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Solar drying study of mango (*Mangifera indica*) and determination of glucose content in dehydrated samples

Estudio del secado solar de mango (*Mangifera indica*) y determinación del contenido de glucosa en muestras deshidratadas

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Abstract

Today, the food industry processes are increasing both the costs and the consumption of energy through fossil fuels. The dehydration process to preserve food is increasingly used worldwide to safeguard both its organoleptic and nutritional properties, so it is essential to use renewable energies to replace conventional technologies. Mexico is a great producer and exporter of different mango varieties, with excellent culinary quality and nutritional properties. In the present work, direct cabinet-type solar dryers were used, and drying times between 420 and 540 min were obtained in fresh samples with 74.5% and 7.5% of initial and final humidity, respectively. Compared to its new mango content, glucose decreased in the dry samples.

Glucose, Moisture Content, Drying Rate

Resumen

Los procesos de la industria alimentaria en la actualidad están incrementando tanto los costos como el consumo de energéticos mediante combustibles fósiles. El proceso de deshidratado para conservar alimentos es cada vez más utilizado en todo el mundo para conservar las propiedades tanto organolépticas como nutrimentales de estos, por lo que es imprescindible utilizar energías renovables para sustituir las tecnologías convencionales. México es un gran productor y exportador de diferentes variedades de mango, con una gran calidad culinaria y propiedades nutrimentales. En el presente trabajo se utilizaron secadores solares directos tipo gabinete, se obtuvieron tiempos de secado entre 420 y 540 min, en muestras frescas con 74.5% y 7.5% de humedad inicial y final, respectivamente. Se encontró que la glucosa disminuyó en las muestras secas, en comparación con su contenido en mango fresco.

Glucosa, Contenido de humedad, Velocidad de secado

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1. Introduction

The mango is a tropical tree species, of permanent vegetation, which can reach 10 to 40 m in height. The fruit is succulent, fleshy, kidney-shaped or oval, greenish, yellowish, reddish, very sweet and enclosing a large stone or cavozo, flattened, surrounded by a woody cover. It is consumed in fresh fruit as well as in juices, ice creams, candies, jams and preserves. Industrially it is processed into pulp, pickles and frozen products. Mango is considered a highly healthy fruit; its high water content (86.1%) is a pleasant way to hydrate (SADER, 2017). Mango production in the country today has the ideal conditions to supply the growing external demand. In 2019, a new maximum in exports of the fruit was observed: 450 thousand 524 tons (Secretaría de Agricultura, 2020).

Mango is also an important source of dietary fiber; apart from its high content of fructose, sucrose and glucose, it is characterized by having a high content of vitamins and minerals (such as ascorbic acid, thiamine, riboflavin, niacin and β-carotene). In particular, almost all varieties are a rich source of ascorbic acid and carotenoids that, together with its phenolic compounds, make a specific synergy in the total antioxidant capacity of each variety. 100 grams of mango pulp is enough to cover 146, 69 and 45% of the recommended daily intake of ascorbic acid in Mexicans aged 4-8, 9-18 and 19-50 years respectively.

Apart from its high fructose, sucrose and glucose content, this pulp is recognized for being a source of uronic acid heteropolysaccharides and neutral sugars (pectins) for the food industry where citrus pectins are commonly used (Wall-Medrano et al., 2015).

Mexico stands out for the production of 9 kinds of mango, Ataulfo, Tommy Atkins, Haden, Kent, Keitt, Manila, Manzanillo Núñez, Irwin and Diplomático. The first five varieties are destined for the international market. In the State of Campeche, the varieties that stand out are Manila, Ataulfo and Tommy Atkins. The average yield in the state's mango-growing regions fluctuates between 12 and 13 tons ha-1. Around 300 direct and indirect jobs and 450 eventual jobs are generated between the field and the industry (Postgraduados & Campeche, 2014).

