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Physicochemical properties of a fibrous fraction from chia (*Salvia hispanica* L.)

Vázquez-Ovando Alfredo, Rosado-Rubio Gabriel, Chel-Guerrero Luis, Betancur-Ancona David*

Facultad de Ingeniería Química, Universidad Autónoma de Yucatán, Avenida Juárez No. 421 Ciudad Industrial, Apdo. Postal 1226, Suc. Las Fuentes, C.P. 97288 Mérida, Yucatán, México

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ABSTRACT

An evaluation was done of some physicochemical properties of a fiber-rich fraction (FRF) obtained by dry processing of defatted chia (*Salvia hispanica*) flour. The fiber-rich fraction (FRF) had 29.56 g/100 g crude fiber content and 56.46 g/100 g total dietary fiber (TDF) content, of which 53.45 g/100 g was insoluble dietary fiber (IDF) and 3.01 g/100 g was soluble dietary fiber (SDF). The FRF water-holding capacity was 15.41 g/g, its water absorption capacity 11.73 g/g, and its organic molecule absorption capacity 1.09 g/g. The FRF also had low oil-holding (2.02 g/g) and water adsorption (0.3 g/g) capacities. Emulsifying activity in this fraction was 53.26% and emulsion stability was 94.84%. Its evaluated antioxidant activity was 488.8 μmol/L Trolox equivalents/g FRF, which is higher than for many cereals and similar to drinks such as wine, tea, coffee and orange juice. The chia FRF values for the evaluated properties, particularly for water-holding, oil-holding and organic molecule absorption capacity, suggest it could be a useful ingredient in dietetic products such as baked and fried foods, among others.

1. Introduction

The beneficial aspects of dietary fiber depend on its physicochemical properties, which group into four categories: (1) hydration properties (solubility, swelling, water-holding and absorption capacity, viscosity and gelling); (2) cationic exchange capacity; (3) particle size, density and surface characteristics (porosity and oil-holding capacity); and (4) organic molecule adsorption capacity (López et al., 1997). The principal physiological effect of fiber is its ability to swell when absorbing water, which occurs due to the presence of carbohydrates with free polar groups, interaction with hydrophilic links or retention within the matrix (López et al., 1997). These lead to formation of gel and a consequent increase in feces volume, which provokes more frequent peristaltic movements of the intestine. This in turn facilitates transit of the fecal bolus and intestinal distention, and thus aids in reducing the probability of intestinal tract disorders and constipation (Oliveira, Reyes, Sgarbieri, Areas, & Ramalho, 1991).

Fiber extracted from some grains and seeds exhibits physiological and functional properties that make it promising for use in food industry and health applications. This promise has led researcher to search for novel raw materials that meet needs in these areas, with a particular focus on the co-products of protein extraction or other components from raw materials such as legumes (Betancur-Ancona, Peraza-Mercado, Moguel-Ordoñez, & Fuertes-Blanco, 2004; Goff, Renard, Bonnin, & Thibault, 2001). There is a parallel interest in new sources of dietary fiber that contain concentrations comparable to those in cereal and legume subproducts such as wheat, rice and oat bran, lupine, etc. (Villarroel, Acevedo, Yánez, & Biolley, 2003).

Fiber source research has focused on tubers, cereals, vegetables, fruit and algae, all of which are characterized by high dietary fiber content with low digestibility and low caloric content. The fiber fraction from chia (*Salvia hispanica* L.) seed has similar characteristics. A native of southern Mexico, chia has been under cultivation in the region for thousands of years. Chia (*Salvia hispanica*, L.) was among the principal crops grown by ancient Mesoamerican cultures. Recent evaluation of chia's properties and possible uses has shown that it has a high content of oil (32%) and 60% of this, is linolenic acid, a fatty acid denominate omega-3 associated with various benefits to consumer health (Rosamond, 2002). However, after extracting the oil to the seeds, defatted chia has fiber (22 g/100 g) and protein (17 g/100 g) contents similar to those of other oilseeds currently used in the food industry (Ayerza & Coates, 1999). This product has not been object of great interest in the investigation. Also, they have been carried out a good number of investigations on the composition in fatty acids of the oil (Bushway, Wilson, Houston, & Bushway, 1984), the benefits that it contributes their consumption to the health and the inclusion of seeds in animal feeding (Ayerza & Coates, 1999).

