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Valorization of prickly pear pericarp (*Opuntia albicarpa* Scheinvar) through aerobic fermentation

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ABSTRACT

Objective: To determine the change in the composition of 'Blanca cristalina' cactus prickly pear's pericarp (*Opuntia albicarpa* Scheinvar) subjected to aerobic fermentation with *Saccharomyces cerevisiae*.

Design/methodology/approach: The pH, total soluble solids, moisture, ashes, total carbohydrates and crude protein were determined on cactus prickly pear's pericarp before and after being fermented by *S. cerevisiae*. Data were compared through a paired t test.

Results: Significant difference ($p<0.05$) was found in the total soluble solids, carbohydrate content and crude protein content after the fermentation process. Total soluble solids and carbohydrates content both decreased from 12.67±0.58 °Brix to 6.33±1.53 °Brix and from 7.43±1.4% to 0.83±0.06%, respectively. Meanwhile, crude protein content increased from 0.47±0.42% to 8.87±1.02%.

Limitations on study/implications: Non-certified commercial yeast was used in this study, so the product obtained of process must be used for animal feeding, and for human food the process must be modified.

Findings/conclusions: The fermentation process described in this work is an alternative, to increase the protein content of cactus prickly pear byproducts, such as the fruit pericarp, making it possible to be used as an animal feeding with high nutritional quality.

Keywords: byproducts, carbohydrates, protein.

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INTRODUCTION

The cactus prickly pear (*Opuntia* spp.) is distributed across various arid and semi-arid regions of Mexico (Torres-Ponce *et al.*, 2015). In 2022, approximately 69,600 hectares were reported as dedicated to the cultivation of *Opuntia* spp. for forage, vegetable cactus pads (nopalitos), and fruit (tunas) (SIAP, 2024). Prickly pear production accounted for nearly 65% of this area (45,000 hectares), positioning Mexico as the world's leading producer of cactus prickly pears (SIAP, 2024).

The largest percentage of land dedicated to prickly pear production is concentrated in the states of México (35%), Zacatecas (26%), and San Luis Potosí, with 2,900 hectares (5%). In terms of production volume, the State of México (35%), Puebla (27%), and Zacatecas (22%) contributed 84% (372,925.09 t), generating an economic revenue of 1.672 billion pesos (SIAP, 2024).

In the Potosino-Zacatecano high plateau region, cactus prickly pear production is a highly significant economic activity. However, this process can generate residues, by-products, and waste, such as pericarp and glochids (Marí-Campos *et al.*, 2024). The pericarp, which constitutes the non-edible part of the fruit, represents approximately 45% to 50% of the total weight and is generally discarded, creating an environmental problem. Therefore, it is essential to explore alternatives for its utilization (El-Beltagi *et al.*, 2023).

Fermentation may represent an alternative for the valorization of cactus prickly pear residues (Derabli *et al.*, 2022) to obtain bioactive compounds (Coronado-Contreras *et al.*, 2023), owing to their high content of fermentable carbohydrates (Carpena, 2023). Solid or semi-solid fermentation of biomass has been used to increase protein content in grasses (Hu *et al.*, 2013) and in cactus pads intended for livestock feed (Flores-Hernández *et al.*, 2019), making it a potential alternative protein source with lower resource consumption (Cortés-Chamorro *et al.*, 2024).

However, the increase in protein content largely depends on the microorganisms used. For instance, fermented cactus pads with *Aspergillus niger* Tiegh achieved a crude protein (CP) concentration of 12% (Oliveira *et al.*, 2001), while fermentation with *Saccharomyces cerevisiae* Meyen ex E.C. Hansen resulted in a 10% increase (Araújo *et al.*, 2008) and 26% CP (Araújo *et al.*, 2005). In this context, the present study aimed to determine the changes in the nutritional composition of 'Blanca Cristalina' cactus prickly pear (*O. albicarpa* Scheinvar) pericarp subjected to aerobic fermentation with *Saccharomyces cerevisiae*.

