BREAD ENRICHMENT WITH CLADODES (*Opuntia ficus-indica*) FLOUR IMPROVES ITS NUTRITIONAL PROFILE

ABSTRACT

Opuntia ficus-indica (L.) Miller is original from Mexico. It arrived at Europe during the Discoveries and expanded to regions with favorable soil and climate conditions. This plant is highly resistant to drought and high temperatures, easily adapting to regions with these characteristics.

Its intensive and orderly cultivation gained greater expression in Portugal from 2009 onwards with the commercialization of the fruits. The cladodes have been mainly used for forage or repopulation. As a result of the growing cultivation, and given the invasive potential of this plant, there is a good opportunity to transform the surplus cladodes into a new raw material. By this way, it is intended to value the mature cladodes finding a sustainable application for them. In this work, a food ingredient (cladodes flour) was produced and characterized in terms of its nutritional profile and a food product was formulated (an enriched bread with cladodes flour). The bread with *Opuntia ficus-indica* cladodes is a strategy to add value to this by-product specifically for the food industry. Due to its nutritional profile, this flour can be a valuable source of fiber and minerals for diets included in healthy, balanced, and sustainable lifestyles.

INTRODUCTION

Opuntia ficus-indica (L.) Mill. belongs to the family of Cactaceae. It is a species native from Mexico, but it is also cultivated in many other countries with warm climates. In Portugal, it is known as “Figueira-da-Índia” (1). The fruit (prickly pear) is a very popular ingredient in the Mexican cuisine. It is used to manufacture juices, sweets, jellies, alcoholic beverages, and other foodstuffs (2). Cladodes, the leaves of the plant, are also commonly used in the Mexican cuisine, however, the older ones are usually rejected due to the high lignin content, which makes them more difficult to process, although FAO (Food and Agriculture Organization) considers them suitable for flour production (3).

The continuous development of the food industry is associated not only with the creation of new products but also with the use of post-production residues (such as mature cladodes). In fact, unused by-products can pose a threat to the environment, and the costs of their storage and disposal have also to be considered.

The trends to use production residues can be increasingly observed in the food market. Following this and the knowledge development about the nutritional value of by-products, producers strive to find various directions for their use in further applications (4). As *Opuntia ficus-indica* is a plant that can grow in a very dry and warm climates, being resilient to extreme edaphoclimatic conditions, it can be planted in places where nothing else would grow (5). The popularization of this plant could be the key to ensure food security and jobs for people living in areas with dry and hot climates and erosion, contributing for the agricultural development in those regions.

OBJECTIVE

The present work aims to add value to older cladodes (the main by-product of prickly pear production), through a sustainable application. A food ingredient was developed (cladodes flour) and characterized regarding its nutritional profile and a novel food product was formulated (an enriched bread with cladodes flour). The effect of different flour percentages in the bread formula was also ascertained.

RESULTS AND DISCUSSION

Cladodes flour

The cladodes (Figure 1) were harvested in November 2021 from a crop of Olaia Natura, a company from Torres Novas, Portugal. All cladodes belonged to the orange variety, thus giving rise to orange-fleshed fruits. Immediately after being harvested, the cladodes were packed and transported to the laboratory where they were promptly prepared.

Figure 1: (A) - *Opuntia ficus-indica* (L.) Miller cladodes in the field; (B) - Selected cladodes.

The cladodes flour is the food ingredient resultant from milling the dehydrated cladodes (by-product of "Figueira-da-Índia"). In this work, it was prepared according to INIAV (6) with slight modifications.

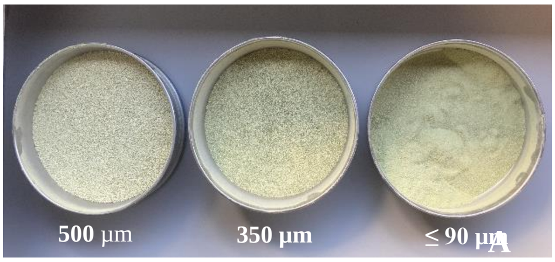

Figure 2: Different fractions of the cladodes powder.

Regarding the aspect of the obtained flour, the color was light green, the appearance a fine powder, and the smell characteristic of cactus. The granulometry of flour was determined by a set of sieves of different pore sizes (90, 125, 180, 250, 350 µm). About 35% of the flour presented a granulometry below 90 µm (Figure 2). In what concerns to its nutritional profile, the following parameters were analysed: moisture, ash, crude protein, total fat, dietary fiber (total, insoluble and soluble), according to AOAC methodologies (7), free sugars (determined by HPLC-ELSD (8) and remaining available carbohydrates (calculated by difference). The chemical composition of the flour is presented in Table 1. The results obtained were first compared with the work carried out by Espírito Santo (9), where the cladodes from the same crop and the same variety (orange), but from a previous harvest (December 2018) were characterized.
The cladode flour presented the following composition (results expressed in dry weight (dw)): 21% of ash, 4% of crude protein, 1% of total fat, and 39% of total fiber, being 97%

of the latter insoluble fiber. According to Espírito Santo (9), orange cladodes presented 27% of ash, 4% of crude protein, 1% of total fat and 36% of total fiber. Although some differences were identified between the different harvests (specifically regarding the ash and total fiber contents), they were minor and should be related to the variations of the edaphoclimatic conditions observed between 2018 and 2021.

Above all, the flour seems to be interesting in terms of its ash content, which reveals a good source of minerals. This is an important quality attribute for some food ingredients (10). Although a protein content relatively low (4%), it may be suggested to integrate low-protein diets, for example, for patients with kidney disease (11). In addition, the cladode flour also presented low fat content.

