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EXPERIMENTAL STUDY OF THE DEHYDRATION OF STEVIA LEAVES (REBAUDIANA BERTONI), UNDER CONTROLLED CONDITIONS AND WITH A TUNNEL-TYPE SOLAR DRYER

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Abstract: Sugar is a natural sweetener, with a high caloric content and its consumption has been associated with some health problems such as obesity, diabetes, heart disease and degenerative diseases. In recent years, various studies have been carried out to find a substitute, resulting in many natural and artificial sweeteners. Among these alternatives is the natural sweetener obtained from the stevia plant (Rebaudiana Bertoni) with zero caloric intake and harmless, with properties such as: oral antibacterial, hypoglycemic, hypertensive and anti-stress. The dry leaves contain 9 to 13% steviolglycosides (sweeteners), the stem less than 3% and nothing in the roots. This paper presents the characteristics and kinetics of dehydration of stevia leaves, using a non-convective oven at controlled temperature conditions: 45, 55 and 65 °C, with drying times of 240, 330 and 420 minutes respectively, and a tunnel-type solar dryer with drying times between 70 and 210 minutes. The initial moisture contents varied between 82 and 85% and the final ones between 10 and 13% on a wet basis, respectively. The tests were carried out in the Solar Drying Laboratory of the Institute of Renewable Energies, IER, of `` Universidad Nacional Autónoma de Mexico`` in Temixco, Morelos. Mexico, located at 18º 51' from NL and 99º 14' from LO, with a warm dry climate, with an average annual relative humidity of 50% and with average maximum irradiance values of 950 W/m2. The results obtained show the technical feasibility of solar drying stevia leaves, obtaining added value and encouraging its production in Mexico.
Keywords: Solar drying, stevia solar drying, indirect solar drying, solar tunnel drying.

INTRODUCTION

Sugar is the most consumed natural sweetener, it contains natural vitamins and elements that allow its metabolization, which, when processed as a refined product, are eliminated and the human organism mobilizes its own reserves to compensate, causing its deficit. Its consumption in this form of commercialization is associated with many health problems, where dental caries, heart attacks, nervous tension, obesity, diabetes, among many others, stand out (SAGARPA, 2011). Biotechnology has introduced artificial sweeteners with low-calorie chemical components into the world market. Alternatives to natural sweeteners similar to artificial ones have been proposed, but which are not harmful to health. Among the natural sweeteners is Stevia, (Stevia rebaudiana Bertoni), sweeter than sugar and contains no calories.

Stevia (Stevia Rebaudiana Bertoni) is a small shrub native to Paraguay, it belongs to the chrysanthemum family. Its sweet components are known as steviolglycosides with a high sweetening power and no caloric intake, because they are not metabolized or accumulated in the body. The dry leaf contains: carbohydrates, proteins and mini nutrients that together provide 275 kcal/100g of dry leaf, 35% less than sucrose. It has a high content of antioxidants, being 5 to 6 times higher than that of green tea.

The dried stevia leaf contains 9 to 13% sweetener, the stem less than 3% and the root does not. In the inflorescence the content in the leaves is reduced by 3% in dry weight. Due to its sweetening characteristics and economic attractiveness, its production has been increasing internationally, being China its main producer, followed by Paraguay and the main consumers China, Japan and Korea. Today stevia is cultivated intensively for the manufacture of the only safe, natural sweetener, and without health risks, the fresh, dried crushed leaf can be consumed (30 times sweeter than sugar) in extract in the form of crystals or liquid solutions and normally in filter bags. As a medicinal plant it has antidiabetic properties (regulates glucose levels), antiglysemic, anti-cavities, reduces blood pressure and anti-stress.

