Vol. 21, No. 1(2022) Alim2650
*Revista Mexicana de Ingeniería Química*
*Ingeniería de alimentos*

# Effect by using a modified solar dryer on physicochemical properties of carambola fruit (*Averrhoa carambola L.*)

# Efecto del uso de un secador solar modificado sobre las propiedades fisicoquímicas del fruto de carambola (*Averrhoa carambola L.*)

O. García-Valladares[1], A.L. Cesar-Munguia[1], E.C. López-Vidaña[2,3], B. Castillo-Téllez[4], C.A. Ortiz-Sánchez[5], F.I. Lizama-Tzec[6], A. Domínguez-Niño[1,2*]

[1]*Instituto de Energías Renovables, Privada Xochicalco, Temixco, Morelos, México.*
[2]*Dirección Adjunta de Desarrollo Científico, Cátedra-CONACYT, Ciudad de México.*
[3]*Centro de Investigación en Materiales Avanzados CIMAV, Durango, México.*
[4]*Centro Universitario del Norte, Universidad de Guadalajara, Colotlán, Jalisco, México.*
[5]*Facultad de Ciencias Químicas, Universidad Veracruzana, Veracruz, México.*
[6]*Centro de Investigación y Estudios Avanzados (CINVESTAV), Mérida, México.*

Received: November 19, 2021; Accepted: February 8, 2022

## Abstract

Carambola is an excellent C-vitamin source and other healthy nutrients; unfortunately, because its high moisture content is a very perishable fruit. Solar drying is a feasible solution for its preservation. However, the optimal drying conditions depend on the dryer material. A natural convection sun-dryer was modified using four different materials: glass, acrylic, polycarbonate, and polyethylene. The moisture content of carambola slices was reduced from 89.23% to final moisture content between 2.2% and 5.9% in a maximum time of 650 min. The final water activity of dried samples ranged from 0.310 to 0.414. The color analysis of carambola indicated a decrease in lightness while a and b parameters increased; the mix of red and yellow resulted in an orange product which turned slightly brown as lightness decreased. In addition, the ascorbic acid reduced from 338.46 mg/100 g (d.b) to 159.50 mg/100 g- 124.37 mg/100 g (d.b), depending on the cover material. In general, polycarbonate dryers show less degradation of components due to the lower temperatures reached in their drying chamber. However, the solar drying of carambola with all the covers is technically, economically, and environmentally feasible compared to conventional technologies, such as the electric oven used in this work.
*Keywords*: Drying of fruit, solar drying, carambola, physicochemical properties, type of cover.

## Resumen

La carambola es una excelente fuente de vitamina C y otros nutrientes saludables; lamentablemente por su alto contenido de humedad es una fruta muy perecedera. El secado solar es una solución viable para su conservación. Sin embargo, las condiciones óptimas de secado dependen del material del secador. Se modificó un secador solar con convección natural utilizando cuatro materiales diferentes: vidrio, acrílico, policarbonato y polietileno. El contenido de humedad de las rodajas de carambola se redujo de 89.23% entre 2.2% y 5.9% en un tiempo máximo de 650 min. La actividad de agua final de las muestras secas osciló entre 0.310 y 0.414. El análisis de color de carambola indicó una disminución en la luminosidad mientras que los parámetros a y b aumentaron; la mezcla de rojo y amarillo dio como resultado un producto anaranjado que se volvió ligeramente marrón a medida que disminuía la luminosidad. Además, el ácido ascórbico se redujo de 338.46 mg/100 g (s.s.) a 159,50 mg/100 g- 124,37 mg/100 g (s.s.), dependiendo del material de la cubierta. En general, el secador de policarbonato presenta una menor degradación de los componentes debido a las menores temperaturas que alcanzan en su cámara de secado. Sin embargo, el secado solar de carambola con todas las cubiertas es factible técnica, económica y ambientalmente frente a tecnologías convencionales, como el horno eléctrico utilizado en este trabajo.
*Palabras clave*: Secado de fruta, secado solar, carambola, propiedades fisicoquímicas, tipo de cubierta.

* *Corresponding author. E-mail*: aldoni@ier.unam.mx
https://doi.org/10.24275/rmiq/Alim2650
*ISSN*:1665-2738, *issn-e*: 2395-8472

# 1 Introduction

Carambola (*Averrhoa carambola L.*) is considered an exotic fruit from southeast Asia. Carambola shapes vary from oblong to ellipsoid, 6 to 15 cm long, and 4 to 5 longitudinal grooves, corresponding to the carpels. The fruit is also known as star fruit, its peel is translucent, smooth, and shiny, and the color varies from green to golden yellow (Santos *et al*., 2010). The physicochemical characteristics and chemical composition of carambola depend on their stage of maturity. The genus *Averrhoa* can be found as *Averrhoa bilimbí L.* and *Averrhoa carambola L.*; this latter is considered the most important. The fruit is available as sweet and sour varieties; however, the sweet type is preferred due to better sensory attributes in terms of flavor and texture (Roopa *et al*., 2014). The carambola becomes more attractive by being cut transversely into slices due to its five-pointed star shape (Leite *et al*., 2016). Carambola is consumed fresh to prepare salads, soft drinks, pickles, juices, and sweets in syrup (Grajales-Agudelo *et al*., 2005) because it is a source of vitamin C, carotenoids, fiber, and phenolic compounds (Chau *et al*., 2004; Ruiz-López *et al*., 2011). It is grown in various warm tropical and subtropical regions such as China, Indochina, Malaysia, Hawaii, Brazil, United States, Mexico, Thailand, Philippines, Haiti, and Colombia, although not all are commercially (Mateus-Cagua *et al*., 2015). In México, Michoacán, Morelos, Jalisco, Colima, Tabasco, Nayarit and Yucatán are the most important states cultivating carambola (SIAP, 2017). With the lack of proper post-harvest techniques, transport, and storage of highly perishable fresh fruits, significant losses are caused. In emerging countries, the losses of some products are estimated at 50% (Santos *et al*., 2010). Carambola is a highly perishable fruit because of its high moisture content (Ruiz-López *et al*., 2011). On the other side, according to Pérez-Tello *et al*. (2001), fruit storage at a temperature below 10 °C affects its appearance (Roopa *et al*., 2014). For this reason, it is necessary to implement processes that can offer ways to preserve this type of food and maintain its availability throughout the year (Santos *et al*., 2010). The methods used to extend the availability of fruits must extend the shelf life and preserve the nutritional properties (Saikia *et al*., 2015). A technique that has been widely used to keep food is the removal of water through the drying process (Grajales-Agudelo *et al*., 2005; Kurozawa *et al*., 2009; Tlatelpa-Becerro *et al*., 2020). Using the drying process has advantages such as: facilitating the preservation of the product, microbiological stability, saving energy, and food availability (Santos *et al*., 2010). In addition, it leads to the preservation of foods in which the organoleptic characteristics, such as flavor and color, are similar to those of fresh products without compromising their integrity (Grajales-Agudelo *et al*., 2005). Some drying methods applied in the food industry for the preservation of carambola are freeze-drying (Grajales-Agudelo *et al*., 2005; Shofian *et al*., 2011), osmotic dehydration (Maharaj & Badrie, 2006; Roopa *et al*., 2014; Ruiz-López *et al*., 2011; Shigematsu *et al*., 2005), spray-drying (Saikia *et al*., 2015) and convective drying (Leite *et al*., 2016; Santos *et al*., 2010; Yeasmin *et al*., 2021). As seen, food preservation through the conventional drying process implies high energy consumption and fossil energy use. The development of energy-efficient technics is essential to solving complex environmental problems (Castillo-Téllez *et al*., 2020). Solar energy can be transformed into heat for food preservation through drying as an alternative with low environmental impact. For this reason, the development of solar dryer devices technology can contribute to preserving the shelf life of food by using the energy from the sun (Figueroa-Garcia *et al*., 2021). Cabinet dryers are built by a box with a transparent cover and trays inside the product; the airflow is by natural convection through holes. Currently, no reports directly related to the study on the solar drying of carambola have been found. Therefore, this work aimed to study the effect of solar dryers' cover material on physicochemical and colorimetric carambola properties. In addition, several existing mathematical models in literature were adjusted to the experimental results.