Its high unsaturated oil content has gained its attention as a dietary component (Ayerza, 1995). Oil extraction in chia, however, produces a subfraction with relatively high dietary fiber content (33.9 g/100 g) (Craig & Sons, 2004), which also contains

* Corresponding author. Tel.: +52 999 460989; fax: +52 999 9460994.
E-mail address: bancona@uady.mx (B.-A. David).

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polyphenols (Taga, Miller, & Pratt, 1984), possibly involved in high antioxidant activity, and compounds conferring functional characteristics with food system applications. As part of an effort to determine possible applications for this fraction, an evaluation was done of the physicochemical and physiological properties of a high dietary fiber content fraction produced by dry processing of defatted chia (*S. hispanica*) flour.

2. Materials and methods

2.1. Seeds and chemicals

Chia (*S. hispanica* L.) seeds were obtained from the February 2000 harvest at Tapachula, Chiapas, Mexico (14°54′N, 92°56′W). All chemicals were reagent grade from J.T. Baker (Phillipsburg, NJ), and enzymes were from Sigma (Sigma Co., St. Louis, MO, USA).

2.2. Flours

The flours were produced with 10 kg seed. All impurities and damaged seeds were removed and the remaining sound seeds milled (Thomas-Wiley®, Model 4, Thomas Scientific, USA). Oil extraction from the milled seeds was done with hexane in a Friedrich system, using four refluxes of 80 min each. The remaining fraction was milled with 1 mm screen, a second oil extraction done and the remaining fraction milled with 0.5 mm screen.

2.3. Fibrous fraction

The fiber-rich fraction was obtained by dry fractionation of the defatted flour according to Otto, Baik, and Czuchajowska (1997). Briefly, 500 g flour was sifted for 20 min using a Tyler 100 mesh (140 μm screen) and a Ro-Tap® agitation system. The fiber-rich fraction was retained in the mesh and stored for later physiochemical property analysis.

2.4. Proximate composition

AOAC procedures were used to determine nitrogen (method 954.01), fat (method 920.39), ash (method 923.03), crude fiber (method 962.09), and moisture (method 925.09) contents of the fiber-rich fraction (AOAC, 1997). Nitrogen content (N_2) was determined with a Kjeltec Digestion System (Tecator, Sweden) using cupric sulfate and potassium sulfate as catalysts. Protein content was calculated as nitrogen × 6.25. Fat content was obtained from a 1 h hexane extraction. Ash content was calculated from the weight of the sample after burning at 550 °C for 2 h. Moisture content was measured based on sample weight-loss after oven-drying at 110 °C for 2 h. Carbohydrate content was estimated as nitrogen-free extract (NFE).

2.5. Total dietary fiber (TDF)

The dietary fiber fractions were determined following Prosky, Asp, Schweizer, Devries, and Furda (1988). Briefly, 1 g (d.b.) fiber samples were placed in four Erlenmeyer flasks (W_1) and weighed, 50 mL phosphate buffer (0.08 mol/L, pH 6) added, and pH adjusted to 6 with 0.325 mol equ/L HCl or 0.275 mol equ/L NaOH. The samples were placed in a water bath at 100 °C for 10 min, 0.1 mL α-amylase (Sigma A-3306) added to each, and incubated at 100 °C for 15 min under constant agitation. The flasks were cooled rapidly and the samples adjusted to pH 7.5. They were then placed in a water bath at 60 °C for 10 min, 0.1 mL protease solution added to each (Sigma P-3910, 50 mg in 1 mL phosphate buffer), and incubated at 60 °C for 30 min. The flasks were cooled and the samples adjusted to pH 4. They were replaced in the water bath at 60 °C until reaching this temperature, 0.3 mL amyloglucosidase (Sigma A-9913) added to each, and incubated for 30 min under constant agitation. Then, 95 mL/100 mL ethanol at 60 °C was added at a 1:4 sample/ethanol ratio and the mixture left in the water bath for 1 h. Samples were filtered at a constant weight into fiber crucibles containing a 1 g cap of Celite. The flasks were rinsed three times with 20 mL of 78 mL/100 mL ethanol, twice with 10 L of 95 mL/100 mL ethanol, and twice with 10 mL acetone. The crucibles were then placed in an oven at 130 °C for 1.5 h, and weighed (W_2). Two crucibles were placed in a furnace at 550 °C for 4 h (W_3), and crude protein determined using the contents of the remaining crucibles (W_4). Calculations were done using the formula:

$$\mathrm{TDF(g/100\ g)} = (W_2 - W_3 - W_4 - W_5) \times 100/W_1$$

where W_5 is reagent weight (blank).

