Article **Journal of Chemical and Physical Energy**
December 2022, Vol.9 No.27 8-14

Epazote solar drying under different conditions: Kinetics, modeling, and colorimetry

Secado solar de epazote bajo diferentes condiciones: Cinéticas, modelado y colorimetría

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DOI: 10.35429/JCPE.2022.27.9.8.14 Received October 15, 2022; Accepted December 30, 2022

Abstract

Epazote (*Chenopodium ambrosioides* L.) is a plant used as a condiment in food and has antioxidant properties promoting human health. Unfortunately, epazote is highly perishable due to its high moisture content. In this work, epazote solar drying is carried out using two different dryers: an indirect solar dryer with a titanium oxide cover (SIT) and a direct one with a polycarbonate cover (SDP) to increase its shelf life. Titanium oxide is a novel material with thermal properties helping solar drying by allowing the preservation of epazote's medicinal and organoleptic properties, which is very sensitive to solar radiation. The drying kinetics show that both dryings were carried out in 2.6 hours, obtaining a final humidity of 0.9 and 0.4 g water/g ss in SIT and SDP, respectively. The highest drying rate (27 g water/g ss· hr) was achieved with the SIT. The model that best fit the drying kinetics for both cases was the Weibull model, with a minimum r^2 of 0.9979. The colorimetric study found that the SIT allows a superior quality in the product with an ΔE of 9.56

Direct solar drying, Indirect solar drying, Titanium oxide, Epazote, Colorimetric study

Resumen

El epazote (*Chenopodium ambrosioides* L.) es una planta utilizada como condimento en los alimentos y presenta propiedades antioxidantes que favorecen la salud humana. Desafortunadamente, el epazote es muy perecedero, debido su alto contenido de humedad. En este trabajo se realiza el secado solar de epazote, utilizando dos diferentes equipos: un secador solar indirecto con cubierta de óxido de titanio (SIT) y otro directo con cubierta de policarbonato (SDP), para aumentar su vida de anaquel. El óxido de titanio es un material novedoso con propiedades térmicas que favorecen el secado solar permitiendo la conservación de las propiedades medicinales y organolépticas del epazote, el cual es muy sensible a la radiación solar. Las cinéticas de secado muestran que ambos secados fueron realizados en 2.6 horas, obteniendo una humedad final de 0. 9 y 0.4 g agua/g ss en SIT y SDP, respectivamente. La velocidad de secado más alta (27 g agua/g ss· hr) se alcanzó con el SIT. El modelo que se ajustó de mejor manera a las cinéticas de secado para ambos casos fue el Weibull con un r^2 mínimo de 0.9979. El estudio colorimétrico se encontró que el SIT permite una calidad superior en el producto con un ΔE de 9.56.

Secado solar directo, Secado solar indirecto, Oxido de titanio, Epazote, Estudio colorimétrico

Citation: CASTILLO-TÉLLEZ, Beatriz, CASTILLO-TÉLLEZ-Margarita, MEJÍA-PÉREZ, Gerardo Alberto and VEGA-GÓMEZ, Carlos Jesahel. Epazote solar drying under different conditions: Kinetics, modeling, and colorimetry. Journal of Chemical and Physical Energy. 2022. 9-26: 8-14

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Introducction

The epazote (Chenopodium ambrosioides L.) is a plant known in Mexico as epazote and is used as a condiment for food or in infusions in traditional medicine. This plant is rich in flavonoids and natural antioxidants used in industry for various uses (Villalobos-Delgado *et al.*, 2017).

Unfortunately, when used fresh, as a condiment, its high moisture content dictates a very short shelf life for the plant, so it is generally wasted or sometimes difficult to obtain, as it is not available all year round (Blanckaert *et al.*, 2012). This is why it is convenient to dehydrate it, in order to stabilise it in ambient humidity and temperature conditions and thus preserve it for a longer period of time.