# 2 Material and methods

## 2.1 Raw material

Carambola fruit (*Averrhoa carambola L.*) was washed and disinfected before drying. Then, the carambola was cut into slices using a stainless-steel slicer (thickness 4 mm). This thin thickness allows assuming that the temperature distribution is uniform, fits the results to literature models, and dry the product in a single day. Finally, the carambola slices were placed on the dryer trays.

Fig. 1. Drybox Mini2 with different drying covers (From right to left: Polyethylene, polycarbonate, acrylic, and glass).

Table 1 Transmittance of the different cover collectors.

| | Average Transmittance (T%) | | | |
|---|---|---|---|---|
| Wavelength | Glass | Acrylic | Polyethylene | Polycarbonate |
| Ultaviolet (190-399 nm) | 26±1 | 10±1 | 0.01±0.01 | 1.3±0.1 |
| Visible (400-780 nm) | 88±1 | 91±1 | 0.22±0.01 | 76±0.1 |
| Infrared (781-2300) | 78±1 | 76±1 | 25±0.01 | 72±0.1 |
| Full spectrum (190-2300) | 71±1 | 70±1 | 12±0.01 | 60±0.1 |

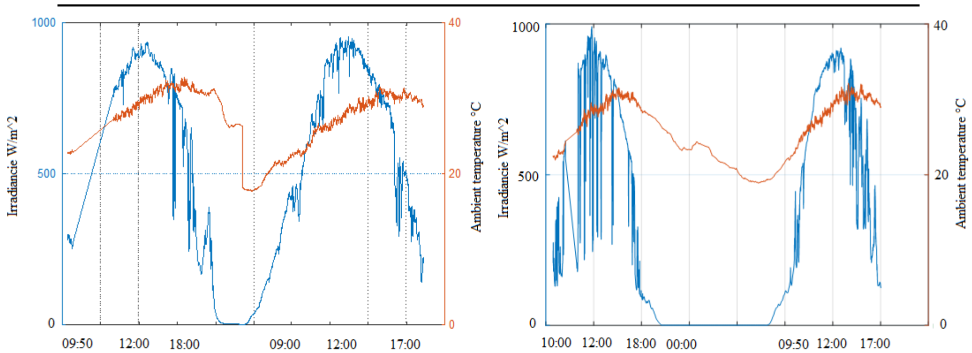


Fig. 2 Variation of the temperature and solar irradiance in the drybox Mini 2: a) 9th-10th of June 2021, b) 15th-16th of June 2021.

The raw fruit's initial average weight and moisture content were 71 ± 0.5 g and 87 ± 3% (w.b), respectively.

## 2.2 *Drying process*

The Drybox mini 2 is a direct type solar dryer; it was designed and modified using four different cover types: glass, polyethylene, acrylic, and polycarbonate with an area of 0.3 $m^2$. The airflow circulates longitudinally by natural convection through the drying tray to the outside. The nominal capacity is 1500 g, and its dimensions are 64 cm long x 35 cm width x 23 cm high (Figure 1)-the thickness of the material of the dryers averages between 2 and 3 mm. Depending on construction material, dryers reached a maximum temperature between 60 and 66 °C.

Table 1 shows the average transmittance of the different covers. Transmittance spectroscopy in the visible ultraviolet was performed by a spectrometer in the wavelength range of 190 to 900 nm. The samples were illuminated with a Deuterium-Halogen light source (AVANTES, AvaLight-DH-S-BAL) with a broad spectrum from 200 to 2500 nm. The transmitted light is taken by an optical fiber connected to the spectrometer. The distance between fibers was 12 cm to avoid saturation, and the sample is in the middle of these. The IR transmittance spectra were obtained with a Perkin Elmer, model Frontier NIR/MIR, spectrometer with a spectral range of 0.7 to 20 $\mu$m.

The drying oven was used at a single temperature (50°C) as a reference to the near temperature reached in cabinet-type solar dryers and the difference in product quality using controlled but conventional energy. The drying process of carambola slices was carried out on sunny days (9th-10th of June 2021 and the 15th-16th of June 2021, around 10 am) on the solar platform of the Instituto de Energías Renovables UNAM-Morelos, Mexico (18.84° N; 99.2356° W). As seen in Figures 2a and 2b, the maximum irradiance and ambient temperature values ranged from was 953.8 W/m$^2$ to 991.6 W/m$^2$ and from 32.69 °C to 32.14 °C, respectively.

## 2.3 Experimental design

A unifactorial design with four levels was adopted. This design established the type of cover (glass, polyethylene, acrylic, and polycarbonate) as an independent variable. The experimental analysis was conducted by triplicate. The data were analyzed statistically using analysis of variance (ANOVA) by NCSS 2004. The data were considered significantly different when $\alpha = 0.05$. The response variables were the final moisture content ($Y_1$), water activity ($Y_2$), lightness ($Y_3$), hue ($Y_4$), chroma ($Y_5$), color difference $\Delta E$ ($Y_6$), browning index ($Y_7$), total soluble solids ($Y_8$), ascorbic acid ($Y_9$), carotenoids ($Y_{10}$), of the dried product.

## 2.4 Analytical methods

The moisture content was measured at 105 °C by using a thermobalance OHAUS, MB45, with a readability of 0.001 g. Approximately 3 g of sample was distributed uniformly on an aluminum pan and placed in the balance. The water activity ($a_w$) was determined at 25 °C using a Rotronic water activity meter (Higrolab C1). The equipment was calibrated using Decagon's verification standards (LiCl, NaCl, and KCl) salt solutions. The sample was placed in a disposable sample cup, completely covering the bottom of the cup. A time of 20 minutes was required for each determination. Reflectance determined the color parameter using a portable colorimeter (High-Quality Colorimeter NR60CP), performed using de CIELAB color space. The values were expressed in terms of rectangular coordinates: parameters L (White-dark), a (red-green), b (yellow-blue), and cylindrical coordinates: parameters H (hue angle) property of color, C (chroma) saturation or intensity. Also, the color difference ($\Delta E$) between the raw and dried samples was determined.