Stevia leaf dehydration: The drying of the plant and leaves is by direct exposure to the sun or in ovens. In open-air drying, the branches and leaves are placed on a semi-shade or plastic mesh, without overlapping them, they are left until sunset and if they have not dried they are collected and stored indoors, continuing the next day, until complete the process and once dry the leaves are separated from the stems. With low humidity and a thin layer, it can be done within 9 to 10 hours, reducing its humidity from 80 to 10% (Oddore, B., 1999). Kiln drying can take two days (Columbus, M., 1997). Quick drying improves the quality of the sheets. If it is not dried quickly after cutting it, the quality deteriorates due to oxidation, losing up to a third of the stevioside content after 3 days of exposure (Oddore, B., 1999) An area of 100 m2 is needed to dry one hectare of planted land. The branches must be exposed to the sun for 4-6 hours. The ideal point to pick and store them is when they become brittle, with 10-12% humidity.

The kinetics of drying between 30 and 80 °C, the effective diffusivity and activation energies have been obtained (Lemus et al, Kaya and Aydin, 2009), the effects of drying conditions on quality (Garcia, 2014), the convective drying of leaves (Jeria and Pozo, 2011, Sadvatha et al., 2011), industrial production, (Cruz and Martinez, 2010, Midmore and Rank, 2002). There are very few published works on the solar drying of Stevia leaves, among them; the kinetics of solar drying in a connective tunnel, (Darshan et al., 2012,) and the proposal of mathematical models for leaf drying, (Mowade, et al.,). The main barriers to its development are; the cost of the crop, the supply of seedlings, the management of the crop, the harvest as well as the drying of the leaves that, if not carried out correctly, can present great losses in the quality of the dehydrated material.

PILOT STUDY

In this work, the drying process of the stevia leaf is experimentally analyzed in a cabinet-type solar dryer and in a conventional dryer with non-convective electrical heating at a controlled temperature in a range between 45 °C and 65 °C, with the objective of to determine the optimal conditions of the drying process with hot air.

MATERIALS

Raw material: Mature Stevia plants of the Morita II variety, cultivated in the municipality of Tenabo, Campeche and in Temixco, Morelos, were selected. The branches were cut, and the leaves were separated and selected to obtain a homogeneous group, based on maturity, color, freshness. They were washed and weighed, the width, length and thickness were measured. The weight of the leaves from Campeche varied between 0.30 and 0.34 g, while those from Morelos oscillated between 0.31 and 0.22 g.

METHODS

In this work, the dehydration process of the.

Non-convective electric dryer: To obtain the drying kinetics, a Riossa brand electric oven without air convection was used. Weight loss was recorded using software and drying temperatures were varied at 55, 65 and 75°C.

Indirect tunnel type solar dryer: The drying chamber is a horizontal rectangular tunnel with a length of 6 m, and a cross section of 0.30 m2. The structure is metallic and has thermal insulation. The tunnel can treat up to 4,000 m3/h, and up to a maximum air speed of 4 m/s can be obtained. In most food drying processes, the recommended speed is less than 3 m/s. At the entrance of the tunnel, an external diffuser and an air filter were placed. At the exit, in order to extract the hot and humid air, a chimney was placed. The tunnel was divided into five sections and in each one there are three trays at different levels, which contain the product to be dried. In this work, 5 flat solar collectors connected in series were used to make drying more efficient, and through a heat exchanger, hot air is transferred to the drying chamber at a temperature of up to 60 °C.

Figure 1 shows the type of tunnel-type indirect solar dryer used and in Figure 2, the flat solar collector system. In said dryer, the interior temperature, the weight and size of the samples, as well as solar irradiance, relative humidity and air temperature were recorded.

INSTRUMENTATION

Humidity: For the determination of humidity, two scales with a humidity analyzer, brand, Sartorius MA 45 and Ohaus MB45, were used, respectively, with an accuracy of ± 0.01% mg. The leaves of the branches were cut and a sample of approximately 1.0 was placed. g and proceeded to dehydration, obtaining the moisture value. This procedure was carried out before and after carrying out the different drying kinetics.

