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Nutritional and Physicochemical Characterization of Vegetable Fibres in Order to Obtain Gelled Products †

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Abstract: The aim of this research was to evaluate the nutritional and physicochemical properties of two combination of vegetable fibres (FBPC: bamboo, *Psyllium* and citric fibre and FPESB: pea, cane sugar and bamboo fibre) and the possibility of using them as a thickener or gelling agent in food. To determine the technological, nutritional and physical parameters the following analysis were carried out: water holding capacity, water retention capacity, swelling, fat absorption capacity, solubility, particle size, moisture, hygroscopicity, water activity, bulk density, porosity, antioxidant activity, phenolic compounds and minerals content. In addition, gels were prepared at concentrations 1 to 7% at 5 °C and analysed at 25 °C before and after a treatment at 65 °C for 20 min. Back extrusion test, pH and colour were carried out. As results, both samples showed significant differences in all tested parameters. Hydration properties of FBPC were higher than in FPESB, but at the functional level high values were found in FPESB. Moreover, FPESB was a source of minerals with an important content of Fe. In gels, significant differences in textural properties were found between samples and also due to the treatment used but further studies are needed to explore their use in the development of functional food products.

Keywords: vegetable fibres; minerals; antioxidant capacity; gelling agent

1. Introduction

There is an increase in consumers interest in health, sustainability aspects of their way of living and their diet. They demand more natural and less processed food that are made using ingredients which are not perceived negatively [1].

Hence, it is a well-known fact that hydrocolloids change the physical properties of the solution to form gels, or enable thickening, emulsification, coating, stabilization, and also provide viscosity and play a role in developing food with high satiating capacity [2]. Besides functional qualities, hydrocolloids have also received enthusiastic countenance due largely to the dietary fibre aspect of food hydrocolloids [2]. This aspect is important for the beneficial effects on health as a dietary fibre (DF), as well as a prebiotic ingredient and its technological attributes such as water binding, gelling, structure building. Therefore, it could be used as a low-calorie sweetener, fat replacer or texture modifier [2,3].

For these reasons, designing future food structures by structuring food colloids such as fibre is of great theoretic and application value, for example, for its use in functional food products aimed at

elderly people with swallowing problems, special food products for diabetes or artificial plant-based meats for vegan and vegetarians [4].

The main purpose of this research was to evaluate the nutritional and physicochemical properties of two different combination of vegetable fibres and the possibility of using them as a thickener or gelling agent in food.

2. Materials and Methods

2.1. Raw Materials

Both samples used in this study were a combination of DFs supplied by the company Productos Pilarica S.A., Paterna, Spain. FBPC a combination of bamboo, *Psyllium* and citric fibre, and FPESB a combination of pea, cane sugar and bamboo fibre.

2.2. Physicochemical Analysis

Moisture (x_w) (g water/100 g sample) was determined by vacuum oven drying (Vaciotem, J.P. Selecta, Spain) at 70 °C until constant weight.

Water activity (aw) of the samples was analysed by the AquaLab PRE LabFerrer equipment (Pullman, DC, USA).

Hygroscopicity (Hg) was determined according to Cai, & Corke [5].

Samples particle size distribution was determined according to the ISO13320 normative (AENOR 2009) using a particle size analyser (Malvern Instruments Ltd., Mastersizer 2000, UK) equipped with a dry sample dispersion unit (Malvern Instruments Ltd., Scirocco 2000). The particle size distribution was characterized by the volume mean diameter (D [4.3]).

The porosity (ε) was determined from the true (ρ) and bulk (ρ_b) densities according to Agudelo et al. [6] with slight modifications.

2.3. Hydration Properties

Water-holding capacity (WHC) and water retention capacity (WRC) was described by Raghavendra et al. [7] and Chantaro et al. [8], respectively.

Swelling water capacity (SWC) and fat adsorption capacity (FAC) was described by Navarro-González et al. [9] with minor modifications.