The color values are calculated according to (Guiné & Barroca, 2012) as follows:

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

$$C = \sqrt{(a)^2 + (b)^2} \quad (2)$$

$$H = \text{arctg}(b/a) \quad (3)$$

Samples of approximately 3 g of carambola were taken for each measurement. The content of total soluble solids in raw and dried carambola was determined by the method reported by Dadzie and Orchard, which consists of measuring the refractive juice index. The color coordinates ($L$, $a$, and $b$) were used to evaluate the carambola browning index (BI) using the following equation proposed by Souza *et al*. (2015):

$$BI = \frac{100 * (A - 0.31)}{0.172} \quad (4)$$

Where $A$ is obtained by:

$$A = \frac{a + (1.75 * L)}{(5.645 * L) + a - (3.021 * b)} \quad (5)$$

Carotenoid content was determined according to the methodology followed by Rascón *et al*., (2011). Around 5 g of every sample was dissolved in a volumetric flask containing 10 mL of acetone, handshake during 10 min, after that the samples were vortexed for 10 min at 5000 rpm. The supernatant was recovered, and its absorbance was read at 472 and 508 nm using a UV-Vis spectrophotometer (Thermo Scientific). All carotenoid determinations were carried out in triplicate, and the concentration was calculated using the following equations.

$$C^R = \frac{A_{508} * 2144.0 - A_{472} * 403.3}{270.9} \quad (6)$$

$$C^Y = \frac{A_{472} * 1724.3 - A_{508} * 2450.1}{270.9} \quad (7)$$

$$C^T = C^R + C^Y \quad (8)$$

Table 2 Mathematical models used

| Model | Equation | Reference |
|---|---|---|
| Page | $MR = \exp(-kt^n)$ | (Page, 1949) |
| Modified page | $MR = \exp((-kt)^n)$ | (Diamante *et al*., 1993) |
| Weibull | $MR = exp(-(t/b)^{\alpha})$ | (Midilli *et al*., 2002) |

Where $C^R$ represents the red isochromatic fraction content ($\mu$ g/mL), $C^Y$ represents the yellow isochromatic fraction content ($\mu$ g/mL), and $C^T$ is the total carotenoid content ($\mu$ g/mL).

The methodology described by Nweze *et al*. (2015) was used to determine the ascorbic acid content in the Carambola fruit.

### 2.5 Mathematical modeling fitting

The kinetics behavior of carambola drying was studied by fitting the experimental moisture radio to the mathematical models used in the drying process (Table 2). The humidity ratio (MR), which depend on the drying time, is calculated using the following equation:

$$MR = \frac{M - Me}{Mo - Me} \quad (9)$$

Where $M$ is the moisture content, $M_e$ is the equilibrium moisture, and $M_o$ is the initial humidity. The equilibrium moisture content $M_e$ was determined using the following equation:

$$Me = \frac{W_1 Mo + W_f W_1}{W_1(1 - M)} \quad (10)$$

$Me$, expressed in (kg water/kg dry matter), $W_1$ is the initial weight, $M_O$ is the initial moisture of the samples, and $W_f$ is the weight of the sample at $Me$. Table 2 shows the mathematical models evaluated for the experimental results of drying kinetics: Page Model considers the constant drying k ($s^{-1}$), which combines drying transport properties such as moisture diffusivity, thermal conductivity, interface heat, and mass coefficient. Also, Page (1949) modified the Lewis model to get a more accurate model by adding a dimensionless empirical constant (n). The Weibull model equation also contemplates a and b dimensionless constants obtained from experimental data.

The coefficient of determination ($r^2$) has been used as the main parameter to choose the appropriate model that fits the experimental data. Likewise, chi-square ($\chi^2$) and Root-Mean-Square Error (RMSE) were considered.

## 3 Results and discussions

### 3.1 Characterization of carambola

The initial moisture content and water activity of carambola were 89.23% (w.b) and 0.986, respectively; thus, the $a_w$ needs to be reduced ($a_w$ < 0.6) to avoid microbial growth. According to (Chan-Gonzálelz *et al*., 2021), the shelf life and some properties such as texture, flavor, and smell of foods are affected by the water activity. In addition, it predicts stability concerning physical properties and microbial growth. According to the water activity scale, osmophilic yeast, xerophilic molds, and most bacteria and yeast grow between 0.62 and 0.91.

The color parameters are shown in Table 3. Initial analysis shows that the carambola had a lightness value of 56.94 and *a* and *b* values of -1.13 and 13.71; the negative *a* value represents the greenness. Similarly, the *b* value represents the yellowness on the positive side. According to the literature, the Hue angle refers to product color, 0° represents red, 90° indicates a yellow, 180° is green, and 270° means blue. The carambola presents a hue angle of 94.72; this shows a yellow hue (Wrolstad & Smith, 2013). Finally, the color's saturation or purity expressed as chroma stated a value of 13.76. The literature indicated that color functions three dimensions: lightness, hue, and chroma. According to the results, the color obtained by mixing the greenness and yellowness (-1.13 and 13.71, respectively) with the lightness and a yellow hue of 94.72 resulted in a yellow product with low saturation. The carambola fruit showed 7 °Brix, Chire Murillo *et al*. (2014) reported 7.3 °Brix. According to Narain *et al*. (2001), the total soluble solids depend on the maturity stage: 6.01 in mature green fruits, 7.3 in half-ripe, and 10.83 in ripe fruits. Moreover, the vitamin C in the carambola juice was 35.224±1.01 mg/100 g, very similar to results reported by Hariadi (2020); however, this value was higher than the reported by Yeasmin *et al*. (2021), which was 91.44% of moisture content 24.2 mg/100 g of vitamin C in their study.

Table 3 Physicochemical analysis of carambolo

| Analysis | Mean values$^{\pm\text{standard deviation}}$ |
|---|---|
| Moisture content (w.b) | 89.23 $^{\pm 0.385}$ |
| Water activity | 0.914$^{\pm 0.002}$ |
| Total soluble solids (°Brix) | 7$^{\pm 0.28}$ |
| Carotenoid ($\mu$g/g) | 3.952$^{\pm 0.152}$ |
| Ascorbic acid (mg/100 g) | 44.03$^{\pm 0.102}$ |
| L | 56.94$^{\pm 1.88}$ |
| a | -1.13$^{\pm 0.23}$ |
| b | 13.71$^{\pm 0.26}$ |
| Chroma | 13.76$^{\pm 0.28}$ |
| Hue | 94.72$^{\pm 0.87}$ |

L (Whiteness-Darkness), a (greenness-Redness), b (Yellowness-Blueness)

According to the literature, the ascorbic acid content is related to the stage of maturity: 25.2 mg/100 g for green fruit, 25.9 mg/100 g for half-ripe, and 23.4 mg/100 g for ripe (Narain *et al*., 2001). The literature stated that the stage of maturity influences the ascorbic acid content and agricultural practices (genetics, fertilizers, insolation, and irrigation), with post-harvest handling and with preparation for consumption (Badui, 2006). The analysis of carotenoids showed a value of 3.953±0.56 $\mu$ g/g.

