Journal of the Science of Food and Agriculture
J Sci Food Agric **84**:1951–1959 (online: 2004)
DOI: 10.1002/jsfa.1902

Physicochemical, functional and structural characterization of fibre from defatted *Rosa rubiginosa* and *Gevuina avellana* seeds

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Abstract: The composition, functional properties and structural features of the fiber from *Rosa rubiginosa* defatted seeds and from *Gevuina avellana* defatted and partially deproteinized seeds were evaluated. The effect of phosphate salts and temperature during the extraction of fibres and the influence of two drying technologies on the distribution of soluble and insoluble dietary fibre were assessed. The extraction of protein and monosaccharides was favoured by increasing temperature in the range studied. Water and oil absorption capacities higher than 10 g g^{-1} were observed for soluble and insoluble fibres from *Gevuina avellana* and for the soluble ones from *Rosa rubiginosa*. The insoluble fibre product from *Rosa* and *Gevuina* contained 650–810 g kg^{-1} and 390–440 g kg^{-1} neutral detergent fibre respectively. The protein content in the insoluble fibre varied in the range 100–150 g kg^{-1} and 120–260 g kg^{-1} and in the soluble fibre between 200–550 g kg^{-1} and 180–370 g kg^{-1} for *Rosa* and *Gevuina* respectively.

Keywords: *Rosa rubiginosa*; *Gevuina avellana*; dietary fibre; functional properties; microstructure

INTRODUCTION

The increasing awareness of the importance of fibre in the human diet has been established by laboratory and medical studies. Clinical studies revealed differences in the disease patterns between populations and showed evidence of an association between low fibre diets and the incidence of numerous chronic diseases.[1] Fibres can be classified as insoluble (such as cellulose and lignin) and soluble (pectins, gums and mucilages), which can form highly viscous solutions. The physiological effects of these two types of fibre are different. Water-soluble fibre reduces the risk of heart disease through binding bile acids (synthesized from cholesterol, which is withdrawn from the blood stream). A high intake of soluble fibre improves glycaemic control, decreases hyperinsulinaemia, and lowers plasma lipid concentrations in patients with type II diabetes.[2] Water-insoluble fibres absorb large amounts of water, favouring stools bulking and speeding the passage of waste through the intestines, functions believed to reduce the risk of colon cancer. Insoluble dietary fibres are more effective than soluble ones in adsorbing carcinogens; soluble ones reduce the absorption of highly hydrophobic carcinogens.[3]

Fibres from varied sources should be present in the human diet, since different kinds of fibre perform different functions and contribute to various health benefits. In order to meet the recommended dietary fibre intake, some diets must be supplemented with fibre. When fibre is added to foods, organoleptic, technological and nutritional properties, as well as considerations of shelf life must be satisfied. Vegetable residues are cheap sources, which can be processed into dietary fibre food ingredients.[4–7]

Rosa rubiginosa (Rosaceae), native from Central and Eastern Europe, was introduced in the Andean area where it grows naturally in dry lands and low quality soils. The main products are the fruits, rich in

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Contract/grant sponsor: INCO-DC Programme of the European Commission; contract/grant number: ERBIC 18 CT 970206
Contract/grant sponsor: Xunta Galicia University Vigo
Contract/grant sponsor: MEC; contract/grant number: ALI98-1641-CE
(*Received 8 October 2002; revised version received 8 March 2004; accepted 16 June 2004*)
Published online 20 August 2004

carotenoids and vitamin C, and the seeds, containing a valuable oil with skin regenerating properties.[8] The residue obtained after oil extraction from the seeds contains up to 100 g kg^{-1} (dry weight) protein and 762 g kg^{-1} (dry weight) neutral detergent fibre.[9]

Gevuina avellana (Proteaceae) trees are native to southern Chile and Argentina; the seeds contain high amounts (500–520 g kg^{-1} dry weight) of good quality oil, suitable for both food and for cosmetic applications. The defatted meal contains 180–220 g kg^{-1} (dry weight) highly nutritious protein,[10] which can be extracted efficiently with aqueous salt solutions yielding a solid fibre-rich residue.

The extraction and characterization of protein isolates from these two seeds was reported by Moure *et al*.[9,11] The aim of the present study was the characterization of the soluble and insoluble fibre products from *Rosa rubiginosa* defatted seeds and from the solid residue of defatted *Gevuina avellana* seeds after protein extraction. Aspects determining their utilization as food ingredients (chemical composition, functional properties and microstructure) were assessed.

