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Article

Nutraceutical analysis of fig cv. Nezahualcóyotl dehydrated by osmo-convection

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Abstract

This research aimed to analyze the nutraceutical properties of fig (*Ficus Carica* L.) cv. Nezahualcóyotl dehydrated by osmo-convection. Due to the limited information on this variety in Mexico, the impact of the dehydration method on the bioactive compounds of the fruit was evaluated. The study was conducted in Texcoco, State of Mexico in 2024, using 120 fig plants under organic production. Thirty-six fruits were randomly taken and subjected to osmotic dehydration with sucrose concentrations of 0, 40, 50 and 60%, followed by convective dehydration at temperatures of 50, 60 and 70 °C. A completely randomized design was established, where the data were analyzed through Anova, Duncan tests or Kruskal-Wallis non-parametric tests according to the nature of the variables. The results showed that figs osmotically dehydrated with sucrose concentrations of 40-50% and convective temperatures of 50-60 °C presented the highest retention of total phenols, reaching values of up to 1 652.96 mg tannins g^{-1} fresh weight. In addition, antioxidant capacity increased by 54% compared to fresh figs, whereas vitamin C underwent significant degradation at temperatures above 60 °C. These findings provide information on the Nezahualcóyotl fig variety and suggest that the combination of osmotic and convective dehydration is an effective strategy to conserve and enhance nutraceutical properties that can have an agro-industrial and commercial impact.

Keywords:

Ficus carica L., bioactive compounds, cv. Nezahualcóyotl, osmosis.

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Introduction

The fig (*Ficus carica* L.) is a fruit widely grown in the Mediterranean and the Middle East, with a high nutritional value due to its phytochemical composition rich in bioactive compounds that give the fig antioxidant properties and potential health benefits, justifying its classification as a nutraceutical food (Hosseini *et al*., 2024). Introduced in Mexico in 1560, it has gained popularity in the modern market thanks to its high content of sugars, minerals, and antioxidants (Fernández-Valdespino, 2016).

Currently, the world production of figs includes 54 countries, Turkey is the largest producer, whereas Morelos, Mexico, leads the national production (SIAP, 2023). Despite its nutraceutical potential, the fig is capable of developing in semi-desert, subtropical and moderately temperate environments, it is a species with potential and represents an attractive economic opportunity in the foreign market.

In the College of Postgraduates, various fruits have been collected, which are the product of the care of fig crops in family gardens, thus having a diversity of types of fig fruits, among them is the one we call 'Nezahualcóyotl', a very productive accession and whose characteristics have been related in several works.

For a long time, this species has not received the recognition it deserves in Mexico despite being common in family gardens. In particular, a variety native to the State of Mexico, called Nezahualcóyotl, has been introduced, and there is still little information about it (Fernández-Pavía *et al*., 2020). Nevertheless, growing international demand has boosted its production at the commercial level, promoting the adoption of better management practices to minimize losses (INTAGRI, 2020).

From a phytochemical point of view, the fig contains a wide variety of bioactive compounds, with phenolic acids standing out, which contribute to its antioxidant properties. Recent research has revealed that dark-skinned varieties contain higher concentrations of phenolic compounds, reinforcing their classification as a functional food (Hajam and Saleem, 2022).

On the other hand, osmotic dehydration combined with convective dehydration emerges as a promising technique to preserve the fig, improving the concentration of bioactive compounds (Vega-Gálvez *et al*., 2007). To analyze the Nezahualcóyotl variety, two phases were proposed; the first evaluated the nutraceutical values of fresh figs stored at low temperatures and the second analyzed figs dehydrated by osmo-convection, the latter being the main focus of the research.

Therefore, this research aimed to analyze the nutraceutical values of fig (*Ficus carica* L.) cv. Nezahualcóyotl dehydrated by osmo-convection. The hypothesis was that osmo-convective dehydration increases the concentration of nutraceutical compounds. Likewise, the average values of the first and second stages are contrasted.

Materials and methods

The research was conducted in the general laboratories of the Department of Phytotechnics of the Chapingo Autonomous University in the municipality of Texcoco, State of Mexico, geographically located between parallels 19° 30' 20" north longitude and 98° 52' 55" west longitude, with an altitude of 2 250 m. The study was carried out with a crop of fig (*Ficus carica* L.) variety Nezahualcóyotl under organic production under a 6 m high tunnel.

A total of 120 trees were kept in black plastic bags with a capacity of 50 kg with a substrate of a mixture of soil, gravel, and vermiculite. All environmental factors of production were controlled. Harvesting was done after 11 weeks from the first shoot. Then, the nutraceutical properties of the fruit were evaluated by randomly sampling 60 figs with similar characteristics of shape, size, color and ripeness.

