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# Freeze-dried pulp and peel from pitahaya (*Selenicereus undatus*): physicochemical properties and potential source of fructooligosaccharides

## Pulpa y cáscara liofilizada de pitahaya (*Selenicereus undatus*): propiedades fisicoquímicas y fuente potencial de fructooligosacáridos

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**Abstract** The pitahaya *Selenicereus undatus* is a fruit widely consumed in the Yucatan Peninsula in Mexico, and its cultivation is promising due to its adaptability to adverse climatic conditions, its nutritional quality, and its bioactive compounds. The objective of this work was to determine the physical parameters of the fresh fruit (weights and diameters) and chemical parameters of the pulp (stored at -18 ºC) of pitahaya grown in two locations in the state of Yucatán, as well as to estimate the yield of fructooligosaccharides (FOS) present in freeze-dried pulp and peel flour, using the solid/liquid extraction method. Six physicochemical and six proximal descriptors (in freeze-dried pulp and peel), which were statistically compared using the t-student test, were quantified. The fruits had an average weight of 534.81 and 520.36 g for the pitahaya grown in Kinchil and Yobain, respectively. The peel weight of the fruit from Kinchil was significantly ($p < 0.05$) higher. The pulp represented between 67 – 72 % of the weight of the fruits. The physicochemical analysis of the fruit pulp indicated that the average total soluble solids/titratable acidity (TSS/TA) ratio was 20.5, and the pH was 3.29. The proximal analysis expressed on a dry basis (% d.b.) showed average values for the pulp of 4.80 % ash, 0.47 % crude fat, 10.42 % crude fiber, and 6.92 % protein; while for the peel 14.20 % ash, 1.39 % crude fat, 22.22 % crude fiber, and 5.31 % protein. The values of crude fiber and total carbohydrates in the peel, as well as the crude fat content in the pulp, were different ($p < 0.05$) between the locations. The estimated extraction yield of FOS with water was 86.49 g/kg for the freeze-dried pulp and 17.64 g/kg for the freeze-dried peel flour. This fruit exhibited good nutritional properties, and the freeze-dried flour from its peel could be used as supplement rich in dietary fiber and, together with the freeze-dried pulp, could be added to products such as juices, yogurt, and jams, among others, with a potential prebiotic effect due to its fructooligosaccharides content.

**Keywords::** Aqueous extraction, chemical composition, dragon fruit, pitahaya, functional food, oligosaccharides, physical characteristics.

**Resumen** La pitahaya *Selenicereus undatus* es una fruta muy consumida en la península de Yucatán, México, y su cultivo es promisorio debido a su adaptabilidad a condiciones climáticas adversas, su calidad nutricional y sus compuestos bioactivos. El objetivo de este trabajo consistió en determinar parámetros físicos del fruto fresco (pesos y diámetros) y químicos de la pulpa (almacenada a -18 ºC) de pitahaya cultivada en dos localidades del estado de Yucatán, así como estimar el rendimiento de fructooligosacáridos (FOS) presentes en pulpa y la harina de la cáscara liofilizadas utilizando el método de extracción sólido/líquido. Se cuantificaron seis descriptores fisicoquímicos y seis proximales que fueron comparados estadísticamente mediante la prueba t-student. Los frutos frescos tuvieron un peso promedio de 534,81 y 520,36 g para la pitahaya cultivada en la localidad de Kinchil y Yobaín, respectivamente. Siendo significativamente ($p < 0,05$) mayor el peso de la cáscara del fruto proveniente de Kinchil. La pulpa representó entre el 67 - 72 % del peso de los frutos. El análisis fisicoquímico de la pulpa de la fruta indicó que la relación sólidos solubles totales/acidez titulable (SST/AT) promedio fue de 20,5 y el pH 3,29. El análisis proximal expresado en base seca (% b. s.), arrojó valores promedio para la pulpa de 4,80 % cenizas, 0,47 % grasa cruda, 10,42 % fibra cruda y 6,92 % proteína; mientras que para la cáscara 14,20 % cenizas, 1,39 % de grasa cruda, 22,22 % fibra cruda y 5,31 % proteína. Los valores de fibra cruda y carbohidratos totales en la cáscara, así como el contenido de grasas cruda en la pulpa fueron diferentes ($p < 0,05$) entre las localidades. El rendimiento estimado de extracción de FOS con agua fue 86,49 g/kg para la pulpa liofilizada y 17,64 g/kg para la harina de la cáscara liofilizada. Este fruto exhibió buenas propiedades nutricionales, pudiendo emplearse harina liofilizada de su cáscara como suplemento rico en fibra dietética y en adición con la pulpa liofilizada podrían ser añadidos en productos como jugos, yogurt, y mermeladas etc., con potencial efecto prebiótico por su contenido de fructooligosacáridos.