Water solubility index (WSI) was analysed according to the method of Mahdavi et al. [10] with small modifications.

2.4. Antioxidant Capacity and Phenolic compounds

Antioxidant capacity (AOA) was assessed using DPPH method following Igual et al. [11] methodology.

Total phenol content (PC) was carried out according to Agudelo et al. [6].

2.6. Mineral Analysis

The multi-mineral determination was analysed using inductively coupled plasma optical emission spectrometer, model 700 Series ICP-OES from Agilent Technologies (Santa Clara, United States), with axial viewing and a charge coupled device detector [12]. Mineral composition (macro and microelements) were expressed as mg/100 g.

2.7. Gel Preparation

The samples were dissolved in cold water (5 °C) during 30 min at concentrations 1, 2, 3, 4, 5, 6 and 7%. Samples were divided in two batch. One of them was directly stored 24 h at 5 °C until the stabilisation of the gels. However, the other batch was heated at 65 °C for 20 min before being stored 24 h at 5 °C. All samples were analysed after this stored at 25 °C.

2.8. Gel Analysis: pH, Colour and Texture

The pH of the gel samples was measured using a pH-meter Crison MultiMeter MM 41 (Hach Lange, Spain).

To determine the colour of the gel's translucency and CIE*L*a*b* colour were carried out according to García-Segovia et al. [12].

Textural characteristics were evaluated by using a TA-XT2 Texture Analyser (Stable Micro Systems Ltd., Godalming, UK). Back extrusion test was performed following the method described by Cevoli et al. [13] with minor modifications.

2.9. Statistical Analysis

Analysis of variance (ANOVA), with a confidence level of 95% ($p < 0.05$), was applied to evaluate the differences among samples, using Statgraphics Centurion XVII Software, version 17.2.04.

3. Results and Discussion

Table 1 shows the physicochemical and hydration properties of samples studied. In general, significant ($p < 0.05$) differences were found between samples, except for Hg. FBPC showed higher moisture than FPESB, these values were lower than those found by de Moraes Crizel [5] for orange fibres. The values of a_w were within the ideal range of 0.11 to 0.40 [5].

Table 1. Physicochemical and hydration properties of fibres tested.

	Mix of Vegetable Fibres	
	FBPC	**FPESB**
Moisture (%)	6.676 ± 0.104 [a]	5.7 ± 0.3 [b]
Water activity (a_w)	0.3590 ± 0.0012 [a]	0.342 ± 0.002 [b]
Hg (g water/100 g dry solid)	26.7 ± 0.7 [a]	27.3 ± 0.2 [a]
Bulk density (g/L)	489 ± 17 [a]	354 ± 10 [b]
Porosity	69.22 ± 0.95 [b]	77.51 ± 0.12 [a]
D[4,3] (μm)	142.6 ± 0.3 [b]	156 ± 2 [a]
WHC (g water/g sample)	21.197 ± 0.097 [a]	6.18 ± 1.03 [b]
WRC (g water/g sample)	8.7 ± 0.8 [a]	4.9 ± 0.3 [b]
SWC (mL water/g sample)	8 ± 2 [a]	9.2 ± 0.8 [a]
FAC (g oil/g sample)	1.44 ± 0.03 [b]	1.91 ± 0.03 [a]
WSI (%)	19.4 ± 0.2 [a]	6.28 ± 0.02 [b]
PC (mg gallic/100 g sample)	52.6 ± 0.7 [b]	64 ± 7 [a]
AOA (mg trolox/100 g sample)	12.4 ± 0.8 [b]	19.7 ± 0.7 [a]

Hg: hygroscopicity; WHC (Water holding capacity); WRC (Water retention capacity); SWC (Swelling capacity); WSI (Solubility); FAC (Fat absorption capacity); PC: phenolic compounds; AOA: antioxidant activity. Results are the mean of three determination ± standard deviation. Different letter in the same row are significantly different as determined by LSD test ($p < 0.05$).

