



Dietary fibre concentrate from Chilean algarrobo (*Prosopis chilensis* (Mol.) Stuntz) pods: Purification and characterization

Ana María Estévez¹, Fernando Figuerola², Enrique Bernuy¹ and Carmen Sáenz¹

Abstract

Prosopis species are generally fast-growing, drought-resistant, nitrogen-fixing trees or shrubs. Fruits of *Prosopis* spp are indehiscent pods, where pericarp is formed by the epicarp, light brown in colour, and fibrous nature; the mesocarp known as pulp, which is rich in sugars; and the endocarp. The aim of this work was to obtain a fibre concentrate from the pods of *Prosopis chilensis* Mol. (Stuntz) and to determine the chemical, physical, and technological properties of the pod flour (PF) and of a fibre concentrate or pod purified flour (PPF). Acetone, ethanol, and water at different conditions of time and temperature were used in the purification process. PF showed 53.7 g/100 g of total sugar content, 4.2 g/100 g of reducing sugar content, 41.8 g/100 g of total dietary fibre, 35.8 g/100 g of insoluble fibre, and 6.0 g/100 g of soluble fibre content. The PPF has a total sugar content of 3.8 g/100 g, reducing sugar content of 2.2 g/100 g, total dietary fibre content of 80.8 g/100 g, insoluble fibre content of 75.1 g/100 g, and soluble fibre content of 5.7 g/100 g. The scanning electron microscopy analysis showed the existence of voids in the structure of PPF flour, which reveals the efficiency of the purification process with a high decrease in the total sugar content.

Keywords

Dietary fibre, food ingredients, physical properties

Date received: 18 January 2013; accepted: 3 July 2013

INTRODUCTION

Chilean algarrobo (*Prosopis chilensis* (Mol.) Stuntz) could be an important resource for the rural people depending on subsistence farming. The genus *Prosopis* has about 45 species distributed mainly in arid and semi-arid lands all over the world (Cardozo et al., 2010; Galera, 2000). *Prosopis* species are generally fast-growing, drought-resistant, nitrogen-fixing trees or shrubs (Briones-Labarca et al., 2011). Many of them have been used to control desertification and to recover degraded ecosystems, especially those that can be used to obtain food and feed and industrial products (Nair, 2007). Fruits of *Prosopis* spp. are indehiscent

pods, light brown in colour, and fibrous nature. *Prosopis* flour has a sweetish, cocoa-like taste and aroma (Felker et al., 2003). According to Cardozo et al. (2010), the whole pod flour (PF) from *Prosopis alba* and *Prosopis nigra* has high amount of sucrose (52.08 g/100 g), which can be easily removed by aqueous extraction and small amount of reducing sugars. Also, they are gluten-free flours, low in phytic acid content and do not show any mutagenic effect. Besides, PF of *Prosopis* species could be a significant source of

Food Science and Technology International 20(8) 629–635

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DOI: 10.1177/1082013213499769

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¹Department Agroindustria y Enología, Facultad de Ciencias Agronómicas, Universidad de Chile, Santiago, Chile

²Instituto de Ciencia y Tecnología de Alimentos, Facultad de Ciencias Agrarias, Universidad Austral de Chile, Valdivia, Chile

Corresponding author:

Ana María Estévez, Department Agroindustria y Enología Agroindustria y Enología, Facultad de Ciencias Agronómicas, Universidad de Chile, Casilla 1004, Santiago, Chile.

Email: aesteve@uchile.cl

natural antioxidant compounds that may have beneficial health effects (Cardozo et al., 2010).

Each tree of Chilean algarrobo can produce between 20 and 100 kg of fruits per year (Galera, 2000). The fruit is a linear, indehiscent legume of 12–18 cm in length and 1–1.8 cm in width, and has several small seeds inside. The fruit is composed of about 70–75% of pericarp (epicarp, mesocarp or pulp and endocarp) and 25–30% of seeds (Bernardi et al., 2006; Escobar et al., 1987; Hurtado et al., 2002). Pods (pericarp) have 3.8–4.6 g/100 g of ash, 6.0–11.9 g/100 g of protein, 0.6–1.4 g/100 g of lipids, and 11.6–20.5 g/100 g of crude fibre (Escobar et al., 1987; Galera, 2000). According to Escobar et al. (1987), pericarp has about 32.9 g/100 g of total sugar and a small amount of reducing sugars (3.4 g/100 g).

