Dehydration of strawberry (*Fragaria vesca*) using a direct solar dryer

Deshidratación solar de fresa (*Fragaria vesca*) usando un secador solar directo

CABRERA-REQUENES, Joshua Salvador†´, GONZÁLEZ-CABRERA, Adriana Elizabeth´´, VILLEGAS-MARTÍNEZ, Rodrigo Cervando´ and GARCÍA-GONZÁLEZ, Juan Manuel*´

´ Unidad Académica de Ciencias Químicas, Universidad Autónoma de Zacatecas, Km. 6 s/n Carr. Zacatecas-Guadalajara, Ejido "La Escondida", Zacatecas, Zacatecas, 98160, México.
´´ Instituto de Geofísica de la Universidad Nacional Autónoma de México, Circuito de la Investigación Científica s/n C.U, Coyoacán, 04150, México.

ID 1st Author: *Joshua Salvador, Cabrera-Requenes* / **ORC ID:** 0009-0002-1799-8586, **CVU CONAHCYT ID:** 1314322

ID 1st Co-author: *Adriana Elizabeth, González-Cabrera* / **ORC ID:** 0000-0003-2802-6811

ID 2nd Co-author: *Rodrigo Cervando, Villegas-Martínez* / **ORC ID:** 0000-0003-0474-6734

ID 3rd Co-author: *Juan Manuel, García-González* / **ORC ID:** 0000-0001-7259-5021, **CVU CONAHCYT ID:** 346241

DOI: 10.35429/JSL.2023.29.10.19.24 Received July 30, 2023; Accepted December 30, 2023

Abstract

Strawberries are a highly perishable fruit and their availability is limited to no more than a week under ambient conditions, so solar dehydration increases their shelf life. The experimentation was carried out at the Solarimetric Station installed in building 6 of the Chemical Engineering Program of the UAZ. Strawberries of similar appearance and size were chosen, washed, disinfected and cut into slices (thickness 0.2 cm). The initial moisture content was determined using an OHAUS thermobalance, the samples were placed in polymer mesh trays (34.2 cm long and 24 cm wide) in two transparent acrylic cabinet dryers (74 x 80 cm base, front height 13 cm and at the bottom 40 cm). Both dryers were instrumented and operated by natural and forced convection. The samples were weighed at 30-minute intervals during the process and their initial and final color was measured. The experimentation was carried out at the Solarimetric Station installed in building 6 of the Chemical Engineering Program of the UAZ. It was possible to reduce the water content in the strawberries to increase their shelf life and be able to preserve them for longer.

Strawberry, Food dehydration, Solar energy

Resumen

Las fresas son una fruta altamente perecedera y su disponibilidad se limita a no más de una semana en condiciones ambientales, por lo que la deshidratación solar aumenta su vida útil. La experimentación se realizó en la Estación Solarimétrica instalada en el edificio 6 del Programa de Ingeniería Química de la UAZ. Se eligieron fresas de apariencia y tamaño similar, se lavaron, desinfectaron y se cortaron en rodajas (espesor 0,2 cm). El contenido de humedad inicial se determinó mediante una termobalanza OHAUS, las muestras se colocaron en bandejas de malla polimérica (34,2 cm de largo y 24 cm de ancho) en dos gabinetes secadores de acrílico transparente (74 x 80 cm de base, altura frontal 13 cm y en el fondo 40 cm). Ambos secadores fueron instrumentados y operados por convección natural y forzada. Las muestras se pesaron a intervalos de 30 minutos durante el proceso y se midió su color inicial y final. La experimentación se realizó en la Estación Solarimétrica instalada en el edificio 6 del Programa de Ingeniería Química de la UAZ. Se logró disminuir el contenido de agua en las fresas para aumentar su vida de anaquel y poder conservarlas durante más tiempo.

Fresa, Deshidratación de alimentos, Energía solar

Citation: CABRERA-REQUENES, Joshua Salvador, GONZÁLEZ-CABRERA, Adriana Elizabeth, VILLEGAS-MARTÍNEZ, Rodrigo Cervando and GARCÍA-GONZÁLEZ, Juan Manuel. Dehydration of strawberry (*Fragaria vesca*) using a direct solar dryer. Journal Simulation and Laboratory. 2023. 10-29:19-24.

*Correspondence to Author (E-mail: jmgarcia@uaz.edu.mx)
†Researcher contributing as first Author.

Introduction

The dehydration of food for its preservation is an issue that has been growing over the years, the use of environmentally friendly sources to reduce the carbon footprint produced by fossil fuels has led to the use of solar radiation as alternative to carry out food dehydration, significantly reducing production costs.