The lowest bulk density was showed by FPESB, this value was lower than that obtained by Lan et al. [14] for DFs from *Polygonatum odoratum* and cellulose. Particle size distribution of samples was similar (Figure 1), but the sample FPESB showed a high D [4,3] (Table 1).

FBPC presented greater values of almost hydration properties such as WHC, WRC and SWC. But FPESB showed a high solubility and fat absorption.

The sample which showed great antioxidant activity and phenols content was FPESB, although these values were lower than those obtained by Navarro-González et al. [11] for tomato peel fibre.

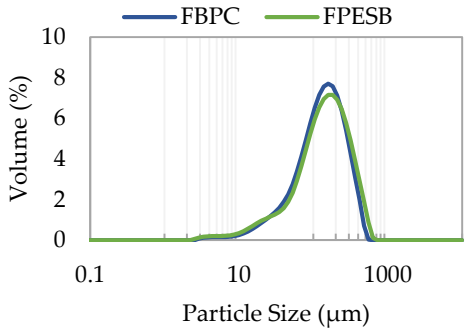

Figure 1. Volume of particle size distributions (representative curves) of fibres studied.

Table 2 showed mineral content of both DFs. In general, FPESB showed a greater mineral content. Values that should be highlighted were Fe content, and also other trace elements such as manganese and zinc, which was only detected in this sample. The values for K, Ca, Mg and Fe were similar to some obtained by Ma, and Mu [15] for DFs obtained from deoiled cumin.

Table 2. Mineral content of samples expressed in mg/100g.

	Mix of Vegetable Fibres	
	FBPC	**FPESB**
P	7.9 ± 0.7 [b]	32.9 ± 1.4 [a]
K	167 ± 14 [a]	141 ± 7 [b]
Ca	96 ± 3 [b]	340 ± 16 [a]
Na	40 ± 4 [b]	60 ± 3 [a]
Mg	3.706 ± 1.002 [b]	107 ± 4 [a]
Zn	– [b]	0.58 ± 0.03 [a]
Fe	1.6 ± 0.3[b]	4.2 ± 0.5 [a]
Mn	– [b]	0.75 ± 0.06 [a]

Results are the mean of three determination ± standard deviation. Different letter in the same row are significantly different as determined by LSD test ($p < 0.05$).

Table 3 showed results of gel's analysis. An interaction between samples and concentrations was observed for both the unheated and heated samples. A decrease in pH was shown as the concentration increases, being this decrease more intense in the case of the FPESB sample. Furthermore, for both samples an interaction between temperature and concentrations was also observed with a pH greater decrease in unheated concentrations.

For both samples unheated and heated colour coordinates (L*, a*, and b*) were increasing as the DFs concentration was increasing (Table 3), the values of FBPC were always significantly ($p < 0.05$) higher than those for FPESB. Just in case of FPESB for a* and b* it was observed an interaction between concentrations and temperature, showing samples unheated (FPESB) for 1–3% concentration a significantly ($p < 0.05$) greater increase than heated (65FPESB).

Back extrusion assay showed that not only the consistency and firmness of gels were increasing as gel's DFs concentration increase, but also the viscosity and cohesiveness in both samples (Table 3). For both samples and for all texture parameters an interaction was shown between concentration and temperature. It was observed a significant ($p < 0.05$) increase in all parameters from concentration 3%. In this way, the sample which presented the greater consistency was 65FBPC (7%). The values of consistency, firmness and cohesiveness were higher in 65FBPC (4%), but this sample presented lower viscosity than that found by Cevoli et al. [13] for xanthan gum (4%). Although, comparing it with 65FPESB (4%), both showed similar consistency and cohesiveness, however 65FPESB (4%) presented a higher strength and lower viscosity. In short, the physicochemical, functional and nutritional properties of both combinations of vegetable fibres, as well as their ability to form gels, make it

possible to use them to modify the texture of different foods and provide the benefits of DF consumption.

Table 3. Results (mean ± deviation) of gel analysis.