Water activity (αw). Water activity is a parameter that determines the stability of food with respect to environmental humidity. The water activity was determined for the fresh leaf and later for the dry leaf. A portable Rotronic Hygropalm brand equipment was used, with a precision of ± 0.01% mg.

Weather conditions: During the testing period, the climatic and solarimetric variables were recorded at the IER weather station. Table 1 shows the values of the determined variables, the equipment used, as well as the accuracy percentages (manufacturer's data).

Figure 1. View of the tunnel-type solar dryer / Figure 2. Solar collector system

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental study was carried out in the Solar Drying Laboratory located in the Solar Platform of the Renewable Energy Institute (IER) of the UNAM, in the city of Temixco, Morelos, located at 18º 51' from LN and 99º 14' from LO and dry hot climate (annual average relative humidity 50%), with average maximum irradiance values of 950 W/m2. The testing period was from April 1 to 15, 2015. Figure 3 shows the evolution of the weather parameters during the tests on April 9. As can be seen, during the test days, the maximum global irradiance reached was 1000 W/m2, with the range of average maximum values between 950 and 990 W/m2. The minimum values of ambient temperature oscillated between 22.0 °C and 27.69 °C, while the maximum measured averages varied between 29.0 °C and 33.29 °C. Regarding relative humidity, the minimum percentages reached varied between 18.11% and 29.2%,

VARIABLE	DESCRIPTION	MODEL	CALIBRATION	MAXIMUM MISTAKE
Global radiation	Eppley pyranometer	PSP	Annual (IGF-UNAM) (K=7.80X10 V/Wm-2 sensor CampbelL	**±0.5 W/m^2**
Ambient Temperature **Relative humidity**	Sensor Campbell, CS500	1000 ΩPRT, DIN 43760B	Bi-annually (Manufacturers)	**±0.4°C** **±3%**
Velocity Direction of the wind	Wind Sentry mod 03002-5 R.M. Young Company	03002-5	Bi-annually (Manufacturers)	**±0.3 m/s** **±3º**

Table 1. Characteristics and description of the measuring instruments of the weather station

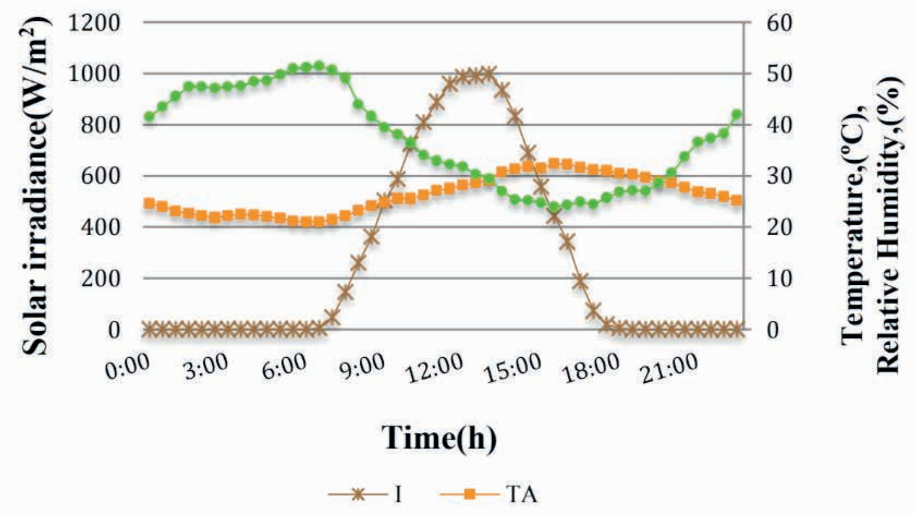

Figure 3. Evolution of global solar irradiance, ambient temperature and relative humidity on April 9, 2015.