MATERIALS AND METHODS

Materials

Dehusked *Rosa rubiginosa* seeds were supplied by Forestal Casino Ltda (Santiago, Chile). *Gevuina avellana* seeds, purchased in local Chilean markets, were hand dehulled. Ground seeds were sieved to select particles smaller than 0.5 mm and were defatted overnight at room temperature in a rotary shaker, using hexane at a solid/liquid ratio of 1:15 g g^{-1}. The solids were recovered by vacuum filtration, submitted to an additional extraction step under the same conditions, and the filtrates were combined.

The fibre from *Gevuina avellana* was obtained after protein extraction of the defatted (as above described) ground seeds. Protein extraction was carried out with 0.1 N NaOH (pH 11.0) at 35 °C for 30 min, using a liquid:solid ratio of 12:1 (w:w) in a stirred tank with temperature and pH control. Some non-cellulosic polysaccharides might be solubilized from the cell walls during the treatment of *G avellana* defatted meals to solubilize protein, but this point was not confirmed experimentally. The slurries were centrifuged at 3250 × *g* during 30 min at 4 °C and further filtered through filter paper (Albet (Barcelona, Spain) model 235) to separate solid and liquid phases. The solids were once more treated under the same conditions and the filtrates were combined. Protein from the filtrates was recovered by ultrafiltration through a Filtron unit (Pall Corporation, Madrid, Spain) equipped with 10 and 5 kDa molecular weight cut-off Omega membranes in series. The liquid phase can be reutilized for further extraction stages.[11] The average composition of the *Gevuina avellana* defatted and deproteinized meals was (g kg^{-1} dry basis) 105 protein, 465 neutral detergent fibre and 78 ash.[9]

Extraction of soluble fibre

The soluble fibre fractions were extracted with hot distilled water at the natural pH of the seeds or with hot 0.05 M phosphate buffer at pH 6.0, which was selected to study the influence of altering the ionic strength of the extracting medium, capable of affecting the physicochemical properties of dietary fibre.[12] The defatted meals from *Rosa rubiginosa* and the deproteinized meals from *Gevuina avellana* (10 g each) were treated separately, at various temperatures in the range 60–121 °C, for 90 min, using a liquid:solid ratio of 20:1 (w:w). After treatment the samples were cooled to room temperature, and the solid and liquid phases were separated by vacuum filtration through filter paper (Albet model 235). The soluble fractions were recovered either by oven drying (50 °C) or by means of ethanol precipitation, followed by centrifugation at 3250 × *g* for 30 min at 4 °C, and freeze-drying. Precipitation of the non-cellulosic polysaccharides solubilized was achieved by the addition of ethanol (final concentration 780 g kg^{-1}). Under these conditions and due to the content in pectins of these seeds,[13,14] it is possible that pectic substances could also be recovered. The effects of the drying technology (freeze-drying, oven drying) was compared for the fibres extracted at 60 and at 95 °C.

Total dietary fibre (TDF), soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) in *Rosa rubiginosa* were determined according to the method of Prosky *et al*.[15]

Analytical methods

Moisture, ash and dietary fibre were determined according to standard methods.[16] The solids were analyzed for total nitrogen content by the Kjeldhal method, and the factor of 6.25 as used to calculate the protein content.

Color values L^*, a^*, b^* of the ground samples, were measured with a Macbeth Color Eye 2180 (Kollmorgen Instruments, Munich, Germany), standardized against a white tile.

Neutral detergent fibre (NDF) (cellulose, hemicellulose and lignin) was determined using the detergent methods.[17]

For carbohydrate analysis, neutral sugars were released by Saeman hydrolysis[18] and analyzed as their alditol acetates by gas-liquid chromatography[19,20] in a Carbo Erba GC 6000 series 2 chromatograph with a FID detector and a DB-225 column (J&W) (30 m × 0.25 mm, film thickness of 0.25 μm). Hexuronic acids (HexA) were determined colorimetrically by a modification of the method of Blumenkrantz and Asboe-Hansen[21] according to Coimbra *et al*.[22]

Functional properties

For water and oil absorption, 0.5 g of fibre was mixed with 50 ml of distilled water or 50 ml of commercial sunflower oil in an Ultra-Turrax T50 (Janke & Kunkel, Staufen, Germany) during 30 min. The samples were allowed to stand at room temperature for 30 min, and

then centrifuged at 3250 × *g* for 30 min at 4 °C. The liquid retained in the solids was determined as the difference in weight of the solids before and after absorption. The water/oil absorption capacity was expressed as g of water/oil bound g^{-1} of the sample on a dry basis.[23]

Scanning electron microscopy (SEM) analysis

Fibre samples were freeze-dried and coated with Au–Pd. The microstructure was observed in a Leica-Cambridge S-360 scanning electron microscope (Leica, Cambridge, UK) at an accelerating voltage of 12 kV.

