International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 09 Issue 02 February 2026
DOI: 10.47191/ijcsrr/V9-i2-41, Impact Factor: 8.048
IJCSRR @ 2026
www.ijcsrr.org

Combined Drying Technologies for Preserving the Quality of Backyard Averroha Carambola L. in Veracruz, Mexico

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ABSTRACT: Star fruit (Averrhoa carambola L.) is cultivated in Asian and Latin American countries and has high nutritional value due to its content of bioactive compounds, polyphenols, vitamins A and C, minerals, and antioxidant activity. However, its high water content makes it highly perishable, limiting its preservation and commercialization; therefore, it is necessary to develop technological alternatives that extend its shelf life without affecting its organoleptic and nutritional quality. The objective of this study was to evaluate combined power ultrasound-assisted drying technologies for obtaining star fruit flakes as a preservation alternative, analyzing their effect on physicochemical, functional, and sensory attributes. Fruit from the Postgraduate College, Veracruz Campus, was used, and osmotic dehydration (OD) curves were performed at 50 and 60 °Brix, using ultrasound (US) as a pretreatment to convective drying (CS). Drying kinetics were performed at 50 and 60 °C, and total phenolic compounds, antioxidant activity (DPPH and ABTS), oxalic acid, color (ΔE), moisture, total solids, water activity (aw), and texture in the center and periphery were evaluated, in addition to sensory analysis. The DO treatments assisted with ultrasound reached equilibrium in less time. The 60°Brix-CUS-60 °C treatment showed lower final moisture content, while the 60°Brix-CUS-50 °C treatment reached an aw of approximately 0.47, favoring microbiological stability. The 60 °Brix DO treatment with ultrasound and 60 °C surface drying showed lower moisture content and higher total solids content. The 60 °Brix DO treatment without ultrasound and 50 °C surface drying preserved phenols better, reducing oxalic acid by >50% and showing improvements in antioxidant activity. High sensory acceptability was obtained. It is concluded that the DO-US-SC combination is effective in preserving carambola with adequate quality and acceptance.

KEYWORDS: Oxalic acid, phenolic compounds, osmotic dehydration, convective drying, ultrasound.

INTRODUCTION

Globally, carambola (Averrhoa carambola L.) is a tropical fruit of growing importance due to its nutritional, functional, and commercial value. The main carambola producers in Latin American countries are small-scale, and its natural star shape makes it a visually appealing product, increasing its consumption, primarily fresh or processed into jams, juices, and sweets. et al., 2025). In international markets in Europe, the United States, and Japan, star fruit is appreciated as an exotic fruit for its distinctive shape, refreshing flavor, and content of bioactive compounds; these compounds are a rich source of antioxidants, vitamin C, potassium, phosphorus, magnesium, and dietary fiber, and contribute to optimal health and a reduced risk of disease (Enríquez - Valencia etal. (2020). Likewise, due to its high content of compounds with antioxidant and nutraceutical properties, the development of new

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preservation technologies and derived products with highly competitive prices has been promoted (SIDEL, 2006). Star fruit is highly perishable; therefore, it is essential to analyze affordable preservation options that maintain the sensory attributes appreciated by consumers. One widely studied alternative is drying by osmotic dehydration (OD), which consists of immersing the fruit in a hypertonic solution (sugars/salts) to induce water loss and partial impregnation of solutes (Ciurzyńska). et al., 2016; Turkiewicz et al., 2020); this practice prior to convective hot air (SC) drying or freeze-drying treatments can significantly decrease water activity, improve the energy efficiency of the subsequent drying treatment and increase the retention of quality attributes (Udomkun et al., 2018). In this sense, it is important to properly control times, temperatures and ratios in the DO, since it can favor the leaching of water-soluble compounds and modify the sweetness or texture of the product by gaining solids (Pandiselvam et al., 2022). Several studies have shown that the combined DO and SC technology has increased the rate of water loss and improved sensory attributes. Bozkir et al. (2019) found a significant reduction in the total SC time of persimmon, an increase in the effective diffusivity of water in the total phenolic compound content, and an improvement in the pulp rehydration rate without significantly altering the color. Guberman et al. (2025) evaluated osmotic dehydration treatments of carambola slices in sucrose and trehalose solutions; the results showed that both osmotic treatments significantly modified the instrumental texture of the snacks compared to the control, providing better crunchiness; in addition, the sensory analysis revealed significant differences in appearance, texture, taste and smell between the samples, with the trehalose treatment obtaining the highest acceptability scores. Other recent research has explored the combination of osmotic dehydration and/or convective drying technologies assisted by high-power ultrasound (US), achieving improvements in organoleptic and nutritional quality in different food matrices. The results of applying ultrasound before or during drying processes are primarily a reduction in convective drying time (Gamboa et al., 2014), a reduction of up to 50% in osmotic dehydration time, and a decrease in energy consumption compared to conventional methods (Biswas). et al., 2025). This is because it favors mass transfer (solute gain through impregnation during DO), reducing drying times and thus preserving the quality of the final products (Camacho et al., 2025). High-intensity ultrasound in fluids causes complex phenomena such as acoustic wave propagation, mechanical vibration, sponge effect, cavitation, and atomization, which accelerate both internal and external mass and heat transfer. Biswas et al., (2025) evaluated the use of combined technologies using osmotic and ultrasonic treatment to improve the quality of dehydrated mango slices. The results of this study showed an improvement in three aspects: 1) a one-third reduction in the drying time for mango slices that received an osmotic treatment at 70 °C ; 2) nutrient preservation, as the pretreatments with trehalose and ultrasonics allowed the dehydrated slices to retain heat-sensitive nutrients such as β-carotene and vitamin C, and better preserved phenolic compounds, flavonoids, and antioxidant activity; and 3) improved texture of the dehydrated mango snacks, as the pretreatments with osmotic sucrose and trehalose improved the firmness, cohesion, elasticity, fragility, and gumminessness of the dried mangoes. Based on the results of previous studies, the objective of this research was to evaluate the effect of high-power ultrasound on the combined osmotic dehydration and convective drying technology of carambola slices produced in family orchards in the central region of the state of Veracruz. The aim was to comprehensively demonstrate an improvement in the physicochemical, functional, and sensory quality attributes of the dehydrated product, including phenolic compounds, antioxidant activity, texture, and oxalic acid content. Disseminating these results will provide a scientific basis for the potential use and processing of carambola, contributing to its valorization in regions of high food insecurity, promoting its cultivation, and opening market opportunities that benefit producers and consumers in the region.