Dietary fibre is highly valued because its role is scientifically recognized in the prevention of some illnesses, such as gastrointestinal disorders and high cholesterol levels (Villanueva-Suarez et al., 2003). Also, it could be used as food-structuring ingredient because it provides water-holding capacity, oil-holding capacity, as well as emulsion and/or gel formation (Elleuch et al., 2011; Foster, 2011). The chemical composition of Chilean algarrobo pods suggests that PF could be a good source of dietary fibre for use in food product development. Larrauri (1999) recommended that a dietary fibre used in foods should be as concentrated as possible and bland in taste, colour, and odour. To meet these characteristics, algarrobo PF should be washed to remove the high amount of sugars and dried to improve the shelf life, allowing its use as a functional ingredient. Bravo et al. (1998) purified *Prosopis pallida* PF by washing with water to obtain a fibre concentrate. Figuerola et al. (2005) obtained fibre concentrates from apples, grapefruits, lemons, and oranges through water washing (30°C) to remove sugars and soluble compounds, while Sáenz et al. (2012) used different temperatures to purify a cactus powder.

The purpose of this research was to obtain a concentrate fibre from the pods of *P. chilensis* Mol. (Stuntz) and to determine the chemical, physical, and technological properties of the PF and a pod purified flour (PPF).

MATERIALS AND METHODS

Algarrobo PF

Algarrobo pods collected in the Central area of Chile were dried at 60°C in an air-forced tunnel, until a remnant moisture content of 8–10 % was reached. After cooling for 1 h, the pods were milled in a vertical pin disc mill, which allowed separating the seeds and milled pericarp. The milled pericarp was sifted to separate the fraction with a particle size lower than 250 µm. The powder obtained was the PF.

PF purification

The PF was purified by washing it with acetone to remove lipid-like compounds. Washing was done for 30 min using a flour–acetone mixture of 1:3 ratio at 25°C. The slurry was filtered using vacuum. The retained cake was suspended in 80% v/v ethanol solution at 40°C in 1:3 ratio of cake:ethanol, to remove sugars and other soluble compounds. The suspension was filtered in Whatman filter paper No 4. Finally, the cake was washed thoroughly with water at 30°C using a cake:water mixture of 1:6 ratio. Finally, the cake was vacuum filtered and dried at 37°C for 8 h. The powder obtained was the PPF.

Chemical analysis

Both PF and PPF were characterized for their proximate composition (protein, fat, ash, crude fibre, and nitrogen-free extract (NFE)) according to official methods of analysis of Association of Official Analytical Chemists (AOAC; 1996), and the contents of total and reducing sugars were determined by the Munson and Walker method (AOAC, 1996). Furthermore, the dietary fibre content was evaluated according to the procedure developed by Lee et al. (1992), and the caloric value was computed using the FAO Atwater coefficients (FAO, 2002).

Physical characterization

Yields related to the whole pod for both PF and PPF were calculated. Colour parameters (L , a^* , b^* , C^* , and h°) were determined with a Minolta CR-200 b colorimeter (Osaka, Japan). Water activity was measured with a Luft equipment model 5830 (Fellbach, Germany).

Technological properties

Flow properties of the powders, such as bulk density (BD), setting density (SD), emptying time (ET), emptying rate (ER), and resting angle (RA) were determined following the procedure developed by Larrauri et al. (1995). Water retention capacity (WRC), swelling capacity (SWC), and fat absorption capacity (FAC) were measured according to the methods reported by Femenia et al. (1997). Texture, expressed as the maximum compression force, was determined in gels formed with a 20% (w/v) concentrated suspension in phosphate buffer (pH 6.3) at room temperature and after heating at 80°C for 2 h. Measurements were done in a Lloyd texturometer, model LRSK with a probe of 500 N, at a compression rate of 1 mm/s obtained with a 25-mm cylinder, recording the

force profile at 1 cm of probe penetration (Femenia et al., 1997).