Sample	C (%)	pH	L *	a *	b *	Consistency (Ns)	Firmness (N)	Viscosity (Ns)	Cohesiveness (N)
FBPC	1	6.90 ± 0.02 ^{a,B}	11 ± 2 ^{I,I}	−0.16 ± 0.05 ^{g,h,i,D,E}	−0.9 ± 0.3 ^{g,J}	1.006 ± 0.013 ^{h,F}	0.187 ± 0.003 ^{h,F}	0.054 ± 0.002 ^{g,G}	0.143 ± 0.007 ^{g,H}
	2	6.7 ± 0.3 ^{c,D}	13.4 ± 0.7 ^{h,G}	−0.13 ± 0.04 ^{g,h,C,D}	0.47 ± 0.13 ^{f,G}	1.02 ± 0.02 ^{h,F}	0.1912 ± 0.0103 ^{h,F}	0.057 ± 0.005 ^{g,G}	0.158 ± 0.012 ^{g,H}
	3	6.22 ± 0.03 ^{e,F}	14 ± 0.5 ^{g,h,G}	−0.23 ± 0.02 ^{i,F}	−0.470 ± 0.098 ^{g,H}	1.884 ± 0.102 ^{g,h,F}	0.377 ± 0.019 ^{g,h,F}	0.221 ± 0.014 ^{f,g,G}	0.30 ± 0.04 ^{g,H}
	4	6.09 ± 0.06 ^{f,G}	17.0 ± 0.2 ^{f,F}	−0.21 ± 0.03 ^{h,i,E,F}	0.43 ± 0.08 ^{f,G}	6.5 ± 0.5 ^{f,E,F}	1.267 ± 0.106 ^{f,g,E,F}	0.71 ± 0.05 ^{e,F}	1.05 ± 0.04 ^{f,G}
	5	5.98 ± 0.02 ^{g,I}	20.3 ± 0.4 ^{e,E}	−0.118 ± 0.009 ^{g,C,D}	0.77 ± 0.12 ^{f,F}	12.4 ± 1.5 ^{e,E}	2.2 ± 0.3 ^{e,f,E}	1.33 ± 0.07 ^{d,E}	1.911 ± 0.096 ^{e,F}
	6	5.99 ± 0.07 ^{g,I}	26.7 ± 0.5 ^{c,B}	0.10 ± 0.05 ^{f,B}	2.78 ± 0.13 ^{e,C}	27 ± 3 ^{c,D}	4.7 ± 0.4 ^{c,D}	2.26 ± 0.15 ^{c,D}	3.22 ± 0.13 ^{d,E}
	7	5.9 ± 0.5 ^{i,J}	28.0 ± 0.4 ^{b,c,A}	0.19 ± 0.03 ^{e,A}	3.43 ± 0.15 ^{c,d,A}	42 ± 8 ^{a,C}	8 ± 2 ^{a,C}	3.6 ± 0.5 ^{b,C}	5.5 ± 0.7 ^{b,C}
65FBPC	1	7.16 ± 0.02 ^{z,A}	12 ± 2 ^{q,H,I}	−0.16 ± 0.05 ^{v,D,E}	−0.8 ± 0.2 ^{s,I,J}	1.05 ± 0.02 ^{s,F}	0.1902 ± 0.0112 ^{s,F}	0.054 ± 0.003 ^{t,G}	0.149 ± 0.002 ^{t,H}
	2	6.8 ± 0.3 ^{y,C}	13 ± 2 ^{r,q,G,H}	−0.15 ± 0.06 ^{v,D}	−0.4 ± 0.2 ^{s,H}	2.28 ± 0.18 ^{s,F}	0.73 ± 0.03 ^{t,s,F}	0.149 ± 0.015 ^{t,G}	0.2200 ± 0.0115 ^{t,H}
	3	6.28 ± 0.03 ^{v,F}	13.5 ± 0.5 ^{r,G}	−0.26 ± 0.03 ^{u,F}	−0.54 ± 0.13 ^{s,H,I}	9.6 ± 0.3 ^{t,s,E,F}	1.800 ± 0.110 ^{t,s,E,F}	0.70 ± 0.03 ^{u,F}	1.00 ± 0.07 ^{u,G}