The results obtained for ash, protein and total fat are also in agreement with those reported by Stintzing *et al.* (12) (19-23%, 4-10% and 1-4% of ash, protein, and fat, respectively) and by Ayadi *et al.* (13) (26%, 9% and 2% of ash, protein and fat, by this order). Despite having high levels of total carbohydrates, the majority was dietary fiber (39%), mainly insoluble fiber (38%). In another study, Ayadi *et al.* (13) reported a total fiber value of 31% and 18% of insoluble fiber, while Stintzing *et al.* reported a total dietary fiber lower than 18% (12, 13). The comparison with literature data highlights the cladodes flour herein studied as a source of fiber, especially insoluble one. Regarding the simple sugars of cladodes flour, the major one was fructose, followed by glucose and saccharose.

Nowadays, consumers look for sustainable foods that are low in fat, sugar and calories, so cladodes flour is in line with this trend, and its use as an ingredient in a nutritionally balanced diet can be highly suggested.

Table 1.: Nutritional composition of cladodes flour (mean ± standard deviation, *n* = 3).

Parameter	**Fresh weight (g/100 g)**	**Dry weight (g/100 g)**
Moisture	7.60 ± 0.13	-
Ash	19.71 ± 0.04	21.34 ± 0.05
Total fat	1.14 ± 0.01	1.24 ± 0.01
Total protein	4.13 ± 0.16	4.47 ± 0.17
Total carbohydrates	75.01 ± 0.20	73.03 ± 0.12
Total fiber	35.72 ± 0.23	38.66 ± 0.25
Insoluble fiber	34.56 ± 0.96	37.40 ± 1.00
Soluble fiber	1.16 ± 0.69	1.25 ± 0.75
Simple sugars	9.96 ± 0.03	10.78 ± 0.03
Fructose	5.23 ± 0.03	5.66 ± 0.03
Glucose	3.46 ± 0.01	3.75 ± 0.01
Saccharose	1.28 ± 0.02	1.38 ± 0.02
Remaining carbohydrates	29.33 ± 0.39	23.59 ± 0.33

Breads enriched with cladodes flour

The results revealed that all breads presented similar moisture contents (39-40%, Table 2). When comparing the control bread with the breads containing different amounts of cladodes flour, it can be observed that the addition of this flour caused a significant ($p<0.05$) increase in the ash contents. Therefore, these breads seem to be a better source of total minerals. The addition of cladodes flour also resulted in breads that are a better

source of dietary fiber. However, in terms of total protein and total fat no differences were noticed. Moreover, there was a slight reduction in total carbohydrates when comparing the control to the enriched breads.
Regarding the bread simple sugars, the major one was maltose, followed by glucose and fructose. Maltose seems to be provided by the wheat flour ingredient since this sugar was not identified in cladodes flour.

Table 2: Nutritional composition of breads enriched with cladodes flour. Results expressed in g/100 g in fresh weight as mean ± standard deviation (*n* = 3).

Parameter	**Control bread[1]**	**Bread 7%[2]**	**Bread 14%[3]**
Moisture	39.33 ± 0.09	39.34 ± 0.36	39.59 ± 0.21
Ash	0.73 ± 0.02	1.49 ± 0.05	2.61 ± 0.02
Total protein	6.51 ± 0.02	6.11 ± 0.20	6.24 ± 0.12
Total fat	0.20 ± 0.02	0.20 ± 0.02	0.34 ± 0.04
Total carbohydrates	53.19 ± 0.03	52.85 ± 0.11	51.32 ± 0.26
Total fiber	3.47 ± 0.63	4.51 ± 0.14	4.34 ± 0.06
Insoluble fiber	2.01 ± 0.26	2.50 ± 0.02	3.57 ± 0.45
Soluble fiber	1.46 ± 0.37	2.00 ± 0.16	0.77 ± 0.51
Simple sugars	3.57 ± 0.02	3.36 ± 0.02	3.33 ± 0.09
Fructose	0.46 ± 0.00	0.47 ± 0.00	0.49 ± 0.00
Glucose	0.36 ± 0.00	0.36 ± 0.00	0.44 ± 0.01
Maltose	2.75 ± 0.02	2.53 ± 0.02	2.40 ± 0.08
Remaining carbohydrates	45.85 ± 0.30	44.48 ± 0.09	43.65 ± 0.25

[1] Control bread - made with wheat flour; [2] Bread 7% - made with a mixture of wheat flour and 7% cladodes flour; [3] Bread 14% - made with a mixture of wheat flour and 14% cladodes flour.

CONCLUSION

In conclusion, cladodes flour and bread made with *Opuntia ficus-indica* cladodes are a great way to add value to this by-product specifically for the food industry. Their use agrees with the ideas of sustainable development and can be a solution for crops in a dry and warm climate with soil erosion. Regarding their nutritional values, they can be a valuable source of fiber and minerals in diets for people interested in a healthy, balanced, and sustainable lifestyle.
From a circular economy perspective, we can conclude that cladodes can contribute to human nutrition and promote sustainable development. Their valorization will contribute to the full use of the plant, avoiding the invasive action of the discarded cladodes, but also reducing waste and improving food security. This fact makes it possible to increase the income of producers and contribute to economic and social sustainability.
At an environmental level, the cultivation of this type of plants will make abandoned or non-productive soils profitable, contributing to the recovery of ecosystems and reducing atmospheric CO_2.
In a global point of view, it can also contribute to the sustainable development of agriculture, to respond to the global concerns identified in 2015, thus falling within the objectives 2 - Eradicate hunger and 12 - Sustainable production and consumption of the 2030 Agenda.

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