MATERIALS AND METHODS

Study Sites

The cactus prickly pear fruit were collected from communal land in the locality of La Palma Pegada, Salinas de Hidalgo, San Luis Potosí, located at 22.717147° N, −101.802674° W. The predominant climate is dry temperate, with an average temperature of 18.7 °C and precipitation of 319 mm (INEGI, 2024).

Plant Material

Pericarp of 'Blanca Cristalina' cactus prickly pear (*O. albicarpa* Scheinvar) was used, collected at the ripe stage. The fruit were manually harvested and transported to Laboratory 2 of the Coordinación Académica Región Altiplano Oeste of the Universidad Autónoma de San Luis Potosí.

Preparation and Fermentation of Prickly Pear Pericarp

The fruit were divided into three groups, and the pericarp was manually removed and crushed to obtain a liquid sample. The crushed pericarp was fermented using commercial yeast (*S. cerevisiae* lyophilized, Mauripan® at 1%) (Day *et al.*, 2018). The yeast was activated

following the methodology of Catacora (2022). The fermentation process was carried out for six hours at 25 °C with an agitation speed of 200 rpm, with resting intervals of 30 minutes.

Response Variables

pH and Total Soluble Solids

The pH was measured using a digital potentiometer (Oakton®), and the total soluble solids (TSS) content was determined using a digital refractometer (Hanna® HI96801).

Determination of moisture

The moisture content was determined according to the method proposed by the AOAC (Association of Analytical Communities) 1990. A 5 mL sample of the crushed material was placed in porcelain capsules at constant weight and dried at 90 °C for 3 hours in a Binder® GmbH oven. The process was performed in triplicate, and the moisture content was calculated using the following expression (equation 1):

$$M(\%) = 100 * (W_w - W_D) * W_D^{-1} \quad (1)$$

where: W_w is the weight of the wet sample (g) plus the weight of the empty (dry) capsule (g); W_D is the weight of the tray (g) plus the weight of the dry sample (g).

Determination of Ashes

The ash percentage was determined according to the method proposed by AOAC 1990. For this, 5 mL of the sample were placed in crucibles at constant weight and incinerated at 500 °C for 50 minutes, then placed in a muffle furnace at 550 °C for 2 hours, and finally placed in a drying oven at 90 °C for 1 hour. The weight of the samples was measured on a Nimbus® ADAM analytical balance.

Determination of Carbohydrates

The carbohydrate content was determined based on the standard (NMX-F-312, 1978), which involves the direct determination of reducing and total carbohydrates in food. In a 50 mL Erlenmeyer flask, 1 mL of each of the solutions (A and B) of Fehling's reagent (measured with a volumetric pipette) was added, along with 5 mL of distilled water and one drop of methylene blue indicator. The burette was filled with a 1.0% glucose standard solution. The Fehling solution mixture was heated to boiling on a magnetic stirrer plate, and then the titration was performed.

The amount of carbohydrates was obtained using the following equation:

$$\text{Fehling's reagent titre} = (\text{mL of 1\% glucose}) \times (\text{Concentration of the same})$$

Determination of Crude Protein

The percentage of crude protein was determined according to the method proposed by AOAC 1990. For this, 1 g of sample was weighed and placed in a flask. Then, 2 g of copper

sulfate, 10 g of anhydrous sodium sulfate, 25 mL of sulfuric acid, and glass beads were added. The flask was then placed in the digester and heated carefully at low temperature until all the material was carbonized. The temperature was gradually increased until the solution became completely clear and maintained for 30 minutes.

The sample was cooled, and 400 to 450 mL of water was added to completely dissolve the sample. Then, 3 zinc granules and 50 mL of 1:1 sodium hydroxide solution were added. The flask was connected to a distillation system, to which a 500 mL Erlenmeyer flask containing 50 mL of boric acid and a few drops of the Shiro Tashiro reagent as an indicator was previously placed at the exit of the condenser. Once the sample was distilled, the content of the receiving flask was titrated with 0.1 N hydrochloric acid. The nitrogen present in the sample, expressed as a percentage (%), was calculated using the following equation:

$$N(\%) = V * N * 0.014 * 100 * m^{-1} \quad (2)$$

Where: N is the percentage (%) of nitrogen; V is the volume of hydrochloric acid used in the titration, in cm^3; N is the normality of hydrochloric acid; m is the mass of the sample in g; 0.014 is the milliequivalent of nitrogen.