Scanning electron microscopy analysis

Scanning electron micrographs of PF and PPF were obtained using a Leitz Scanning Microscope, model LEO 420 (Carl Zeiss NTS GmbH, Oberkochen, Germany), at an accelerating voltage of 15 kV.

Statistical analysis

One kilogram of algarrobo pods was used for each replication. The procedures for obtaining PF and PPF, as well the analytical procedures, were done with five replications. To determine the differences between PF and PPF, analytical data from chemical, physical, and technological analysis were compared using Student's *t* test with a significance level of 5%.

RESULTS AND DISCUSSION

Purification effect on the chemical composition

The purification process significantly increased the protein and crude fibre contents from 7.8 to 11.7 and from 10.8 to 27.7 g/100 g, respectively, and significantly decreased the lipid, ash, and NFE content (from 1.7 to 0.3, from 2.4 to 2.2, and from 74.4 to 51.4 g/100 g, respectively). Total and reducing sugar levels decreased significantly after the purification process (Table 1) from 53.7 to 3.8 and from 4.2 to 2.2 g/100 g, respectively. The protein content of PF obtained in the present study was similar to that reported by Díaz et al. (2001) in *P. alba* (7.9 g/100 g), by Escobar et al. (1987) in *P. chilensis* (8.0 g/100 g), and by Astudillo et al. (2000)

Table 1. Chemical composition of pod flour (PF) and purified pod flour (PPF)

Component	g/100 g dry weight	
	Pod flour	Purified pod flour
Protein (N × 6.25)	7.8b	11.7a
Lipids	1.7a	0.3b
Ash	2.4a	2.2b
Crude fibre	10.8b	27.7a
NFE (by difference)	74.4a	51.4b
Reducing sugars	4.2a	2.2b
Total sugars	53.7a	3.8b
Caloric value (kcal/100 g)	231.7a	69.5b

NFE: nitrogen free extract.

Different letters mean significant differences at $p < 0.05$.

in *Prosopis tamarugo* (8.4 g/100 g); however, it was lower than the values reported by Barba de la Rosa et al. (2006) in *Prosopis laevigata* (10.0 g/100 g). An increase in the protein content after the purifying process was also reported by Sáenz et al. (2012) in cactus pear powder. The content of crude fibre obtained in this study was similar to that reported by Galera (2000) in *P. chilensis* (11.6 g/100 g) and lower than that reported by Escobar et al. (1987) in *P. chilensis* from two different locations (15.6 and 20.5 g/100 g). In PF, 72.2% of NFE were total sugars (53.7 g/100 g) and 5.7% were reducing sugars (4.2 g/100 g). Felker et al. (2003) reported similar values for total sugars (59.1 g/100 g) in PF obtained from *P. pallida*, while Escobar et al. (1987) demonstrated lower values for total sugars (30.6–32.9 g/100 g) and similar values for reducing sugars (3.4–7.0 g/100 g). The contents of total sugars, ash, and lipids in the PPF obtained in the present study were similar to those reported by Bravo (1999) in *P. pallida* PF obtained after several water washes (total sugars (1.9 g/100 g), ash (1.7 g/100 g), and lipids (1.8 g/100 g)).

Purification effect on dietary fibre

The total and insoluble dietary fibre increased significantly with purification; however, no differences were observed in the soluble dietary fibre (Table 2). The insoluble dietary fibre of the PF was found to be the main component of the total dietary fibre (85.6%), which was increased by the purification process to 92.9%. Bravo (1999) obtained 52.4 g/100 g of total dietary fibre in PF of *P. pallida*, similar to the values obtained in the present study, after a purifying process (80.8 g/100 g).