It is estimated that the energy used during the dehydration process is approximately 12% to 40% of the total energy consumption in drying industries. The use of solar energy can play an important role in the dehydration of food or drying of materials and in such a way that it would be possible to reduce the consumption of conventional energy sources by between 27% to 80%. Therefore, the use of solar energy for dewatering applications should be encouraged to a greater extent, as it is a source of economical clean energy and reduces the carbon footprint produced by conventional energies (fossil fuels) (Lingayat et al., 2021).

The Sun is a source of energy that has existed since the creation of our universe, we have the Sun with us all the time, it has millions of years of life left, so it can be said that its energy is an inexhaustible resource, in addition, the Energy from the sun is considered a primary renewable energy, since energies such as solar, wind, hydraulic, oceanic, geothermal, biomass and other energy sources are derived from it (Agbo et al., 2021).

Depending on the area in which they are located, the amount of solar radiation received varies, with Africa being the part of the world that receives the most radiation, but Mexico is one of the countries on the American continent most favored by solar radiation, specifically the northern area, so solar dehydration is a viable activity to implement and exploit in Mexico. The state of Zacatecas, according to the National Institute of Electricity and Clean Energy, receives an annual average daily solar radiation between the values of 4.7 and 5.8 kWh/m^2 day (Valladares & Figueroa, 2017).

However, there is a wide variety of perishable foods that are not consumed due to lack of availability for long periods of time, their waste contributes to the pollution of the atmosphere and the soil, an example of these foods are strawberries, their durability does not It takes more than a week and the processes for its conservation are highly expensive. Therefore, solar dehydration can be an opportunity to add value to strawberries. If this fruit is dehydrated where it is produced, this can reduce food losses and help small farmers have higher incomes (Arroyo et al., 2018).

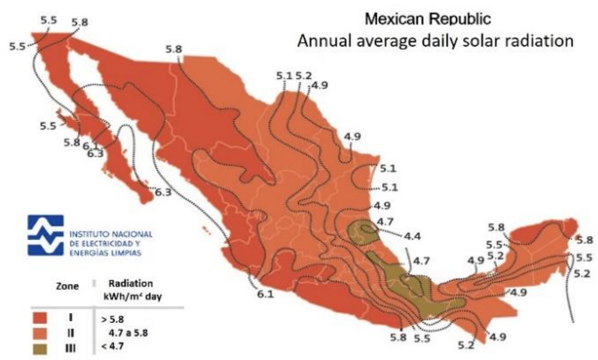


Figure 1 Annual average daily solar radiation in Mexico
Source: (Valladares & Figueroa, 2017)

Due to this problem, solar food dehydration is one of the oldest methods to preserve food, it reduces its moisture content, providing stability to the product, which is why solar dehydrators are an alternative energy source for dehydrating food. foods, but they must be improved to produce large quantities of good quality products in short times (Roratto et al., 2021).

Drying kinetics studies the moisture content removed by evaporation, time or energy consumption. The drying process is a unit operation that involves the transfer of heat from the surrounding hot air to the surface of the product to be dried and the transfer of matter from the water inside the product to its surface, followed by the transport of moisture to the surface of the product. the air found in the surroundings (Pérez-Lozano et al., 2019).

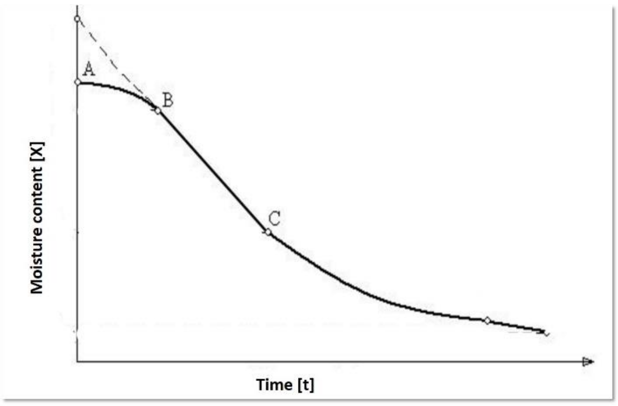


Figure 2 Typical drying curve
Source: (Ortiz, 2018)

Where there is an induction period (A), a period of constant speed (B) and a period of decreasing speed (C) (Ortiz, 2018).

Methodology

The steps followed during the experimentation are generally described:

1. Selection with a similar degree of maturation of the samples for washing and disinfection (cut slices with a thickness of 2 mm).