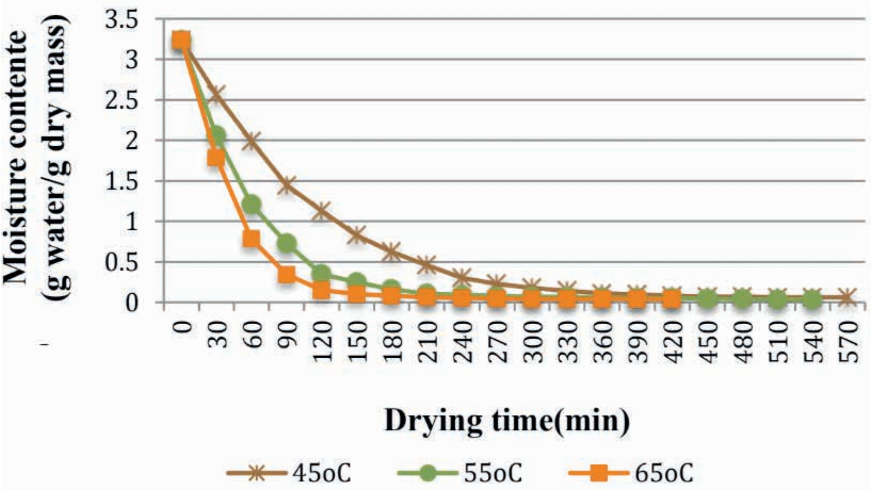

Figure 4. Variation of moisture content with respect to drying time under controlled conditions at 45 °C, 55 °C and 65 °C in the electric dryer.

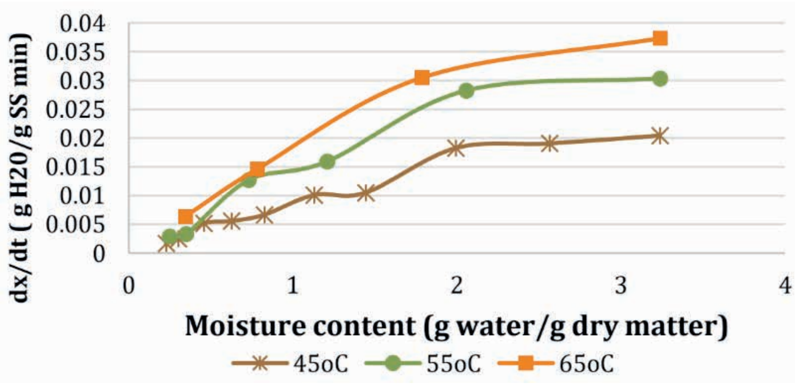

Figure 5. Variation of drying speed as a function of moisture content at different drying temperatures; 45 °C, 55 °C and 65 °C in the electric dryer.

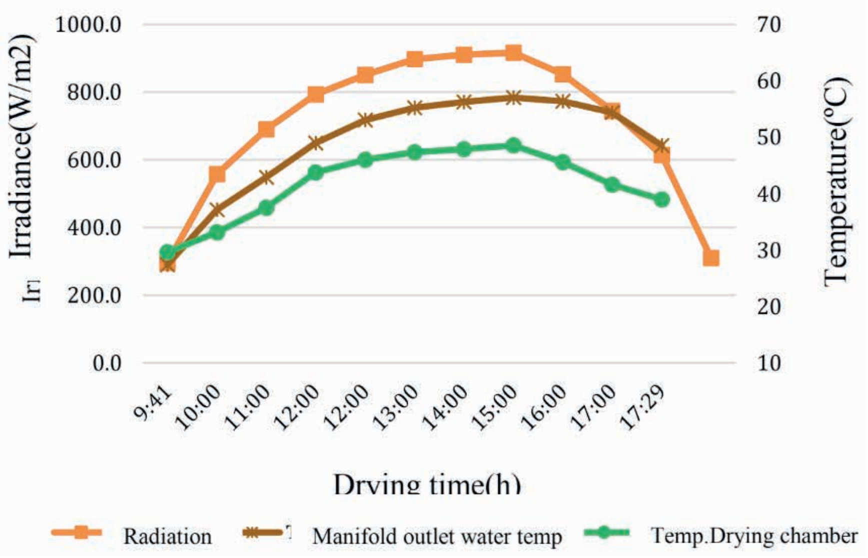

Figure 6. Evolution of solar irradiance, the temperature of the water in the collectors and the temperature inside the drying chamber.