MATERIALS AND METHODS

Geographic location The research was carried out at the facilities of the Postgraduate College Campus, Veracruz; which is located in the Tepetates area, on the Veracruz-Xalapa federal highway at km 88.5, in the municipality of Manlio Fabio Altamirano, Veracruz, Mexico, between the towns of Puente Jula and Paso San Juan. Geographically, it is located at 19° 11´ 53” North Latitude and 96° 19´ 47” West Longitude at an elevation of 32 meters above sea level (García 2004).

Obtaining the raw material Starfruit at maturity stage 3 (yellow) was used; these were collected at the Postgraduate College Campus Veracruz (COLPOS, VER.), located on the Xalapa-Veracruz highway at kilometer 88.5, Tepetates, municipality of Manlio Fabio Altamirano, Veracruz. The fruits were transported to the Food Analysis Laboratory located within COLPOS, VER., where they were washed, peeled, and sliced into 5 mm thick rounds. To evaluate the use of combined preservation technologies, three methods were employed: osmotic dehydration, ultrasound, and convective drying ; eight treatments were carried out, which are presented in Table 1.

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Table 1. Treatments evaluated in the research

Treatment	Osmotic dehydration	Ultrasound*	Convective drying
1	50° Brix	THEIR	50 °C
2	50° Brix	CU	50 °C
3	50° Brix	THEIR	60 °C
4	50° Brix	CU	60 °C
5	60° Brix	THEIR	50 °C
6	60° Brix	CU	50 °C
7	60° Brix	THEIR	60 °C
8	50° Brix	CU	60 °C

*SUS = Treatment without ultrasound; *CUS = Treatment with ultrasound

Osmotic dehydration kinetics were determined at a 1:4 ratio, using 100 g of fruit slices per 4 kg of solution. The solution was prepared at 50 °Brix with 2 kg of distilled water and 2 kg of refined sugar. For osmotic dehydration at 60 °Brix, 1.6 kg of distilled water and 2.4 kg of refined sugar were used. The ° Brix of the solutions was measured. For treatments without ultrasound, the fruit was placed in a 5-liter plastic jar. A CIMAREC® brand heating and stirring plate was placed inside the jar, along with a magnetic stirrer to keep the sample in motion. For treatments with ultrasound, the solution and fruit were placed in a BRANSON® brand ultrasonic bath, model CPX3800H, at 40 kHz and a temperature of 27 °C. Subsequently, during the first 2 hours, a sample was taken every 15 minutes to be weighed. After 2 hours, samples were weighed every 30 minutes for another 4 hours, and subsequently, weights were recorded every hour until 24 consecutive hours were completed.

Convective drying kinetics The experiment was conducted in the food engineering laboratory of UNIDA, Veracruz, Veracruz, using an APEX® brand tray dryer, series A 39854-14. The previously osmotically dehydrated samples were placed on trays, with a separation of 2 cm, and introduced into the dryer at temperatures of 50 and 60 °C. Consecutively, for the first 2 h, a slice was taken out every 15 minutes to be weighed; after 2 h, they were weighed every 30 min for another 2 h, and subsequently, weights were recorded every hour, until completing 8 consecutive hours.

Determination of aw An AquaLab® hygrometer was used to determine water activity. A slice of the sample was placed in the cell and the water activity reading was taken. The value provided by the hygrometer is the ratio between the partial vapor pressure of the product in the slice and the vapor pressure of pure water at the same temperature; for this reason, it is a dimensionless number with a value that varies between 0 and 1 respectively.

Color Determination The response variables were the chromaticity coordinates L*, a*, and b*, measured using a Hunter Lab® MiniScan XE Plus colorimeter, Model No. D/8-L. Color analysis was performed on the surface of carambola slice samples treated with different combinations of osmotic dehydration, ultrasound, and drying temperatures, with three measurements taken per sample. The data obtained by the colorimeter were L*, a*, and b*.

Determination of moisture and total solids Following the OFFICIAL MEXICAN STANDARD NMX-F-083-1986, "Foods. Determination of moisture in food products," the fruits were washed, peeled, and cut. The crucibles were weighed to constant weight, and then the slices were weighed on an ADAM® AAA 300L analytical balance and subjected to heat in a VIEW LINE® drying oven at 100°C for 24 h. They were then transferred to a desiccator to be weighed again, and the percentage of moisture was expressed in relation to the weight loss. The percentage of total solids was expressed in relation to the moisture content using the formula: % of S or free $totales = 100 - h\ umedad$.