2. Placement of samples in polymer mesh trays

3. Initial characterization, measurement of weight, humidity and color

4. Drying Operation

5. Final characterization, measurement of weight, humidity and color.

The drying operation is detailed below:

1. The transparent acrylic dryers (Natural and Forced Convection) are placed in operation 30 min before to stabilize the drying chamber facing south.

2. The trays with the samples are introduced into the dryers.

3. Samples are selected to evaluate the change in color, the loss of humidity and are weighed every 30 minutes, until the equilibrium humidity is reached.

4. In each measurement, the temperature and relative humidity of the air are determined

5. Solar radiation, temperature, and wind speed corresponding to the test day are measured.

The conditions under which the drying operation was carried out were recorded using two Checktemp thermometers for measuring the internal temperature of the dryers, determining the global irradiance using a Kipp & Zonen CMP 22 pyranometer and measuring the wind speed. using an RM-Young vane anemometer (Bañuelos Mireles et al., 2019).

Results

The experimentation took place in the summer and winter periods with the different inclinations that the Sun presents throughout the year.

In the summer test, the average initial humidity of the strawberry samples was 85.22%.

The total dehydration time for natural convection was 7 hours with a final humidity percentage of 8.40% and for samples using forced convection it was 5.5 hours with a final humidity of 9.74%.

In Table 1 we can see that the strawberry samples have an initial average mass of 2.367 g and a final average mass of 0.233 g. It can be seen that, after 360 minutes of dehydration time, the masses of the samples remain constant. While in table 2, the masses of samples 1 and 2 began to remain constant after 270 minutes, samples that for sample 3 began to remain constant after 210 minutes.

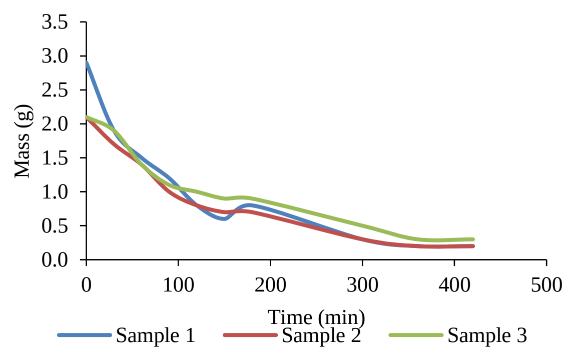
Natural Convection			
Time (min)	Sample mass 1 (g)	Sample mass 2 (g)	Sample mass 3 (g)
0	2.9	2.1	2.1
30	1.9	1.7	1.9
60	1.5	1.4	1.4
90	1.2	1.0	1.1
120	0.8	0.8	1.0
150	0.6	0.7	0.9
180	0.8	0.7	0.9
300	0.3	0.3	0.5
360	0.2	0.2	0.3
420	0.2	0.2	0.3

Table 1 Sample masses due to natural convection in summer

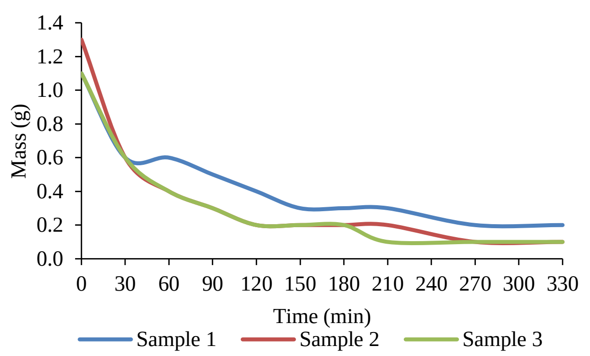
Forced Convectión			
Time (min)	Sample mass 1 (g)	Sample mass 2 (g)	Sample mass 3 (g)
0	1.1	1.3	1.1
30	0.6	0.6	0.6
60	0.6	0.4	0.4
90	0.5	0.3	0.3
120	0.4	0.2	0.2
150	0.3	0.2	0.2
180	0.3	0.2	0.2
210	0.3	0.2	0.1
270	0.2	0.1	0.1
330	0.2	0.1	0.1

Table 2 Sample masses by forced convection in summer

Graph 1 shows the drying curve through natural convection in which we can observe a decrease and subsequently an increase in mass after 150 minutes of the strawberry samples because they were stored to be able to continue the next day with the drying process. dehydrated, during this storage time they continued to lose moisture until reaching equilibrium. For the drying curve of the samples by forced convection that is observed in graph 2, the periods of induction, constant speed and decreasing speed are not as marked as in the operation using natural convection.



