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Evaluation of physicochemical changes of Nopal (*Opuntia ficus-indica*) at different steam cooking times

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Abstract. The objective was to evaluate and schematically characterize the physicochemical changes of nopal (*Opuntia ficus-indica*) due to steam cooking at different times. Cladodes were cut into pieces (25 x 30 x 15 mm) and mixed to obtain four samples of 1250 g each on a fresh basis and randomly assigned to each treatment: T1 or Control; T2, cooking for 4 min; T3, for 7 min; and T4, for 10 min. After cooking, samples were dehydrated, and then a proximal chemical analysis was performed. The data were analyzed through a fixed-effect model, and the differences between treatments were obtained by least-squares means. Correlation analysis of chemical components was conducted. T2, T3, and T4 showed higher values of protein (≥16.0/ 100 g DM), lipids (≥1.3 g/100 g DM), and nitrogen-free extract (≥20.2 g/100 g DM) than T1; whereas dietary fiber (≤ 33.6 g/100 g DM) and insoluble fiber (≤ 22.0 g/100 g DM) in these were lower than T1. Soluble fiber decreased in T3 and T4 (5.9 and 5.5 g/100 g DM, respectively) but increased in T2 (14.5 g/100 g DM). In this study, steam cooking at 100 °C modified the chemical composition of nopal (*O. ficus-indica*) suggesting that cooking for 4 min might help to preserve cladode components.

Keywords: *Nopal, chemical-proximal analysis, thermal effect.*

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Introduction

Opuntia ficus-indica, also known as nopal, belongs to the Cactaceae family, in its parts are cladodes and fruits (Sciacca *et al*., 2021). Nopal is found in arid and semi-arid areas of México (Contreras-Padilla, 2012; FAO, 2018); it is also cultivated in Central and South America, Africa, and the Mediterranean for human consumption or as forage for animals (El - Mostafa *et al.,* 2014). In Mexico, nopal has been consumed by humans since pre-Hispanic times (Ventura-Aguilar *et al*., 2017). Nowadays, nopal is a relevant component of the Mexicans' diet, and is cooked using different methods (roasted, boiled, fried, and steamed) (Hernández-Castillo *et al*., 2016). Also, it is commonly used to treat certain pathologies, such as diabetes, obesity, cardiovascular diseases, hyperlipidemia, and cancer (Santos *et al*., 2017; Aragona *et al*., 2017; Urquiza-Martínez *et al*., 2020). In the case of animals, it has been used as forage to feed cattle and goats, mostly in marginalized areas with prolonged drought periods (de Andrade *et al*., 2012; Gebremezkel *et al*., 2013; Urrutia-Morales *et al*., 2014).

In a study that evaluated the effect of fresh nopal intake on the regulation of insulin resistance in sows during the lactation phase, a reduction in the levels of blood glucose and an increase in feed consumption were observed, followed by a positive impact on the sow's reproductive performance (Ordaz-Ochoa *et al*., 2017). In ruminants, the consumption of nopal improves milk production and bacteriological quality, body weight, and meat quality (Urrutia *et al*., 2014; Pérez-Sánchez *et al*., 2015; Flores-Hernández *et al*., 2019). Despite these benefits, fresh nopal, once harvested, has a limited shelf life due to its high-water content. On the other hand, the low pH of fresh nopal has limited its usage in large quantities (Contreras-Padilla *et al*., 2012).

Given the limited storage period of fresh nopal, some alternatives, such as heat treatment, could allow for longer shelf life and improvement of palatability. However, heat processing could change food's physical and chemical composition (Yuan *et al*., 2009; Roncero-Ramos *et al*., 2017). De Santiago *et al*. (2018), informed that polyphenols (quercetin), total dietary fiber (TDF), soluble dietary fiber content (SDF), and proteins increased when nopal is subjected to cooking by roasting, frying, and microwaves. Meanwhile, Contreras-Padilla *et al*. (2012) observed a decrease in protein content when nopal was freeze-dried (-50 °C) compared to drying by heat (50 °C and 70 °C).