The Tommy Atkins species has a slightly sweet flavor, firm texture, juicy flesh and low fiber content. Its size is medium to large, it is oval and elongated in shape. The dark red color covers much of the fruit, but is accompanied by green, orange and yellow. Harvest time is from the end of February to August, it is produced in Michoacán, Jalisco, Colima, Guerrero, Nayarit, Sinaloa and Campeche. The size ranges from 12 cm to 14.5 cm, with a width of 10 cm to 13 cm and a weight of 450 gr to 700 gr. It is also consumed in its original form, but it stands out as an accompaniment to main entrees and grills (LEGISCOMEX, 2014).

There are two important varieties in the state, Tommy Atkins and Manila. Mango is a priority product at the state and national level (Campeche Government, 2012).

The agricultural harvest is usually greater than the immediate consumption of the populations, which causes significant waste, in addition to shortages in the post-harvest periods. Therefore, a reduction in post-harvest losses of food products will bring a considerable positive effect on the countries' economy.

Solar drying of food supports the improvement of product color, flavor and shelf life by reducing the risk of microorganism growth and preventing insect infection and contamination by toxic materials (Devan et al., 2020).

Currently, there is a great diversity of solar dryer designs, which in many cases have the purpose of studying the properties of dehydrated agricultural products and specifically tropical fruits (Iglesias Díaz et al., 2017).

Studies have been found in the literature mainly related to mango drying using indirect dryers with forced convection (Wang et al., 2018), indirect by adding solar collectors (Dissa et al., 2009) mathematical modeling (Koua et al., 2009), tunnel type with natural convection (Koua et al., 2009) and greenhouse dryers (Mugododo & Workneh, 2021).

In the present work, the drying of Tommy Atkins mango was experimentally studied using direct cabinet-type solar dryers, with and without forced convection, mathematical modeling was performed and studies of glucose levels in the dehydrated samples were carried out.

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2. Experimental Study

The study was carried out in the city of San Francisco de Campeche, Campeche, Mexico, located at the geographical coordinates: between parallels 17°49' and 20°51' north latitude and meridians 89°06' and 92°27' west longitude. The climate of the State of Campeche is warm sub-humid.

An experimental study was carried out on the drying of Tommy Atkins mangoes using cabinet-type solar dryers, evaluating two modes of operation: with natural convection and with forced convection. The glucose parameter in the dried samples was analyzed in order to evaluate the conservation of this parameter once the mangoes were dehydrated using solar energy.

2.1 Experimental setup

Direct cabinet-type solar dryer. A direct solar dryer made of acrylic, with a treatment surface of 0.5 m^2, was used. The chamber contains a solar radiation absorbing tray where the product is placed. It has perforations on the sides, bottom and rear, to allow the circulation and extraction of hot humid air.

The front surface has a 20° slope to take advantage of the incident solar radiation and to allow condensation and water runoff. It can operate in natural or forced convection, by means of a fan placed at the rear, with a power of 20 W, and allows a maximum air speed of 2 m/s^{-1}. Figure 1 shows the solar dryer in operation.

Figure 1 Cabinet type direct solar dryer
Source: Photo by author

2.2 Materials and Methods

2.2.1 Materials

Tomy Atkyns mango variety, purchased in the Municipal Market of Campeche, Mexico, was used for the experiment. Sliced samples were used as samples, taking care of their homogeneity in terms of ripeness, size, unit weight and thickness. Samples weighed between 20 and 22 g, with an average fresh moisture content of 80%.

2.2.2 Methods

In this work, two similar drying chambers were used for natural convection and forced convection drying. In each dryer, the interior temperature, weight and size of the samples, as well as solar irradiance, relative humidity and air temperature were recorded.

Mango weight measurements were taken every 30 minutes using a high-precision scale from 9 a.m. to 4 p.m.

The humidity of the different samples was carried out using a moisture analyzer Ohaus model MB45 halogen type, with an accuracy of 1mg ± 0.01% in a temperature range of 50 to 200 °C.

Climatic conditions. During the testing period, climatological parameters were recorded at the UAC Faculty of Engineering weather station. The characteristics (manufacturer's data) are as shown in Table 1.