Graphic 1 Strawberry drying curve through natural convection in summer



Graphic 2 Strawberry drying curve through natural convection in summer

The winter samples presented an initial average humidity percentage of 95.6%.

Dehydration by natural and forced convection had a total time of 6.5 hours with final humidity percentages of 8.51% and 8.9% respectively.

In table 3, there was an initial average mass of 2.2 g and a final average of 0.19 g through natural convection. For samples 1 and 3, after 300 minutes their mass begins to be constant. However, from Table 4 it can be seen that the masses of the samples due to forced convection remained constant after 300.

Natural Convection			
Time (min)	Sample mass 1 (g)	Sample mass 2 (g)	Sample mass 3 (g)
0	2.1	2.0	2.3
30	1.8	1.7	1.9
60	1.5	1.4	1.6
90	1.2	1.2	1.3
120	1.0	0.9	1.0
150	0.8	0.7	0.8
180	0.5	0.5	0.5
240	0.3	0.3	0.3
300	0.2	0.2	0.2
360	0.2	0.17	0.2
390	0.2	0.17	0.2

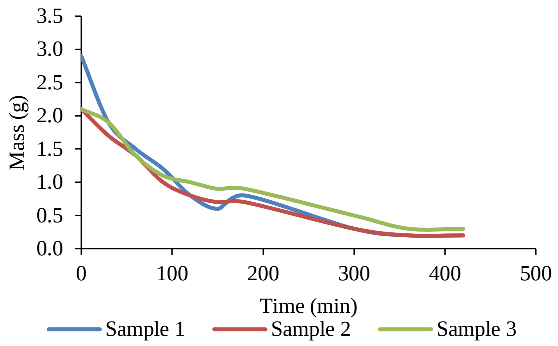
Table 3 Sample masses due to natural convection in winter

Forced Convectión			
Time (min)	Sample mass 1 (g)	Sample mass 2 (g)	Sample mass 3 (g)
0	1.7	1.8	1.6
30	1.4	1.4	1.3
60	1.1	1.1	1.0
90	0.9	0.8	0.7
120	0.6	0.6	0.5
150	0.4	0.4	0.3
180	0.3	0.2	0.2
240	0.3	0.2	0.2
300	0.18	0.16	0.16
360	0.18	0.15	0.15
390	0.18	0.15	0.15

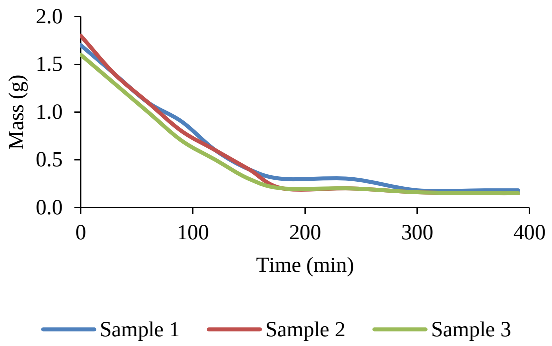
Table 4 Masses of the samples by forced convection in winter

In graphic 3 it can be seen that the samples using natural convection presented a similar behavior in the decrease in their mass and the periods of induction, constant speed and decreasing speed are not as noticeable as in the summer samples. However, for samples using forced convection (graph 4), these periods are not more noticeable.

ISSN: 2410-3462



Graphic 3 Strawberry drying curve through natural convection in Winter



Graphic 4 Strawberry drying curve through forced convection in winter

For the annual irradiance and irradiation in the state of Zacatecas, the information was taken from the thesis work carried out by Rodríguez in 2018 as seen in Table 4.

Month	Global Mean Irradiance (W/m^2)	Average Sun Hours	Average daily irradiation kWh/m^2
January	389.02	10.77	4.19
February	430.33	11.26	4.85
March	573.95	11.86	6.81
April	611.85	12.53	7.67
May	593.06	13.09	7.77
June	484.64	13.37	6.48
July	527.70	13.25	6.99
August	507.10	12.77	6.47
September	401.38	12.12	4.87
October	409.35	11.46	4.69
November	371.73	10.90	4.05
December	352.19	46.96	4.45
Annual	471.02	15.03	5.73

Table 5 Annual information on solar radiation in Zacatecas for the year 2018
Source: (Rodríguez Ramos et al., 2021)

An annual daily irradiation of 5.73 kWh/m^2 was considered, with which a monthly irradiation of 172.8 kWh/m^2 was obtained in the state of Zacatecas.