## 3.2 *Moisture content and water activity*

The carambola fruit had an initial moisture content of 89.23% and, during drying, was reduced in a range between 3.49 % to 6.36 %± 0.3 (w.b). On the other hand, the initial $a_w$ value was 0.986, and the final values ranged from 0.310 to 0.414± 0.01, depending on the dryer material used.

The variance analysis showed a significant difference in the final moisture content obtained in the dried carambola slices using the stove compared to the sun-dryers' moisture content (Table 4). As seen from Figure 3, the moisture content of carambola samples decreased faster in the dryer with the glass cover. The dryer with acrylic cover was the second faster, then the stove, polycarbonate, and finally the dryer with the polyethylene cover. The drying times obtained are due to the temperatures and humidity achieved inside the drying chambers. The final moisture content in dried samples was 2.6%, 2.2%, 2.8%, 5.4%, and 5.9% in the dryers with glass, acrylic, polycarbonate, stove, and polyethylene plastic. All these values are adequate to ensure the carambolo stability. During the drying process, the maximum temperatures ranged from 63 °C to 80 °C depending on the chamber's material (Figure 4). The final water activity of dried samples ranged from 0.310 to 0.414. Foods with a water activity value of less than 0.60 are microbiological stable because water availability for the different biochemical processes is limited. The analysis of variance showed that the type of dryers did not significantly affect the water activity of dried samples.

## 3.3 *Color analysis*

During the drying process, color parameters changed depending on the dryer used. Table 5 shows the color differences values after drying ($\Delta L$, $\Delta a$, $\Delta b$, $\Delta C$, $\Delta H$, and $\Delta E$).

A negative $\Delta L$ means that the carambola samples will be darker. In contrast, the positive $\Delta L$ infers that samples will be lighter than the standard (Wrolstad & Smith, 2013), as was observed in the dehydrated samples in the dryer with the glass cover (Table 5). In this case, during the sun-drying process, the lightness decreased; the highest $\Delta L$ was observed in the dryer with the glass cover (-3.57); therefore, the carambola slices turned darker. However, the lowest $\Delta L$ (-1.69) was observed in the polyethylene dryer; in this case, the carambola slices were lighter.

On the other hand, positive $\Delta a$ values were observed in all dryers; this means that carambola samples will be redder. The highest positive $\Delta a$ value was observed in the polyethylene dryer (11.30), and the lowest $\Delta a$ value was in the stove dryer (9.31). Also, positive $\Delta b$ values were observed after the drying process with the different dryers: according to Wrolstad & Smith (2013), positive $\Delta b$ values mean that the carambola samples will be more yellow. Studies have shown that carotenoids contribute to the yellow color found in many fruits and vegetables (Khoo *et al*., 2011), and are responsible for the color property in many foods; therefore, there is a

Table 4. Variance analysis of dependent variables.

| Responses | | | | | |
|---|---|---|---|---|---|
| Moisture content | | | | | |
| Factor | Df | Sum of squares | Mean squares | F-Ratio | P-Value |
| Dryer type | 4 | 11.05 | 2.763 | 8.92 | *0.002 |
| Error | 10 | 3.099 | 0.31 | | |
| Total | 14 | 14.149 | | | |
| Water activity | | | | | |
| Dryer type | 4 | 0.00024 | 0.00006 | 0.04 | 0.997 |
| Error | 10 | 0.01516 | 0.00152 | | |
| Total | 14 | 0.0154 | | | |
| Lightness | | | | | |
| Dryer type | 4 | 113.8 | 28.4 | 0.95 | 0.474 |
| Error | 10 | 298.7 | 29.9 | | |
| Total | 14 | 412.5 | | | |
| Hue | | | | | |
| Dryer type | 4 | 76.3 | 19.1 | 1.41 | 0.301 |
| Error | 10 | 135.7 | 13.6 | | |
| Total | 14 | 212 | | | |
| Chroma | | | | | |
| Dryer type | 4 | 92.1 | 23 | 1.06 | 0.424 |
| Error | 10 | 216.5 | 21.7 | | |
| Total | 14 | 308.6 | | | |
| Color difference | | | | | |
| Dryer type | 4 | 103.3 | 25.8 | 1.12 | 0.4 |
| Error | 10 | 230.9 | 23.1 | | |
| Total | 14 | 334.2 | | | |
| Total soluble solids | | | | | |
| Dryer type | 4 | 9.1 | 2.3 | 0.11 | 0.975 |
| Error | 10 | 200.7 | 20.1 | | |
| Total | 14 | 209.7 | | | |
| Browning Index | | | | | |
| Dryer type | 4 | 260 | 65 | 0.22 | 0.921 |
| Error | 10 | 2955 | 295 | | |
| Total | 14 | 3215 | | | |
| Ascorbic acid | | | | | |
| Dryer type | 4 | 25.6 | 6.4 | 0.9 | 0.502 |
| Error | 10 | 71.49 | 7.15 | | |
| Total | 14 | 97.09 | | | |
| Carotenoids | | | | | |
| Dryer type | 4 | 19.3505 | 4.8376 | 279.19 | *0.020 |
| Error | 10 | 0.1733 | 0.0173 | | |
| Total | 14 | 19.5238 | | | |

* Indicate significant differences at $\alpha = 0.05$

direct association between color changes carotenoid content. In this way, after drying, by concentrating the carotenoid fraction, an intensification of the optical properties is observed, which is reflected in positive $\Delta b$ and $\Delta E$. (Mulokozi & Svanberg, 2003).

On the other hand, positive $\Delta C$ values were observed in dehydrated carambola samples; this behavior indicated that samples had greater intensity or were more saturated. Moreover, the negative $\Delta H$ values in carambola slices indicate that the hue angle shifts from yellow to red.

Table 5. Experimental results of physicochemical properties of dehydrated carambola slices.

| Responses | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dryer type | Moisture content | Water activity | Color properties | | | | | | Total soluble solids | Browning index | Ascorbic acid | Carotenoids |
| | | | $\Delta L$ | $\Delta a$ | $\Delta b$ | $\Delta C$ | $\Delta H$ | $\Delta E$ | | | | |
| Glass | 4.03 | 0.35 | -3.57 | 10.76 | 2.35 | 5.06 | -9.92 | 14.53 | 46 | 83.6 | 159.5 | 1.4322 |
| Acrylic | 4.44 | 0.36 | -1.81 | 9.83 | 3.49 | 6.04 | -8.55 | 21.06 | 45.6 | 88.38 | 126.95 | 1.4398 |
| Polycarbonate | 4.67 | 0.35 | -2.64 | 10.53 | 5.5 | 8.39 | -8.41 | 13.83 | 47 | 88.41 | 129.32 | 4.2605* |
| Polyethylene | 4.02 | 0.35 | -1.69 | 11.3 | 8.63 | 11.4 | -8.9 | 16.56 | 45 | 96.55 | 124.37 | 1.9323* |
| Oven | 6.34* | 0.35 | 3.2 | 9.31 | 9.19 | 11.09 | -7.29 | 14.69 | 47 | 70.84 | 125.36 | 3.3745* |

