7 °C in humid condition and 18.0 °C in dry condition, recording temperatures of up to 48.5 °C in the humid condition and 47.4 °C in dry condition. In relation to humidity of air inside dryer, it decreases on average up to 7.9% compared to outside. According to grain drying curves, in solar dryer, 7 and 10 days were required to reach a grain humidity between 10-12%, under dry and humid conditions, respectively. Therefore, solar dryer generated less aggressive drying and with lower humidity fluctuations in grain compared to traditional drying, which could increase quality of grain produced in Mazatec region, through use of this technology.

Drying, Temperature, Air humidity, Grain moisture, Drying rate

Resumen

Se evaluó un secador solar tipo cenital, durante dos ciclos de secado: uno bajo condición ambiental de días lluviosos y nublados; y el otro, bajo una de días soleados y despejados. Se comparó la temperatura y humedad del aire, dentro y fuera del secador solar mediante el registro de estos parámetros cada 20 minutos. Los resultados indicaron que el secador solar incrementa en promedio la temperatura en 6.0 °C para la condición húmeda y de 4.3°C para la seca. La diferencia máxima de temperatura entre el interior y el exterior del secador fue de 17.7 °C en la condición humedad y de 18.0 °C en la condición seca, registrándose temperaturas de hasta 48.5 °C en la condición húmeda y de 47.4 °C en el ciclo seco. En relación con la humedad del aire al interior del secador, esta disminuye en promedio hasta 7.9 % en comparación con el exterior. De acuerdo a las curvas de secado del grano, en el secador solar se requirió de 7 y 10 días para alcanzar una humedad del grano entre 10-12%, bajo la condición seca y húmeda, respectivamente. Por lo tanto, el secador solar generó un secado menos agresivo y con menores fluctuaciones de humedad en el grano en comparación con el secado tradicional, lo cual podría incrementar la calidad del grano que se produce en la región mazateca, mediante el uso de esta tecnología.

Secado, Temperatura, Humedad del aire, Humedad del grano, Tasa de secado

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Introduction

In Mexico, coffee is one of the most extensive and economically important crops, as it is among the five most important export products. Production areas are concentrated in 12 states, mainly in small production units in mountainous areas, where the state of Oaxaca accounts for 17.3% of national production (SIAP, 2023).

The industrial process for the transformation of cherry coffee into parchment is called processing and comprises the stages of: classification, washing, pulping, removal of mucilage and drying. Of these stages, drying is fundamental, as its purpose is to reduce the moisture content of the washed coffee (48-56% on a wet basis) to a range between 10% and 12% moisture (Ortega, 2010; Ventura-Cruz *et al.*, 2019).

One of the alternatives for drying coffee is to use solar energy, through the use of solar dryers (Hii *et al.*, 2019). Currently, there is a wide variety of designs and sizes of solar dryers that can be used for drying various agricultural foodstuffs. They are low capital and low maintenance cost installations, easy to construct and any material available in the construction area can be used, with designs tending towards simplicity, as there is no significant difference in the results obtained with more primitive designs compared to more sophisticated ones (Sharma *et al.*, 2018).

The operation of solar dryers is based on the greenhouse principle, where solar energy is captured to raise the temperature of the internal fluid (air). They are installations that require little capital and low maintenance costs, are easy to construct and any material available in the construction area can be used, with designs tending towards simplicity, as there is no significant difference in the results obtained with more primitive designs compared to more sophisticated ones. 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).

Solar energy collection systems are classified into two main groups: those with a collection device independent of the drying chamber and those that use the drying chamber itself as the solar radiation collection area.

Furthermore, depending on the way the fluid is moved in the solar dryer, they can be classified as greenhouse-type solar dryers with natural convection or passive mode and with forced convection or active mode (Nidhi and Verma, 2016; Kumar et al, 2016).

On the other hand, it should be noted that solar dryers perform the conversion of solar energy to useful thermal energy for the drying process, thus, the thermal performance is a reliable indicator to study the merits of the system and can be quantified by energy analysis (Quintanar and Garcia, 2023). To characterise the performance 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-Coronado *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).

Also, the temperature must be kept at a constant level during certain periods of drying, in addition, the temperature affects the relative humidity, since the higher the temperature, the higher the water vapour saturation pressure increases, therefore, the greater the margin of water uptake to the grain. (Guevara-Sánchez *et al.*, 2019). Another important parameter that characterises the behaviour of the dryer is the ratio between the internal and external relative humidity of the dryer. The internal relative humidity has a behaviour that depends on the stage of the drying process. In the first stages of the drying process, the internal relative humidity increases, due to the fact that the product releases the greatest amount of water vapour (Chaverri and Moya, 2008).

Given the difficulties encountered in drying coffee in the Cañada region in the state of Oaxaca by Mazatec producers, who use the traditional drying process, where the wet beans are exposed directly to the sun's rays on concrete slabs (asoliaderos) or mats. However, this method is not recommended due to the many factors that threaten the quality of the product, such as sudden rains, dust, rubbish and animals (Duque et al., 2023); they must also store or cover the coffee at night to prevent it from re-absorbing the ambient humidity, making it impossible to dry a larger volume of coffee.