Open solar drying is one of the oldest methods of preservation (FAO, 1990). This technique is cheap and simple; however, drying times are long and the food is exposed to a variety of factors that can reduce its quality and hygiene, such as rodents or flies, dust, rain, insects, solar radiation or wind (Grados and Cruz 2015; Prakash and Kumar 2013). On the other hand, industrial dryers eliminate these drawbacks and allow them to be efficient through appropriate designs, thus improving the nutritional and organoleptic properties of foods compared to traditional drying (Domínguez-Niño *et al.*, 2020; Kaya & Aydin, 2009).

The problem with industrial drying systems is the enormous energy consumption they present, which comprise up to 15% of the consumption of the entire industry worldwide (Castillo Téllez *et al.*, 2018). Additionally, industrial drying uses polluting fossil fuels, which worsen the already deteriorated environment and collateral problems such as climate change, among others. That is why solar drying is presented as an interesting technological option, since it eliminates the use of this polluting energy. Free and abundant solar energy allows for low production costs and environmentally sustainable processes (Tlatelpa-Becerro *et al.*, 2018).

The design of solar dryers is very important for the good performance of the dryers, so they are continuously improved and adapted to the characteristics of the food and the climatic conditions of the drying site.

For example, the design of the dryer used for drying mango waste with transparent polycarbonate cover (Wilkins *et al.*, 2018) to control environmental conditions. Another interesting design was used by Toĝrul and Pehlivan (2004): a solar greenhouse dryer employing an air conditioning control system for red chilli drying. Şevik *et al.* (2019) dried mint and apple with a solar dryer with air heaters and assisted infrared to supplement solar radiation when it is cloudy. In addition, a mixed solar dryer with forced convection was used to dry turmeric (Lakshmi *et al.*, 2018). Finally, (Chan-Gonzálelz *et al.*, 2021) designed a dryer with an integrated dehumidification system to decrease drying times in very humid places.

However, some of these devices present a complicated fabrication, which has to be built by a company dedicated to their manufacture, or the parts have to be purchased separately from different suppliers.

In this study, we present a direct solar dryer with a polycarbonate cover that is easy to manufacture and with very cheap materials that can be used in any home or can be used as a base to scale it up for a production with higher quantity requirements, to which a very important and novel element has been incorporated: a titanium oxide cover that allows a greater heat transfer inside the drying chamber, eliminates damage to foods sensitive to solar irradiance and reduces the risk of damage to the foodstuffs.

Methodology

The epazote was purchased at a local market and the leaves were sorted to ensure uniformity until a sample of approximately 10 g was collected. The samples were then placed in trays and placed in the two dryers. Figure 1 shows the colour and texture of the fresh epazote.

Figure 1 Fresh epazote leaves

The epazote leaves were dehydrated in two solar dryers modified in their cover, polyethylene and selective titanium oxide membrane. The dryers were built at the Institute of Renewable Energies of the UNAM, and have a drying chamber of 0.3 m2. The hot, dry air circulates longitudinally by natural convection penetrating through holes at the bottom and is extracted by the chimney effect at the top rear, with the moisture already extracted from the feed. The dimensions of the dryer are 64 35 X 23 cm. figure 3 shows the dryers used 2022, in Temixco, Mor.,

Figure 2 Equipment used

The dehydration process was carried out in May with a maximum irradiance and temperature of 952.6 W/m2 and 32.5 °C, respectively.

An OHAUS thermobalance, MB45, with an accuracy of 0.001 g. was used to determine the moisture content and the water activity aw was assessed with a HIGROLAB equipment. The equipment can be seen in Figure 3.