**Palabras clave:** Alimentos funcionales, características físicas, composición química, extracción acuosa, fruto del dragón, oligosacáridos.

## Introduction

The pitahaya *Selenicereus undatus* (Haw.) D.R Hunt (Korotkova *et al.*, 2017) is the fruit of a cactus native to America that bears fruit between June and October. It is considered an exotic fruit with pink peel and white pulp, a characteristic sweet flavor, and high water content (Castillo *et al.*, 2016). It is currently in great demand in the international market, and in 2019, 95 % of the world's production was focused on this variety (Mordor Intelligence, 2022). Its popularity derives from the physicochemical and nutritional characteristics and the bioactive compounds present in both the pulp and the peel, which makes it a functional food (Verona-Ruiz *et al.*, 2020). Although pitahaya has been cultivated in Mexico in home gardens since pre-Hispanic times, its commercial cultivation began in 1996, yet the boom initiated at the beginning of the 21$^{st}$ century (Castillo *et al.*, 2016).

In the Yucatan Peninsula, pitahaya is also grown in small plots and a few larger-scale plantations, being one of the main producers of the genus *Selenicereus.* The National Service for Agrifood Health, Safety and Quality (SENASICA, 2023) reported that, in the season from June to November 2023, pitahaya production in Yucatan was estimated at 156.99 ha and 1803.97 tons registered for export to the United States. However, it is very important to promote the preservation of home gardens, which are now in decline (Castro *et al.*, 2018), not only to preserve the pitahayas but also the diversity they harbor (Soza & Pérez-Orozco, 2022).

Regarding its composition, pitahaya is a low-calorie fruit since 89 % of fresh pulp is water. The inedible part, the peel, represents 33 % of the total weight of the fruit and is considered an unusable waste; however, several studies indicate that it can be a good source of pigments and antioxidants, such as betalains and polyphenols, among others, which can be used as functional ingredients (Fathordoobady *et al.*, 2021). Using residues derived from industrial processes, mainly those from fruits and vegetables given their content of bioactive compounds, it is becoming increasingly attractive for obtaining by-products with added value (Jimenez-Garcia *et al.*, 2022).

Both pitahaya pulp and pitahaya peel contain fructooligosaccharides (FOS), carbohydrates that are the energy reserve of the plant and have a chemical structure composed of one glucose bonded to multiple fructose residues (from 2 to 10 units) with glycosidic bonds of the $\beta$-(2→1) type (Rahim *et al.*, 2021).

Human digestive enzymes are specific for breaking a-glycosides bonds and thus cannot break the $\beta$-bonds of the anomeric carbon 2 of fructooligosaccharides, which classifies them as non-digestible; they reach the large intestine intact, where they are susceptible to fermentation by the intestinal microbiota. Thus, pitahaya fructooligosaccharides are considered a source of natural prebiotics (Wichienchot *et al.*, 2010). The analysis of the physicochemical composition of the pitahaya peel grown in the state could encourage its use, contributing to the reduction of waste generated in the food industry. The extraction of FOS using environmentally friendly techniques is promising for adding value to the fruit.

The objective of this research was to determine the physicochemical characteristics of the whole fruit and its pulp, and the proximal characteristics of the freeze-dried pulp and peel of pitahaya grown in two locations in Yucatan, Mexico, in addition to the fruit's FOS extraction yield using water as a solvent.

## Methodology

Pitahayas (*S. undatus*) cultivated in two localities of Yucatan were used. The first batch of pitahayas was grown in Kinchil, Yucatan, located at the coordinates 20º54'59''N 89º 56'51''W, with a temperature range between 26.7 - 31 ºC, wind from the N at 5 km/h, an humidity range of 22.54 - 45 %, and an average altitude of 6 meters above sea level (INEGI, 2017). The second batch was grown in the municipality of Yobain, with the following coordinates 21° 14' 00'' N 89° 06' 59'' W, a temperature range between 24 - 26 ºC, wind from the north at 6 km/h, an humidity range between 49 – 60 %, and an average altitude of 4 meters above sea level (INEGI, 2017). Eleven units of pitahayas were obtained for each location.

Fruits were selected based on their commercial maturity, the color of their peel (red-pink), and their phytosanitary conditions (only those free of pests, diseases, rot, and mechanical damage were chosen) in accordance with the Codex Alimentarius 237 (CODEX STAN, 2003). According to their weight, they were classified as: "very good appearance", "F" caliber, or superior, with their weight being > 400 g. (Castillo *et al*., 2016). **Figure 1** shows the appearance of the fruits.