Purification effect on yield and physical properties

The PF obtained had a particle size ranging between 150 and 1410 µm. In previous assays, it was determined that particles smaller than 250 µm may interfere in the purification process; hence, it was decided to discard

Table 2. Dietary fibre content in pod flour and purified pod flour (g/100 g)

Fibre	Pod flour (PF)	Purified pod flour (PPF)
Total dietary total	41.8 ± 0.2b	80.8 ± 0.8a
Insoluble fibre	35.8 ± 1.4b	75.1 ± 0.3a
Soluble dietary fibre	6.0 ± 1.2a	5.7 ± 0.5a

Mean ± standard deviation (SD). Different letters mean significant differences at $p < 0.05$.

Table 3. Colour parameters of pod flour (PF) and purified pod flour (PPF)

Parameters	PF	PPF
<i>L</i>	67.5a	54.1b
<i>a</i> *	6.5a	6.9a
<i>b</i> *	23.7a	17.4b
<i>C</i> *	24.6a	18.7b
<i>h</i> °	74.7a	68.4b

Mean \pm standard deviation (SD). Different letters mean significant differences at $p < 0.05$.

the smallest particles, obtaining a PF yield respect to the whole fruit of 58.5% (particles $> 250 \mu\text{m}$). A similar procedure was followed by Bravo et al. (1998) to obtain fibre from *P. pallida*. After the purification process, 38.91% (PPF) related to PF was obtained. In relation to the whole fruit, the purification yield was 15.14%.

The yield of PPF was very similar to the value reported by Saura-Calixto (1988) in *Ceratonia siliqua* pods; both the species belong to the same botanical family. From the whole process (in relation to the pods), the yield of PPF was in the same range as that of other fibrous purified powders from orange (13.9%) and lime (18.4%; Fernández and Rodríguez, 2001).

Colour parameters showed differences in *L*, *b**, *C**, and *h*°, with the PF being more bright and yellowish (Table 3). The purification process may have leached some yellow components, producing a darker PPF. In comparison, the PF obtained by Bravo et al. (1998) from *P. pallida* had lower *L* value ($L = 58.82$) and a lower red contribution ($a^* = 4.99$), but similar *b** value. However, after water purification, they reported a more bright and yellowish flour. Thus, the difference in the colour of the flour obtained in the present study can be due to the acetone and ethanol used in the washing process, which may have dissolved some polyphenols and pigments. The water activity was 0.68 and 0.40 for PF and PPF, respectively. The water activity of the PPF guarantee microbiological stability of this flour, while the higher *aw* of PF, probably be due to the higher sugar content that allows higher water retention, make the flour safe just for bacteria and mold development.

Purification effect on the flow and technological properties

Table 4 shows the flow and technological properties of the flours. The BD, SD, and ER were higher in PF than in PPF. No differences were observed in RA, and PPF showed higher values in ET. The bulk densities of PF and PPF were low and similar to those observed in pineapple fibre (0.426 g/mL; Larrauri et al., 1995),

Table 4. Flow and technological properties of pod flour (PF) and purified pod flour (PPF)

Properties	PF	PPF
Bulk density (g/mL)	$0.46 \pm 0.002a$	$0.43 \pm 0.002b$
Setting density (g/mL)	$0.51 \pm 0.008a$	$0.47 \pm 0.003b$
Emptying time (s)	$2.63 \pm 0.15b$	$2.73 \pm 0.06a$
Emptying rate (g/cm ² s)	$10.02 \pm 0.57a$	$9.66 \pm 0.24b$
Resting angle (°)	$29.87 \pm 0.39a$	$29.19 \pm 0.26a$
Water retention capacity (mL/g)	$2.39 \pm 0.21a$	$2.21 \pm 0.01a$
Swelling (mL/g)	$5.16 \pm 0.00b$	$6.84 \pm 0.19a$
Fat absorption capacity (g/g)	$1.23 \pm 0.04b$	$1.62 \pm 0.00a$

Mean \pm standard deviation (SD). Different letters mean significant differences at $p < 0.05$.