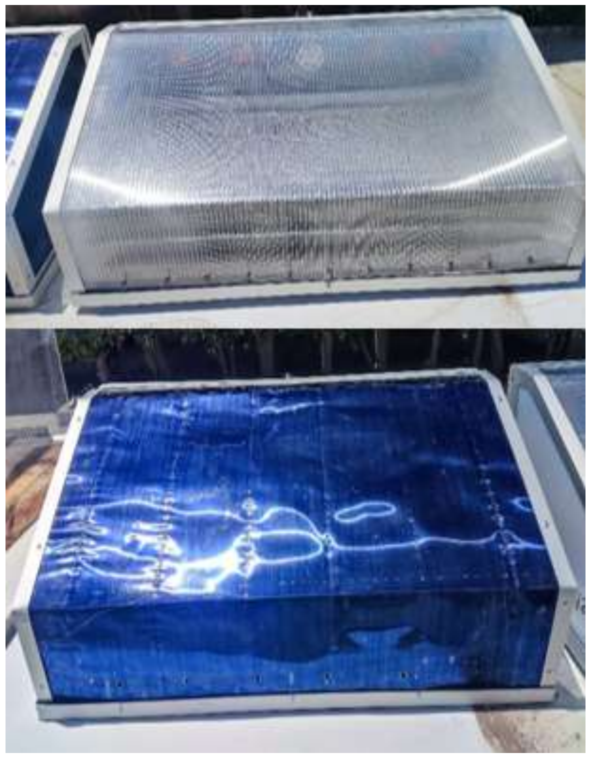


Figure 3 Equipment used

In addition, the evolution in the values of ambient temperature and inside both cabins, the weight and moisture loss, as well as the values of drying speed and moisture radius were recorded. Thin film mathematical modelling to standardise the behaviour of the drying kinetics was performed by comparing the moisture radius MR with those found in the literature. The MR was calculated using the equation:

$$MR = \frac{M-Me}{Mo-Me}$$

Where M is the moisture content and Me is the equilibrium moisture, while Mo is the initial moisture. The mathematical models used are listed in Table 1.

Model	Equation	Reference
Newton	$MR = exp\ (-kt)$	(Tunde-Akintunde, 2011)
Page	$MR = exp(-kt^n)$	(Page, 1949)
Modified page	$MR = exp((-kt)^n)$	(Diamante & Munro, 1993)
Henderson and Pabis	$MR = a\ exp(-kt)$	(Henderson & Pabis, 1961)
Logarithmic	$MR = a\ exp(-kt) + c$	(Togrul & Pehlivan, 2002)
Two-term	$MR = a\ exp\ (-kt) + b\ exp\ (-k_0 t)$	(Koua *et al.*, 2009)
Two-term exponential	$MR = a\ exp(-kt) + (1-a)\ exp(-kat)$	(Y. I. Sharaf-Eldeen *et a*l., 1980)
Wang and Singh	$MR = 1 + at + bt^2$	(Wang & Singh, 1978)
Weibull	$MR = exp(-(t/b)^{\alpha})$	(Midilli *et a*l., 2002)

Table 1 Thin film models used

The quality of fit was defined by the coefficient of determination r2. For this selection, the software Data Fit version 9.1 from Oakdale Engineering was used.

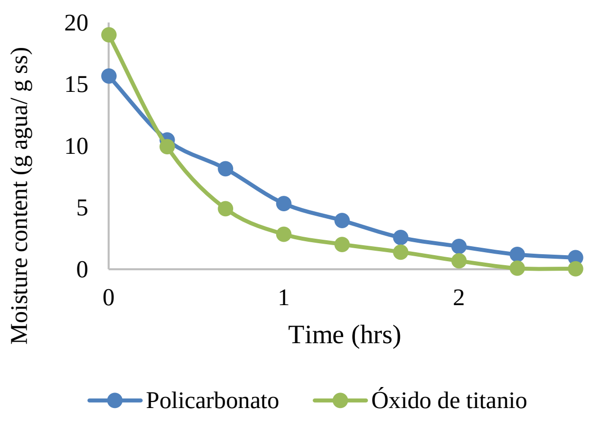
On the other hand, in the colourimetry study, the parameters L (lightness-darkness), a (red-green), b (yellow-blue), H (hue angle), chroma C (saturation or intensity) were determined before and after drying. In addition, the ΔE (colour difference) between the initial and final samples were analysed.