* Indicate significant differences at $\alpha = 0.05$

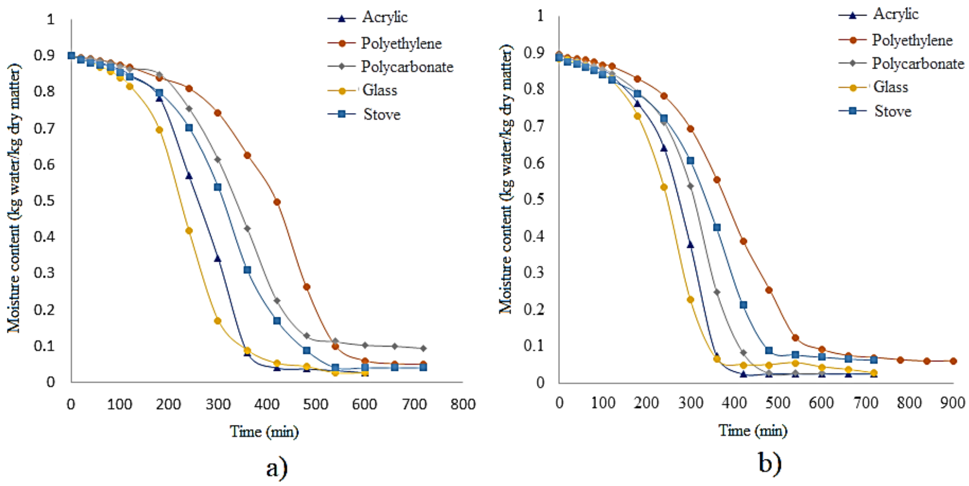


Fig. 3 Moisture content versus drying time by using modified solar dryers with a different cover and an electric oven at 50 °C. a) 9th-10th of June 2021, b) 15th-16th of June 2021.

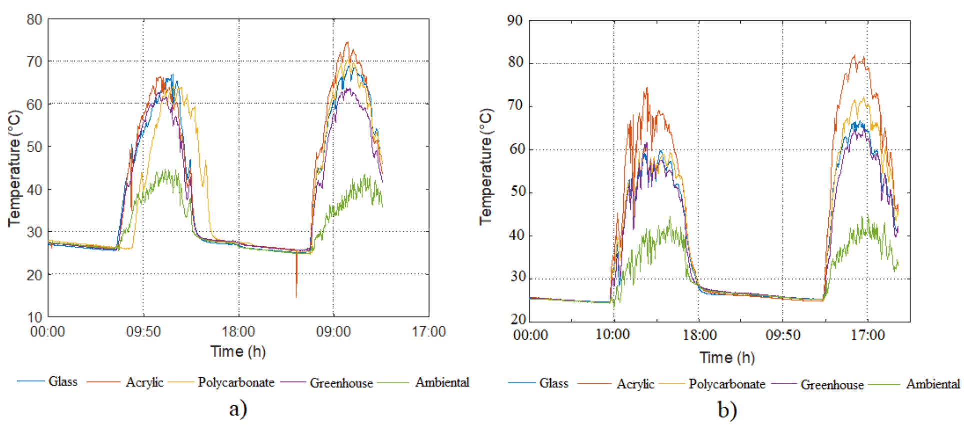


Fig. 4 Maximum temperatures reached inside the dryers during the carambola drying process.

This observation is because the standard has a hue angle up to 90°.

Finally, although the highest color difference was observed in the acrylic dryer (21.6), the analysis of variance revealed that the type of dryers did not significantly affect the color in the final product. A significant difference in $\Delta E$ is not desirable because consumers prefer products close to the characteristic color of fresh fruit. Besides, an important color difference indicates a higher degree of browning. According to the literature, when the final product has a value of up to 3, the color difference is noticeable (Hii & Law, 2010).

## 3.4 Browning index (BI)

This parameter is determined in foods that contain sugar and represents the purity of brown color. The results indicate a decrease in lightness while *a* (redder) and *b* (more yellow) increased; the mix of red and yellow resulted in an orange product which turned slightly brown as lightness decreased. Similar behavior was reported by Quan and Benjakul (2019) in the study of the drying methods on the properties of duck albumen powder. According to the study, the browning index increased as drying temperature increased from 140 to 180 °C. Their results demonstrated that the increase in red (*a*) and yellow (*b*) indicated a browning reaction. The initial browning index of raw fruit was 25.14; however, this value increased markedly during the drying process (from 70.84 to 96.55 in the dryers). An increment in the BI from 71.90 to 135.32 was reported by Souza *et al*. (2015) during the Lyophilization of avocado. Although the analysis of media comparison showed the polyethylene dryer as the highest browning index, the study of variance revealed that the type of dryers did not significantly affect the *BI* (Table 4). According to Hatami *et al*. (2017), the highest air temperature (63.4 °C), the most extended drying duration, and the minimum airflow (0.016 kg/s) caused more browning in the dried banana slices. This result is because of the role of sucrose in caramelization and Maillard's reaction to browning. This study observed the highest BI (96.55) in the polyethylene dryer due to the longer drying time. The BI changed according to the type of dryer, as seen from Table 5.

## 3.5 Ascorbic acid

The initial vitamin C content of carambola was 44.03 mg/100 g. However, some other researchers have reported different ascorbic acid content in carambola fruit: 74 mg/100 g (Hernández *et al*., 2006), 25.2 mg/100 g for green fruit, 25.9 mg/100 g for half-ripe, and 23.4 mg/100 g for ripe (Narain *et al*., 2001). This difference in ascorbic acid content could be related to the stage of maturity and agricultural practices. The statistical analysis showed that the type of dryer did not significantly affect the ascorbic acid content (Table 4). According to the results, ascorbic acid increased from 44.03 mg/100 g to 152.63 mg/100 g, 121.32 mg/100 g, 123.28 mg/100 g, 119.37 mg/100 g, and 117.41 mg/100 g in the dryer with glass, acrylic, polycarbonate, polyethylene, and stove, respectively (Table 5). The stability of ascorbic acid depends on the drying conditions, moisture content, and water activity. When the water activity is low, vitamin C is relatively stable, whereas it is rapidly destroyed at a high-water activity (Lund, 1988). As seen from the results, the ascorbic acid content in dried samples was retained, showing ascorbic acid values up to 152.63 mg/100 g (Table 5). However, this behavior contradicts results obtained during the drying of Mango slices with the different drying processes. According to the results, the initial ascorbic acid of raw mango was 49.53 mg/100 g; however, the ascorbic acid decreased from 49.53 to 35.47 in tray drying, 41.06 in freeze-drying, 33.18 mg/100 g in sun-drying, and 41.24 mg/100 g in fluidized bed drying (Dereje & Abera, 2020).