Variable	Description	Model	Maximum error
Global radiation	Pyranometer brand LICOR	LI-200R	Azimut: < ± 1% over 360o at 45o elevation.
Relative humidity	NRG Systems	RH-5X	± 3%
Ambient temperature	NRG Systems	110S	± 1.1°C
Wind direction	NRG Systems	Series #200P	± 3º
Anemometer	Windsensor	P2546C-OPR	± 0.3 m/s

Table 1 Characteristics of weather station measuring equipment
Source: Author with manufacturer's data

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For the glucose tests, a Thermo Scientific spectrophotometer was used, with a deviation of <0.002 A/hr.

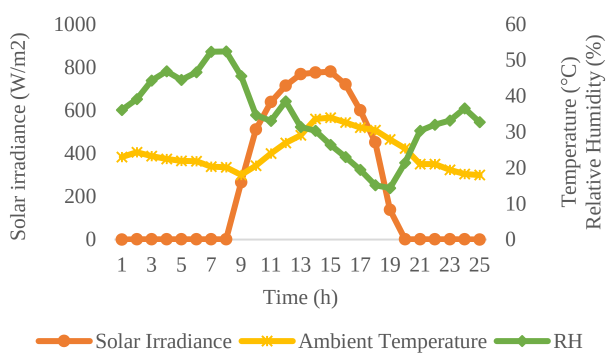
Likewise, for greater precision, a Thermo Scientific automatic pipette was used, with a precision of 0.01 µL. To dilute the portions of mangoes, they were placed in a solution of different densities of sulfuric acid mixed with water.

The portions of dried mangoes were cut into 5 mm squares and 3 different solutions were obtained in order to obtain a larger solution for evaluation.

3. Experimental results and discussion.

3.1 Climatological parameters.

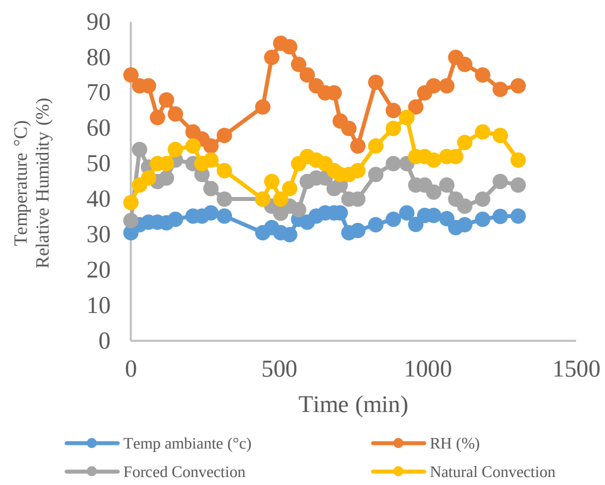
The experimental study was carried out in the Solar Drying Laboratory of the Faculty of Engineering of the Autonomous University of Campeche. Figure 1 shows the evolution of the climatological parameters, taking a test day as a reference.



Graphic 1 Solar irradiance, ambient temperature and relative humidity during the sunniest day of the test period
Source: Author with data from weather station

As can be seen, the maximum global irradiance reached was 780 W/m^2. The ambient temperature values were between 30.0 °C and 33.3C. On the other hand, the average value of relative humidity during the peak hours of solar irradiation was 30%.

Graph 2 shows a comparison of the ambient temperature, relative humidity and temperatures in the drying chambers, both with natural convection (NC) and forced convection (FC).

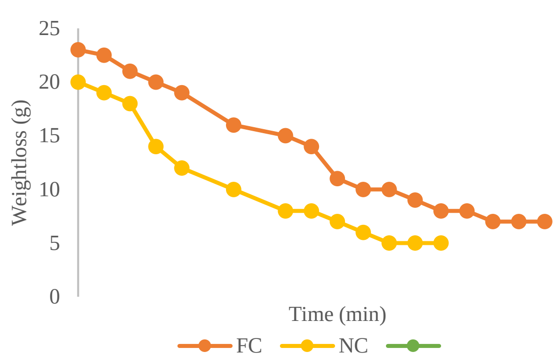


Graphic 2 Ambient temperature, relative humidity and temperatures in the drying chambers (natural convection and forced convection)
Source: Author, with data from meteorological station

The previous graph shows that the maximum temperature obtained with the natural convection dryer was 65°C, while the forced convection dryer obtained 52°C, with an ambient temperature of 36°C maximum and a relative humidity of 63°C.

