Drying of medicinal plants through hybridization of solar Technologies, as a proposal to support food security in Mexico.

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Abstract

For millennia, humans have used hundreds of species of plants to treat diseases, these practices continue to this day. In the traditional knowledge of medicinal plants can be reported many species with important characteristics to alleviate very diverse health problems, mainly in rural areas, where the use of these resources is very high, even comes to replace almost completely scientific medicine. This paper presents the dehydration of the main medicinal plants grown in the Campeche State, Mexico through direct and indirect solar technologies; the experimental results showed that the greenhouse solar dryer with solar heater coupling of evacuated pipes, solar collector of air and photovoltaic pumping, is the most efficient technology of the evaluated one, with average drying times of 315 min and final humidity of 9.6%. A study of colorimetry, analysis of water activity, and drying speed was carried out in order to control the drying process. It is proved that it is possible to use solar energy to dehydrate food as a means of conservation, also obtaining significant energy savings and contributing to the care of the environment.

Keywords: Solar drying technologies, Solar heater evacuated tubes, Hybridization of solar technologies.,

Introduction

It is estimated that 80% of the world's population uses traditional herbal remedies and at least 35,000 species of plants have potential for medicinal use (Ramírez Hernández et al., 2018). In Mexico, according to Ministry of Healthat least 90% of the population uses medicinal plants (Lugo & Lugo, 2009). Drying is the most common method of preserving medicinal plants, but due to the high investment and energy costs, drying represents an elevated expense in the production of medicinal plants (Singh & Singh, 2017). It is necessary to adopt technologies that effectively reduce post-harvest losses through the application of appropriate management, processing and conservation methods (Mewa, Okoth, Kunyanga, & Rugiri, 2019); Some post-harvest practices can limit the obtaining quality of the products, due the losses of their natural properties as colour, flavour and aroma, as well as their healing properties. This can be during drying of the product or any subsequent conditioning and storage (Banchero, Carballo, & Telesca, 2007). Solar drying provides high product quality with minimal environmental impacts. It is an effective, inexpensive and safe method for conservation of agricultural and food products (Kumar, Sansaniwal, & Khatak, 2016). There are different technologies for solar energy use. In contrast to energy sources such as fossil fuels, which depend on limited resources, solar energy is received naturally throughout the planet, and its use does not imply the destruction of the environment (Rodríguez et al., 2017).

There are two methods of solar drying (direct cabinet solar dryer and indirect cabinet solar dryer) that were tested under tropical conditions to dry aerial parts of sacha coriander (*Eryngium foetidum L.*) The indirect method was found more suitable for drying E. (Banout et al., 2010); Moreover, a comparative study of the solar tunnel and

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open sun drying of *moringa oleifera* leaves was carried out. It is found that the tunnel dryer requires less drying time and is economically viable (Vaghela, Bhautik, Sengar, & In, 2018). The thermal models for greenhouse dryers was also studied (Chauhan, Kumar, & Gupta, 2017). The study evaluates the previous work on the thermal modelling of greenhouse drying systems, greenhouse air temperature, relative humidity inside the greenhouse, drying velocity, drying kinetics and drying potential.

On the other hand, colorimetry is a non-destructive physical method widely used to determine the colour of a sample. The CIELab colour system is widely used for food colour determination. The three parameters measured in this investigation are: luminosity (L), redness (a) and yellowness (b). The value of L varies from 100 (for perfect white) to 0 (for black) (Doymaz & Pala, 2002), The difference in clarity is analysed by ΔL and the deviation of the red-green achromatic point is Δa, while that yellow-blue deviation is Δb and the total colour change is ΔE.

In this work, three medicinal plants were selected to determine the best conditions of solar drying by different direct technologies in terms of the effect of final humidity (db), water activity (aw) and colorimetry study. The plants were selected due to their medicinal properties and abundance in the Campeche region.