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In this study, a small-scale, low-cost, zenithal-type solar dryer was built and evaluated for the producer. The use of this structure is a good alternative to provide communities with a drying solution, as it allows them to increase and optimise the production obtained, reducing construction costs by using local materials such as wood and bamboo, among others.

Objective

To evaluate the drying of coffee beans in a zenithal solar dryer and in the open air on sieves, under two different environmental conditions: cloudy and rainy days and sunny and clear days in the region of La Cañada, Oaxaca.

Materials and method

The work was carried out in the Cañada region of the state of Oaxaca, in the municipality of Santa Cruz Acatepec belonging to the district of Huautla de Jiménez, located at the geographical coordinates 18° 9' 44" N and 96° 52' 36" W, at an altitude of 1,617 masl and an average annual rainfall of 2300. 8 mm, concentrated in the months of June to September, however, during the harvest season (January to April) there is an average monthly rainfall of 38.6 mm and an average of 12.1 cloudy days per month during this period (CONAGUA, 2022).

The zenith type solar dryer was built with a wooden base and lined with 720 gauge greenhouse plastic with UV ray treatment, it has an area of 30 m2 (7.5 m x 4 m), with three drying levels (12 screens per level) with a total of 36 screens of 1 m2 each.

A drying cycle was evaluated under an environmental condition of cloudy and rainy days, corresponding to the period from 24 February to 06 March 2023. The data collection of environmental conditions (temperature and relative humidity) inside and outside the dryer was carried out with a Datalogger equipment model RC-4HC of the Elitech brand, programmed to collect data every 20 min. The equipment was installed at a height of 1.80 m, both inside and outside the dryer.

To determine the moisture loss of the coffee beans, a Draminski TwistGrain pro bean and seed moisture meter was used, recording the percentage of moisture in the beans three times a day (morning, afternoon and evening), until a moisture content between 10 and 12% was reached (optimum moisture for storage). Three sieves were randomly monitored inside the solar dryer, 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 analyse the drying time.

Results and discussion

Based on the data recorded by the Dataloggers, the average maximum, minimum and average temperatures and humidity of the air were calculated under cloudy and rainy environmental conditions (Table 1), resulting in a difference between the outside and inside of the solar dryer of 6. 0°C with respect to the average temperature, of 13.6°C when the maximum temperatures are reached, mainly at midday, highlighting the maximum temperature of 48.5°C reached inside the dryer when the outside temperature was 35.1°C, and of only 0.8°C when the minimum temperatures are reached, especially at night.

Variable		Wet condition		Dif	Dry condition		Dif
		Dryer	Outside		Dryer	Outside	
T (°C)	Prom	29.1	23.1	6.0	26.5	22.2	4.3
	Máx	41.6	28.0	13.6	46.3	33.6	12.7
	Mín	19.3	18.5	0.8	14.7	15	0.3
HR (%)	Prom	45.2	50.9	5.7	56.3	64.2	7.9
	Máx	64.5	65.7	1.2	80.2	84.6	4.4
	Mín	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 under cloudy and rainy day conditions in the canyon region, Oaxaca

These results are congruent with those reported by Quintanar and García (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 1). Therefore, the temperatures reached both inside and outside the dryer are lower than 50°C, appropriate values for the drying process of the vast majority of agricultural products that require this process for their preservation. (Costales, 2010).

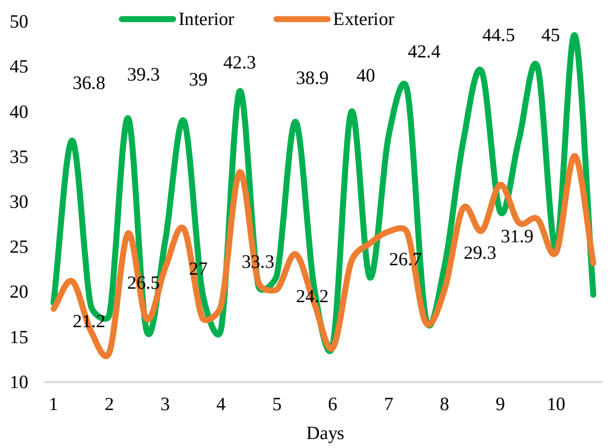

Figure 1 Temperature conditions inside and outside a solar coffee dryer

In relation to the temperature differences inside the dryer with respect to the ambient temperature, the average temperature calculated in the present study is lower than the 10°C difference between the temperatures inside the dryer and the environment reported by Dhurve *et al* (2017) and the 13.6°C difference reported by Menya and Komakech (2013), however, the difference of the maximum temperature reached is identical to that reported by these same authors for a greenhouse type dryer located in Uganda.