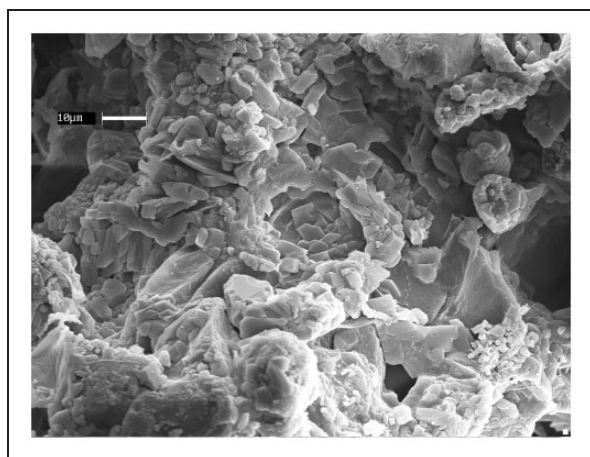
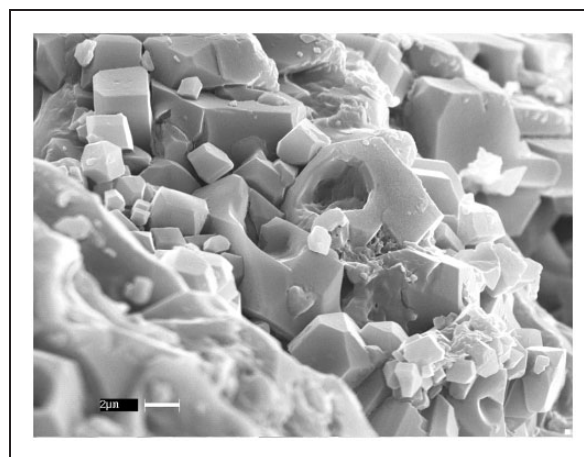
barley bran (0.478 g/mL; Fernández and Rodríguez, 2001), and cactus pear cladodes powder (0.35–0.45 g/mL; Sáenz et al., 2012). However, the SD was higher than BD, similar to that reported by Larrauri et al. (1995) in pineapple fibre (0.526 g/mL) and by Sáenz et al. (2012) in cactus pear cladodes powder (0.39–0.55 g/mL). The RAs observed were similar to that reported by Larrauri et al. (1995) in pineapple fibre (32.1°), and values close to 30° were found to be appropriate for pack filling. PPF showed higher values in WT than PF, and the values obtained in the present study were higher than those reported by Larrauri et al. (1995) for pineapple fibre (2.3 s).

PPF showed higher values in SWC and FAC. No differences were observed in WRC and the values obtained in this research were similar to that reported by Figuerola et al. (2005) in grapefruit fibre concentrate (2.09–2.26 g/g) and lower than that reported by other authors such as Bravo (1999) in *C. siliqua* powder (5.53 mL/g) and *P. pallida* (5.41 mL/g), and by Sáenz et al. (2012) in cactus pear cladodes powder (5.20 and 5.86 g/g), which could be due to the lower amount of soluble dietary fibre of the algarrobo pods. The higher value of SWC in PPF (6.84 mL/g) than in PF (5.16 mL/g) could be due to the higher insoluble dietary fibre content in PPF (Bravo, 1999). These values were similar to those reported by Figuerola et al. (2005) in fibre concentrate of apple (6.59–6.89 mL/g) and orange residues (6.11 mL/g). The values of FAC were higher in PPF (1.62 g/g), similar to that reported in purified cactus pear powder washed at 20°C (1.45–1.87 g/g), and in lemon (1.48 g/g), apple (1.45 g/g), and grapefruit (1.52 g/g) residues washed at 30°C (Figuerola et al., 2005). According to Femenia et al. (1997) and López et al. (1996), FAC depends on surface properties, overall charge density, thickness, and hydrophobic nature

Table 5. Temperature effect over the compression force (N) and rigidity (N/mm) of pod flour (PF) and purified pod flour (PPF)

Fibre type	Compression force (N)		Rigidity (N/mm)	
	18°C	80°C	18°C	80°C
PF	0.12 ± 0.00bA	0.21 ± 0.00aA	0.014 ± 0.00bA	0.021 ± 0.00aA
PPF	0.14 ± 0.01bA	27.80 ± 1.88aB	0.014 ± 0.00bA	2.781 ± 0.19bB

Different case letters mean significant differences between columns for each parameter. Different capital letters mean significant differences between rows ($p < 0.001$), according Duncan test.