2.6. Insoluble (IDF) and soluble dietary fiber (SDF)

The same method (Prosky et al., 1988) was used to quantify IDF, the only difference being that alcohol was not added to precipitate IDF. Calculation of sample IDF percentage was done in the same way as for TDF. Sample SDF was calculated by subtracting the IDF proportion from TDF.

2.7. Functional and physiological properties

2.7.1. Water-holding (WHC) and oil-holding capacity (OHC)

Both capacities were determined following Chau, Cheung, and Wong (1997). Briefly, 1 g (d.b.) of sample was weighed and then stirred into 10 mL distilled water or corn oil (density = 0.89 g/mL; Mazola, CPI International) for 1 min in a vortex (Thermolyne Vortexer). These fibrous suspensions were centrifuged at 2200*g* for 30 min and supernatant volume measured. Water-holding capacity was expressed as g of water held per g of sample, and oil-holding capacity as g of oil held per g of fiber.

2.7.2. Water adsorption capacity (WA_dC)

This property was determined according to Chen, Piva, and Labuza (1984). Briefly, 1 g (d.b.) of sample was placed in an equilibrium micro-environment at 98% relative humidity, generated by placing 20 mL of saturated potassium sulfate saline solution in tightly sealed glass flasks and placing these in desiccators at 25 °C. The sample was left in the micro-environment until reaching constant weight (72 h). Water adsorption capacity was expressed as g of water per g of sample.

2.7.3. Water absorption capacity (WA_bC)

This property was determined according to AACC (1984) method 88-04. Approximate water absorption capacity was first determined by weighing out 2 g (d.b.) of sample, adding water until saturation (approx. 40 mL) and centrifuging at 2000*g* for 10 min in a Beckman GS-15R centrifuge. Excess water was discarded and the residue weighed. Approximate water absorption capacity was calculated by dividing the increase in sample weight (g) by the quantity of water needed to complete original sample weight (2 g d.b.) to 15 g. Water absorption capacity (WA_bC) was then determined by placing samples in four tubes, adding different quantities of water to bracket the measurement (1.5 and 0.5 mL water above original weight, and 1.5 and 0.5 mL water below; one in each tube), agitating vigorously in a vortex for 2 min, and centrifuging at 2000*g* for 10 min in a Beckman GS-15R centrifuge. The supernatant was discarded and the residue weighed. Average water absorbed was calculated and the WA_bC calculated, expressed as g water absorbed per g of sample.

2.7.4. Emulsifying activity (EA) and emulsion stability (ES)

These properties were evaluated following Chau et al. (1997). Briefly, 100 mL of 2 g/100 mL fibrous suspension were homogenized using a Caframo RZ-1 homogenizer at 2000 rpm for 2 min. Then, 100 mL of corn oil (Mazola, CPI International) were added to each sample and homogenized for 1 min. The emulsions were centrifuged in 15 mL graduated centrifuge tubes at 1200*g* for 5 min, and emulsion volume measured. Emulsifying activity was expressed as the mL of the emulsified layer volume of the 100 mL entire layer in the centrifuge tube. Emulsion stability was determined by heating the prepared emulsions to 80 °C for 30 min, cooling them to room temperature and centrifuging at 1200*g* for 5 min. Emulsion stability was expressed as mL of the remaining emulsified layer volume of 100 mL the original emulsion volume.

2.7.5. Organic molecule absorption capacity (OMAC)

Organic molecule absorption capacity was determined according to Zambrano, Meléndez, and Gallardo (2001). A 3 g (d.b.) sample was placed in an excess quantity of corn oil (approx. 10 mL) for 24 h at 25 °C, and then centrifuged at 2000*g* and 25 °C for 15 min in a Beckman GS-15R centrifuge. Organic molecule absorption capacity was expressed as the absorbed hydrophobic component and calculated in terms of sample weight gain (g oil/sample g).