Another strategy used in food preservation is steaming, which could increase the nopal's shelf life. This method has higher efficiency in retaining or increasing plant nutrients (Ahmed *et al*., 2013; Cortez-García *et al*., 2015; Armesto *et al*., 2019). However, studies about the effect of the nopal cooking method on its physicochemical composition are limited, particularly using steam cooking. The objective of this study was to evaluate and model schematically the physicochemical changes of nopal cooked by steam for 4, 7, and 10 minutes.

Material and Methods

Opuntia ficus-indica cladodes were harvested in a placed called "La Posta" from the Facultad de Medicina Veterinaria y Zootecnia of the Universidad Michoacana de San Nicolás de Hidalgo, located at the municipality of Tarimbaro, Michoacán, Mexico at 19° 46′ 14.90″ N and 101° 08′ 49.06″ W and 1855 masl, with a mean temperature of 18.6 °C, and 773.9 0mm annual rainfall (CONABIO, 2008).

Eight cladodes of 90 days were randomly selected and harvested in June 2020. The cladodes were washed and disinfected with a 4 % sodium hypochlorite solution; later, the weight, length, and width of cladodes were recorded, and thorns were manually removed. Each cladode was cut into pieces of approximately 25mm x 30 mm; then, all the pieces were mixed. Eight samples of 1250 g were taken from the mixture and randomly assigned to each treatment: T1 or Control; T2, 100 °C steam cooking for 4 min; T3, 100 °C steam cooking for 7 min; and T4, 100 °C steam cooking for 10 min.

A regular steam cooker (Vasconia®, 5.0 L capacity) was used to cook the cladodes; each treatment was subdivided into five portions of 250 g, placed in the cooker, and subjected to heating for different times, as per the conditions of each treatment T2, T3, and T4. After that, the portions were immersed in cold water at 7 °C for 5 min and drained. Later, the portions were placed on aluminum trays and dehydrated in a drying oven at 50 °C until they lost humidity of approximately 94%. Subsequently, all the portions of each treatment were grounded and stored in a desiccator until their physicochemical analysis.

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Proximal analysis was carried out at the Food Research and Development Laboratory of the Universidad Michoacana de San Nicolás de Hidalgo. An 80 g subsample was taken from each portion. Moisture, ash (AS), protein crude (CP), and ether extract (EE, corresponding lipids) contents were determined by triplicate by methods number 934.06, 923.03, 960.52, and 960.39, respectively, of the AOAC (1990). Soluble dietary fiber (SF), insoluble dietary fiber (IF), and total dietary fiber (TDF) were determined according to Prosky *et al*. (1985) using a commercial kit (Sigma Aldrich®). Nitrogen free extract (NFE, corresponding to non-structural carbohydrates), was determined as follows, NFE: 100 - (% protein + % ether extract + % ash + % total dietary fiber).

The data collected was analyzed using a fixed-effect model (Herrera and Barreras, 2000):

$$\gamma_{ij}=\mu+\tau_i+\varepsilon_{ij}$$

Where:

γ_{ij} = Response variable: FM, DM, PC, AS, EE, NFE, TDF, SF, and IF

μ = General average

τ_i = Treatment with ith treatment = T1, T2, T3, T4

ε_{ij} = Random error associated with each observation (~ NID = 0, O'^2e)

The differences between groups were obtained using the methodology of least squares means (LSM) (Littell *et al*., 1998). To evaluate the association and changes in those associations, Pearson correlation analysis for the chemical components was used (SAS, 2010).

Results and Discussion

Table 1 shows the physicochemical changes of the control and cooked samples. The moisture range was from 3.9 to 6.5 g, and the dry matter ranged from 93.5 to 96.1 g. The values of moisture and dry matter contents were similar to those reported by Castillo *et al*. (2013), who analyzed nopal meal using a forced draft oven at 72 °C for 24h, obtaining values of 5.25g moisture and 94.75 g dry matter, respectively.