Determination of phenolic compounds Two grams of dry sample were weighed and mixed with 95% ethanol in a 1:5 ratio in an Erlenmeyer flask covered with aluminum foil. The mixture was extracted at 35 kHz and 50°C for 2 h in a BRANSON® CPX3800H ultrasonic bath. The sample was filtered through Whatman No. 42 filter paper to obtain a clear solution. Subsequently, a 1:10 dilution was made with distilled water in 10 mL volumetric flasks.

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Construction of the calibration curve for the determination of total phenols (adapted from Singleton and Rossi (1965)) A 0.1 g/L gallic acid standard solution was prepared. 25 mg of gallic acid were weighed, placed in a 25 mL volumetric flask, and diluted to the mark with distilled water. A 1:10 dilution was then prepared with distilled water. From this gallic acid standard dilution, several dilutions were made in light-protected vials (amber vials). 20 µL , 40 µL , 60 µL , and 100 µL of the 0.1 mg/L gallic acid standard solution were taken and added to 3 mL amber vials . 250 µL of Folin-Ciocalteu reagent, diluted 1:10 in a graduated cylinder, was added to each vial. The mixtures were vortexed for one minute and allowed to react for 5 minutes. 1250 µL of a 7.5 g/100 mL Na_2CO_3 solution was added to each solution. Each vial was brought to a final volume of 2 mL with distilled water and allowed to stand at room temperature for 90 minutes. A blank was prepared with all components except the gallic acid solution. These solutions then had concentrations of 0 mg/L, 1 mg/L, 2 mg/L, 3 mg/L, 4 mg/L, and 5 mg/L. Finally, the absorbance of each solution and the standard was measured at 760 nm using a UV-Vis spectrophotometer.

Technique for the determination of total phenols. 200 µL of extracted and diluted sample were placed in light-protected vials and mixed with 1.5 mL of Folin-Ciocalteu reagent. The diluted mixture was stirred constantly and allowed to react for 5 min. The resulting solution was mixed with 1.5 mL of a 7.5 g/100 mL Na2CO3 solution and incubated at room temperature in the dark for 90 min. The total phenol content was measured at 760 nm using a UV-Vis spectrophotometer.

Determination of antioxidant activity Extraction of antioxidant compounds was carried out using solvents (ethanol, methanol, acetone, water, etc.) (Pérez-Jiménez and Saura-Calixto, 2007; Salas et al., 2022). 0.5 g of osmotically dehydrated sample was weighed into a capped test tube, and 10 mL of methanol/water acidified with 2N HCl (50:50 v/v, pH 2) was added. The mixture was then covered and kept in the dark. It was stirred at 50 °C for 30 min. Subsequently, the mixture was centrifuged at 6000 rpm for 15 min at 4 °C, and the supernatant was recovered and stored in the dark in a 50 mL volumetric flask at 4 °C. The residue was subjected to a second extraction with 10 mL of acetone/water (70:30 v/v) and stirred at 50 °C for 30 min. The mixture from the second acetone/water (70:30 v/v) extraction was then centrifuged at 6000 rpm for 15 min at 4 °C, and the supernatant was recovered. A total of four acetone/water (70:30 v/v) extractions were performed. The five supernatants were combined and diluted to 50 mL with double-distilled water. The resulting extract was then used for analysis.

DPPH Method Antioxidant activity was determined using the method described by Molyneux (2004). A 0.1 mM DPPH solution was prepared in methanol (absorbance was adjusted with methanol to 0.7 ± 0.1 at 515 nm). To 3.9 mL of the solution (0.1 mM DPPH, absorbance 0.70 ± 0.1), 0.1 mL of extract was added. The mixture was vortexed for 30 seconds. Absorbance was measured at 515 nm 30 minutes after the start of the reaction using a Genesys 10S UV-visible Thermospectrometer. Scientific). Trolox was used for the calibration curve. The results were expressed as a percentage of DPPH radical inhibition. They were calculated using the following formula: $\% \text{ Inhubición} = \frac{(A0-At)}{A0}(100)$

Where:

A0: is the absorbance of the control (100)

At: is the absorbance of the sample. The analyses were performed in triplicate.

ABTS Method The TEAC antioxidant activity was determined using the method described by Re et al. (1999), based on the ABTS radical inhibitory capacity. The ABTS radical was prepared using 7 mM ABTS reagent and 2.45 mM potassium persulfate, dissolved in distilled water to a final volume of 5 mL. The mixture was left in the dark at room temperature for 12–16 hours before use. The ABTS radical solution was diluted in ethanol to obtain an absorbance of 0.70 ± 0.02 at 734 nm. One mL of the ABTS radical was mixed with 10 µL of extract, and the absorbance was measured at 6 min at 734 nm using a Genesys 10S UV-visible Thermospectrometer. Scientific). Trolox was used for the calibration curve. The results were expressed as a percentage of ABTS radical inhibition.