2.7.6. Antioxidant activity

Phenolic compounds were extracted according to Iqbal, Bhanger, and Anwar (2005). A 5 g (d.b.) sample was weighed, 20 mL of 80 mL/100 mL methanolic solution added to it and then agitated magnetically for 3 h at 25 °C. It was then centrifuged at 2500*g* for 15 min, and the sediment submitted to a second extraction under the same conditions. Both resulting extracts were centrifuged again at 2500*g* for 15 min, the two supernatants mixed and filtered through Whatman 41 paper. Antioxidant activity in this filtrate (approx. 17 mL) was quantified with an $ABTS^+$ decolorization assay according to Sánchez-González, Jiménez-Escrig, and Saura-Calixto (2005). The $ABTS^+$ radical cation was produced by reacting the ABTS with potassium persulfate. The stock solution was prepared by dissolving 2 mmol/L ABTS in 50 mL phosphate buffer saline (PBS) prepared from 8.1816 g NaCl, 0.2694 g KH_2PO_4, 1.4196 g Na_2HPO_4, and 0.1498 g KCl dissolved in 1 L ultrapure water. If lower than 7.4, pH was adjusted with NaOH. The $ABTS^+$ radical cation was produced by reacting 20 mL ABTS stock solution with 80 μL of $K_2S_4O_8$ solution (prepared with 70 mmol/L $K_2S_4O_8$ solution in ultrapure water) and allowing the mixture to stand at room temperature in darkness for 16 h before use. The radical remained stable in this form for more than 48 h when stored at room temperature in darkness. Antioxidant compounds were measured by diluting the $ABTS^+$ solution with PBS to an absorbance of 0.800 ± 0.030 AU at 734 nm; this value was considered blank absorbance. Sequential dilutions of 4 mmol/L Trolox stock solution (10 mg of 6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid in 80 mL/100 mL methanolic solution) were done to produce concentrations of 3.5, 2.5, 1.5, 1.0 and 0.5 mmol/L. After addition of 990 μL diluted $ABTS^+$ solution to 10 μL Trolox standard, absorbance (734 nm) was measured at room temperature exactly 6 min after initial mixing. The appropriate solvent blanks were run in each assay. All determinations were done in triplicate. The same procedure was repeated, mixing 990 μL $ABTS^+$ solution + 10 μL sample solution, and the percentage decrease in absorbance at 734 nm calculated and plotted as a function of Trolox concentration for the standard reference data. The Trolox equivalent antioxidant coefficient (TEAC) was calculated by comparing the slope of the absorbance inhibition percentage plot to the antioxidant concentration divided by the slope of the Trolox plot.

2.8. Statistical analysis

All determinations were done in triplicate. Statistical analysis was done to determine the data's central tendency and standard deviation using the Statgraphics plus 5.1 computer software.

3. Results and discussion

3.1. Proximate composition

Proximate composition analysis showed fiber content to increase from 26.5 g/100 g in the chia flour to 29.56 g/100 g in the chia fiber-rich fraction (FRF) (Table 1), an increase that could be reflected more in TDF than crude fiber content. This increase may not seem substantive, but the FRF fiber content is appropriate for a fibrous product. The FRF also had a higher fiber content than *Canavalia ensiformis* fibrous residue (22.68 g/100 g) extracted by wet milling (Betancur-Ancona et al., 2004), suggesting that the dry processing method used here is viable. As fiber content increased, crude protein content decreased. Ash content also decreased, possibly because minerals remain in the smaller sized fractions of seed flours (Craig & Sons, 2004).

3.2. Total (TDF), soluble (SDF) and insoluble (IDF) dietary fiber

Total dietary fiber (TDF) content in the chia FRF was 56.46 g/100 g (Table 2), with most of this content represented by IDF (53.45 g/100 g) and the remainder by SDF (3.01 g/100 g). Compared to the fiber values reported by Craig and Sons (2004) for chia seeds (TDF: 33.91 g/100 g; IDF: 30.43 g/100 g; SDF: 3.07 g/100 g), the present values show that dry fractionation with 100 mesh effectively concentrated TDF content. The chia FRF had an IDF/SDF proportion generally similar to that reported for fibrous residues of the legume *C. ensiformis*. Its SDF content differed from that reported for many fruits such as passion fruit (Table 2), orange (peel) (TDF: 57 g/100 g; IDF: 47.6 g/100 g ; SDF: 9.4 g/100 g) (Chau & Huang, 2003) and guava (64.1 g/100 g; 55.2 g/100 g; 8.9 g/100 g) (Ruales & Zumba, 1998). The relatively high IDF percentage in chia FRF suggests possible applications in dietetic–physiological products. Intake of this kind of fiber is linked to a sensation of satiety, since as the fiber absorbs water it takes up space in the stomach and diminishes the need to consume more food. It also increases the volume and weight of the fecal bolus, promoting improved functioning of the digestive system and preventing disorders such as constipation and colon cancer.