3.2 Drying kinetics

Graphic 3 presents the experimental results of mango dehydration in the direct dryers with forced convection and natural convection. The initial weights of the samples were 20 g (CN) and 23 g (CF). The drying kinetics in both cases follow the same trend.



Graphic 3 Weight loss of samples in direct solar dryers
Source: Author with data from measuring equipment

Graphic 4 shows the moisture content (dry basis) as a function of drying time for both samples.

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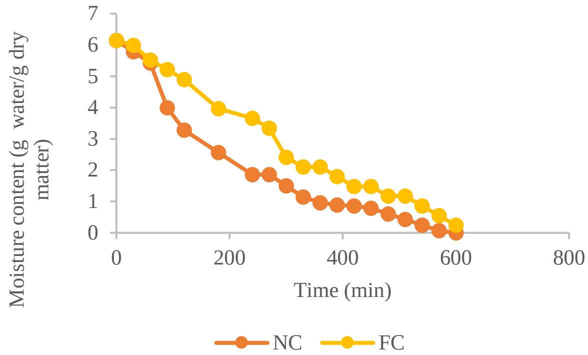
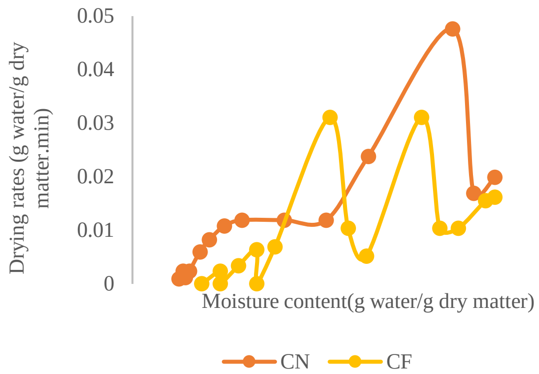


Graphic 4 Moisture content as a function of drying time
Source: Author with data from measuring equipment

As can be seen, the drying kinetics is faster with natural convection than with forced convection; the drying time in the first case was 420 min, while in the second case it was 540 min. Graphic 5 shows the drying rate as a function of moisture content in the dehydrated samples.



Graphic 5 Drying rate as a function of moisture content
Source: Author with experimental data

It can be observed in graph 6 that the highest drying rates in the dried samples with natural convection and with forced convection are found at points 5.4 and 4.9 g of water/g of dry matter, respectively.

It is also very noticeable that the highest drying rate was presented in the samples with natural convection, this was reflected in all the tests performed.

It is important to note that despite the fact that the sunniest day was selected, we obtained cloudiness during the test day, this can be seen in the oscillations of the climatic parameters throughout the day (Figure 3), and we see these temperature changes reflected in graph 6:

The drying speed varies more in the dryer with forced convection while in the dryer with natural convection it is more stable, this is due to the fact that because of the extraction of the interior air by the action of the fan, the dryer does not retain the temperatures that are reached during periods of high ambient temperature, however, in the second case, the dryer reaches higher temperatures and during periods of cloudiness, it maintains high temperatures for a longer time, by accumulation of heat in the drying chamber, the temperature is lost, but more slowly.

The initial percentage of humidity was practically the same in both cases; however, the final humidity was in a range between 8.9% and 6.06% in all samples, with an average of 7.48%. The average moisture reduction was set at 72.52%.