**Figure 1**

*Pitahaya from the localities of Kinchil (left) and Yobain (right)*

The fruit was washed with running tap water and dried with sterile gauze. The diameters were measured with a digital vernier, and the weight of the whole fruit was registered; then, the pulp was manually separated from the peel, and the weight of each was registered according to its locality.

Both the pulp and the peel were chopped into pieces of approximately 2 x 8 x 1 cm and stored in food-grade, environmentally friendly silicone bags in accordance with the U.S. Food and Drug Administration (FDA). The bags were labeled according to the origin of the fruits (Kinchil or Yobain) and were stored at - 18 ºC until their use to determine their chemical characteristics.

### Freeze-dried pulp and peel of pitahaya

To ensure preservation and reduce moisture content, the frozen fruit was freeze-dried at – 46 °C and 0.340 mbar vacuum pressure for 48 h in the LABCONCO freeze-dryer (FreeZone, 4.5). With the freeze-dried peel, flour was obtained. The flour and the pieces of freeze-dried pulp were stored in amber glass bottles with labels identifying the origin of the fruit and finally stored in a Polar brand horizontal freezer model CH-25R at -18 ºC until use to determine the proximal characteristics and the estimation of freeze-dried pulp and peel the fructooligosaccharides content.

## Physicochemical characteristics of whole pitahaya fruit and defrosted pulp

To determine pH, titratable acidity, and soluble solids, pulp pieces were thawed at room temperature and mashed with a pestle and mortar for each of the samples (Kinchil and Yobain). The analyses were performed in triplicate.

The following fruit characteristics were quantified:

1. **Weight determination.** An ETEKCITY digital scale model EK4150 (China), with a capacity of up to 5 kg, was used. The whole fruit was weighed, then the pulp was separated from the peel, and each part was weighed. All weights were recorded, and the percentages of pulp and peel were calculated.

2. **Equatorial and polar diameters.** A PSQME digital Vernier caliper model JS-01-150, with an accuracy of 0.007/0.02 mm, was used to measure the polar and equatorial axes. The polar diameter was measured from the base to the tip of the fruit, and the equatorial diameter was measured from the middle transverse part.

3. **Total soluble solids (TSS)**. They are expressed in ºBrix and were estimated in the pulp puree by reading in an electronic refractometer (ATAGO, Japan, model RX-7000) at 20 ºC, using method 932.12 of the Association of Official Analytical Chemists (AOAC, 2005a).

4. **pH.** The pH value in the previously blended pulp was determined using a Yabely potentiometer (model ML1-MX-0004, USA), with a precision of 0.01, following the method 981.12 (AOAC, 2005a).

5. **Titratable acidity (TA).** For the determination of titratable acidity, 10 g of pulp was blended in 50 mL of distilled water, and the mixture was filtered through a strainer. 50 mL of the filtered mixture was placed in a beaker and, with the help of an automatic burette, titrated with 0.1 N sodium hydroxide (NaOH), using 1 mL of 0.5 % phenolphthalein as an indicator and stopping the titration process when an 8.3 pH was reached (with the help of a previously calibrated potentiometer). The results were expressed as the percentage of malic acid (milliequivalent 0.064), following AOAC official method 942.15 (AOAC, 2005b).

6. **TSS/TA ratio.** It was calculated from the concentration of total soluble solids in relation to the titratable acidity value obtained.

## Proximate composition of pulp and peel from pitahayas

The freeze-dried pulp and the flour obtained from the freeze-dried peel were used to determine their proximate composition (*moisture, ash, crude fat, crude fiber, crude protein, and carbohydrates expressed as nitrogen-free extract*) quantified using the procedures by the Association of Official Analytical Chemists (AOAC). All analyses were performed in triplicate, and the results were expressed on a dry basis (% d.b.).

1. **Moisture.** This method 925.10 (AOAC, 2005c) was based on the gravimetric determination of the mass loss of the sample. Moisture was evaluated based on weight loss after drying in a Fisher Scientific™ convection oven (model 851 F) at 110 ºC until a constant weight was reached.

2. **Ash.** Method 923.03 (AOAC, 2005d), which is based on the incineration of the organic matter from a sample to quantify the remaining inorganic fraction corresponding to the ash, was used to determine the ash content. The samples were incinerated in a muffle Thermo Scientific™ (model F48020) furnace at 550 °C for 3 hours. The remaining inorganic material was cooled and weighted to perform the corresponding calculation.