Results

The initial moisture value of epazote leaves was 88.92 %, while water activity (aw) was 0.984, To eliminate microbial growth, it is vital to reduce these values, according to (Jangam & Mujumdar, 2010). The final aw values for the samples were 0.597 for SIT and 0.533 for SDP, thus ensuring the stability of the dehydrated product in both dryers.

Drying kinetics

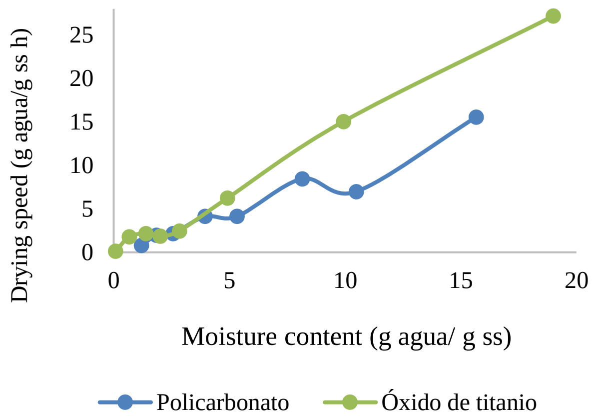
The time required to reach the equilibrium moisture content of the epazote was approximately 2.6 hours for both dryers. This is due to the fact that even though more solar radiation passes through the SDP chamber and therefore the temperature is higher, the titanium oxide coating is at a much higher temperature than the polycarbonate coating, removing the moisture that reaches the surface more quickly. The temperature inside the SDP chamber was 69.2 °C, while that of the SIT was 56 °C.



Graph 1

On the other hand, the final moisture content of the dehydrated epazote leaves in the SDP was 0.9 g water·ss, while that of the SIT was valued at 0.4 g water·ss.

Additionally, the drying rate was calculated in both cases. As can be seen in Figure 5, the SIT reached a maximum drying rate of 27.17 g water·ss·h, while the SDP reached 15.55 g water·ss·h. The titanium oxide shell heats up faster than the polycarbonate shell, so at the beginning of the kinetics the heat is higher inside this dryer.



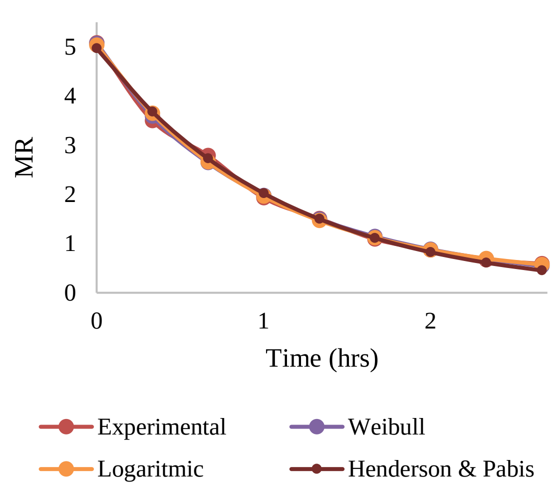
Graph 2 Drying speed of both equipment

Mathematical modelling

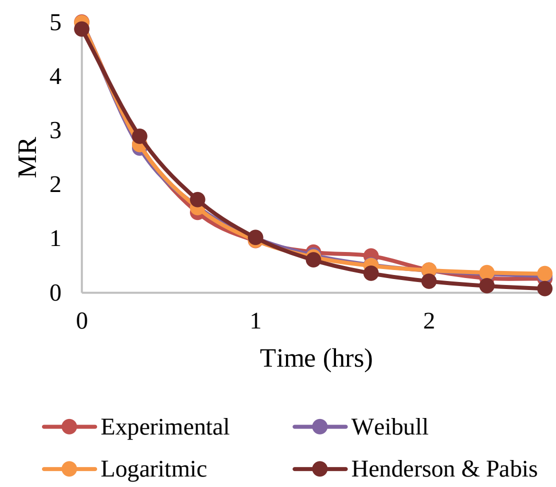
Weibull	R^2	0.9979
	a	8.19E-02
	b	-4.9855
	k	0.9667
	n	0.91974
Logarithmic	R^2	0.9975
	a	4.7644
	c	0.2704
	k	1.0350
Henderson and Pabis	R^2	0.9954
	a	4.9657
	k	0.8976