The *Mentha spicate* is native to Europe, it is grown in different regions of the country, because it gathers good culinary and agronomic characteristics, among its benefits is that it fights germs that produce bad odours in the oral cavity, giving the person some freshness and menthol, minimizes bowel symptoms irritable, gastric inflammation, excess gas, is antioxidant, among other properties (Alonso & Desmarchelier, 2014). *Annona muricate L*, Is a plant native to Mesoamerica cultivated mainly in the tropics of America, Africa and the Pacific Islands extending from Mexico to Brazil; among the many benefits it offers are some that stand out for being of great help to combat highly specialized diseases such as its anti-cancer elements that fight different types of tumours, also among others, important properties are found to be anti-inflammatory, anti-diabetic, anti-ulcer, contain enzymatic antioxidants and not enzymatic act for protection against the effects of deterioration (Madridejos Mora, 2016); finally, *Cymbopogon,* Currently grown in countries of subtropical to warm climate, its main medicinal property is to be anti-inflammatory and antioxidant due to polyphenols, it contains, so it is used in cases of cancer and to combat arthritis among other properties (Luardini, Asi, & Garner, 2019).

2. Experimental set up

In this study, the kinetics of drying medicinal plants using direct and indirect solar drying technologies were analysed experimentally to determine optimal operating conditions, evaluating the possibility of solar drying integration.

2.1 Materials y methods

Raw material. Mature medicinal plants, grown in Campeche, Mexico, were selected. The branches were cut, and the leaves were separated and selected to obtain a homogeneous group, based on maturity, colour, freshness and size. They were washed and weighed, the width, length and thickness were measured. The plants that were selected for experimentation were: *Mentha spicate*, *Annona muricate L.* and *Cymbopogon*, in sustainable Mexican agriculture, seeking to contribute to the country's food security.

2.1.1 Solar drying technologies.

Solar dryer tunnel. The tunnel dryer is hermetically sealed, is composed of 3 front gates and contains 2 trays in each section which have a metallic mesh with the intention of supporting the flow of hot air evenly, each tray has a separation of 20 cm. The drying chamber is connected to a solar water heater by means of a hopper, which drives preheated air inside, supported by a heat exchanger; additionally, the dryer has a solar air collector installed at the top, this collector consists of a fan that extracts the ambient air through its interior and directs it, with an increase in temperature, to the interior of the drying chamber. Figure 1 shows the technical specifications of this dryer.

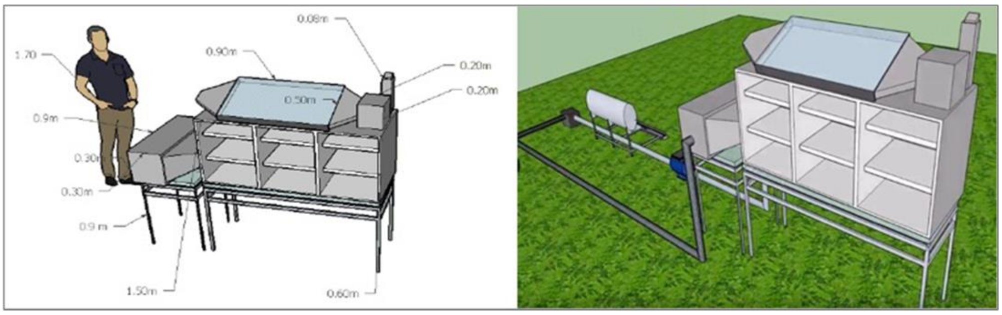


Fig. 1: Technical specifications of solar tunnel dryer

Solar direct dryer. In this case, the solar drying process was carried out in a direct solar dryer cabinet (figure 2) built using transparent plastic material with a 0.5 m^2 surface for raw material. The side, bottom and rear have perforations to allow hot and humid air circulation and extraction. The DSD can be operated with natural air circulation or forced convection using a fan placed at the back with a maximum air velocity of 2.9 m/s. Two direct solar dryers were used to dry the leaves, one with natural air flow and the other with forced convection).

Fig. 2: Direct solar dryer cabinet

Greenhouse solar dryer. The measures of this dryer are 2x2x2 m, the structure is steel PTR (square section tubing), the envelope is made of polyethylene plastic with UV protection, has ventilation to improve the drying system and is portable and disassembled (figure 3).