## 3.6 Total soluble solids (°Brix)

The carambola fruit showed 7 °Brix; however, the total soluble solid increased because of water loss during the drying process. As seen from Table 5, the °Brix ranged from 45 to 47 °Brix according to the dryer type. Although the analysis of variance did not show a difference between the dryers (Table 4), the highest total soluble solids were observed in the polycarbonate and stove (47 °Brix), and the lowest was observed in the polyethylene dryer (45 °Brix). Guiné *et al*. (2011) reported the influence of drying temperature on the total soluble solids during the comparative study of the drying pears with different drying systems. According to their results, the lowest total soluble solids were observed in drying systems with the highest temperatures (60 °C in the solar drying). In contrast, the highest total soluble solids were registered in the designs (42 °C drying tunnel) with the lowest drying temperature. This behavior is because of the Maillard reactions, which occur in the systems with higher drying temperatures. This behavior is not entirely noticeable in our study because the ? between temperatures is negligible. In the acrylic dryer (with higher temperatures), the UV average transmittance has a medium value (10±1). The drying of carambola in the stove reached 47 °Brix because the drying temperature was constant during the drying process, whereas in solar drying, the temperature fluctuates according to environmental conditions.

## 3.7 Carotenoids

Carotenoid concentration (CA) is a significant parameter determining the final quality of thermally processed fruits such as carambola because it is a decisive factor in color and nutritional value. The initial carotenoid content in the raw fruit was 3.952±0.56 $\mu$ g/g; Gross *et al*. (1983) found 15 to 22 $\mu$ g/g, whereas Zainudin *et al*. (2014) reported around 6.5 $\mu$ g/g and Gol *et al*. (2015) reported values from 2 to 16 $\mu$ g/g. This difference could be related to the maturity, cultivar conditions, environmental factors such as weather, soils, and sun exposure. CA is responsible for the yellow color in the foodstuff; during the sun-drying of carambola fruit, it is interesting to evaluate the relationship between carotenoid content and the values of *a* and *b*. $\Delta b$ values in all treatments are positives indicating a yellowness in the samples. When the drying process is slow, the red fraction of CA is synthesized from their yellow precursor, as can be noticed from the color changes (positive $\Delta a$ values from Table 5) stated before in section 3.3 (Topuz *et al*., 2011). Chemically, CA is conformed by conjugated double bonds that are highly sensitive to oxidation. It is vital to control the temperature and the residence time to protect carotenoids during processes (Zainudin *et al*., 2014).

Table 5 presents the total carotenoid content of carambola slices; the highest amount of carotenoids (4.26 $\mu$ g/g) was found when polycarbonate was employed during the drying process and the lowest value when glass and acrylic were used (1.43 $\mu$ g/g). As seen from Table 1, higher carotene degradation was observed in the dryers with the higher transmittance, which correlates with the most elevated temperatures reached inside the dryers. According to (Shofian *et al*., 2011), carotenoids are highly susceptible to degradation during drying, especially when the exposure period increases during solar drying. Besides, carotenoids are stable in natural conditions. Still, when the food is sliced or triturated, they become more labile (Topuz *et al*., 2011), so the reduction in the CA concentration of the different dried samples compared to the raw fruit could be due to a long time that the solar drying takes. Another critical factor during solar drying is the cover transmittance because it influences the solar energy absorbed by the cover (Ekechukwu & Norton, 1999). As shown in Table 5, cover with higher transmittance resulted in products with higher carotenoid degradation. Carotenoids are susceptible to several degradation reactions because of the double bonds in their structure. One significant degradation reaction is isomerization; usually, trans-isomers are stable in foods, whereas cis-isomers are formed during food processing. Carotenoid isomerization leads to substantial color changes and decreased biological activities. The occurrence of isomerization depends on several factors such as the concentration of oxygen in the surrounding atmosphere, the severity of heat treatment, and exposure to light (Provesi & Amante, 2015), being this last one the most related to transmittance.

## *3.8 Fitting to mathematical models*

Table 6 shows the model's coefficient and fit parameters obtained when the experimental MR and models' equations were compared. As can be seen, Weibull is the model that better represents the experimental results for the five dryers used with a minimum r$^2$ of 0.993. Consequently, carambola drying under similar conditions can be successfully described by the Weibull model. This data is relevant because it can be used to design dryers depending on needed production.

Table 6. Mathematical models parameters and coefficients.

| Acrylic | | | Glass | | | Greenhouse | | | Polycarbonate | | | Oven | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model | Parameters | Value | Model | Parameters | Value | Model | Parameters | Value | Model | Parameters | Value | Model | Parameters | Value |
| Weibull | a | -0.009 | Weibull | a | -0.007 | Weibull | a | -0.033 | Weibull | a | -0.012 | Weibull | a | -0.046 |
| | b | -0.961 | | b | -0.962 | | b | -0.999 | | b | -0.959 | | b | -1.003 |
| | k | 0.123 | | k | 0.224 | | k | 0.081 | | k | 0.063 | | k | 0.174 |
| | n | 1.869 | | n | 1.626 | | n | 1.617 | | n | 1.997 | | n | 1.393 |
| | $r^2$ | 0.997 | | $r^2$ | 0.997 | | $r^2$ | 0.998 | | $r^2$ | 0.994 | | $r^2$ | 0.996 |
| | RMSE | 0.023 | | RMSE | 0.02 | | RMSE | 0.019 | | RMSE | 0.031 | | RMSE | 0.023 |
| | $\chi^2$ | 0.001 | | $\chi^2$ | 0.001 | | $\chi^2$ | 0 | | $\chi^2$ | 0.001 | | $\chi^2$ | 0.001 |
| Page Modificado | k | 0.343 | Page Modificado | k | 0.272 | Page Modificado | k | 0.23 | Page Modificado | k | 0.265 | Page Modificado | k | 0.322 |
| | n | 1.691 | | n | 1.493 | | n | 1.562 | | n | 1.753 | | n | 1.358 |
| | $r^2$ | 0.994 | | $r^2$ | 0.995 | | $r^2$ | 0.995 | | $r^2$ | 0.991 | | $r^2$ | 0.992 |
| | RMSE | 0.029 | | RMSE | 0.025 | | RMSE | 0.027 | | RMSE | 0.038 | | RMSE | 0.032 |
| | $\chi^2$ | 0.001 | | $\chi^2$ | 0.001 | | $\chi^2$ | 0.001 | | $\chi^2$ | 0.002 | | $\chi^2$ | 0.001 |
| Page | k | 0.163 | Page | k | 0.418 | Page | k | 0.101 | Page | k | 0.097 | Wang and Sing | a | -0.239 |
| | n | 1.691 | | n | 1.493 | | n | 1.562 | | n | 1.753 | | b | 0.014 |
| | $r^2$ | 0.994 | | $r^2$ | 0.995 | | $r^2$ | 0.995 | | $r^2$ | 0.991 | | $r^2$ | 0.997 |
| | RMSE | 0.029 | | RMSE | 0.025 | | RMSE | 0.027 | | RMSE | 0.038 | | RMSE | 0.02 |
| | $\chi^2$ | 0.001 | | $\chi^2$ | 0.001 | | $\chi^2$ | 0.001 | | $\chi^2$ | 0.002 | | $\chi^2$ | 0 |