	4	6.05 ± 0.05 ^{u,G}	21.51 ± 1.18 ^{v,u,E}	−0.11 ± 0.04 ^{v,C,D}	1.6 ± 0.4 ^{u,E}	24 ± 2 ^{u,D}	4.5 ± 0.6 ^{v,D}	1.3 ± 0.2 ^{v,E}	2.21 ± 0.16 ^{v,F}
	5	5.97 ± 0.02 ^{t,I}	23.0 ± 0.7 ^{v,D}	−0.08 ± 0.07 ^{v,C}	2.2 ± 0.3 ^{v,D}	39 ± 6 ^{v,C}	7 ± 2 ^{w,C}	2.20 ± 0.17 ^{w,D}	4.0 ± 0.4 ^{w,D}
	6	5.97 ± 0.06 ^{t,s,I}	25.3 ± 0.2 ^{w,C}	0.06 ± 0.02 ^{w,B}	3.1 ± 0.2 ^{w,B}	75 ± 13 ^{x,B}	14 ± 2 ^{y,B}	4.3 ± 0.5 ^{x,B}	8.0 ± 0.9 ^{y,B}
	7	5.9 ± 0.5 ^{r,J}	28.1 ± 0.3 ^{y,x,A}	0.1060 ± 0.0114 ^{w,B}	3.53 ± 0.13 ^{w,A}	107 ± 21 ^{z,A}	20 ± 4 ^{z,A}	6.0 ± 0.6 ^{y,A}	10.4 ± 1.3 ^{z,A}
FPESB	1	6.8 ± 0.2 ^{b,Z}	9 ± 3 ^{j,S}	0.226 ± 0.104 ^{e,V}	0.8 ± 0.6 ^{f,S}	0.97 ± 0.03 ^{h,T}	0.176 ± 0.007 ^{h,T}	0.052 ± 0.007 ^{g,U}	0.1486 ± 0.0115 ^{g,U}
	2	6.33 ± 0.04 ^{d,X}	15 ± 2 ^{g,U}	0.64 ± 0.14 ^{c,Y}	3.1 ± 0.6 ^{d,e,U}	0.99 ± 0.03 ^{h,T}	0.171 ± 0.006 ^{h,T}	0.052 ± 0.008 ^{g,U}	0.142 ± 0.008 ^{g,U}
	3	6.10 ± 0.08 ^{f,W}	22.2 ± 0.3 ^{d,W}	0.66 ± 0.05 ^{c,Y}	3.7 ± 0.3 ^{c,V}	1.23 ± 0.12 ^{h,U,T}	0.47 ± 0.17 ^{g,h,T}	0.057 ± 0.003 ^{g,U}	0.1548 ± 0.0105 ^{g,U}
	4	5.93 ± 0.02 ^{h,V}	22.1 ± 0.8 ^{d,W}	0.45 ± 0.04 ^{d,X}	3.23 ± 0.08 ^{d,V,U}	5.7 ± 0.7 ^{f,g,V,U}	1.274 ± 0.103 ^{f,g,U,T}	0.49 ± 0.06 ^{e,f,V}	0.92 ± 0.19 ^{f,V}
	5	5.76 ± 0.02 ^{j,T}	27.2 ± 0.4 ^{c,X}	0.67 ± 0.07 ^{c,Y}	4.6 ± 0.3 ^{b,X,W}	14 ± 6 ^{d,e,W}	2.5 ± 0.8 ^{d,e,V}	1.3 ± 0.2 ^{d,W}	2.1 ± 0.4 ^{e,W}
	6	5.67 ± 0.02 ^{k,R}	29.2 ± 0.5 ^{a,b,Y}	0.81 ± 0.09 ^{b,Z}	5.0 ± 0.3 ^{a,Y,X}	16.9 ± 0.7 ^{d,W}	3.204 ± 0.115 ^{d,W,V}	2.4 ± 0.2 ^{c,X}	3.73 ± 0.14 ^{c,X}