Determination of oxalic acid An adaptation of NMX-F-102-S-1978 was performed. DETERMINATION OF TITRATABLE ACIDITY IN PRODUCTS MADE FROM FRUITS AND VEGETABLES. This analysis was performed on fresh carambola fruit at maturity stage III (Yellow) and on osmotically dehydrated slices. 10 g of crushed and homogenized sample was transferred to a 50 mL beaker, approximately 27 mL of water were added, and the mixture was heated to 70 °C for one hour. It was filtered using rapid filtration paper, washing the residue with hot neutralized water. The filtrate and washings were transferred to a 100 mL graduated cylinder, cooled, and brought up to a final volume of 67 mL. The solution was thoroughly shaken before taking the aliquot for analysis. A HANNA® brand potentiometer, model HI 2211, was used for the reading. It was calibrated with buffer solutions and then washed with water until the reading of freshly boiled and cooled water reflected a pH of 6.0. A 25 mL aliquot of the prepared and diluted sample was transferred to a 250 mL volumetric flask and diluted to 50 mL with freshly boiled, cooled, and neutralized water. The electrodes were inserted into the sample with moderate stirring. The 0.1 N sodium hydroxide solution was rapidly added until a pH close to 6.0 was reached, followed by slow addition of NaOH until a pH of 7.0 was achieved. After reaching the target pH, the titration was completed by adding NaOH in 4-drop increments until a pH of 8.3 was reached. The pH reading and the total volume of NaOH were recorded. consumed after each addition. To express the results, the following formula was used, using the milliequivalent of oxalic acid since it is the compound of interest: $\% \text{ de Acidez} = \frac{\text{V x N x Me.x 100}}{\text{g o ml de myestra}}$

Where: V: Volume of NaOH used

N: Normality of NaOH

Me.: Milliequivalent of oxalic acid which is equal to 0.004502.

Texture determination The dehydrated samples were analyzed at 25 °C using a puncture test with a Shimadzu® Universal Texture Analyzer, Model EZ - S 500N. The test was performed with a cylindrical punch 1.5 mm in diameter, at a constant penetration speed of 1.5 mm/s until the sample was completely penetrated. Determinations were performed in triplicate on different slices obtained after each treatment in two replicates, taking one reading on part of the pulp and a second in the center of the slice. The results obtained were expressed in kgF for each treatment.

Sensory analysis A hedonic acceptance test was carried out with 100 inexperienced judges. The osmo -dehydrated samples were placed on a plastic tray, and staff and students from COLPOS, VER. were invited to take a sample from the tray, taste it, and then answer a survey. The information was collected and the evaluation was assessed qualitatively.

Experimental design and data análisis Each variable was evaluated using a completely randomized design with a factorial arrangement of treatments, with 3 factors: factor A (° Brix in DO) at 2 levels (50° and 60 °Brix), factor B (temperature in SC) at 2 levels (50° and 60°C), and factor C (use of ultrasound) at two levels (with and without ultrasound), with 3 replicates. Statistical analysis was performed using ANOVA. For statistical differences, a comparison of means was performed using Tukey's test . To evaluate the effect of time on the physical, chemical, and antioxidant variables, a repeated measures analysis was performed using the SAS 9.3 statistical package (2011).

RESULTS AND DISCUSSION

Osmotic dehydration kinetics Figure 1 shows a comparison of moisture loss in carambola slices during osmotic dehydration (OD) at 50 and 60 °Brix, with and without the application of ultrasound (US). The results demonstrate that the concentration of the osmotic solution significantly influenced the final water content of the samples. At 50 °Brix without US, the final moisture content was 46.44%, while at 60 °Brix without US it was reduced to 38.13%, confirming that a higher osmotic gradient favors mass transfer. Regarding the effect of ultrasound, its application reduced the moisture content at both concentration levels, although to different degrees. At 50 °Brix, the samples treated with US reached an average moisture content of 45.51%, showing a reduction of approximately 1% compared to the treatment without US. In contrast, at 60 °Brix with ultrasound, a final moisture content of 33.33% was obtained, approximately five percentage points lower than without ultrasound. This suggests that the intensifying effect of ultrasound is more pronounced when combined with higher concentration solutions. These results are consistent with those reported by Gamboa-Santos et al. (2012), who noted that the application of ultrasound during osmotic dehydration accelerates water loss and solids gain due to cavitation phenomena that increase the permeability of plant tissue. Similarly, Barman and Badwaik (2017), also working with carambola, reported that the use of an ultrasonic bath reduces moisture content and increases solids gain, attributing this effect to improved mass transfer. Taken together, the results obtained confirm that combining a higher osmotic concentration with the application of ultrasound increases the efficiency of the carambola dehydration process.

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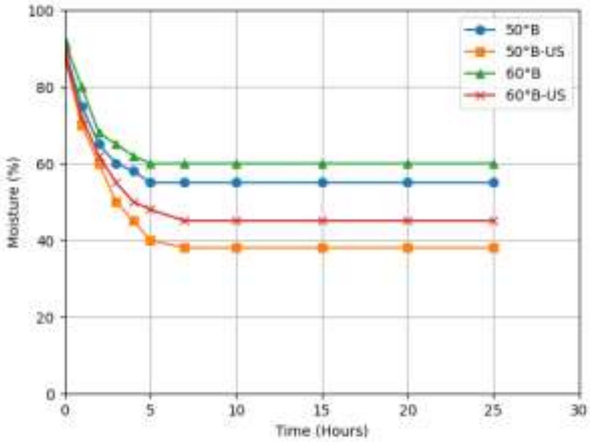

Figure 1. Kinetics of moisture loss with respect to time.