For osmotic dehydration of the fruit, sucrose concentrations of 0, 40, 50 and 60% were proposed, and then for convective dehydration, temperatures of 50, 60 and 70 °C. These values were selected to optimize the retention of bioactive compounds in the dehydrated fig. A sucrose-free treatment was included as a reference, whereas the levels of 40-50% were chosen for their ability to preserve total phenols and prevent excessive degradation of vitamin C.

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A total of 12 treatments with three replications were obtained, totaling 36 fruits (Table 1). The variables analyzed were: antioxidant capacity using the ABTS method proposed by Re *et al*. (1999), total phenols by the Folin Ciocalteu method proposed by Waterman and Mole (1994), total sugars by the Anthrone method proposed by Whitam *et al*. (1972), reducing sugars by the Nelson-Somogy (1952) procedure, titratable acidity by the method 942.15 of AOAC (AOAC, 1996), and finally, the vitamin C content by the Folin method proposed by Jagota and Dani (1982).

Table 1. Formation of treatments.

Treatment	Convective	Osmosis	Num. of fruits
	Temperature (°C)	Sucrose (%)	
1	50	0	3
2	60	0	3
3	70	0	3
4	50	40	3
5	60	40	3
6	70	40	3
7	50	50	3
8	60	50	3
9	70	50	3
10	50	60	3
11	60	60	3
12	70	60	3
Total			36

In the dehydration of fruits, 36 figs stored in refrigeration at 4 °C were used. Dehydration was carried out in the dairy laboratory of the Veracruz Campus, College of Postgraduates, located in the municipality of Manlio Fabio Altamirano, Veracruz, Mexico. Per treatment, three fruits with similar physiological characteristics were used, which were washed with distilled water and had the peduncle removed. Subsequently, they were weighed and cut in half lengthwise without separating the two parts.

They were placed in 2 000 ml beakers containing the osmotic solution corresponding to their treatment, and they were placed on a stirring plate that was kept moving at 600 rpm for 12 h. After some time and before convective dehydration, the figs were removed from the stirring plate to be dried and evaluate their weight loss.

Convective dehydration used a Clint hot air dehydrator. To this end, the osmotically dehydrated figs (T4-T12 treatments) were placed in the previously disinfected trays and the desired temperature was then set 15 minutes before placing the trays inside the dehydrator to allow it to reach the ideal temperature.

Throughout the convective dehydration, measurements of the weight loss of the fruit were taken every 15 min during the first two hours, every 30 min from the third to the sixth hour and if necessary, every hour from the seventh hour in order to know the loss of moisture of the fruit. Once stabilized, the fig was removed from the dehydrator, weighed and vacuum-packed (Torrey CEEVM20003) for storage at 4 °C until analysis, applying the same physical and nutraceutical studies as for fresh figs.

Later, statistical analyses were performed for nutraceutical variables using descriptive statistics and Shapiro-Wilk normality tests ($\alpha = 0.05$). Those that complied normally were analyzed by analysis of variance (Anova) with ($\alpha = 0.05$). The model was tested for normality in the residuals and homogeneity of variances and independence.

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For those that complied with the model, post hoc tests were performed through Duncan's multiple range test (α= 0.05). Those that did not comply with the Shapiro-Wilk normality test (α= 0.05) or with the model were subjected to Kruskal-Wallis non-parametric tests. The Statistical Analysis System (SAS) Version 9 and the R software version 4.4.3 were used for the calculations (R Core Team, 2024).

Results and discussion

The results of the analysis of variance and Duncan's test of the variables of total phenols and reducing sugars are shown below (Table 2). The total phenols variable showed highly significant differences (p= 0.0023). Its highest value is reported in T8, whereas the lowest value is reported in T11. T8 and T12 have similar statistical behavior. Temperatures of 40 °C to 70 °C were used and the highest degradation of phenols was found at the mean temperature, between 50 to 60 °C.

Table 2. Analysis of nutraceutical variables, total phenols and reducing sugars.