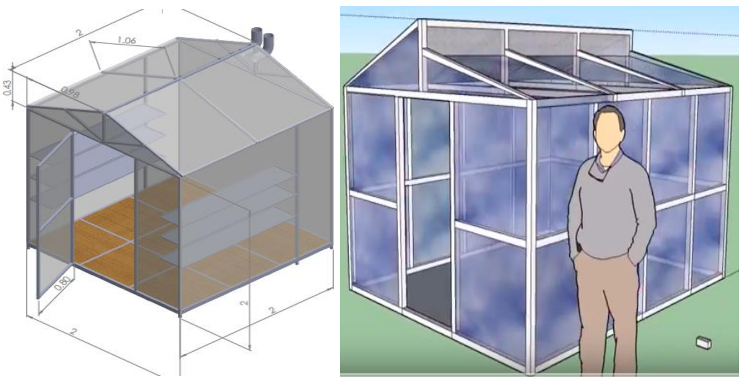


Fig. 3: Greenhouse solar dryer

In each case, the indoor temperature, weight and size of the samples, solar irradiance, relative humidity and air temperature were measured. In all cases we worked with photovoltaic technology.

2.1.2 Instrumentation

Humidity. A moisture analyser, Boeco BMA150, with an accuracy of ± 1 mg (0.001%) was used to determine the humidity of the leaves. The leaf sample of approximately 1.5 g and was cut and placed in the analyser. This procedure was performed for each condition before and after the drying process.

Water activity (aw). Water activity is a parameter that determines the stability of the food with respect to the ambient humidity. It was measured for both fresh and dried leaves before and after the drying process using portable water activity meter, Rotronic HygroPalm, with an accuracy of ± 0.01% mg. The mean of three measurements was reported at a room temperature of 24.5 ± 1 °C.

Temperature. The temperature and humidity inside the drying chambers were measured using a thermo-hygrometer Brannan with temperature and relative humidity accuracy of ± 1 °C and ± 3%, respectively.

Weight. The weight of the samples was measured using a Boeco balance, model BPS40plus, with an accuracy of ± 0.001 g.

Colorimetric analysis. The colour measurement tests in fresh and dehydrated samples used a Huanyu digital colorimeter, model SC-10, repeatability ≤ 0.03 ΔE * ab.

Climatic parameters. During the trial period, climatic parameters including temperature, humidity, air velocity and global solar irradiation were recorded by means of a meteorological station installed just in the experimental area. The specifications of the measuring instruments used in the experiments were considered from the data provided by the manufacturer (Table 1).

Tab. 1: Specifications and description of measuring instruments from the weather station

VARIABLE	***DESCRIPTION***	***MODEL***	***ACCURACY***
Global solar irradiance	LI-COR Pyranometer	LI-200R	Azimuth: < ± 1 % on 360° to 45° of elevation
Relative humidity	NRG Systems	RH-5X	± 3 %
Ambient temperature	NRG Systems	110S	± 1.1 °C
Wind velocity and direction	NRG Systems Wind sensor	Series #200P P2546C-OPR	± 3° ± 0.3 m/s

3. Results and Discussion

3.1. Weather conditions

Figure 4 shows the change in the weather parameters during the test period with three sunny days. As can be seen, a maximum solar global irradiance of 952 W/m^2 was achieved, with the average maximum values ranging between 874 and 962 W/m^2. The average ambient temperature they varied of 30 °C y 33.3 °C, whereas the average maximum ambient temperature was 35.7 °C. On the other hand, the minimum RH ranged between 44 % and 46 %, the maximum average on the test days ranged between 60 % and 81 %.

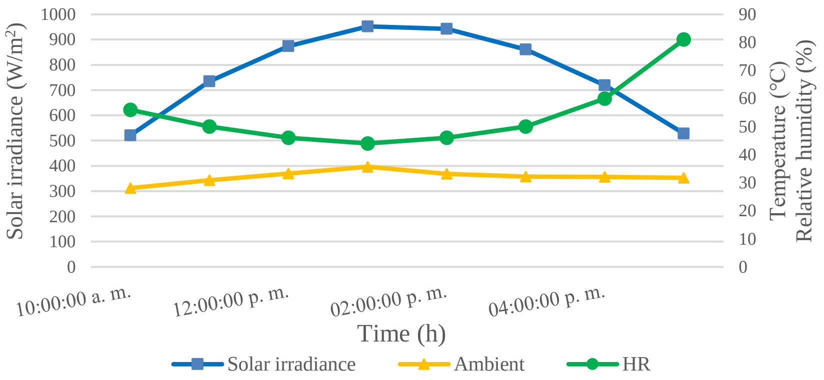


Fig. 4: Solar irradiance, ambient temperature, and relative humidity in one day during test period

3.2. Solar drying of medicinal plants

The dehydration of medicinal plants that are grown in the State of Campeche, Mexico through direct and indirect solar technologies is presented in order to evaluate the influence of air flow and temperature on the colour of the final product through the L* a* b* scale. The activity of water and humidity is analysed during the drying process. Curves of drying kinetics, moisture content in dry basis and drying rate are presented in order to corroborate the process control.