3. **Crude fat**. In the flour samples, crude fat was quantified using the 2003.06 method (AOAC, 2012). This method is based on the extraction of oils and fats, known as ethereal extract, to determine the crude fat content of the sample. The content was obtained from an extraction with hexane using a Soxtec™ 8000 system.

4. **Crude fiber.** Using method 962.09 (AOAC, 1990), the sample was digested with 1.25 % sulfuric acid and then with 1.25 % sodium hydroxide using a Fibertec™ 8000 system. The residue composed of fiber was determined by drying to constant weight, calcining, and reweighting.

5. **Crude protein.** It was determined by the Kjeldahl-Gunning method 992.23 (AOAC, 2000), which consisted of digestion, distillation, and acid-base titration of the nitrogenous material present in the sample with a Kjeltec™ 8200 digestion system. The crude protein content was calculated as nitrogen content ($N_2$) × 6.25.

6. **Total carbohydrates.** It was obtained as the result of the difference, 100 - ash (%), crude fat (%), crude fiber (%), and crude protein (%).

## Procedure for the extraction of fructooligosaccharides (FOS)

The extraction of FOS was done using the method by Wichienchot *et al.* (2010). The sample/solvent ratio was 1 g of freeze-dried pulp to 5 mL of water (1:5 w/v). For the peel, 1 g of freeze-dried flour was added to 20 mL of water (1:20 w/v). The samples were mixed with water in beakers, stirring continuously for 1 h at room temperature (28 ± 2 °C) inside the laboratory. Subsequently, the mixture was filtered through a gauze cloth bag while pressing it to remove seeds and sediment. The concentrated extracts were centrifuged at 10000 x g for 10 min, and the supernatant was frozen at -20 °C until further use.

For the FOS content estimation, the method reported by Montañez *et al.* (2011) was used, which requires subjecting the extracts to hydrolysis with the enzyme invertase, catalyzing the cleavage of non-reducing terminal residues of FOS, and releasing the reducing sugars (RS) molecules fructose and glucose (Apraez & Castillo, 2015).

Initially, reducing sugars (RS) were measured for each of the extracts. The colorimetric method proposed by Miller (1959) was used due to its high sensitivity. It is based on the reaction between 3,5-dinitrosalicylic acid and the reducing group of fructose or glucose, forming an orange-brown colored compound quantifiable colorimetrically; the intensity of the color is proportional to the concentration of reducing sugars. It was read at a wavelength of 510 nm since, according to the results of Lam *et al.* (2021), at this length, there is a maximum absorbance. The concentration of reducing sugars in the samples was calculated by interpolation on a standard fructose curve.

Subsequently, Maxinvert® invertase enzyme (EC 3.2.1.26) was used 300 U/mg of solid. 1 mL of enzyme was added for each kg of sugar, so each extract was measured for its °Brix level, and the result was registered as g of sucrose in the extract. To add the corresponding amount of the enzyme, the pH of the solution was changed to 4.5 and then incubated at 65 ºC for 6 h. In the end, the enzyme was inactivated by heat shock at 80 ºC in a water bath.

In the extracts already hydrolyzed by the invertase enzyme, the content of reducing sugars (RSi) was determined again. The increase in RS release in the post-invertase measurement would evidence the existence of FOS in pitahaya pulp and peel extracts. To determine the FOS, the RS before hydrolysis were subtracted from the RSi after hydrolysis, as expressed in **Equation 1.**

**Eq 1.** $$FOS = RSi - RS$$

Where:

RSi: reducing sugars invertase.

RS: reducing sugars.

For each test, three replicates were performed. Each result was expressed as the average of the determinations made.

### Statistical analysis

All data was expressed as the mean ± standard deviation of three replicates. The experimental unit was 22 pitahaya fruits (11 from each locality). A Student's t-test was applied to differentiate the means of the physical characteristics (weight, diameters, and total soluble solids), the chemical characteristics in the fruit pulp defrosted (pH, titratable acidity) and the proximate components (moisture, ash, crude fat, crude fiber, crude protein, and total carbohydrates) of the two locations (Kinchil vs. Yobain). For FOS extraction yield, the difference between means was between pulp and freeze-dried peel flour (regardless of locality). Data was analyzed using the statistical program STATA 13.0.

## Results and Discussion

### Physicochemical characteristics of whole pitahaya fruit and defrosted pulp

The results of the physical characteristics of the fruits are shown in **Table 1**. It was observed that the weight of the fresh fruits was within the average reported by other authors, which ranges from 406.70 to 556.80 g (Warusavitharana *et al.*, 2017).