Convective drying kinetics Figure 2 shows the water loss curves, expressed as grams of water per gram of dry solid (g water/g dry solid), in carambola slices, as a function of dehydration time. The results show that the treatments carried out at 50 °Brix exhibited less water loss compared to the treatments at 60 °Brix . The 50 °B CUS 50 °C treatment reached a value of 0.1216 g water/g dry solid, while the 60 °Brix treatments showed considerably lower values, reaching 0.0173 g water/g dry solid in the 60 °B CUS 60 °C treatment, confirming that higher osmotic concentrations favor greater water removal. Furthermore, the ultrasonic treatments showed lower water content per gram of dry solid and, additionally, reached constant weight in less time than the treatments without ultrasound. This indicates that ultrasound not only intensifies mass transfer, but also accelerates the kinetics of the process. These results are consistent with those reported by Robles-Ozuna and Ochoa-Martínez (2012), who indicate that the application of ultrasound in food processing reduces processing times and can improve quality attributes compared to conventional methods. Similarly, Gamboa-Santos et al . (2012) report that the use of ultrasound significantly decreases drying time after osmotic dehydration and highlight its low thermal effect as an advantage, which favors its application in low-temperature processes, especially in plant matrices with heat-labile compounds. The results obtained reinforce that the combination of higher osmotic concentration and ultrasound improves process efficiency, both in terms of water loss and the reduction of the time required to reach equilibrium.

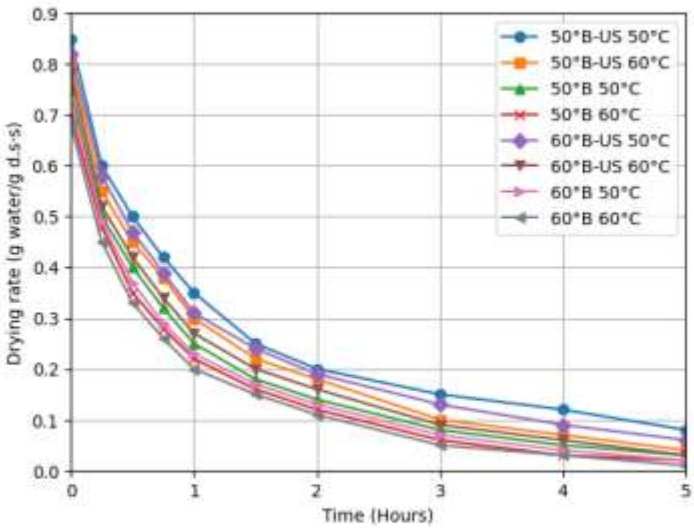

Figure 2. Difference in water content loss expressed in grams of water over grams of dry solid in relation to time.

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Determination of a _w Significant differences in water activity (a_w) were observed among the different combinations of osmotic dehydration (OD), convective drying (CD), and the use of ultrasound (US). In the case of OD of carambola slices, the concentration of the osmotic solution directly influenced this parameter, with lower a _w values obtained at 60 °Brix compared to 50 °Brix, which is associated with greater removal of free water due to the increased osmotic gradient. convective drying, temperature also affected the final water activity (aw). Slightly higher aw values were obtained at 60 °C compared to 50 °C, which could be attributed to possible structural changes in the tissue affecting the distribution and availability of wastewater. During desaturation (DO), the use of ultrasound showed a significant effect on reducing water activity. The ultrasound-assisted treatments exhibited lower aw values, demonstrating a greater decrease in free water content, attributable to the intensification of mass transfer promoted by cavitation phenomena. The aw values of the eight treatments ranged from 0.469 ± 0.006 to 0.551 ± 0.006, with the ultrasound treatments registering the lowest values. Statistically significant differences were found among all treatments, indicating that each technological combination produced a differential effect on this quality parameter. From a microbiological stability standpoint, all treatments exhibited water activity (aw) values below 0.6, meeting the stability criteria reported by Badui-Dergal (2006), who indicates that above this value, the growth of fungi and yeasts, as well as various deterioration reactions, may be favored. In this regard, lower aw values imply less water availability for microbial growth; therefore, the 60 °Brix (OD) treatment with ultrasonic cleaning and drying at 50 °C appears to be the most favorable condition from a product stability perspective.

Color Determination Color analysis was evaluated using the parameters hue, chroma, and total color difference (ΔE), the significant differences between treatments of which are presented in Table 2. In osmotic dehydration (OD), sugar concentration was a determining variable for all three parameters evaluated (hue, chroma, and ΔE), with significant differences observed between concentration levels. These results indicate that a higher solute content influenced both the hue and intensity of the color and the magnitude of the total change compared to the fresh sample. In convective drying (CD), temperature significantly influenced only chroma, with statistically significant differences observed between 50 and 60 °C. In contrast, hue and ΔE values did not show significant variations between these temperatures. This can be explained by the sensitivity of chroma to modifications in plant pigments during drying, as noted by Maskan, who indicates that increased temperature can affect color intensity due to browning reactions and structural changes in the tissue. Regarding the use of ultrasound (US), significant differences were observed in chroma and ΔE, with less color variation recorded in the US-assisted treatments. In contrast, HUE did not show significant differences. This effect can be attributed to the fact that ultrasound reduces the thermal exposure time and, therefore, the heat-related deterioration, favoring the preservation of chromatic quality, as reported by Noor and Noriham (2014) and Gamboa-Santos (2012). Taken together, the results indicate that both the sugar concentration in the DO and the application of US are key variables for maintaining color quality in carambola slices, while the SC temperature mainly affects the intensity (chroma) without significantly modifying the hue or the total color difference (ΔE).