The initial and final humidity and water activity values of the fresh and dried leaves are listed in Table 2 for each solar drying technology studied. The initial and final humidifies presented values within the ranges reported in the literature as normal. The final aw values indicate that there is no possibility of microbial growth in the dehydrated product obtained.

Table 2. Initial and final humidity and water activity obtained by different drying methods (average)

		DSD Natural Convection		
Planta medicinal	Initial humidity (%)	Final humidity (%)	Aw initial	Aw final
Cymbopogon	73.63	8.64	0.99	0.33
Mentha spicate	79.58	8.73	0.96	0.43
Annona muricata L	68.2	10.49	0.98	0.49
		DSD Forced convection		
Cymbopogon	73.63	9.54	0.99	0.42
Mentha spicate	79.58	11.02	0.96	0.4
Annona muricata L	68.18	10.43	0.98	0.44
		Solar dryer tunnel		
Cymbopogon	73.632	8.27	0.99	0.46
Mentha spicate	79.581	11.11	0.96	0.4
Annona muricata L	68.177	10.03	0.98	0.42
		Greenhouse solar dryer		
Cymbopogon	73.63	8.53	0.99	0.45
Mentha spicate	79.58	9.86	0.95	0.51
Annona muricata L	68.18	10.53	0.98	058

3.2.1 Thermal characterization of solar dryers

The figure 5 shows the effect of solar irradiation and ambient temperature of the drying chamber of the tunnel dryer, as can be seen, the first section (the preheated air intake area from both the solar water heater and the air collector) reaches a higher temperature (51 °C) that the two remaining sections, however, temperatures are very similar, the maximum temperatures in the 3 cases vary between 48 °C and 51°C.

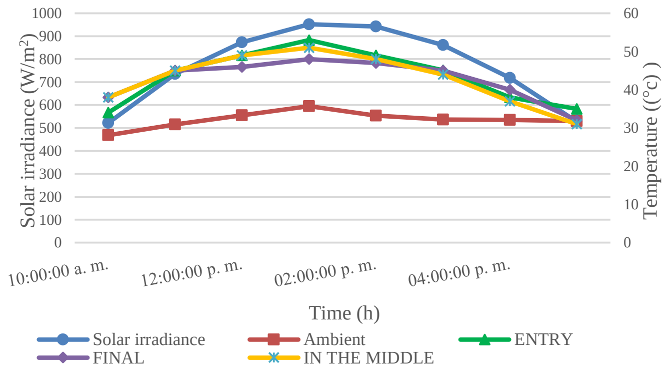


Fig. 5: Solar irradiance and ambient temperature, Comparison of climatic parameters and temperatures reached in the indirect solar tunnel dryer, one sunny day during test period

In the case of the greenhouse dryer, figure 6 shows the change in the received solar irradiance, the ambient temperature and the temperature variations inside the drying chambers. It was also measured the internal temperature generally ranged between 50 °C and 55 °C, with a maximum value of 59.4 °C.

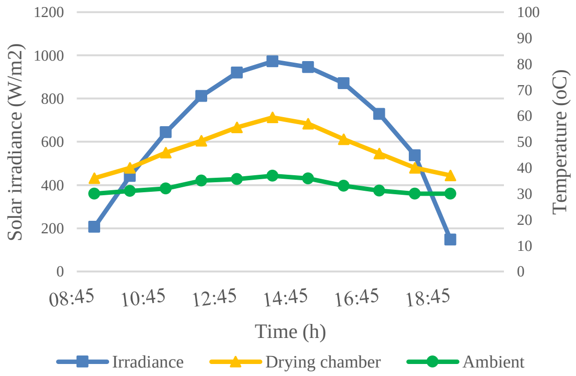


Fig. 6: Variation in solar irradiance and temperature inside the drying chamber under greenhouse dryer

Figure 7 shows the temperatures reached inside the drying chambers of the dryers that work with natural convection and forced convection as well as the irradiance during the day as an example. As can be seen in this graph, the temperatures in the drying chamber of the dryer with natural convection are higher than those presented by the dryer with forced convection, which is normal due to the low convection that occurs in the first case.