In Table 6, the irradiances, masses and average times of the dehydration process for natural and forced convection of the summer and winter periods were determined.

	Mass (g)	Time (h)	I (kWh/m^2)	Total I (kWh/m^2)
Natural Convection	74	6.75	2.94	19.86
Forced Convection	70.6	6	2.55	15.32

Table 6 Average data of the total dehydration process

Considering a minimum installed capacity (1 tray) and maximum (3 trays) in the dryers, the results obtained for the quantity of strawberries that can be dehydrated monthly and annually are summarized in Tables 7 and 8.

Minimum (1 tray)			
Mass	Initial (kg)	Month (kg)	Year (kg)
Natural Convection	0.071	0.614	7.37
Forced Convection	0.0706	0.792	9.51

Table 7 Minimum capacity of the dehydration process

Maximum (3 trays)			
Mass	Initial (kg)	Month (kg)	Year (kg)
Natural Convection	0.213	1.843	22.12
Forced Convection	0.212	2.376	28.52

Table 8 Maximum capacity of the dehydration process

Conclusions

In the summer test, during the dehydration days there were moments of cloudy skies, however, it did not make it difficult to carry out the process. Forced convection showed better results in the quality of the product in terms of color, smell and final flavor, with a final humidity of 9.74%. Natural convection presented a lower final humidity with a value of 8.4%, but the final quality of the product was not as desired, it had a darker color compared to the forced convection samples, and a burnt smell and taste.

For the winter tests, despite having cold air compared to summer, appropriate temperatures were achieved inside the houses, 39.5°C for natural convection and 37.9°C for forced convection. The best color quality of the product was achieved through forced convection, showing a tone a little lighter than natural and with a final humidity of 8.9%. Regarding the smell and flavor, the best results were through natural convection with a final humidity of 8.514%, which was mentioned that the dehydrated strawberries had a sweeter flavor, close to jam.

For both dehydration periods, it is proposed to start as early as possible to avoid having to store the samples and continue the next day, and to be able to obtain better results and drying curve graphs.

References

Agbo, E. P., Edet, C. O., Magu, T. O., Njok, A. O., Ekpo, C. M., & Louis, H. (2021). Solar energy: A panacea for the electricity generation crisis in Nigeria. *Heliyon*, *7*(5), e07016. https://doi.org/10.1016/j.heliyon.2021.e07016

Arroyo, P., Mazquiaran, L., Rodriguez, P., Valero, T., Ruiz, E., Ávila, J., & Valera, G. (2018). Frutas y hortalizas: Nutrición y Salud en la España del S. XXI. *Fundación Española de La Nutrición (FEN)*, 198. https://www.fen.org.es/storage/app/media/imgPublicaciones/INFORME_FRUTAS_Y_HORTALIZAS_FEN_2018-v1.pdf

Bañuelos Mireles, J. A., Arellano Carrera, E. U., García Saldívar, V. M., & García González, J. M. (2019). Deshidratado de durazno (Prunus persica). *Investigación y Desarrollo En Ciencia y Tecnología de Alimentos Deshidratado*, *4*, 411–415.

Lingayat, A., Balijepalli, R., & Chandramohan, V. P. (2021). Aplicaciones de tecnologías de secado basadas en energía solar en diversas industrias: una revisión. *Solar Energy, May*. https://doi.org/10.1016/j.solener.2021.05.058

Ortiz, E. (2018). *Cinética de secado, caracterización y determinación del tiempo óptimo de pulverizado para un concentrado de plomo, cobre y zinc a nivel de laboratorio*. http://repositorio.uncp.edu.pe/bitstream/handle/UNCP/5395/T010_43017402_T.pdf?sequence=1&isAllowed=y

Pérez-Lozano, L., Carrera-Arellano, E., Garcia-González, J., & Carranza-Téllez. (2019). Deshidratado de zanahoria (Daucus carota) empleando secado solar. *Programa Académico de Ingeniería Química. Campus UAZ Siglo XXI*, *4*, 411–415. jmgarcia@uaz.edu.mx

Roratto, T. B., Monteiro, R. L., Carciofi, B. A. M., & Laurindo, J. B. (2021). An innovative hybrid-solar-vacuum dryer to produce high-quality dried fruits and vegetables. *Lwt*, *140*(December 2020). https://doi.org/10.1016/j.lwt.2020.110777

Valladares, O. G., & Figueroa, I. P. (2017). *Aplicaciones térmicas de la energía solar en los sectores residencial, servicios e industrial*.