The pulp was found in the range of 60 to 80 % of ripe fruit weight reported by Mercado-Silva (2018). In terms of dimensions, the fruit was generally ellipsoidal in shape, with values that were within those stated by Wichienchot *et al.* (2010), with 8 to 15 cm in length and 6 to 10 cm in diameter. Among the differences found, the fruit from Kinchil had significantly ($p < 0.05$) more peel and was more elongated (ellipsoidal shape) than the fruit from Yobain. These morphological differences at the fruit level could be due to a dispersion crop species that presents high polymorphism. The species has undergone human selection due to fruit collection, a situation that has promoted the diversity of fruits in shape, size, color, and organoleptic quality (Manzanero-Acevedo *et al.*, 2014).

Castillo *et al.* (2016) documented that in the Yucatan Peninsula, the harvest is classified according to weight into three classes: I. fruits of very good appearance > 400 g, II. fruits of 250 to 400 g, and III. fruits < 250 g. The fruits of this analysis **Table 1**, presented the best classification or classes I, since their weight was bigger than 400 g, being the average weight of the pitahaya fruit for Kinchil and Yobain equal to 534.81 g and 520.36 g, respectively. However, if we were looking for fruits with a higher pulp content, the samples from the Yobain would be better suited, considering that, on average, their pulp content was higher (371.09 g).

**Table 1**

*Physical characteristics of fruit fresh of pitahaya cultivated in two localities of Yucatan*

| Characteristics | Pitahaya Kinchil | Pitahaya Yobain |
|---|---|---|
| **Fruit dimensions (cm)** | | |
| Length (polar axis) | 9.86 ± 0.74[a] | 9.18 ± 0.74[b] |
| Diameter (equatorial axis) | 9.32 ± 0.60[a] | 9.38 ± 0.40[a] |
| Polar/equatorial axis ratio | 1.05 ± 0.05[a] | 0.97 ± 0.06[b] |
| **Weights (g)** | | |
| Fruit weight | 534.81 ± 87.96[a] | 520.36 ± 67.02[a] |
| Peel | 175.36 ± 38.00[a] | 149.27 ± 17.86[b] |
| Pulp | 359.45 ± 70.89[a] | 371.09 ± 53.03[a] |
| **Ratio (weight/weight %)** | | |
| Peel | 32.88 ± 5.45[a] | 28.78 ± 2.13[b] |
| Pulp | 67.11 ± 5.45[a] | 71.21 ± 2.03[b] |
| Peel/Pulp ratio | 2.10 ± 0.44[a] | 2.49 ± 0.25[b] |

*Note.* Mean ± standard deviation (n = 11). [a–b] Different letters in the same row indicate a significant difference ($p < 0.05$).

The physicochemical characteristics are observed in **Table 2**. In the present analysis, an average pH of 3.29 was found. The pH in the pitahaya pulp increases as the fruit matures because, during ripening, the organic acids are used as a substrate during respiration and are partly transformed into sugars (Magaña *et al.*, 2013). Our average was not as high compared to the average reported by Obregon-La Rosa *et al.* (2022), describing a pH of 4.16 and a maturity index MI (SST/AT) of 53.17 in the pitahaya pulp of this genus grown on the central coast of Peru. This lower pH in the pitahayas from both locations could be associated with their state of maturity (Sanin *et al.*, 2020), which was 20.95 on average; in addition, the samples were analyzed in a defrosted state, which could influence the result.

**Table 2**

*Physicochemical characteristics measured in pitahaya pulp (values of defrosted sample)*

| Locality | pH | Total soluble solids (°Brix) | Titratable acidity (%) | Total soluble solids/ Titratable acidity |
|---|---|---|---|---|
| **Kinchil** | 3.28 ± 0.06[a] | 10.34 ± 0.37[a] | 0.50 ± 0.02[a] | 20.73 ± 1.36[a] |
| **Yobain** | 3.31 ± 0.03[a] | 11.60 ± 0.53[b] | 0.55 ± 0.03[a] | 21.17 ± 1.94[a] |

*Note.* Mean ± standard deviation (n = 3). [a–b] Different letters in the columns indicate significant difference ($p < 0.05$).

Of the variables reported in **Table 2**, only the variable of total soluble solids (TSS) showed significant differences ($p < 0.05$) between the localities, the value was higher in the fruits harvested in Yobain (11.60 ± 0.53 ºBrix) than those coming from Kinchil (10.35 ± 0.37 ºBrix). TSS are mostly made up of sugars (glucose and fructose), but also other compounds such as organic acids. During maturation, these acids are partly transformed into sugars, the loss of water as the fruit ripens concentrates the sugars, which gives the fruit a sweeter flavor. (Verona-Ruiz *et al.*, 2020). The differences found in the fruits may be due to the state of physiological maturity since it has been proven that the higher the degree of maturity, the greater the concentration of sugars in a fruit (Centurión Yah *et al.*, 2008). The values found in the pitahaya grown in Kinchil with 10.34 º Brix coincide with those reported by Magaña *et al.*, (2013) of 10.56 º Brix measured in pitahaya (*S. undatus*), cultivated in Yucatan and exposed to room temperature (26 ± 2 °C) for three days, after harvest.