**Figure 1.** Scanning electron microscopic photograph of pod flour (PF).**Figure 2.** Scanning electron microscopic photograph of sugar crystals in pod flour (PF).

of the fibre particle. According to Chau et al. (2004), the low BD and hydrophobicity could also play a role in elevating the capillary attraction of the powder, leading to a higher level of oil entrapment as well as FAC.

In PF and PPF, the texture, expressed as the compression force and rigidity of the gels at 18 and 80°C (Table 5), showed higher values at higher temperature. In both fibres, there was an increase in the compression force with the heat treatment, which was much higher in the PPF (from 0.14 to 27.8 N) than that in the PF (from 0.12 to 0.21 N). Also, the rigidity increased with the heat treatment from 0.014 to 0.021 N/mm for PF, and from 0.014 to 2.78 N/mm for PPF. This behaviour is in agreement with the values reported by Femenia et al. (1997) in cauliflower stems (27 N) and by Sáenz et al. (2012) in a cactus pear powder which changed with the heat treatment from 3.4 to 10.4 N (particle size < 600 μm). Chen et al. (2006) suggested the formation of a more solid food matrix and that, at a higher dissolution temperature, the molecules exhibited a much larger hydrodynamic radius due to sufficient hydration and extension, stronger molecular interaction, and more junction zones.

Scanning electron microscopy

The scanning electron microscopy (SEM) photographs revealed the physical structure of the Chilean algarrobo PF and PPF. PF is shown in Figure 1. Conglomerates of polyhedral structures can be seen, which may correspond to sugar crystals. According to Meyer et al. (1986), the sugar content in *Prosopis* spp. is mainly sucrose found in the pod pericarp. Figure 2 shows a close-up view of the sugar crystal and Figure 3 shows the PF tissue after the purification process (PPF), without sugar crystal and many voids, allowing broadening of the interaction area with water and other molecules. These observations are in agreement with the results of the sugar content (Table 1), which exhibited a high decrease in the total sugar content after the purification process as well as an increase in the total fibre content.

CONCLUSIONS

It can be concluded that the purification method yielded a concentrated source of dietary fibre with a major fraction of insoluble fibre as well as low values

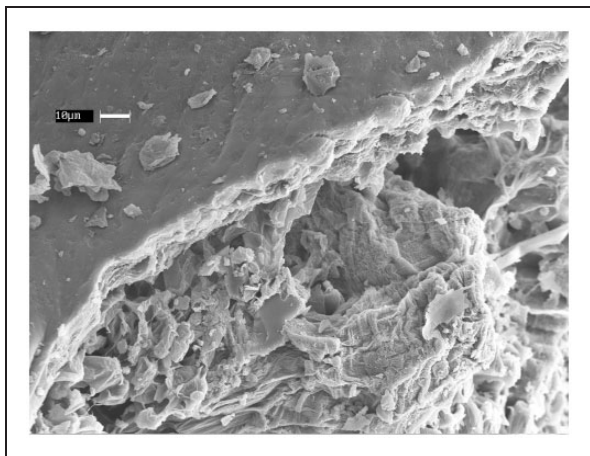


Figure 3. Scanning electron microscopic photograph of purified pod flour (PPF).

of total and reducing sugars, lipids, and calories. The technological properties and physical characteristics of the PPF would allow its use in food products, contributing to its volume, compressive strength, and WRC. PF showed good WRC due to a high content of total and reducing sugars, which would help in retaining moisture in the baked products. SEM analysis revealed the efficiency of the purification method with the removal of sugars.

FUNDING

The authors thank the partial support of the Grant FONDECYT No 1010245.

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