The percentage (%) of protein was obtained by multiplying the percentage of nitrogen by the corresponding factor.

Data Analysis

The pH, total soluble solids, moisture, ash, carbohydrate, and protein variables of the tuna pericarps, before and after fermentation, were compared using a paired t-test (α=0.05). The analysis was performed using the R programming language® 4.2.2 under the RStudio® interface RStudio 2023.09.1+494.

RESULTS AND DISCUSSION

The non-fermented cactus prickly pear pericarps and the fermented cactus prickly pear pericarps showed no significant difference in pH (p=0.065), ash (p=0.888), and moisture (p=0.27) (Table 1). In contrast, there were significant differences in the crude protein content (p=0.002), with the fermented tuna pericarps having a value 18 times higher than that of the non-fermented tuna pericarps. This increase in protein was accompanied by a 50% reduction in total soluble solids (p=0.034) and an 89% reduction in carbohydrates (p=0.015).

Table 1. Composition of prickly pear pericarp before and after aerobic fermentation.

	pH	TSS (°Brix)	Ash (%)	Protein (%)	Carbohydrates (%)	Humidity (%)
Before	5.68±0.29[a]	12.67±0.58[a]	2.44±0.07[a]	0.47±0.42[a]	7.43±1.40[a]	92.54±0.59[a]
After	5.05±0.04[a]	6.33±1.53[b]	2.38±0.69[a]	8.87±1.02[b]	0.83±0.06[b]	94.68±0.11[a]

The protein content (8.87%) achieved after 6 hours of fermentation with *S. cerevisiae* was similar to that obtained in the fermentation of prickly pear pericarp with *Aspergillus niger* (9.1%) and *Ryzopus* sp. (8.6%), although with these two latter microorganisms, it was after a fermentation period of 192 hours (Carvalho-Do Santos *et al.*, 2015). Other studies have achieved protein levels of up to 33% in the fermentation of nopal with the addition of external nitrogen (Flores-Hernández, 2019). This study did not include an external source of nitrogen, which could explain the lower protein percentage; in this regard, Hu *et al.* (2012) suggest adding 2.5% external nitrogen to improve protein increase.

The total carbohydrate content decreased, which is consistent with other studies, due to the action of microorganisms on cellulose and hemicellulose (Carvalho-Do Santos *et al.*, 2015). Although there is limited information on the fermentation of prickly pear pericarp, in the case of nopal fermentation, a metabolizable energy of 2.3 to 2.67 Mcal*kg^{-1} has been obtained, and non-fibrous carbohydrates decreased from 48.9% to 26.4% (Flores-Hernández, 2019).

The ash content did not show any difference after the fermentation process, which is consistent with the findings of Flores-Hernández *et al.* (2019) during nopal fermentation. Due to the fermentation time, there were also no changes in pH or moisture content.

The application of a fermentation process to the tuna pericarp allows for the utilization of this waste to obtain a product that can be reintroduced into animal or human feed due to its high protein content. It could also become an alternative protein source with lower natural resource consumption, making it necessary to conduct studies on protein quality. Implementing this process at low technological levels could help reduce the environmental impact of tuna by-products.

CONCLUSIONS

The fermentation of 'Blanca Cristalina' cactus prickly pear pericarp (*Opuntia albicarpa* Scheinvar) with *Saccharomyces cerevisiae* for 6 hours at 25 °C with agitation at 200 rpm increases the crude protein content to 8.87%, reduces carbohydrate content to 0.83%, and total soluble solids to 6.33 °Brix, without affecting pH or ash content. This microorganism achieved the protein increase in very short times compared to the time required by other microorganisms to achieve similar results, and without the use of external sources. This makes this technology an alternative for utilizing tuna waste, either for animal or human feed, with the potential for improved yields.

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