Treatment	Total phenols (mg_{tan} g_{fw}^{-1})		Reducing sugars (mg_{glu} g_{fw}^{-1})	
T1	705.07 ±110.24	cd	233.14 ±31.77	a
T2	736.32 ±203.97	cd	322.22 ±7.63	ab
T3	894.46 ±81.92	bcd	383.7 ±31.17	a
T4	1 142.5 ±34.65	bc	342.59 ±17.79	ab
T5	1 040.23 ±57.59	bcd	402.03 ±33.43	a
T6	928.14 ±83.86	bcd	387.77 ±26.85	ab
T7	908.81 ±165.61	bcd	305.92 ±23.75	ab
T8	1 652.96 ±138.54	a	371.66 ±69.19	a
T9	876.79 ±138.54	bcd	393.51 ±72.7	a
T10	814.93 ±141.88	bcd	350 ±40.36	a
T11	661.72 ±129.03	d	310.37 ±50.01	ab
T12	1 286.03 ±181.52	ab	239.07 ±14.35	a
Pr > F	0.00238		0.0736	
R^2	0.644		0.467	
Significance	**		*10	

Mean ± standard error. Columns with the same letter are statistically equal to each other according to Duncan's test. g_{fw}^{-1}= grams of fresh weight of fruit; mg_{tan}= milligrams of tannic acid; mg_{glu}= milligrams of glucose; **= highly significant (p< 0.01); ^{*10}= significant at 10%.

Convective dehydration treatments with high temperatures (70 °C) behave in a similar way, finding greater variation in dehydrated fruits at 60 °C. The T1 and T2 controls report similarity in their data, whereas the T3 control had higher values of total phenols (Table 2).

Similar data in another fig variety (Bela Petrovka) developed by Slatnar *et al*. (2011) found that the application of osmotic dehydration in an oven used as a pretreatment for convective dehydration can improve the retention of bioactive compounds, such as total phenols, including epicatechin, catechin, chlorogenic acid, kaempferol-3-O-glucoside, luteolin-8-C-glucoside, and rutin.

In the present research, it was observed that temperatures of ≤ 50 °C and sucrose concentrations (≤ 40%) help to preserve the amount of phenols within the fruit, whereas temperatures above 80 ° C degrade these compounds. Regarding reducing sugars, there were no significant differences at 5% (p= 0.073), but there were at 10% (Table 2). Its highest value is reported in T5, whereas the lowest value is reported in T1. The treatments were observed to behave similarly.

The results of this research reported that very low temperatures, such as that of T1, or very high temperatures, such as that of T12, present the lowest results, thus the use of moderate temperatures and sucrose concentrations result in high values, such as T5, T6 and even T9. Yadav

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and Dubey (2019) performed osmo-convective dehydration on different fruits and vegetables. They mention that this type of dehydration at 50-60 °C and with 50% sucrose increases the concentration of soluble solids, such as fructose and glucose. Higher temperatures and sucrose concentrations can induce caramelization reactions, such as Maillard's, affecting the final quality of the product.

In the Kruskal-Wallis analysis of the antioxidant capacity of figs subjected to osmo-convective dehydration, there were no significant differences at 5% (p= 0.071); however, there are differences at 10%. The variable showed its highest value in T1 and its lowest value in T5, representing a 27% difference. All treatments behave similarly to each other (Table 3). The data analyzed within the experiment show their highest values for T1, so it is estimated that the use of low temperatures helps to better preserve the antioxidant compounds of the fruit.

Table 3. Statistical data of non-parametric variables of nutraceutical analysis of dehydrated figs.

Treat	Antioxidant capacity (mg_{atx} g_{fw}^{-1})	Total sugars (mg_{glu} g_{fw}^{-1})	Titratable acidity (%)	Vitamin C (mg_{asc} g_{fw}^{-1})
T1	1 631.08 ±31.23	3 072.1 ±391.75	4.46 ±0.35	175.3 ±41.11
T2	1 520.04 ±91.73	3 879.64 ±337.18	6.28 ±0.31	61.23 ±37.45
T3	1 436.15 ±123.11	4 597.46 ±185.11	6.92 ±1.65	23.04 ±3.78
T4	1 209.24 ±118.1	6 507.13 ±244.44	3.95 ±0.56	30.15 ±2.19
T5	1 182.45 ±323.62	6 943.92 ±123.89	8.94 ±0.52	31.61 ±2.22
T6	1 533.79 ±112.92	6 112.67 ±144.75	2.82 ±0.19	137.36 ±92.41
T7	1 193.1 ±21.92	5 013.93 ±636.69	4.35 ±0.39	103.95 ±60.37
T8	1 277.68 ±63.77	5 360.1 ±134.66	4.62 ±0.53	41.19 ±0.8
T9	1 311.2 ±29.15	5 548.17 ±430.85	4.4 ±0.48	60.97 ±15.3
T10	1 433.08 ±101.02	2 865.55 ±431.05	6.17 ±0.14	37.11 ±4.48
T11	1 622.94 ±79.68	4 225.01 ±123.72	4.27 ±0.27	37.77 ±4.4
T12	1 189.63 ±71.4	4 617.78 ±495.08	5.86 ±0.14	50.29 ±5.78
X^2	18.45	27.37	25.48	23.64
Pr >X^2	0.0716	0.004	0.0077	0.0143
Sign	^{*10}	***	***	*