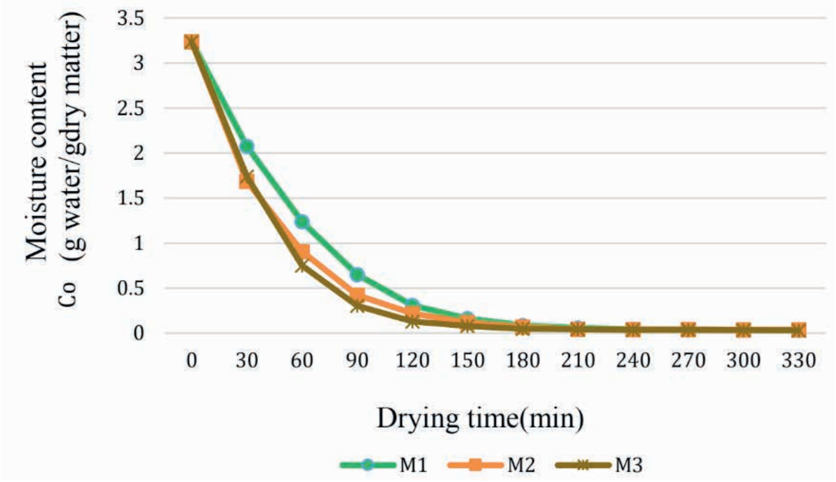

Figure 7. Variation of moisture content in solar dryers with natural convection and forced convection.

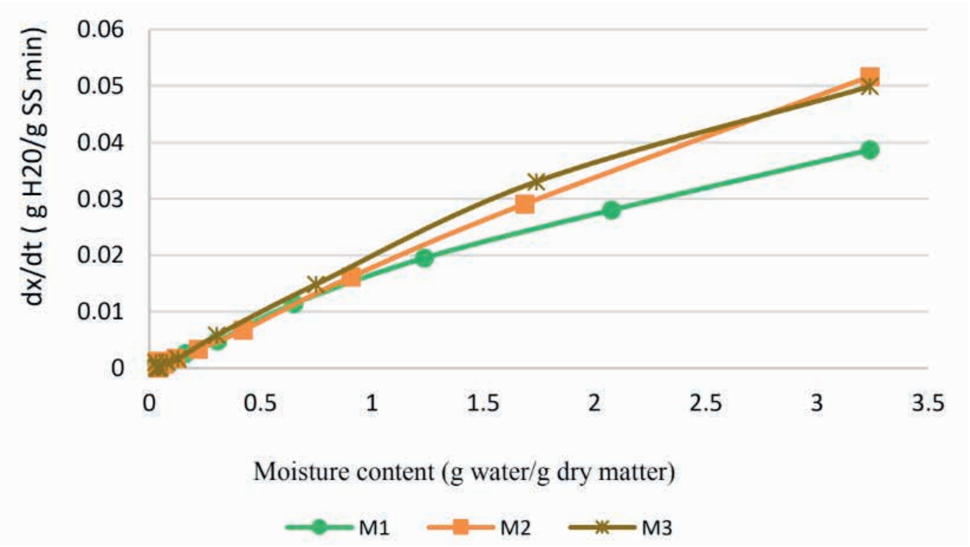

Figure: Variation of the drying speed with respect to the variation of the moisture content obtained with solar dryers with and without forced convection while the maximum values measured were between 32.65% and 50.0%.

NON-CONVECTIVE DRYING AT CONTROLLED TEMPERATURE

Stevia leaves dehydration tests were carried out, obtaining the drying kinetics at controlled temperatures of 45 °C, 55 °C and 65 °C, carrying out three experiences for each of them. The treated leaves had an average weight of 1.2 g. and 20 g were introduced into the tray.