The average titratable acidity (TA, % malic acid) value found was 0.52 %, and there were no significant differences ($p > 0.05$) in TA between samples from the two locations. Generally, the acidity of the fruit decreases as it ripens (Magaña *et al.*, 2013). The percentage of titratable acids for the locality of Kinchil was the same as the value reported by Magaña *et al.* (2013), with an acidity percentage of 0.50 % in pitahaya (*S. undatus*) grown in Yucatan and exposed to room temperature (26 ± 2 °C) for three days, after harvest.

The TSS/TA ratio, also known as maturity index (MI), was 20.73 ± 1.36 and 21.17 ± 1.94 for fruit from Kinchil and Yobain, respectively. Centurión-Yah *et al.* (2008) observed the evolution of the physicochemical characteristics of pitahaya fruits during ripening, finding that fruits 29 days after flowering had an acidity of 0.6 (% malic acid), a TSS of 11.8 ºBrix, and a TSS/TA ratio of 20.6. Considering these values, the studied pitahayas from both locations could have approximately 29 days of ripening after flowering.

When evaluating the chemical composition of the freeze-dried pulp between the different locations, only total soluble solids (ºBrix) presented a statistical difference ($p < 0.05$) (**Table 2**). This suggests that the pulp of this species, regardless of its origin, has properties that could benefit the consumer if commercialization is considered in the future. Even so, in this study, it was observed that the pitahaya pulp collected in the town of Yobain presented higher values at the level of physicochemical analysis. This implies a potential to deepen future studies on its nutritional value to recommend its consumption and production on a large scale.

## Proximal analysis in freeze-dried pulp

It should be noted that the freeze-drying process is the best drying method to preserve the nutritional properties of foods, compared to other techniques (Jude *et al.*, 2023). In the analysis done by Ayala *et al.* (2010), it allowed the preservation of pitahaya slices by reducing water activity below 0.4, preserving the volume significantly, increasing porosity, and allowing rehydration to approximate its initial moisture content. Our results are on a dry basis and are compared with studies reported in the same way.

The values of the proximal chemical components are shown in **Table 3**. The average ash content in the freeze-dried pitahaya pulp was 4.80 %; this value was higher than that reported by Chik *et al.* (2011), which evaluated the quality and proximal characteristics of three types of pitahaya grown in Malaysia, finding that the genus *S. undatus* had an ash content of 2.6 % in the pulp. In Yucatan, the soil is predominantly calcareous (high in minerals) (Castillo *et al.*, 2016), which could influence the content of mineral salts in the sample, as reflected in the ash weight. Although there were no significant differences ($p > 0.05$), the mean ash content of pitahaya from Yobain was higher than that of Kinchil.

The average crude fat content in the pulp was 0.47 %, a percentage considered normal when considering that the concentration of lipids in fruits is generally less than 1 % (e.g., 0.2 % in grapes, 0.1 % in bananas, and 0.06 % in apples) (Vicente *et al.*, 2021). The value found in this study is higher than that reported by Chik *et al.* (2011) of 0.1 %; however, there are reports of up to 4.5 % crude fat in other varieties of pitahaya like *Hylecereus polyrhizus* (Jaafar *et al.*, 2009).

The average fiber content was 10.42%; the fiber content varies depending on the state of maturity of the fruit. This value was lower than that reported by Obregón-La Rosa *et al.* (2022), with 27.1 % in pitahayas of this genus grown on the central coast of Peru, which could be due to their higher state of maturity MI = 53.17 compared to the state of maturity MI=20.95 of the fruits of this study.

The mean value of protein percentage was 6.92 %. Protein represents < 1 % of the fresh mass of most fruits (Vicente *et al.*, 2021). Although it is not an important source of this nutrient, its content is not negligible, and it is important to note that, as shown in **Table 3**, the fruit from Kinchil had a higher average value (7.24 ± 0.47) if compared to the pulp analyzed from Yobain (6.59 ± 0.50). The percentage found was close to the total obtained by Chick *et al.* (2011) of 7.7 %, analyzing the same pitahaya species.