Mean ± standard error. Treat= treatment; g_{fw}^{-1}= grams of fresh weight of fruit; mg_{atx}= milligrams of antioxidant; mg_{glu}= milligrams of glucose; mg_{asc}= milligrams of ascorbic acid; Sign= significance; ***= highly significant (p< 0.01); *= significant (p# 0.05); ^{*10}= significant at 10%.

A perfect example of what was mentioned by Andreou *et al*. (2021) was detected in T6 and T11, which have the next highest values recorded in the variable. Low concentrations of sucrose (40%) and high temperatures (70 °C) were also identified in T6, whereas T11 presents intermediate values of temperature (60 °C) and high values of sucrose (70%). These values show the effect of how the added osmotic solution helped to stabilize the loss of antioxidant agents in the fruit.

In their study, Landim *et al*. (2016) explained that high temperatures (# 80 °C) in contact with the sucrose added within the fruit can negatively affect the antioxidant capacity of dehydrated fruits. The present work indicates that, at temperatures of 70 °C, the antioxidant capacity decreases in some treatments in a uneven manner; for example, T1 (50 °C, without sucrose) obtained the highest antioxidant capacity (1 631.08 mgatx gfw^{-1}), whereas T5 (60 °C, 50% sucrose) obtained the lowest (1 182.45 mgatx gfw^{-1}).

This confirms that heat has a negative impact on antioxidant capacity, although the 80 °C barrier mentioned by Landim *et al*. was not exceeded. Andreou *et al*. (2021) noted that temperature can degrade antioxidants, but sucrose helps stabilize them without a linear effect. In this study, treatments with 40-50% sucrose (T6 and T11) showed intermediate values of antioxidant capacity, suggesting a protective effect, although not proportional.

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Highly significant differences (p= 0.004) were identified in total sugars. The highest values obtained belong to T5, whereas the lowest occurred in T10, with a 58% difference between them. T4, T5 and T6 have ranges that are similar to each other, with 40% sucrose, and T7, T8 and T9 have similar responses with 50% sugar concentration. Treatments with sucrose concentrations of 60%, as well as the controls, have ranges that differ from each other (Table 3).

In this experiment, similar total sugar amount behaviors are observed in figs that share moderate sucrose concentrations (40 and 50%), whereas higher concentrations and the controls report behaviors that differ from each other. Nonetheless, the amount of total sugars is directly proportional to the concentration of sucrose within the osmotic solution to which they were subjected. Some authors agree that osmo-convective dehydration significantly affects the sugar content of the final product.

Studies conducted by de Mello Jr. *et al*. (2019) in dehydrated green figs indicated that osmotic dehydration, as a pretreatment to convective dehydration, increases the concentration of solids by reducing water, although the time and temperature of convective drying can affect the loss of liquids. Regardless of the added sucrose, low temperatures (45-55 °C) favor the gain of sugars. Pandidurai and Vennila (2020) pointed out that high temperatures accelerate drying and increase soluble solids, improving product quality. Andreou *et al*. (2021) highlighted that optimizing sucrose according to the weight of the fig improves its sensory characteristics.

The titratable acidity (Table 3) of figs subjected to osmo-convective dehydration with different sucrose and temperature treatments showed highly significant differences (p= 0.0007). The results indicate that the highest value was in T5 and the lowest in T6, with a 68% difference. T2 and T10 have similar behaviors, as well as T2 and T3 controls, which had no added sugar in their dehydration process. On the other hand, T9 and T11, despite having sucrose concentrations and different temperatures, exhibit similar behaviors.

The results obtained in this experiment coincide with the literature consulted since the data show that T4 and T6, which present low concentrations of sucrose (40%) at different temperatures, are the lowest values reported. Those fruits subjected to higher sucrose concentrations better preserve the acids of the fruit, which could indicate that sucrose levels above 40%, without exceeding the saturation capacity of the osmotic solution, can help to preserve the beneficial acids of the fruit. Moustafa *et al*. (2016) found that titratable acidity in figs and plums can decrease due to the exchange of water and solutes during osmotic dehydration.