In Table 2, the initial and final humidities and water activity of the fresh and dry leaf are presented. The initial humidities fluctuated very little, while the final ones were lower than those obtained in commercial products between 12 % and 13 %.

SAMPLING	*HUMIDITY (%)*		a_w	
	INITIAL	FINAL	INITIAL	FINAL
45 °C	83.40	9.46	0.591	0.205
55 °C	81.58	6.88	0.426	0.139
65 °C	82.06	7.71	0.600	0.205

Table 2. Humidity and water activity for the three selected temperatures.

Figure 4 represents the evolution of humidity on a dry basis for the three established temperatures, with drying times of 240 minutes for a temperature of 65 °C, min for 330 minutes for 55 °C and finally 420 minutes for 45 °C. Figure 5 represents the evolution of the drying speed as a function of the moisture content for each of the drying temperatures. In the interval from 55 °C to 65 °C, the highest speeds were presented and at 65 °C, only a period of decreasing speed was obtained, however at 55 °C and 45 °C, two periods of speed were observed almost constant between the intervals of moisture content on a dry basis of: 3.23 and 2.05 for 55 °C and 3.3 and 1.99 for 45 °C.

Tunnel Type Indirect Solar Dryer: Table 3 shows the values of water activity (aw), initial humidity and final humidity of four tests carried out on fresh Stevia leaves in the solar tunnel dryer. As can be seen, as in the case of the readings obtained in the oven, the final humidity is below the humidity that is handled commercially, in terms of the measurements obtained in the final water activity, it can be observed which are very low values, which is guaranteeing the inhibition of microorganism activity in the final product.

In Figure 6, the evolutions of the temperatures inside the drying chambers, the temperature of the water coming from the solar collectors and the solar irradiance received during the test day are presented, where an interval of solar irradiance was received between 558 W/m2 and 850 W/m2, and a maximum value of 9160 W/m2. Regarding the temperatures in the drying chamber, an interval between 45 °C and 46 °C was obtained with a maximum value of 49 °C, and the water temperatures of the solar collectors reached an interval between 53 °C and 56 °C. °C with a maximum value of 57 °C.

Parameter Gage	***HUMIDITY (%)***	***WATER ACTIVITY (a_w)***
INITIAL	80.77	0.992
FINAL	7.83	0.212

Table 3. Initial and final humidity and water activity of the Stevia leaf in a solar dryer with natural and forced convection.

Figure 7 presents the evolution of the humidity of three samples of dehydrated stevia leaves in the tunnel-type solar dryer. The initial weights of these samples were, M1: 21.2 g, M2: 20.78 g, M3: 20.6 g. As can be seen in the graph, the slopes of the curves originated by the three samples are very similar, although the kinetics of M2 and M3 are slightly faster than those corresponding to M1, basically because this sample has more mass than the previous ones. Regarding the drying times, there are 180 minutes for M2 and M3 and 210 minutes for M1.

Figure 8 presents the variation of the drying rates in each of the samples as a function of moisture content. In all three cases a period of constant speed was observed, the highest speed being that of samples M1 and M2, with a value of 0.0552 and 0.0551 with a drying time of 180 min. In the case of electric drying at 65 °C, the maximum speed reached was 0.037 in a drying time of 480 min.

CONCLUSIONS

The drying kinetics under controlled conditions showed dehydration times between 5 and 8 hours, and temperatures varied between 45 °C and 65 °C, with 55 °C being optimal, with a time of 6.0 h. The drying times obtained in the tunnel-type solar dryer supported by flat collectors were much shorter (three hours, with an average temperature of 45 °C) and similar to the controlled conditions of 55 °C. Based on the results obtained, the solar drying technology in a tunnel-type solar dryer is more economical, more friendly to the environment and is the most suitable for the treatment of Stevia leaves, having significant energy savings, with little investment. and with an acceptable quality of the dehydrated product.

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