3.3. Functional and physiological properties

3.3.1. Water-holding capacity (WHC)

Water-holding capacity is the ability of a moist material to retain water when subjected to an external centrifugal gravity force or compression. It consists of the sum of linked water, hydrodynamic water and physically trapped water, the latter of which contributes most to this capacity. The chia FRF exhibited a WHC of 15.4 times its

Table 1
Proximate composition of chia (*Salvia hispanica*) fiber-rich fraction (FRF) compared to defatted flour (g/100 g d.b.)

Component	Chia FRF	Defatted flour
Moisture	(6.96 ± 0.02)	(6.87 ± 0.10)
Protein	28.14 ± 0.36	32.24 ± 0.17
Crude fiber	29.56 ± 0.07	26.50 ± 0.28
Fat	0.46 ± 0.00	0.45 ± 0.02
Ash	6.51 ± 0.04	7.09 ± 0.02
Nitrogen-free extract (NFE)	35.33 ± 0.38	33.72 ± 0.49

Table 2
Dietary fiber fractions of chia (*Salvia hispanica*) compared to other fiber sources (g/100 g d.b.)

Component	Chia FRF	Jack bean FRF[a]	Passion fruit FRF[b]
Total dietary fiber	56.46 ± 0.35	55.88	63.25
Insoluble dietary fiber	53.45 ± 1.62	52.49	46.75
Soluble dietary fiber	3.01 ± 0.28	3.38	16.50

[a] Betancur-Ancona et al. (2004).
[b] Cruz-Salazar (2002).

weight. This is higher than reported for fibrous residues from soy bean, shoyu (a soy derivative), wheat and maize hulls (Fig. 1). This WHC is also higher than the fibrous residues of some fruits with higher SDF content, such as the 7.2 g water/g sample of passion fruit (Cruz-Salazar, 2002), and the 8.39 g water/g sample of orange fiber (Tamayo & Bermudez, 1998). The chia FRF had an IDF content similar to the 16.2 g water/g sample of orange (Chau & Huang, 2003). This demonstrates that even though the SDF content of the chia FRF was comparatively low, it still had comparable WHC. This may be due to the polysaccharide and non-polysaccharide compounds in this fiber, or, in the specific case of chia FRF, to the fact that the mucilages in the seeds may act like SDF. These mucilages do not quantify in the SDF because some components may not precipitate during the ethanol treatment for SDF determination and therefore SDF may be underestimated (Saura-Calixto & García-Alonso, 2001). This mucilaginous fraction may contribute to WHC since mucilages are known to have excellent water-holding properties. Fiber structure may also augment WHC (López et al., 1996), and the high proportions of hemicellulose and lignin (both have a certain amount of WHC) in the chia FRF may have increased this property. A fiber's WHC is highly indicative of its physiological role in intestinal function and blood sugar level control (Wolever, 1990). Some vegetable fibers with high WHC have been employed as meat product ingredients (Dalgetty & Baik, 2003). Chia FRF has possible applications in products requiring hydration, viscosity development and conservation of freshness, such as baked goods.

3.3.2. Oil-holding capacity (OHC)

In contrast to its WHC, the chia FRF had a low oil-holding capacity (OHC) of 2.02 g oil/g sample (Fig. 2). This is similar to the OHC of fiber residues of *C. ensiformis*, barley and passion fruit (1.99 g oil/g sample; Cruz-Salazar, 2002). It is higher than the 1.09 g oil/g sample of flour from *Jessenia polycarpa* fruit (Belén, Alemán, Alvarez, & Alvarez, 2004), but lower than the OHC of soya (shoyu) and pea fibrous residues (Fig. 2), and the 3.36 g oil/g sample of orange peel IDF (Chau & Huang, 2003). Particle size may influence