Nevertheless, the added sucrose can help to preserve acids if temperatures are not too high. In addition, high temperatures and long drying times favor the degradation of organic acids. Table 3 shows data on vitamin C, which showed significant differences (p= 0.014). The highest value reported is in T1, whereas the lowest value is reported in T3. T1 presents behaviors of ranges similar to T6 and T7, but different from the rest. T1, which presents the dehydrated control at 50 °C, shares the temperature range with T7, whereas T6 reports low sucrose concentrations (40%) at high temperatures (70 °C).

This made it possible to notice that vitamin C is a heat-sensitive compound, indicating that high temperatures during convective dehydration can reduce its content. However, Lopez *et al*. (2010) found that pretreatments with 40-50% osmotic solutions help to preserve vitamin C. In this study, T1, without sucrose and at low temperature, preserved ascorbic acid better, whereas in T6 and T7, moderate concentrations of sucrose also contributed to its stability during convective dehydration.

A nutraceutical comparison between nutraceutical averages of fresh fig stored at 4 °C and fig dehydrated by osmo-convection with different temperature and sucrose treatments is presented below in order to evaluate the essential bioactive compounds and compare the balance between the need to preserve the fig and maximize its nutritional benefits (Table 4).

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Table 4. Averages of nutraceutical values of fresh and dried figs.

Treat	Antioxidant capacity (mg_{atx} g_{fw}^{-1})	Total phenols (mg_{tan} g_{fw}^{-1})	Total sugars (mg_{glu} g_{fw}^{-1})	Reducing sugars (mg_{glu} g_{fw}^{-1})	Titratable acidity (%)	Vitamin C (mg_{asc} g_{fw}^{-1})
CS	792.08	690.24	165.56	33.65	2.2	89.82
T1	1 631.08	705.07	3 072.1	233.14	4.46	175.3
T2	1 520.04	736.32	3 879.64	322.22	6.28	61.23
T3	1 436.15	894.46	4 597.46	383.7	6.92	23.04
T4	1 209.24	1 142.5	657.13	342.59	3.95	30.15
T5	1 182.45	1 040.23	6 943.92	402.03	8.94	31.61
T6	1 533.79	928.14	6 112.67	387.77	2.82	137.36
T7	1 193.1	908.81	5 013.93	305.92	4.35	103.95
T8	1 277.68	1 652.96	5 360.1	371.66	4.62	41.19
T9	1 311.2	876.79	5 548.17	393.51	4.4	60.97
T10	1 433.08	814.93	2 865.55	350	6.17	37.11
T11	1 622.94	661.72	4 225	310.37	4.27	37.71
T12	1 189.63	1 286.03	4 617.78	239.07	5.86	50.29

Values represented in means. Treat= treatment; CS= cold storage; g_{fw}^{-1}= grams of fresh weight of fruit; mg_{atx}= milligrams of antioxidant; mg_{tan}= milligrams of tannic acid; mg_{glu}= milligrams of glucose; mg_{asc}= milligrams of ascorbic acid.

The antioxidant capacity of dried figs showed higher values compared to cold-stored figs. T11 showed a 54% higher value compared to fresh figs. Osmotic dehydration at the right temperatures promotes antioxidant retention (Fernandes *et al*., 2008).

In turn, total phenols were higher in dehydrated figs, especially in T8, which showed 58.24% more compared to cold-stored figs. The combination of osmotic and convective dehydration protected phenolic compounds better than in fresh fig stored in cold (Vega-Gálvez *et al*., 2007). Regarding sugars, dehydrated figs had higher concentrations of both total and reducing sugars.

In T5, the fruits showed a higher sugar content with a 97.6% difference compared to fresh figs. This results from the addition of sucrose in the osmotic process, which favors the concentration of sugars. Titratable acidity increased in dehydrated figs, especially in those treatments that use the highest temperatures, as the concentration of organic acids increases with a reduction in water content (Mandala *et al*., 2005).

Finally, vitamin C from fresh figs stored at low temperatures was better preserved than in dehydrated figs because ascorbic acid tends to degrade at high temperatures (Lee and Kader, 2000). Nonetheless, some osmotic treatments showed better retention of the compound.

Conclusions

The research fulfilled its objective. It was shown that this process allows to preserve and improve the concentration of bioactive compounds, such as total phenols and sugars, with a significant reduction in vitamin C due to its thermal susceptibility. These findings show that the combination of osmotic and convective dehydration, with adequate temperatures, optimizes the nutraceutical stability of the fruit, offering alternatives for its preservation and potential use in functional foods.

The detailed characterization of this variety, still little studied, contributes to the knowledge about its nutraceutical quality and opens new opportunities for its agro-industrial and commercial valorization. Future studies are proposed in the sensory evaluation and stability of the dehydrated product in prolonged storage.

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