Table 2. Hue, chroma and ΔE per variable

Variables	HUE	CHROMA	ΔE
50°B	1.319±0.024 ^{b}	32.628±1.795 ^{a}	8.8888±1.799 ^{b}
60°B	1.352±0.024 ^{a}	28.836±1.795 ^{b}	13.5248±1.799 ^{a}
50°C	1.347±0.024 ^{a}	31.947±1.795 ^{a}	10.42±1.799 ^{a}
60°C	1.324±0.024 ^{a}	29.518±1.795 ^{b}	11.9936±1.799 ^{a}
THEIR	1.327±0.024 ^{a}	29.035±1.795 ^{b}	12.8091±1.799 ^{a}
CU	1.344±0.024 ^{a}	32.429±1.795 ^{a}	9.604±1.799 ^{b}

Determination of moisture and total solids Figure 3 shows the percentage of moisture and total solids after each combination of drying technologies (OD, US, and SC), as well as compared to the fresh fruit. Osmotic dehydration reduced the moisture content by approximately 50% compared to the initial moisture content of the fresh fruit, in addition to increasing the total solids content. This incorporation of solutes contributes to enhancing the organoleptic properties of the product, as noted by Moreira and Oliveira (2008), who describe osmotic dehydration as a pretreatment that reduces water content and improves the physicochemical and sensory

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characteristics of food. The figure also shows that convective drying produced an additional moisture reduction of approximately 70% compared to the fresh fruit. The treatment with the lowest final moisture content was the combination of osmotic dehydration at 60 °Brix with ultrasound application, followed by convective drying at 60 °C. In general, treatments carried out at 60 °C showed greater moisture loss and a higher percentage of total solids, indicating that increased temperature promotes water removal and solids concentration in the final product. The results confirm that the combination of higher osmotic concentration, the use of ultrasound, and higher drying temperature intensifies moisture reduction and promotes greater incorporation and concentration of total solids in the carambola slices.

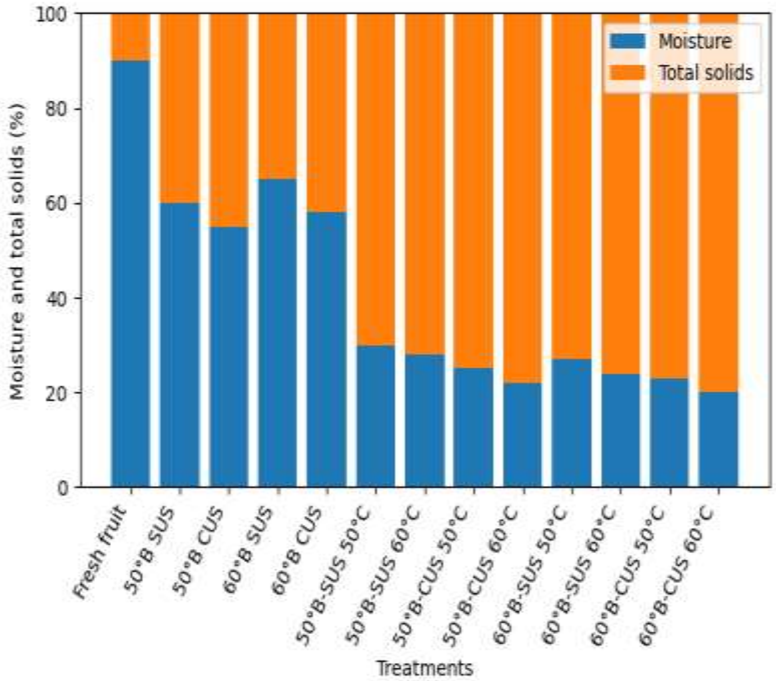

Figure 3. Comparison of moisture and total solids of the drying process, using different DO pretreatments and drying temperatures.

Determination of phenolic compounds The analysis of the total phenolic compound (TPC) content allowed the identification of the effects of each applied technology (DO, US and SC) on these bioactive compounds:

- Osmotic dehydration (OD): The sugar concentration of the osmotic solution significantly influenced the total phenolic content (TPC). It was observed that lower solute concentrations resulted in a higher preservation of phenolic content, while higher sugar concentrations led to a decrease in TPC. This suggests that elevated osmotic pressure may favor the extraction of soluble compounds or their degradation during the process.
- Convective drying (SC): The drying temperature, evaluated at 50 and 60 °C, did not produce statistically significant differences in the CFT content, indicating that within this thermal range the phenols present in the carambola slices are relatively stable against the applied heat.
- Ultrasound (US): The application of ultrasound during DO negatively influenced the TFC content. Samples subjected to DO with US showed a decrease in phenols, while samples without ultrasound retained higher amounts of these compounds. This could be explained by cavitation effects that accelerate the extraction or degradation of phenolic compounds during the process.