Heat treatment increased protein values (Table 1). The PC values in T2 (17.6 g/100 g), T3 (17.4 g/100) g and T4 16.3 g/100 g) were comparatively higher than in T1. T2, and T3 values in turn were significantly different from T4. On the other hand, PC content was higher than the protein values reported by Hernández-Urbiola *et al*. (2011) who worked with 90 days old of cladodes from *O. ficus-indica* cultivar from Silao, Guanajuato, Mexico (7.8 g/100g DM); lower values were reported by Perez *et al*. (2015b) (5.91 g/100 g DM in drought season and 5.61 g/100 g DM during rainy season) from cultivars from Morelia, Michoacán, México. Ramirez-Moreno *et al*. (2013) also obtained lower values in two commercial cultivars in Hidalgo State (12.9 g/100 g DM and 13.8 g/100 g DM), in comparison with our results. In our study, the CP was not affected by the cooking process; all the cooking treatments had higher CP content than T1, and similar results were obtained by Ramírez-Moreno *et al*. (2013) when boiled cladodes for 20 min. The cooking temperature used in our study could have contributed to breaking some of the hydrophobic attractions, hydrogen bonds, or electrostatic bonds. These forces of attraction let the proteins bind with other chemical compounds such as carbohydrates, lipids, fiber compounds, and others. Also, these attraction forces maintain the stable structure of a

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protein. Then, when heat is applied, it breaks these bonds, and protein is released and let to quantify in major quantity proteins. Generally, proteins present in foods denature in a temperature range of 40 to 80 °C, at atmospheric pressure; however, water content greatly facilitates the thermal denaturation of proteins (Damodaran, 2007), but other elements can also affect the thermostability of proteins in aqueous solutions such as sugars and salt. Kulmyrzaev *et al*. (2000) reported that carbohydrates such as sucrose, lactose, glucose, and glycerol stabilize proteins against thermal denaturalization. Damodaran (2007) also mentioned that pressure processing, unlike thermal processing, does not harm essential amino acids, natural color, and flavor; therefore, processing foods with high hydrostatic pressure may prove advantageous for certain foods. Few studies have evaluated the effect of cooking on the nutritional content of nopal, however, there are some studies evaluating different cooking methods on mushrooms, which were found to have an increase of CP after microwaving and frying, possibly associated with enzyme hydrolysis of insoluble protein (Reid *et al*., 2016).

Table 1. Values of the mean and standard error of the physical-chemical components of nopal (*O. ficus-indica*) in each treatment.

Variable	T1	T2	T3	T4
Moisture (g)	5.7 ± 0.16^{a}	6.0 ± 0.16^{a}	3.9 ± 0.16^{b}	6.5 ± 0.16^{a}
Dry Matter (g)	94.2 ± 0.16^{b}	94.0 ± 0.16^{b}	96.1 ± 0.16^{a}	93.5 ± 0.16^{b}
CP (g/100g DM)	14.3 ± 0.10^{c}	17.6± 0.10^{a}	17.4 ± 0.10^{a}	16.3 ± 0.10^{b}
EE (g/100g DM)	2.3 ± 0.13^{a}	1.6 ± 0.13^{b}	1.4 ± 0.13^{b}	1.3 ± 0.13^{b}
AS (g/100g DM)	27.8 ± 0.02^{a}	20.9 ± 0.02^{c}	21.2 ± 0.02^{b}	20.7 ± 0.02^{d}
NFE (g/100g DM)	13.16 ± 0.88^{c}	21.9 ± 0.88^{b}	29.5 ± 0.88^{ab}	30.9 ± 0.88^{a}
TDF (g/100g DM)	39.0 ± 0.90^{a}	33.6 ± 0.90^{b}	27.9 ± 0.90^{c}	25.6 ± 0.90^{c}
SF (g/100g DM)	7.5 ± 0.50^{b}	14.5 ± 0.50^{a}	5.9 ± 0.50^{b}	5.5 ± 0.50^{b}
IF (g/100g DM)	31.5 ± 0.73^{a}	19.1 ± 0.73^{b}	22.0 ± 0.73^{b}	20.1 ± 0.73^{b}
IF/SF ratio	4.2	1.32	3.73	3.65

Values are expressed as mean ± SEM. Different letters in the same row indicate significant differences ($p < 0.001$).