## Conclusions

Four different materials were used to modify a solar dryer to study drying time, bio components, and colorimetry effects. According to the findings, the material's transmittance is vital in creating essential drying conditions (temperature and humidity) inside the chamber for drying kinetics. Consequently, the drying time needed to achieve the moisture content equilibrium diminishes as the material transmittance increases, but final moisture content and $a_w$ are less sensitive to transmittance. However, the ascorbic acid degradation is lower in glass dryers (159.50 mg/100 g) and higher in polyethylene dryers (124.37 mg/100 g), negatively correlating to drying materials transmittance values. Nevertheless, the lowest total color difference (13.83) was achieved when polycarbonate was employed during the sun-drying, which correlates with the highest carotenoids values (4.26 mg/g) and high ascorbic acid content (129.32 mg/100 g). The findings imply that solar drying is a feasible method for preserving the properties of the carambola, and all the solar dryers used proved to be very competitive compared to the electric oven with minimum ambient impact. Furthermore, the Weibull model fits better to all experiments; thus, this model can be used to predict carambola drying in similar conditions.

*Acknowledgments*

To CATEDRA-CONACYT and the project solar drying of agricultural products, PAPIIT IN103021, developed in the solar food drying laboratory.

## References

Badui, S. (2006). Salvador Badui Dergal. In *Química de los Alimentos*.

Castillo-Téllez, B., Pilatowsky Figueroa, I., Castillo Téllez, M., Marzoug, R., & Allaf, K. (2020). Experimental analysis of saline diffusion during saltwater freezing for desalination purposes. *Water and Environment Journal 34*, 929-936. https://doi.org/10.1111/wej.12603

Chan-Gonzálelz, J. de J., Castillo Téllez, M., Castillo-Téllez, B., Mejía-Pérez, G. A., & Vega-Gómez, C. J. (2021). Improvements and evaluation on bitter orange leaves (*Citrus aurantium L.*) solar drying in humid climates. *Sustainability (Switzerland)*. https://doi.org/https://doi.org/10.3390/su13169393

Chau, C. F., Chen, C. H., & Lee, M. H. (2004). Characterization and physicochemical properties of some potential fibres derived from *Averrhoa carambola. Nahrung - Food 48*(1), 43-46. https://doi.org/10.1002/food.200300354

Chire Murillo, E. T., Dávila T., R., & Ríos Ríos, E. M. (2014). Evaluación del contenido de vitamina C, taninos condensados y capacidad antioxidante después de un tratamiento a tres temperaturas de los frutos de carambola (*Averrhoa carambola L.*). *Anales Científicos 75*(2), 370. https://doi.org/10.21704/ac.v75i2.977

Dereje, B., & Abera, S. (2020). Effect of pretreatments and drying methods on the quality of dried mango (*Mangifera Indica L.*) slices. *Cogent Food and Agriculture 6*(1). https://doi.org/10.1080/23311932.2020.1747961

Ekechukwu, O. V, & Norton, B. (1999). 99/02112 Review of solar-energy drying systems III: low temperature air-heating solar collectors for crop drying applications. *Fuel and Energy Abstracts 40*(3), 216. https://doi.org/10.1016/s0140-6701(99)97882-7

Figueroa-Garcia, E., Segura-Castruita, M. A., Luna-Olea, F. M., Vázquez-Vuelvas, O. F., & Chávez-Rodríguez, A. M. (2021). Design of a hybrid solar collector with a flat plate solar collector and induction heating. *Revista Mexicana de Ingeniería Química 20*(3). https://doi.org/https://doi.org/10.24275/rmiq/Alim2452

Gol, N. B., Chaudhari, M. L., & Rao, T. V. R. (2015). Effect of edible coatings on quality and shelf life of carambola (*Averrhoa carambola L.*) fruit during storage. *Journal of Food Science and Technology 52*(1), 78-91. https://doi.org/10.1007/s13197-013-0988-9

Grajales-Agudelo, L. M., Cardona-Perdomo, W. A., & Orrego-Alzate, C. E. (2005). Liofilización de carambola (*Averrhoa carambola L.*) osmodeshidratada. *Ingeniería y Competitividad 7*(2), 19-26.

Guiné, R. P. F., & Barroca, M. J. (2012). Effect of drying treatments on texture and color of vegetables (pumpkin and green pepper). *Food and Bioproducts Processing 90*(1), 58-63. https://doi.org/10.1016/j.fbp.2011.01.003

Guiné, R. P. F., Barroca, M. J., & Lima, M. J. R. (2011). Comparative study of the drying of pears using different drying systems. *International Journal of Fruit Science 11*(1), 55-73. https://doi.org/10.1080/15538362.2011.554071

Hariadi, H. (2020). The influence of carambola starfruit (Averrhoa bilimbi) and Papaya (Carica papaya) on the quality of the organoleptic properties, vitamin C content, and fiber at jelly candies. *IOP Conference Series: Earth and Environmental Science 443*(1). https://doi.org/10.1088/1755-1315/443/1/012017

Hatami, S., Sadeghi, M., & Mireei, S. A. (2017). Indirect forced solar drying of banana slices: phenomenological explanation of non-isotropic shrinkage and color changes kinetics. *International Journal of Green Energy 14*(15), 1277-1283. https://doi.org/10.1080/15435075.2017.1402773

Hernández, Y., Lobo, M. G., & González, M. (2006). Determination of vitamin C in tropical fruits: A comparative evaluation of methods. *Food Chemistry 96*(4), 654-664. https://doi.org/10.1016/j.foodchem.2005.04.012

Hii, C., & Law, C. (2010). Product quality evolution during drying of foods, vegetables and fruits. *Drying of Foods, Vegetables and Fruits 1*, 125-144.

Khoo, H. E., Prasad, K. N., Kong, K. W., Jiang, Y., & Ismail, A. (2011). Carotenoids and their isomers: Color pigments in fruits and vegetables. *Molecules 16*(2), 1710-1738. https://doi.org/10.3390/molecules16021710

Kurozawa, L. E., Morassi, A. G., Park, K. J., & Hubinger, M. D. (2009). Spray drying of protein hydrolysate of chicken breast meat. *4th InterAmerican drying conference*. Montreal, Canada.

Leite, D. D. de F., Pereira, E. M., Albuquerque, A. P., Mendes, F. D. A., & Alexandre, H. V. (2016). Avaliação da cinética de secagem da carambola em secador convectivo. *Revista Verde de Agroecologia e Desenvolvimento Sustentável 11*(2), 01. https://doi.org/10.18378/rvads.v11i2.4026

Lund, D. (1988). Effects of Heat Processing on Nutrients. In *Nutritional Evaluation of Food Processing* (pp. 319-353).