The statistical analysis by treatment, presented in Table 3, indicates that all treatments differ from one another, with no statistically equivalent replicates. These results reflect that each combination of osmotic concentration, ultrasound application, and drying temperature has a distinct effect on the TFC content in the carambola slices.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 09 Issue 02 February 2026
DOI: 10.47191/ijcsrr/V9-i2-41, Impact Factor: 8.048
IJCSRR @ 2026
www.ijcsrr.org

Table 3. CFT content in mg of galac. /100 gms by treatment

Treatments	Total phenolic compounds (mg of gal. acetic acid/100 gms .)
50SUS50	31.185±1.354 [e]
50CUS50	33.547±1.354 [d]
50SUS60	44.922±1.354 [b]
50CUS60	37.31±1.354 [c]
60SUS50	49.21±1.354 [a]
60CUS50	28.21±1.354 [f]
60SUS60	17.972±1.354 [h]
60CUS60	22.785±1.354 [g]

Determination of antioxidant activity Antioxidant activity was determined using two complementary methodologies: DPPH and ABTS. The results, organized by dependent variable, are presented in Table 4. Regarding the concentration of the hypertonic solution during osmotic dehydration (OD), significant differences were observed in both methodologies. For DPPH and ABTS, the antioxidant activity (AA) values (% IRD DPPH and % IR ABTS) were lower in the samples treated with higher concentrations (60 °Brix), while at lower concentrations (50 °Brix) a higher percentage of antioxidant activity was preserved. This suggests that a greater osmotic gradient may favor the extraction or partial degradation of phenolic and antioxidant compounds during the process. As for the convective drying (CD) temperature, no significant differences were observed in ABTS, while in DPPH a trend toward decreased antioxidant activity was recorded with increasing temperature. These results are consistent with reports in the literature, which indicate that heat can degrade thermolabile antioxidant compounds, reducing the radical- scavenging capacity of foods. Taken together, these findings show that both the concentration of the osmotic solution and the drying temperature have different effects on the preservation of antioxidant activity in starfruit slices, with lower concentration and temperature conditions being more favorable for preserving these bioactive compounds.

Table 4. Activity antioxidant in % IRD DPPH and % IR ABTS by variable.

Variables	Antioxidant activity by DPPH (% IRD DPPH)	Antioxidant activity by ABTS (% IR ABTS)
50°B	35.5381±0.933 [a]	11.974±0.884 [a]
60°B	30.747±0.933 [b]	9.957±0.884 [b]
50°C	36.741±0.933 [a]	10.565±0.884 [a]
60°C	29.544±0.933 [b]	11.365±0.884 [a]
THEIR	35.713±0.933 [a]	11.735±0.884 [a]
CU	30.572±0.933 [b]	10.195±0.884 [b]

Oxalic acid determination Oxalic acid levels were determined in fresh fruit and in a control treatment of osmotically dehydrated fruit. A content of 0.45% was found in the fresh fruit and 0.21% in the dehydrated fruit, showing a significant decrease after osmotic dehydration. These results agree with those reported by Pirone (2002), who observed that during drying processes at low temperatures (50 °C), ascorbic acid undergoes enzymatic degradation due to the prolonged exposure of the fruit to high moisture content. Thermal degradation of these compounds is also considered in high-temperature drying. Pirone et al. concluded that ascorbic acid levels during dehydration depend on both air temperature and the moisture content of the sample. Similarly, other researchers have documented that the degradation of acidic compounds and heat-labile vitamins is influenced by the combination

International Journal of Current Science Research and Review

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IJCSRR @ 2026

www.ijcsrr.org

of temperature and exposure time, highlighting the importance of controlling these variables to preserve the nutritional quality of food during dehydration processes.

Texture determination Texture analysis was performed considering two regions of the carambola slice: the center and the periphery. Regarding sugar concentration during osmotic dehydration (OD), no significant differences in texture were observed in the center between 50 and 60 °Brix. However, the concentration did influence the texture of the periphery, showing a directly proportional relationship: higher sugar concentration resulted in a higher texture value. With respect to convective drying (CD) temperature, it was observed that, in both regions of the slice, lower temperatures were associated with higher texture values (KgF). The application of ultrasound (US) increased texture in both the center and periphery of the slices, indicating that this technology contributes to tissue hardening. The comparison between treatments revealed statistically similar results; however, extreme values were identified. For osmotically dehydrated slices, lower texture values are desirable, as this is associated with greater crunchiness. In this regard, the treatment with the lowest texture in the center was treatment 7 (60 °Brix with ultrasound and subsurface drying at 60 °C), with 0.73651 KgF, while in the periphery, the lowest value corresponded to treatment 3, with 0.34599 KgF. These results indicate that the crunchiness of the starfruit slices can be optimized by adjusting the sugar concentration during osmotic dehydration, the drying temperature, and the use of ultrasound, thus achieving a more palatable texture.

Sensory Analysis (Acceptance or Liking Level Test) The acceptance test allowed us to evaluate consumers' perception of the product. Of the 100 people surveyed, only 2 indicated that they disliked the product. Figure 4 presents a pie chart showing the percentages obtained for each category of the survey scale (I like it very much, I like it moderately, I like it slightly, I neither like nor dislike it, I slightly dislike it, I moderately dislike it, I dislike it very much). It can be seen that 89% of respondents rated the product positively, either "I like it very much," "I like it moderately," or "I like it slightly"; 9% expressed indifference ("I neither like nor dislike it"), and only 2% expressed dislike. These results indicate that the combination of the three technologies applied (DO, US, and SC) was satisfactory, achieving sensorially pleasing osmotically dehydrated slices. The high acceptability obtained confirms that the treatments used are not only effective from a physicochemical point of view, but also attractive to the end consumer.