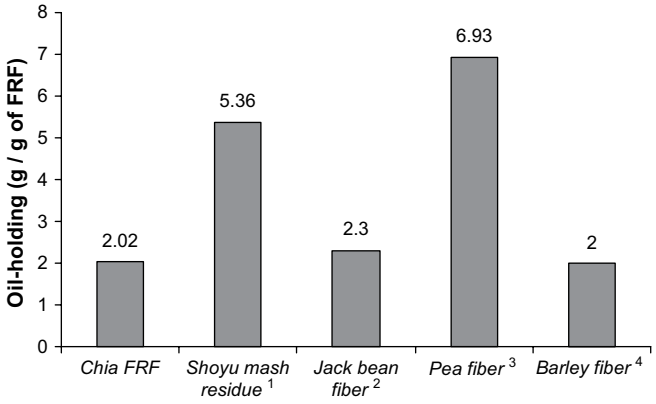

Fig. 2. Oil-holding capacity of chia (*Salvia hispanica*) compared to other fiber sources ([1]Yeh et al., 2005; [2]Betancur-Ancona et al., 2004; [3]Dalgetty & Baik, 2003; [4]Mongeau & Brassard, 1982).

OHC in that smaller particles have relatively more contact surface and therefore would theoretically be able to hold more oil (López et al., 1996). In this sense, it is possible the chia FRF particles were not small enough to increase this property. The method used to produce the fraction may also influence OHC; for example, treatment with alcohol can expose lipophilic components (Chau & Huang, 2003). The chia FRF extracted here was not exposed to any chemical processes and did not exhibit lipophilic behavior. Due to its low OHC, the chia FRF is a potential ingredient in fried products since it would provide a non-greasy sensation.

3.3.3. Water absorption (WA_bC) and adsorption (WA_dC) capacities

Water absorption capacity is indicative of a structure's aptitude to spontaneously absorb water when placed in contact with a constantly moist surface or when immersed in water and water adsorption capacity is the ability of a structure to spontaneously adsorb water when exposed to an atmosphere of constant relative humidity. It is initially a surface phenomenon but at higher hydration levels absorption can occur inside the structure, leading to swelling and eventual solubilization. The chia FRF had a water absorption capacity of 11.73 g water/g sample, which is almost double that of carrot (6.36 g water/g sample) and beet (6.04 g water/g sample) (Zambrano et al., 2001), and nearly three times greater than maize, wheat or soy hulls (Fig. 3). Selvedran and Stevens (1985) link vegetable cell wall composition to WA_bC behavior, meaning vegetable type affects this property. This may also manifest the possible underestimation of SDF since its components have good WA_bC. A possible additional effect is that the proteins in the chia FRF (28.14 g/100 g d.b.) (Table 1) may be denaturalized due to

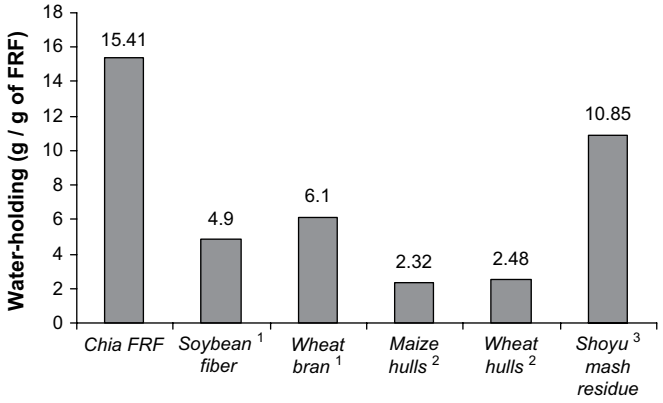

Fig. 1. Water-holding capacity of chia (*Salvia hispanica*) compared to other fiber sources ([1]Mongeau & Brassard, 1982; [2]Zambarano et al., 2001; [3]Yeh et al., 2005).

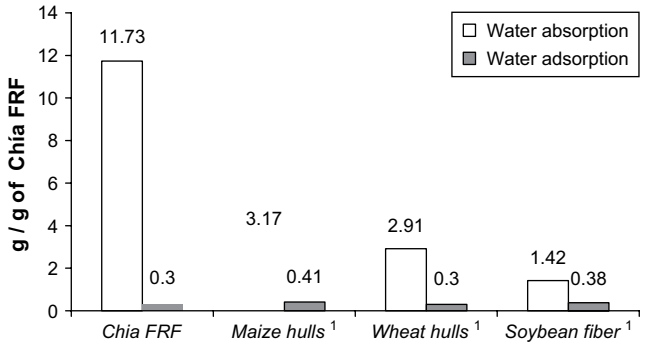

Fig. 3. Water absorption (WA_bC) and adsorption (WA_dC) capacities of chia (*Salvia hispanica*) compared to other fiber sources ([1]Zambrano et al., 2001).

the effect of the solvent and heat treatment during defatting. In this case, the proteins would have a large number of exposed hydrophilic sites that could be interacting with water and increasing WA_bC. However, denaturalization would also expose hydrophobic sites and thus favor protein–protein interaction that would reduce WA_bC (Yeh, Su, & Lee, 2005).