The analysis of total carbohydrates in pulp did not show significant ($p < 0.05$) differences between locations. Carbohydrates represent up to 90 % of the pulp (Peerakietkhajorn *et al.*, 2020). In this sense, it can be said that the pulp of the two localities could be considered for use as a source of fructooligosaccharides due to their content of indigestible carbohydrates, which had previously been reported in other investigations (Wichienchot *et al.*, 2010).

**Table 3**

*Proximal composition on dry basis (freeze-dried pulp and peel flour) cultivated in two localities of Yucatan*

| Component (%) | Pulp Kinchil | Pulp Yobain | Peel Kinchil | Peel Yobain |
|---|---|---|---|---|
| Crude protein | 7.24 ± 0.47$^{A}$ | 6.59 ± 0.50$^{A}$ | 5.43 ± 0.11$^{a}$ | 5.20 ± 0.30$^{a}$ |
| Crude fiber | 9.94 ± 1.17$^{A}$ | 10.89 ±2.28$^{A}$ | 19.58 ± 0.26$^{a}$ | 24.87 ± 0.42$^{b}$ |
| Crude fat | 0.61 ± 0.1$^{A}$ | 0.33 ±0.09$^{B}$ | 1.60 ± 0.34$^{a}$ | 1.18 ± 0.16$^{a}$ |
| Ash | 4.54 ± 0.32$^{A}$ | 5.05 ± 0.36$^{A}$ | 13.64 ± 0.82$^{a}$ | 14.76 ± 0.41$^{a}$ |
| Total carbohydrates | 77.64 ± 1.13$^{A}$ | 76.78 ±2.75$^{A}$ | 59.73 ±1.27$^{a}$ | 53.97 ± 1.02$^{b}$ |

*Note.* Mean ± standard deviation (n = 3)–$^{a-b}$ Different letters in the rows for the same peel component between localities indicate a significant difference ($p < 0.05$).) $^{A-B}$ Different letters in the rows for the same pulp component between localities indicate a significant difference ($p < 0.05$).

## Proximal analysis of freeze-dried peel

Evaluating freeze-dried peel flour, the average ash content was 14.20 % (**Table 3**). Previous studies carried out on varieties of this genus had reported values of 15.0 % (Chik *et al.*, 2011) and 18.54 % (Zhuang *et al.*, 2012). Even without differences at the average level for ash, the town of Yobain had a better performance, which could be related to the composition of the soil, which is variable in the Yucatan Peninsula. The amount of predominant minerals (calcium and magnesium) in the calcareous soil could influence the mineral content present in the fruit peel (Hernández Alva *et al.*, 2018)

The average fat content was 1.39 %, which was very close to the 1.34 % reported by Zhuang *et al.* (2012) in the study carried out on pitahaya peel flour of this genus. Although the mean value was higher in the fruit from Kinchil, there were no significant differences. Jiang *et al.* (2021) reported in their comprehensive review that the fat content represents between 0.10% and 2.34% of the dry weight of pitahaya peels. This content is low compared to the peel of other fruits like papaya 2.48 ± 0.40 % and blueberry 4.13 ± 0.19 % (De Moraes Crizel *et al.*, 2016).

The crude fiber content in the peel of the fruit from Yobain (24.87 ± 0.42) was significantly ($p < 0.05$), higher than the peel of the fruit from Kinchil (19.58 ± 0.26). Crude fiber is mainly composed of cellulose and lignin, which are the structural components of the peel cell wall. The difference in crude fiber content may be due to the anatomical characteristics and chemical diversification of the cell wall (Maceda *et al.*, 2021). The average value of 22.22 % was similar to the one indicated by Chia & Chong (2015), with 23.75 % in fruit peel of *Hylocereus polyrhizus*. This work did not determine the fiber fractions (soluble and insoluble), but it's reported that pitahaya peel flour has a high fiber content, approximately 79 % by dry weight, and the ratio of insoluble fiber to soluble fiber is close to 1:32. However, further research is needed to investigate its biological properties *in vivo* (Zhuang *et al.*, 2012).

The average value of the protein content in the peel was similar between the locations, with an average value of 5.31 %. Since the peel is not usually consumed, its contribution to the diet is not considered, but it is noteworthy that the percentage reported by Morais *et al.* (2021), in flour peels of pitahaya (*Selenicereus megalanthus*) was 7.48 ± 0.62 %, even superior to the content found for the pulp from Kinchil (7.24 ± 0.47 %) in the present analysis.