Table 2 Adjustment parameters with polycarbonate dryer

Table 2 shows the coefficient values of the three best models that were fitted to the epazote drying kinetics and graph 3 shows that the quality of fit is very high (over .99 in all cases).



Graph 3 Polycarbonate Dryer Model Setting

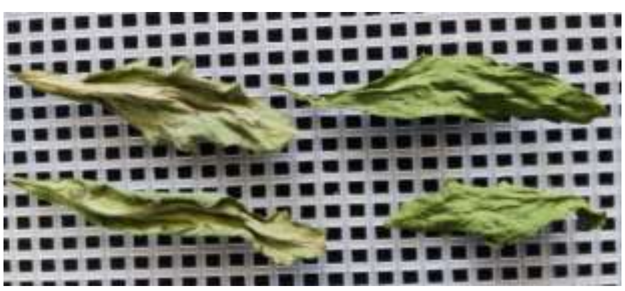


Graph 4 Model adjustment, dryer with titanium oxide coating

Similarly, Table 3 and Figure 4 show the kinetic fits of the models found in the literature with the drying kinetics in the SIT.

Weibull	R^2	0.9969
	a	2.60E-01
	b	-4.7484
	k	1.8404
	n	0.9097
Wang and Sing	R^2	0.9964
	a	4.6619
	c	0.3274
	k	1.98E+00
Henderson and Pabis	R^2	0.9835
	a	4.8716
	k	1.5647

Table 3 Fitting parameters with titanium oxide coating



a b

Figure 4 a) Dehydrated leaves in the SDP and b) SIT

We can then use especially the Weibull model, which for both cases was the best fit, to predict drying times and moisture contents, scale up production, design dryers for epazote drying, and to design a new drying system for epazote.

Colorimetric study

The colourimetric parameters were evaluated at the beginning of the drying process showing an average brightness of 45.88, and chromaticity values a and b of -11.68 and 30.06, respectively. Negative values of a indicate that the sample tends towards a green hue. The Hue angle was 111.22, which indicates a yellow-green shade. At the end of the drying process, the following colourimetric values were obtained: ΔL= -3.89, Δa= 17.50, Δb= -9.10, ΔC= -10.49, ΔH= -16.70, ΔE= 20. 11 for SDP, while the colorimetric values for SIT were ΔL= -2.78, Δa= 5.90, Δb= -6.98, ΔC= -8.46, ΔH= -3.46 and ΔE= 9.56. Negative values in ΔL indicate that the sample becomes darker than the initial sample, negative values in Δa show that the epazote becomes more green, negative values in Δb indicated that the epazote will be less yellow, negative values in ΔC indicate that the sample is less saturated, negative values in ΔH indicate that the sample changes from green to yellow. It is also observed that the smallest colour difference occurred in the SIT.

Conclusions

This study compares the kinetics of solar drying of epazote in a direct solar dryer made with commonly used materials with another one that uses a novel material for these applications: titanium oxide. In addition to matching the times obtained with the polycarbonate dryer, the final moisture content is lower. The final water activity was the same in both cases. Additionally, the highest drying speeds are observed in the SIT.

ISSN: 2410-3934

However, the most important advantage found in the SIT is that it provides a much higher quality product, according to the colourimetry results observed. The lower colour difference compared to fresh epazote is correlated with the preservation of the desired medicinal compounds in the epazote. Finally, it was determined that the model that best represents both kinetics is the Weibull model. The authors received no financial support for the research of this article.

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