It is also similar to the temperature difference of 14.1°C reported by Almuhanna (2012) for a greenhouse solar dryer, and lower than the 29.9°C difference in temperature inside a solar dryer over ambient temperature reported by Sreekumar (2013).

On the other hand, the relative humidity of the air is a critical factor in controlling the drying rate; the lower the relative humidity, the higher the drying air absorption capacity. The relative humidity behaviour during the drying process under study, the relative humidity was always higher outside than inside the solar dryer (Figure 2).

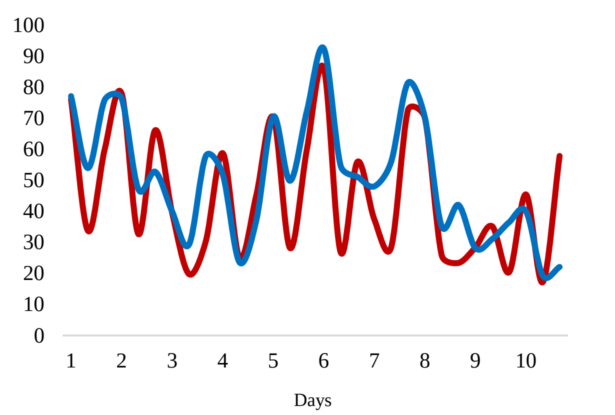

Figure 2 Relative humidity conditions inside and outside a solar coffee dryer

The average initial moisture content of the wet parchment coffee samples was 55%, but the moisture meter only works when the bean has 35% moisture in order to monitor moisture loss. In the first cycle under rainy conditions and high cloud cover, the optimum moisture content of 10-12% was reached in the beans 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 behaviour of moisture losses in the first four days is similar both indoors and outdoors; from the fifth day onwards, there was a difference in the drying rate between the grains exposed outdoors and indoors, being slower inside the solar dryer (Figure 3).

In the second drying cycle under dry conditions (sunny and clear days), even when temperatures higher than the ambient temperature were generated, grain drying was not accelerated, having a similar behaviour to the cycle under humid conditions, with similar moisture loss during the first three days both indoors and outdoors, after this point, the drying rate between the grains exposed outdoors and indoors is different, being slower inside the solar dryer (Figure 4).

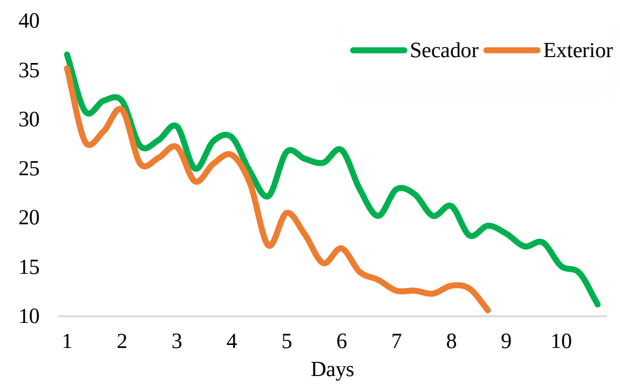

Figure 3 Drying curves of coffee beans inside and outside a solar dryer under an environmental condition of cloudy and rainy days

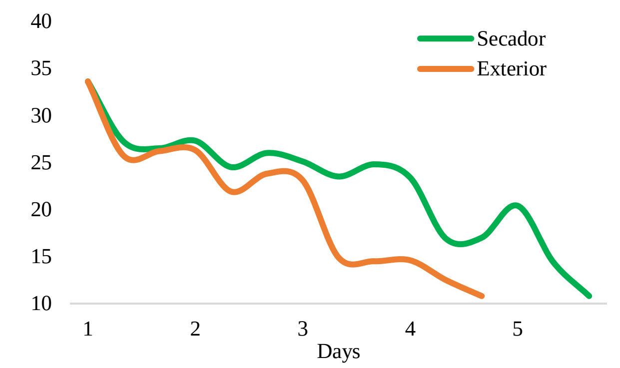

Figure 4 Coffee bean drying curves inside and outside a solar dryer under an environmental condition of sunny and clear days

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At the end of the drying process, the drying rate of the bean inside the dryer is slower, generating a less aggressive curve in the drying of the bean, therefore, the drying of the bean is more uniform, but extending the drying time by one day with respect to traditional drying in both drying cycles. The final moisture content of the grain obtained in both cases was appropriate for storage, according to the SCA protocol.

Conclusions

– The maximum temperature recorded inside the solar dryer was 48.5 °C in the wet condition and 47.4 °C in the dry cycle.
– The solar dryer increased the temperature on average by 6.0 °C for the wet condition and 4.3 °C for the dry condition.
– The maximum temperature difference between the inside and outside of the dryer was 17.7 °C in the wet condition and 18.0 °C in the dry condition.
– The time period required for drying the coffee beans in the solar dryer was 7 and 10 days to reach a moisture content between 10-12% in the dry and wet conditions, respectively.

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