	7	5.65 ± 0.02 ^{k,R}	30.6 ± 0.2 ^{a,Z,Y}	0.89 ± 0.03 ^{a,Z}	5.2 ± 0.3 ^{a,Y}	36 ± 6 ^{b,X}	6.6 ± 1.5 ^{b,X}	4.2 ± 0.6 ^{a,Y}	6.2 ± 0.6 ^{a,Y}
65FPESB	1	6.7 ± 0.2 ^{x,Y}	13 ± 2 ^{r,q,T}	−0.13 ± 0.08 ^{v,T}	0.5 ± 0.3 ^{t,S}	0.99 ± 0.02 ^{s,T}	0.177 ± 0.006 ^{s,T}	0.054 ± 0.004 ^{t,U}	0.145 ± 0.012 ^{t,U}
	2	6.32 ± 0.04 ^{w,X}	17 ± 2 ^{s,U}	0.10 ± 0.05 ^{w,U}	2.1 ± 0.7 ^{v,T}	1.5 ± 0.3 ^{s,U,T}	0.43 ± 0.07 ^{s,T}	0.070 ± 0.004 ^{t,U}	0.161 ± 0.007 ^{t,U}
	3	6.08 ± 0.05 ^{u,W}	19 ± 2 ^{t,V}	0.4 ± 0.2 ^{x,X,W}	2.5 ± 0.5 ^{v,T}	8.2 ± 0.8 ^{s,V}	2.32 ± 0.19 ^{u,t,V,U}	0.80 ± 0.06 ^{u,V}	1.0 ± 0.2 ^{u,V}
	4	5.93 ± 0.03 ^{s,V}	20.2 ± 0.7 ^{u,t,V}	0.33 ± 0.05 ^{x,W}	2.5 ± 0.3 ^{v,T}	18 ± 2 ^{u,t,W}	3.7 ± 0.4 ^{v,u,W}	1.24 ± 0.18 ^{v,W}	1.8 ± 0.3 ^{v,W}
	5	5.85 ± 0.04 ^{q,U}	26.7 ± 0.4 ^{x,w,X}	0.60 ± 0.03 ^{y,Y}	4.28 ± 0.07 ^{x,W}	38 ± 5 ^{v,X}	7.01 ± 1.04 ^{w,X}	2.4 ± 0.3 ^{w,X}	3.8 ± 0.4 ^{w,X}
	6	5.77 ± 0.02 ^{p,T}	29.1 ± 0.4 ^{y,Y}	0.81 ± 0.05 ^{z,Z}	5.0 ± 0.2 ^{y,Y,X}	63 ± 3 ^{w,Y}	12.08 ± 1.12 ^{x,Y}	4.5 ± 0.9 ^{x,Y}	6.4 ± 0.3 ^{x,Y}
	7	5.72 ± 0.02 ^{o,S}	31.6 ± 0.5 ^{z,Z}	0.88 ± 0.06 ^{z,Z}	5.8 ± 0.2 ^{z,Z}	94 ± 9 ^{y,Z}	19 ± 2 ^{z,Z}	7.3 ± 0.4 ^{z,Z}	10.1 ± 0.4 ^{z,Z}

To samples with the same conditions the same small letter in superscript within column indicates homogeneous groups established by ANOVA ($p < 0.05$) ($^{a–k}$ for FBPC vs FPESB, and $^{z–o}$ for 65FBPC vs 65FPESB). To compare the same sample with the temperature effect the same capital letter in superscript within column indicates homogeneous groups established by ANOVA ($p < 0.05$) ($^{A–H}$ for FBPC vs 65FBPC and $^{Z–S}$ for FPESB vs 65FPESB). C: Concentration.

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