Maharaj, L. K., & Badrie, N. (2006). Consumer acceptance and physicochemical quality of osmodehydrated carambola (*Averrhoa carambola L.*) slices. *International Journal of Consumer Studies 30*(1), 16-24. https://doi.org/10.1111/j.1470-6431.2005.00428.x

Mateus-Cagua, D., Arias C., M. E., & Orduz-Rodríguez, J. O. (2015). El cultivo de carambolo (*Averrhoa carambola L.*) y su comportamiento en el piedemonte del Meta (Colombia). Una revisión. *Revista Colombiana de Ciencias Hortícolas 9*(1), 135. https://doi.org/10.17584/rcch.2015v9i1.3752

Mulokozi, G., & Svanberg, U. (2003). Effect of traditional open sun-drying and solar cabinet drying on carotene content and vitamin A activity of green leafy vegetables. *Plant Foods for Human Nutrition 58*(3), 1-15. https://doi.org/10.1023/B:QUAL.0000041153.28887.9c

Narain, N., Bora, P. S., Holschuh, H. J., & Vasconcelos, M. A. D. S. (2001). Physical and chemical composition of carambola fruit (*Averrhoa carambola L.*) at three stages of maturity. *Ciencia y Tecnologia Alimentaria 3*(3), 144-148. https://doi.org/10.1080/11358120109487721

Nweze, C. C., Abdulganiyu, M. G., & Erhabor, O. G. (2015). Comparative analysis of vitamin C in fresh fruits juice of *Malus domestica, Citrus sinensi, Ananas comosus* and *Citrullus lanatus* by iodometric tritration. *International Journal of Science, Environment and Technology 4*(1), 17-22.

Page, G. E. (1949). *Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin Layes*. Pardue University.

Pérez-Tello, G. O., Silva-Espinoza, B. A., Vargas-Arispuro, I., Briceño-Torres, B. O., & Martinez-Tellez, M. A. (2001). Effect of temperature on enzymatic and physiological factors related to chilling injury in carambola fruit (*Averrhoa carambola L.*). *Biochemical and Biophysical Research Communications 287*(4), 846-851. https://doi.org/10.1006/bbrc.2001.5670

Provesi, J. G., & Amante, E. R. (2015). Chapter 9 - Carotenoids in Pumpkin and Impact of Processing Treatments and Storage. In V. Preedy (Ed.), *Processing and Impact on Active Components in Food* (pp. 71-80). Academic Press. https://doi.org/10.1016/B978-0-12-404699-3.00009-3

Quan, T. H., & Benjakul, S. (2019). Impacts of desugarization and drying methods on physicochemical and functional properties of duck albumen powder. *Drying Technology 37*(7), 864-875. https://doi.org/10.1080/07373937.2018.1469509

Rascón, M. P., Beristain, C. I., García, H. S., & Salgado, M. A. (2011). Carotenoid retention and storage stability of spray-dried encapsulated paprika oleoresin using gum Arabic and Soy protein isolate as wall materials. *LWT - Food Science and Technology 44*(2), 549-557. https://doi.org/10.1016/j.lwt.2010.08.021

Roopa, N., Chauhan, O. P., Raju, P. S., Das Gupta, D. K., Singh, R. K. R., & Bawa, A. S. (2014). Process optimization for osmo-dehydrated carambola (*Averrhoa carambola L*) slices and its storage studies. *Journal of Food Science and Technology 51*(10), 2472-2480. https://doi.org/10.1007/s13197-012-0756-2

Ruiz-López, I. I., Ruiz-Espinosa, H., Herman-Lara, E., & Zárate-Castillo, G. (2011). Modeling of kinetics, equilibrium and distribution data of osmotically dehydrated carambola (*Averrhoa carambola L.*) in sugar solutions. *Journal of Food Engineering 104*(2), 218-226. https://doi.org/10.1016/j.jfoodeng.2010.12.013

Saikia, S., Mahnot, N. K., & Mahanta, C. L. (2015). Effect of spray drying of four fruit juices on physicochemical, phytochemical and antioxidant properties. *Journal of Food Processing and Preservation 39*(6), 1656-1664. https://doi.org/10.1111/jfpp.12395

Santos, C. T., Bonomo, R. F., Chaves, M. A., Da Costa Ilhéu Fontan, R., & Bonomo, P. (2010). Cinética e modelagem da secagem de carambola (*Averrhoa carambola L.*) em secador de bandeja. *Acta Scientiarum - Technology 32*(3), 309-313. https://doi.org/10.4025/actascitechnol.v32i3.6048

Shigematsu, E., Eik, N. M., Kimura, M., & Mauro, M. A. (2005). Influência de pré-influência de pré-tratamentos sobre a desidratação osmótica de carambolas. *Ciência e Tecnologia de Alimentos 25*(3), 536-545. https://doi.org/10.1590/s0101-20612005000300024

Shofian, N. M., Hamid, A. A., Osman, A., Saari, N., Anwar, F., Dek, M. S. P., & Hairuddin, M. R. (2011). Effect of freeze-drying on the antioxidant compounds and antioxidant activity of selected tropical fruits. *International Journal of Molecular Sciences 12*(7), 4678-4692. https://doi.org/10.3390/ijms12074678

SIAP. (2017). Avance de siembras y cosechas. Resumen por cultivos. http://infosiap.siap.gob.mx:8080/agricola_siap_gobmx/AvanceNacionalSinPrograma.do

Souza, D. S., Marques, L. G., Gomes, E. de B., & Narain, N. (2015). Lyophilization of avocado (*Persea americana Mill.*): Effect of freezing and lyophilization pressure on antioxidant activity, texture, and browning of pulp. *Drying Technology 33*(2), 194-204. https://doi.org/10.1080/07373937.2014.943766

Tlatelpa-Becerro, A., Rico-Martínez, R., Urquiza, G., & Calderón-Ramírez, M. (2020). Obtaining of Crataegus mexicana leaflets using an indirect solar dryer. *Revista Mexicana de Ingeniería Química 19*(2), 669-676. https://doi.org/https://doi.org/10.24275/rmiq/Alim896

Topuz, A., Dincer, C., Özdemir, K. S., Feng, H., & Kushad, M. (2011). Influence of different drying methods on carotenoids and capsaicinoids of paprika (Cv.; Jalapeno). *Food Chemistry 129*(3), 860-865. https://doi.org/10.1016/j.foodchem.2011.05.035

Wrolstad, R. E., & Smith, D. E. (2013). Physical properties of food: Color Analysis. In S. S. Nielsen (Ed.). *Food Analysis* (Fourth, Vol. 53, Issue 9, pp. 572-886). Springer. https://doi.org/10.1017/CBO9781107415324.004

Yeasmin, F., Rahman, H., Rana, S., Khan, J., & Islam, N. (2021). The optimization of the drying process and vitamin C retention of carambola: An impact of storage and temperature. *Journal of Food Processing and Preservation 45*(1), 0-3. https://doi.org/10.1111/jfpp.15037

Zainudin, M. A. M., Hamid, A. A., Anwar, F., Osman, A., & Saari, N. (2014). Variation of bioactive compounds and antioxidant activity of carambola (*Averrhoa carambola L.*) fruit at different ripening stages. *Scientia Horticulturae 172*, 325-331. https://doi.org/10.1016/j.scienta.2014.04.007