The chia FRF water adsorption capacity was 0.3 g water/g sample, which is substantially lower than values for carrot (0.82 g water/g sample) and beet (1.58 g water/g sample) (Zambrano et al., 2001), and similar to those of maize, wheat and soy hulls (Fig. 3). The IDF is responsible for most WA_dC since it adsorbs water like a sponge, however, no direct relation between IDF and WA_dC was observed here or in commercial products with similar IDF contents (Pérez-Navarrete, 2003).

3.3.4. Emulsifying activity (EA) and emulsion stability (ES)

Emulsifying capacity is a molecule's ability to act as an agent that facilitates solubilization or dispersion of two immiscible liquids and emulsion stability is the ability to maintain an emulsion and its resistance to rupture. Emulsifying activity (EA) of the chia FRF was 53.26 mL/100 mL and its emulsifying stability (ES) was 94.84 mL/100 mL. This EA is similar to that reported by Pérez-Navarrete (2003) for fiber-rich passion fruit powders and that reported by Betancur-Ancona et al. (2004) for *Phaseolus lunatus* fibrous residue (Fig. 4). The 28.14 g/100 g protein content of the chia FRF may be contributing to this EA, since most proteins are strong emulsifying agents (Karleskind, Laye, Morr, & Schenz, 1996). It is noteworthy, however, that passion fruit fiber (Pérez-Navarrete, 2003), which has similar EA and ES to the chia FRF, does not have significant protein content. Given that its ES is greater than 94 mL/100 mL, the chia FRF studied here may be a good emulsifying agent (poor ES is approx. 50 mL/100 mL). It can therefore be used, and should function well, in foods requiring emulsion formation and ones with long shelf life. The EA of a fibrous residue is also very indicative of its ability to adsorb biliar acids. This has potential health benefits since a fibrous component adsorbs biliar acids and increases feces excretion, consequently limiting absorption of these acids in the small intestine and therefore reducing blood cholesterol levels. Consequently, incorporation of chia FRF into foods may have a hypocholesterolemic effect (López et al., 1997).

3.3.5. Organic molecule absorption capacity (OMAC)

The chia FRF organic molecule absorption capacity (OMAC) was 1.09 g oil/g sample, similar to that reported for beet (1.25 g oil/g sample; Zambrano et al., 2001). This capacity is lower than that of maize and wheat hulls (Fig. 5), and higher than that of soy hulls (Zambrano et al., 2001) and passion fruit fibrous residue (0.28 g oil/g sample; Pérez-Navarrete, 2003). Given its OMAC, the chia FRF could function efficiently interacting with fats, biliar acids, cholesterol, drugs and even toxic or carcinogenic compounds at the intestinal level, as has been reported for other fibers (Scheneeman, 1987). These would then be eliminated in the feces (Zhang, Lundin, & Hallman, 1994). Lignin, an IDF component, is probably the main compound responsible for OMAC in the chia FRF since, like other soluble compounds (pectin, guar gum), it is among the fiber components with the highest capacity to link to organic molecules. As a result, fractions with high IDF content, such as the chia FRF, more effectively absorb organic molecules (López et al., 1997), as is the case with wheat and maize hulls (Zambrano et al., 2001). Incorporation of chia FRF into foods would therefore provide the physiological benefits of its high OMAC.

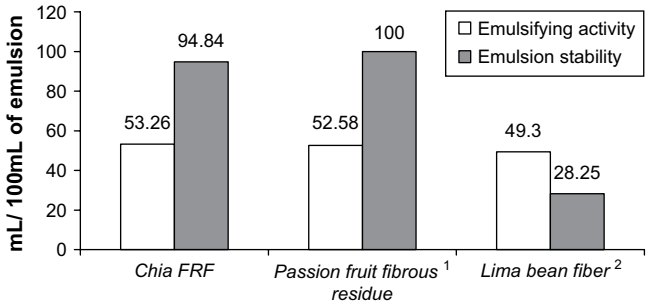

Fig. 4. Emulsifying activity (EA) and emulsion stability (ES) of chia (*Salvia hispanica*) compared to other fiber sources ([1]Pérez-Navarrete, 2003; [2]Betancur-Ancona et al., 2004).