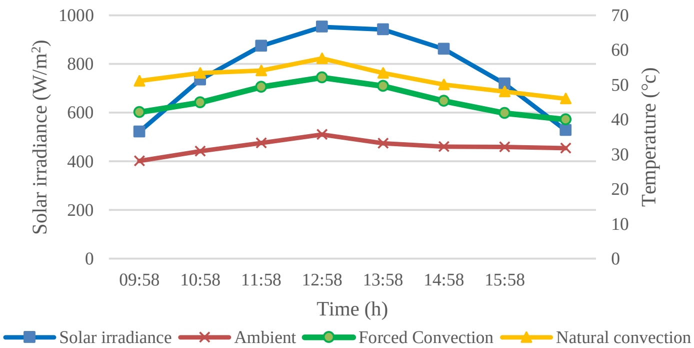


Fig. 7: Behaviour of solar irradiance and temperatures inside the drying chambers for the different operating modes of the cabinet dryer

3.2.2 Drying kinetics

In figures 8, 9 and 10, shows the variation of the drying rate as a function of moisture content (db), obtained in the three medicinal plants studied.

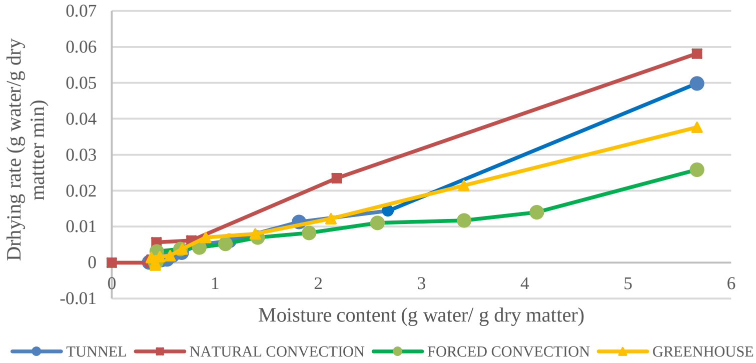
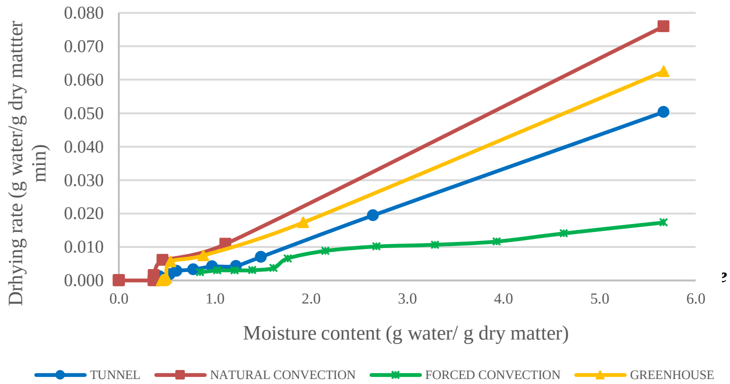


Fig. 8: Variation of moisture content with respect to the drying rate in *Cymbopogon*



In figures 8, 9 and 10 very important aspects can be observed when relating the moisture content and the drying rate as a function of time in each medicinal plants studied. In all three cases the drying kinetics of both the tunnel and the greenhouse are very similar, the drying times in these two cases vary between 300 and 350 minutes. The drying rate with natural convection in all cases is faster, varying between 0.06 and 0.08 g water/g dry matter•min, in the different plants. Forced convection is slower in all cases, although it is important to mention that the drying time of dehydrated plants by this method was more uniform than in the rest, this can be observed in the three graphs since the curves follow a trend very even, in this drying method the final time varied between 400 and 450 minutes.