3.3 Glucose content in dry samples

The objective of these tests was to observe and quantify the loss of properties of the dried fruits, in this case, the dried mango samples. As mentioned in the Methodology section, the dried mango samples obtained in the two drying methods were diluted in order to perform the glucose content analyses. Once the mango was diluted, it was prepared to perform the respective tests in the spectrophotometer and for this purpose, 5 solutions of 5 different densities of sulfuric acid and distilled water were prepared.

The diluted mango was poured into each of these 5 solutions in a test tube and labeled, obtaining 5 tubes per type of mango (dry samples in natural convection and forced convection), plus a stock solution of 30% sulfuric acid solution and 70% water that served as a reference to calibrate the spectrophotometer between each measurement.

These tests were performed in duplicate in order to have two values at the end to make an average. The aim was to have values as close as possible to reality. Figure 7 shows the solutions obtained.

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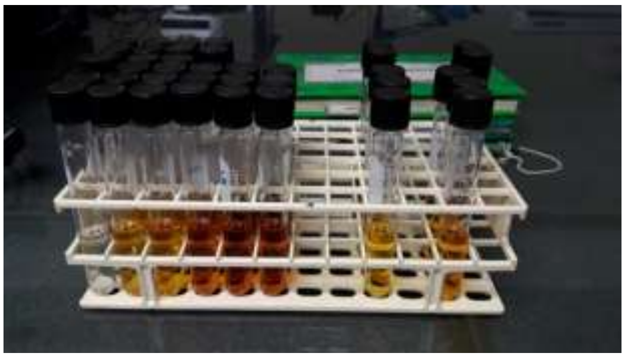
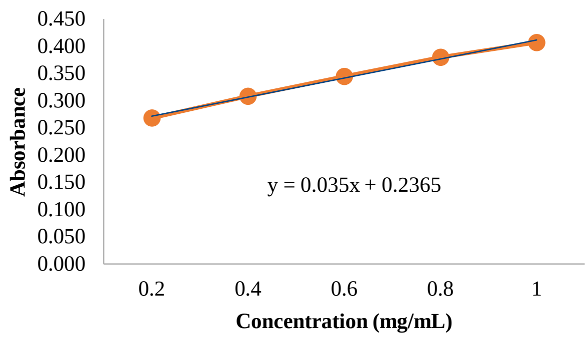


Figure 2 Samples of dehydrated mangoes obtained in solar dryers, for analysis of glucose content
Source: Photo by Author

Graphic 6 shows the absorbances obtained as a function of concentration.



Graphic 6 Absorbance for each solution as a function of concentration
Source: Author with data from measuring equipment

Table 2 shows the glucose concentrations obtained in the samples of mangoes dehydrated with solar dryers.

	FC sample (forced convection)	NC sample (natural convection)
Concentration x (in mg/ml)	**0.64**	**0.59**

Table 2 Glucose concentrations obtained in the dry samples.
Source: Author with experimental data

According to the results shown in Table 2, "x" represents the concentration and means that the mango sample in forced convection contains 63.7% and the mango sample in natural convection 59.4% glucose, without rounding the final values obtained. According to previous studies, Glucose represents 82.5 % of the total neutral sugars in fresh mango (Cardenas-Coronel et al., 2012), thus decreasing the glucose content in the dried hand, although not significantly.

4. Conclusions

The drying kinetics of mango was determined in a direct solar dryer operating by two different modes of operation: natural convection and forced convection

The fresh ripe mango samples weighed between 20 g and 22 g, with an average initial moisture content of 80%. The drying kinetics was faster with natural convection than with forced convection, drying times were 420 min and 540 min, respectively.

In both cases, the average final moisture content was 7.48%. The average moisture reduction was 72.52%.

These results for the dried mangoes are similar to the moisture percentages found commercially in national markets.

Regarding the glucose study, the results of the present study indicate that the content of this parameter decreased in both solar drying modes, compared to the content in fresh mangoes. This result is important in the case of health problems in people such as diabetes, since it is less likely to affect health when consuming dried mangoes than fresh mangoes.

In addition to the above, it is important to emphasize that solar drying supports the reduction of environmental pollutants and the use of conventional energy, contributing to the care of the environment.

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