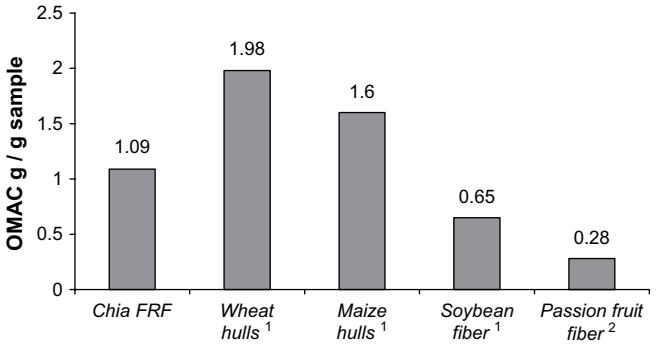

Fig. 5. Organic molecule absorption capacity (OMAC) of chia (*Salvia hispanica*) compared to other fiber sources ([1]Zambrano et al., 2001; [2]Pérez-Navarrete, 2003).

3.3.6. Antioxidant activity

Antioxidant activity in the chia FRF was 488.8 μmol Trolox equivalents (TE)/g (Table 3), similar to that of sorghum bran with high tannin content (Awika, Rooney, Wu, Prior, & Cisneros-Zevallos, 2003) and to those of high antioxidant drinks such as ground coffee (Sánchez-González et al., 2005), tea (631 μmol TE/100 mL) and orange juice (249 μmol TE/100 mL). The chia FRF value is higher than those for some wheat grains and sorghum (Iqbal et al., 2005; Ragaee, Abdel-Aal, & Noaman, 2006), and half that of red wine, which has one of the highest antioxidant activities (1093 μmol TE/100 mL; Saura-Calixto & Goñi, 2006). This activity in chia FRF is especially significant compared to the above drinks since the ration used here was 1 g and that in the other reports was 100 mL. This high antioxidant activity in chia FRF is mainly due to the presence of caffeic and chlorogenic acids, as well as other phenolic compounds in chia (Taga et al., 1984). Among the latter is quercetine, one the most powerful and stable pure compounds for which antioxidant activity has been evaluated (Huang, Ou, & Prior, 2005). Given the above, as little as 7 g of chia FRF could contribute substantially to trapping free radicals, and to meeting total dietary antioxidant activity levels (quantified as 3549 μmol TE/day in a Mediterranean diet) (Saura-Calixto & Goñi, 2006).

Table 3
Antioxidant activity of chia (*Salvia hispanica*) fiber-rich fraction (FRF) measured as $ABTS^+$ decolorization and compared to other sources

Source	Trolox equivalent antioxidant coefficient (TEAC, μmol/g)
Chia FRF	488.8
Wheat bran	48.5[a]
Sorghum grain	51.7[b]
Sorghum bran (tannin-rich)	512[c]
Freeze-dried coffee	450[d]

[a] Iqbal et al. (2005).
[b] Ragaee et al. (2006).
[c] Awika et al. (2003).
[d] Sánchez-González et al. (2005).

4. Conclusion

The fiber-rich fraction of chia (*S. hispanica*) had a high proportion of TDF (56.46 g/100 g), composed mainly of IDF (53.45 g/100 g) with a low SDF content (3.01 g/100 g). Its water-holding capacity (15.41 g/g), water absorption capacity (11.73 g/g) and organic molecule absorption capacity (1.09 g/g) were all high. In contrast, its oil-holding capacity (2.02 g/g) and water adsorption capacity (0.3 g/g) were low. Its emulsifying activity was 53.26 mL/100 mL with high emulsion stability (94.84 mL/100 mL). The chia FRF exhibited high antioxidant activity (488.8 μmol TE/g FRF), which confirms the presence of polyphenols. The physicochemical properties described here indicate the chia fiber-rich fraction to be a potential ingredient in health and diet food products such as powders, nutrition bars, breads and cookies.

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