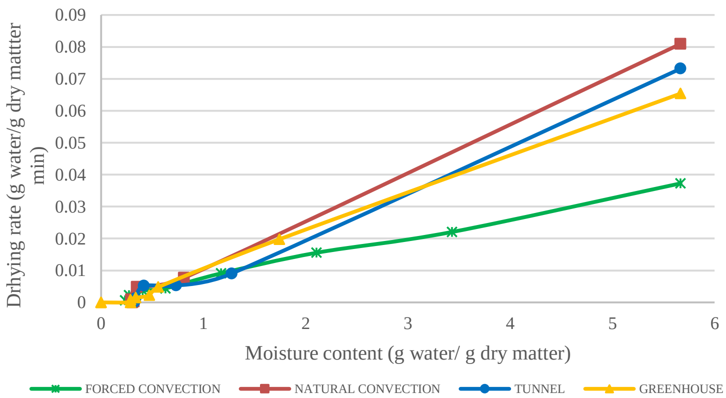


Fig. 9: Variation of moisture content with respect to the drying rate in *Annona muricate L.*

Table 3 shows the results of △E obtained in the study of colorimetry performed on medicinal plants in each of the solar drying technologies analysed (Mendoza, Dejmek, & Aguilera, 2006):

$$\Delta \boldsymbol{E} = [\![(\Delta \boldsymbol{L}^2) + (\Delta \boldsymbol{a}^2) + (\Delta \boldsymbol{b}^2]\!]^{1/2} \quad (1)$$

The results obtained indicate that in the case of the dryer that worked with natural convection, there was a significant increase of a* in the leaves, which reveals a tendency towards reddish colours and therefore, a decrease in the green colour; the luminosity decreased on all three floors in a very similar way. The conservation of the green colour in both forced convection and the tunnel was very remarkable, but it was conserved much more in the greenhouse (see table 4). Regarding b*, in all three cases this value decreased, this indicates a tendency towards grey colours.

It is important to highlight that the greatest colour change occurred in the solar cabinet dryer with natural convection, and the colouring of the leaves in the greenhouse solar dryer was further preserved. The solar dryer conserved more the green colour in the Cymbopogon and in the *Annona muricata L*, degrading of important form the leaf of Mentha spicate.

Table 2. Colour variation ΔE as a function of drying time, considering the three modes of drying operation of the medicinal plants studied

Medicinal plant / **Dryer operation mode**	***Annona muricata L.***		***Cymbopogon***		***Mentha spicate***	
	△E	**Time**	**△E**	**Time**	**△E**	**Time**
Natural Convection	16	250	15	250	18	200
Forced convection	8	450	10	400	9	400
Greenhouse	7	350	7	300	13	300
Tunnel	10	330	11	300	14	300

Table 2. Visual result of the colorimetry study carried out in dehydrated medicinal plants by different solar technologies

Medicinal plants / ***Drying method***	***Annona muricate L***	***Cymbopogon***	***Mentha spicate***
Tunnel			
Greenhouse			

Natural convection			
Forced convection			

4. Conclusions

By introducing hot air in the indirect tunnel type dryer, average temperatures up to 55 °C are obtained, these temperatures are similar at the reached in the greenhouse dryer. The DSD cabinet type with natural convection reached temperatures close to 60 ºC, and an average of 45 ºC is obtained when forced convection is implemented. The best drying time was achieved with the direct dryer with natural convection, but lower quality was found in terms of changing the colour of the leaves. The tunnel dryer was very efficient since the introduction of hot air into the drying chamber decreased drying times. Nevertheless, the best solar drying technology was the greenhouse solar dryer; the green coloration was better conserved and shorter drying times were obtained in all the experiments conducted. In all the cases studied, a final moisture was obtained in the products according to the commercial standards, therefore, it is guaranteed that the proliferation of microorganisms that degrade the dehydrated product is avoided; in the same way, the temperatures reached in the solar dryers in which greater quality was achieved in terms of colouring of the dehydrated leaves, the range of maximum temperatures reached varied between 45 ºC and 55 ºC, therefore the quality of the final product was also optimal with regard to this parameter, these results are in accordance with (Müller & Heindl, 2006). For Mexican producers, these results are very important since is demonstrated the feasibility of use solar energy and the drying technologies evaluated, to dehydrate agricultural products. The use of this technologies is possible to reduce energy costs and at the same time, contribute to environmental care.

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