Lower EE content was observed on cooked cactus as compared to raw cactus, although there were no significant differences among cooking times. T3 and T4 had the lowest values, 1.4 and 1.3 g/100 g, respectively. Kulmyrzaev *et al*. (2000) pointed out that lipids are degraded at high temperatures. AS content observed in our study was higher than the values reported by González-Becerril *et al*. (2016) and similar to those found by Perez *et al*. (2015b), such differences can be influenced by the genetics of the plant, type, and fertility of the soil, and the environment in which the plant grows (BeMiller, 2017). Kimura and Itokawa (1990) suggested that the mineral loss can be the result of lixiviation from plants in which the higher losses were related to boiling methods.

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The TDF in T1 was 39.0 g/100 g DM. Ayadi *et al*. (2009) reported higher values of TDF (51 g/100 g DM and 41 g/100 g DM, for spiny and spineless cladodes, respectively) than those observed in our study. Similar results were obtained by Bensadón *et al*. (2010) and Saenz *et al.* (2010); Khanum *et al*. (2000) and Rojas-Molina *et al*. (2015) pointed out that TDF variations could depend on several edaphic factors such as plant´s stage of maturity, environmental and seasonal differences. In our study, TDF decreased by 13.85% in T2, 28.46% in T3, and 34.36% in T4 as compared to T1. In a study conducted by Cárdenas *et al*. (1998), when they compared raw nopal and cooked nopal, they found a slight reduction in the TDF content due to cooking; however, the values obtained by these authors are higher than the values observed in this work (42.8 g/100 g DM and 41.3 g/100 g DM for raw nopal and cooked nopal, respectively). Chang and Morris (1990) observed a significant decrease in TDF content on apple and oat bran fiber when processed by autoclaving at 121 °C for 15 min in comparison to 100 °C for 30 min, but they did not observe a decrease in corn fiber and soy fiber. The authors related to such differences in the insoluble/soluble ratios and observed that vegetables with low content of IF (< 40 g/100 g DM) had a higher decrease in IF content. In our study, SF did not show any statistical differences in T1, T3, and T4; a dramatic increase was observed in T2. A possible explanation is that when applying the temperature for four minutes, some components of the soluble fiber could be released from the interior of the plant cell structure and a higher SF content could be quantified. And, by intensifying the cooking for 7 and 10 minutes, the SF components could interact with each other or with other chemical compounds present in the nopal, through hydrogen bonds, forming more insoluble compounds, and consequently decreasing the value of SF. More studies are recommended to know the type of structural and chemical changes that have occurred because of the thermal treatment of the nopal. In T2, T3, and T4 there were no observed significant differences in IF, such values were lower than in T1. Wang *et al*. (2010) suggested that cooking may modify the structure of both cell wall and storage polysaccharides, thus reducing the solubility of dietary fiber and affecting the glycemic response, which agrees with the findings of Cárdenas-Medellín *et al*. (1998) when they measured blood glucose on rats fed with raw nopal and cooked nopal and observed lower values with raw nopal. Kalala *et al*. (2017), conducted a study aimed to determine the TDF profile of 29 vegetables and the impact of steaming on these profiles; they found that the TDF content varies considerably among the investigated vegetables, but the influence of steaming is limited to a shift from IF in favor to SF for 18 of the 29 tested vegetables. In our research, is important to mention that the ratio IF/SF decreased in all treatments submitted to cooking as compared to raw nopal, with values for T1, T2, T3, and T4, of 4.2, 1.32, 3.73, and 3.65, respectively. This means that when applying the heat treatment there was a redistribution in the composition of the SF in relation to the IF, which is important since the value of SF improved concerning the value of IF in T2. This is important since SF helps to reduce the values of triglycerides, cholesterol, glucose, and cardiovascular diseases in humans.

Table 2 shows a strong negative relationship between NFE and TDF, IF and SF, and a positive correlation between TDF, SF, and IF. However, a study that may explain those correlations was not found, first, because there is not a general agreement on what is considered a fiber since the definitions are established using physiological and chemical criteria (Lunn and Buttriss, 2007). However, considering that most of the plant cell wall materials are primarily cellulose, hemicellulose, lignin, and other non-starch polysaccharides, the common feature is that they are non-digestible, so those compounds are commonly considered dietary fiber (BeMiller and Huber, 2008).