If we talk about the proximal contribution according to the type of sample, it was found that the percentage of crude fiber in the peel of the fruit from Yobain was significantly higher ($p < 0.05$) than that of the fruit from Kinchil. Therefore, total carbohydrates for the peel of the fruit from Kinchil (59.73 ± 1.27) were significantly higher ($p < 0.05$) since their relationship is inverse.

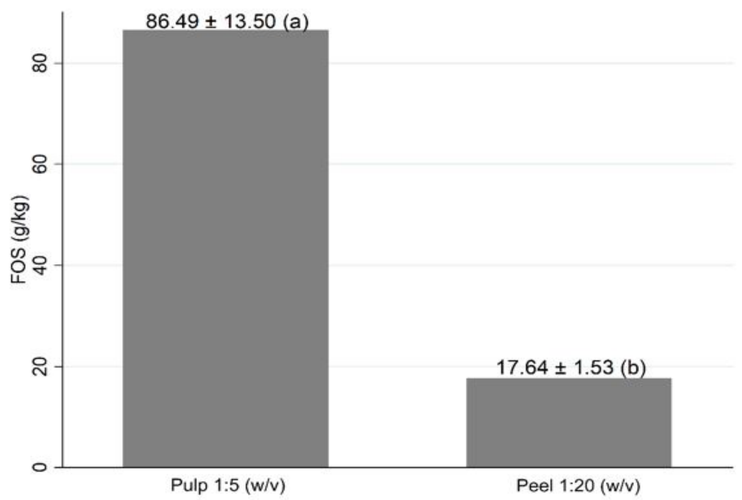
## Analysis of the extracted FOS

The results of the estimation of extracted FOS content for the freeze-dried pulp were 86.49 ± 13.50 g/kg and for the peel (freeze-dried peel flour) 17.64 ± 1.53 g/kg, as shown in **Figure 2**. These differences in FOS according to the type of sample may be due to the peel having a higher content of insoluble fiber and a lower content of fructose and glucose (Mohd Adzim Khalili *et al.*, 2014); these are constituent monomers of fructooligosaccharides. However, the peel is also a source of antioxidants, of which 51 % is related to the presence of flavonoids 357 mg RE/g (rutin equivalents/g of sample) (Jimenez-

Garcia *et al.*, 2022); therefore, if the fruit is used as a whole, it would provide a prebiotic effect and antioxidant fiber. FOS are widely recognized for their impact on human health due to their prebiotic properties associated with satiety, appetite regulation, intestinal transit, and lipid metabolism, among others (Nobre *et al.*, 2021).

**Figure 2**

*Estimated content of fructooligosaccharides (FOS) extracted from pitahaya pulp and peel (report on freeze-dried sample w/v)*




***Note.*** Mean ± standard deviation (n = 3). [a-b] Different letters in the columns indicate significant difference ($p < 0.05$).

Although the use of ethanol as the FOS extraction solvent is preferred, water was used in this study, as it is an environmentally friendly solvent. Wichienchot *et al.* (2010) reported an oligosaccharide content (extracted with 80% ethanol) in pitahaya pulp of 86.2 g/kg, a content similar to that found in the present analysis of 86.49 g/kg.

Even though our results seem to indicate that extraction with water allows for effective extraction of oligosaccharides, it is important to remember that, in this study, an estimate was used, and an analysis by high-performance liquid chromatography (HPLC) is required to ensure that the molecular weights correspond to fructooligosaccharides and not to another type of oligosaccharides.

Rohin *et al.* (2014) reported a lower content (14.92 µg/100 g) of fructooligosaccharides in pitahaya peel extracted with 50 % ethanol and concluded that the composition of fructooligosaccharides is significantly higher in the fruit's flesh (104.94 ±3.20 ug/100 g) compared to the peel.

The extraction of FOS from the pulp would contribute to promoting a better use of pitahaya, giving added value to the fruit, and allowing the enhancement of its commercialization and its position in the market. Furthermore, the FOS in pitahaya behaves like prebiotics that are not digested but fermented in the colon, presenting positive physiological effects that will benefit the health of consumers (Dasaesamoh *et al.*, 2016).

## Conclusions

Although the fruits had the same state of maturity, the present study found that the pitahaya grown in the town of Yobain had better performance, highlighting the variables on fruit shape (less elongated) and pulp weight, as well as a greater degree of sweetness expressed in ºBrix. As for the proximal analysis carried out on the freeze-dried pulp and peel flour, both the pulp and the peel of the fruit from Yobain contained more crude fiber and less fat, while the fruit from Kinchil contained more protein; although this difference it was not significant. The extraction using water as a solvent was feasible to recover a relevant amount of fructooligosaccharides from the freeze-dried pulp (86.49 g/kg), being a promising way to add value to pitahaya fruits.

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