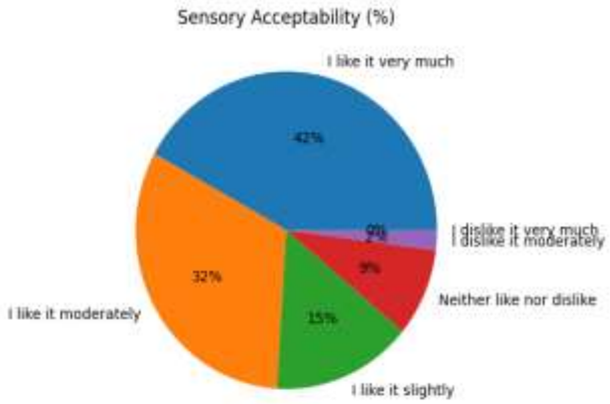

Figure 4. Hedonic test pie chart.

In the second part of the sensory interview, based on the weighting of each evaluated parameter, passing scores were obtained for all criteria, as shown in Figure 5. The attributes most highly valued by the panelists were appearance and color, with scores of 77.358 and 77.735, respectively. The attribute with the lowest score was aroma, with 60.754. The high score for appearance is related to the star shape of the carambola and its bright, attractive yellow color. The aroma evaluation was limited by the food's presentation: the slices were kept separate on a tray exposed to the elements, which likely allowed volatile compounds to disperse, diminishing the aromatic perception compared to the packaged product. The flavor was well-received, especially by consumers with a preference for sweetness. Regarding texture, the slices exhibited a crisp exterior and a slightly chewy interior, which some panelists found less appealing due to their preference for completely crisp or chewy products. Overall, these results indicate that the combination of technologies (DO, US and SC) made it possible to obtain sensorially attractive osmo- dehydrated slices, with good acceptance in appearance, color and flavor, although some aspects such as aroma and texture could be optimized according to consumer preferences.

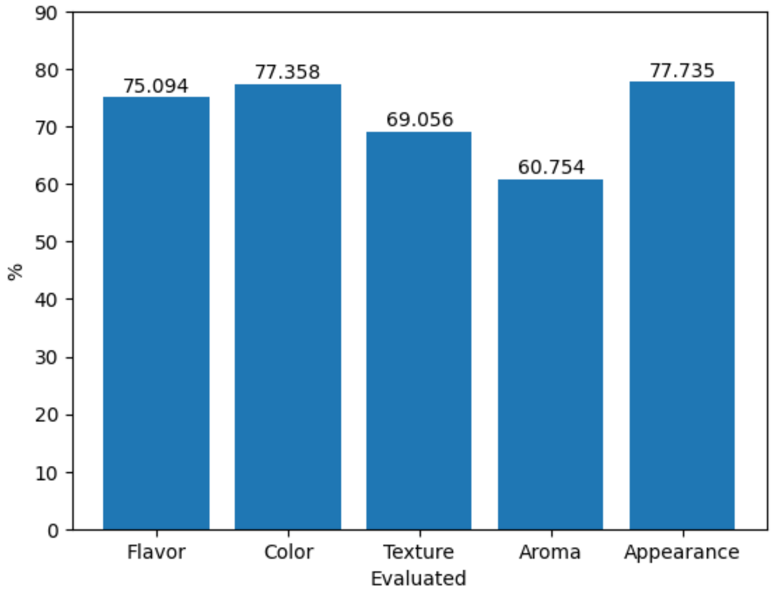

Figure 5. Bar chart of rating awarded by criterion.

Figure 6 shows the results of the third part of the survey, in which the five basic tastes were evaluated by the panel. Sweetness was the most frequently identified taste, at 84.90%, followed by umami (11.32%) and sourness (3.77%). It is noteworthy that bitter and salty tastes were not perceived by any panelist. These results align with the previously conducted acidity analysis, as panelists perceived the sweet taste, considered pleasant and characteristic of fresh fruit, before the natural acidity of the star fruit. This suggests that the osmotic dehydration process, combined with ultrasound and convective drying, preserves the fruit's sweet sensory profile, while bitter and salty tastes are not intensified during processing.

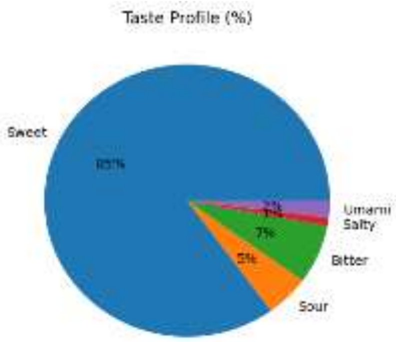

Figure 6. Pie chart of identified flavors.

CONCLUSIONS

Taken together, the results demonstrate that combining osmotic dehydration, ultrasound, and convective drying optimizes both drying efficiency and the preservation of the carambola's functional and sensory attributes. Treatments with higher osmotic concentration and the use of ultrasound achieved lower moisture content and water activity, promoting microbiological stability and solids concentration. These technologies also helped maintain color, retain phenolic compounds and antioxidants, and reduce oxalic acid content, while preserving the crisp texture and sweet flavor, ensuring high consumer acceptance. These findings confirm that the strategic application of combined technologies not only improves processing efficiency but also yields a safe, functional, and sensorially appealing final product, positioning carambola as a viable alternative for preservation and marketing in high-value dehydrated food markets.

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Cite this Article: Vidaña Reyes, T.I., Castillo Zamudio, R.I., Prieto, A.C., Burela, A.C., Bonilla Engr, C.G. (2026). Combined Drying Technologies for Preserving the Quality of Backyard Averroha Carambola L. in Veracruz, Mexico. International Journal of Current Science Research and Review, 9(2), pp. 966-978. DOI: https://doi.org/10.47191/ijcsrr/V9-i2-41