Table 2. Matrix of Pearson correlations between chemical components of nopal in T1.

	CP	EE	AS	NFE	TDF	SF	IF
CP	1						
EE	0.02	1					
AS	0.47	-0.49	1				
NFE	-0.44	0.11	0.16	1			
TDF	0.12	-0.24	-0.32	-0.93**	1		
SF	0.27	-0.04	-0.04	-0.82*	0.80*	1	
IF	0.02	-0.31	-0.41	-0.85*	0.95**	0.58	1

** Highly significant (P <0.001); * Significant (P <0.05)

In the case of NFE, this is a complex fraction that includes soluble sugars, starchy polysaccharides, polyphenols, and other compounds, where the main limitation is due to its form of being calculated, it makes NFE highly dependent on other compounds of the proximate analysis, and perhaps, the negative correlation between NFE and the fiber components is the result of such situation.

Khanum *et al*. (2000) evaluated the effect of two types of cooking (open pan and pressure-cooking) on IS and SF in the vegetables most consumed in India and found alterations in the content of SF and IF in opposite directions, in all cases was observed a significant increase of SF with a concomitant decrease in IF content. That was not observed in our treatments; since comparing the correlations with the data from Table 1, it can be observed a general decrease in both cases either IF or SF, which might explain why there is not a significant correlation between SF and the other types of fiber.

Table 3. Matrix of Pearson correlations between chemical components of nopal in T2.

	CP	EE	AS	NFE	TDF	SF	IF
CP	1						
EE	-0.09	1					
AS	-0.25	-0.10	1				
NFE	-0.09	-0.09	0.20	1			
TDF	-0.16	-0.24	-0.05	-0.90*	1		
SF	-0.66	-0.25	-0.20	-0.49	0.72	1	
IF	0.19	-0.17	0.06	-0.90*	0.90*	0.35	1

** Highly significant (P <0.001); * Significant (P<0.05).

Table 4. Matrix of Pearson correlations between chemical components of nopal (*O. ficus-indica*) in T3.

	CP	EE	AS	NFE	TDF	SF	IF
CP	1						
EE	0.27	1					
AS	0.07	-0.06	1				
NFE	0.69	-0.15	-0.01	1			
TDF	-0.75	0.02	-0.01	-0.98**	1		
SF	-0.67	0.20	-0.28	-0.75	0.76	1	
IF	-0.60	-0.12	0.19	-0.87*	0.88*	0.36	1

** Highly significant (P <0.001); * Significant (P<0.05)

Table 5. Matrix of Pearson correlations between chemical components of nopal (*O. ficus-indica*) in T4.

	CP	EE	AS	NFE	TDF	SF	IF
CP	1						
EE	-0.60	1					
AS	-0.16	0.48	1				
NFE	-0.14	0.16	0.17	1			
TDF	0.10	-0.28	-0.42	-0.95**	1		
SF	-0.63	0.69	-0.04	0.03	-0.05	1	
IF	0.42	-0.59	-0.33	-0.80*	0.85*	-0.57	1

** Highly significant (P <0.001); * Significant (P<0.05)

Chang and Morris (1990) studied the effect of heat (100 °C and 121 °C) on TDF, IF, and SF in apple fiber, corn fiber, oat fiber, and soy fiber; they associated the decrease in TDF with the significant decrease in the IF. The results of this study coincide with those obtained in our study. In our investigation, the IF value decreased to a greater extent in all treatments, and to a lesser extent in those of SF, except for T2 where an increase in SF was observed.

Conclusions

Our results show that steam cooking increases the protein content of nopal (*O. ficus-indica*). The dietary fiber value and later correlation suggest that the insoluble fiber fraction was the most affected by the steam-cooking process. These results may suggest that the nopal cooked for up to 4 minutes

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improves its nutritive and functional properties because it increases the protein and SF values, and the ratio of IF/SF was favorably modified.

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