RESULTS AND DISCUSSION

Effects of the temperature and solvent on the fibre solubilization

The effect of temperature and solvent on the extraction yield of soluble fibre from *Rosa rubiginosa* and *Gevuina avellana* seeds were determined. Table 1 summarizes the yields of soluble fibre and insoluble fraction in dried samples obtained after extraction of *Rosa rubiginosa* defatted seeds. The lowest soluble fibre yield of the ethanol precipitated and freeze-dried fibres samples was observed for those extracted with water at 95 °C; among the oven-dried ones the yield of soluble fibre was minimal for those contacted with water at 60 °C. The amount of soluble fibre obtained by freeze-drying was, for both extracting solvents (water and phosphate buffer), significantly lower than that obtained by oven-drying. Probably the material solubilized was selectively precipitated by ethanol and recovered, whereas, after oven-drying, all the solubilized material could be recovered. In addition, for the ethanol-precipitated soluble fibre, slight differences were associated with the extracting solvent employed. Phosphate buffer solubilized more fibres than water, probably due to the ionic strength of the medium, which influences fibre structure and the amount of fibre extracted.[24] Fibre solubilization was favoured by increasing temperature regardless of the extracting solvent.

The distribution of soluble and insoluble fractions of *G avellana* after extraction with distilled water or phosphate buffer is shown in Table 2. The increase in temperature during water extraction did not affect the insoluble fraction yield of freeze-dried samples, but the yield of soluble fibre was much higher at 95 °C and that at 121 °C slightly higher than that obtained at 60 °C. Except for the water-soluble and buffer-insoluble fractions extracted at 60 °C, no significant differences were associated with the drying methods used, but the freeze-dried samples were more maneageable than the oven dried ones, and were used for further analyses.

The soluble:insoluble fibre mass ratio was affected by both the extracting solvent and the drying method, the values ranging from 0.005:1 to 0.065:1 for *R rubiginosa* and from 0.07:1 to 0.35:1 for *G avellana* fibre. The soluble/insoluble ratios reported for other fibrous materials obtained from residual sources vary in a wide range: 0.005:1 for corn bran and 0.09:1 for rice bran,[7] 0.18:1 to 0.45:1 for wheat bran,[6] 0.11:1 to 0.36:1 for potato peels,[5] in the range 0.08:1

Table 1. Effect of the extraction and drying conditions on the solubilization and recovery yield of fibre from defatted *Rosa rubiginosa* seeds

	Fractional yield (g kg^{-1}, ddb)			
	Freeze-drying		Oven-drying (50 °C)	
Extraction conditions	Soluble	Insoluble	Soluble	Insoluble
Distilled water, 60 °C	16 ± 1	758 ± 39	21 ± 1	800 ± 17
Distilled water, 95 °C	4 ± 0.4	741 ± 7	46 ± 1	774 ± 6
Distilled water, 121 °C	52 ± 0.4	797 ± 3	—	—
Phosphate buffer, 60 °C	22 ± 1	813 ± 25	35 ± 5	742 ± 9
Phosphate buffer, 121 °C	46 ± 2	773 ± 5	—	—

ddb: defatted dry basis. Data are means of three experiments.

Table 2. Effect of the extraction conditions on the solubilization and recovery yield of fibre from the partially deproteinized residue from defatted *Gevuina avellana* seeds

	Fraction yield (g kg^{-1}, ddb)			
	Freeze-drying		Oven-drying (50 °C)	
Extraction conditions	Soluble	Insoluble	Soluble	Insoluble
Distilled water, 60 °C	63 ± 0.8	509 ± 5	36 ± 1	498 ± 4
Distilled water, 95 °C	169 ± 2	497 ± 10	164 ± 2	466 ± 8
Distilled water, 121 °C	87 ± 0.9	497 ± 35	—	—
Phosphate buffer, 60 °C	116 ± 0.1	528 ± 8	116 ± 16	487 ± 23
Phosphate buffer, 121 °C	115 ± 7.4	559 ± 29	—	—

ddb: defatted dry basis. Data are mean of three experiments.

Table 3. Total monosaccharide (g kg^{-1}) and protein (g kg^{-1}) contents in soluble and insoluble freeze-dried fraction from *Rosa rubiginosa* and *Gevuina avellana*

	Soluble fraction		Insoluble fraction		
Seed/solvent	Total monosaccharides[a]	Protein	Total monosaccharides[a]	Protein	NDF
Rosa rubiginosa					
Distilled water 60 °C	399	311	693	155	649
Distilled water 95 °C	479	548	—	136	728
Distilled water 121 °C	560	268	805	151	781
Phosphare buffer 60 °C	204	300	747	91	813
Phosphate buffer 121 °C	459	203	721	—	809
Gevuina avellana					
Distilled water 60 °C	97	356	892	167	436
Distilled water 95 °C	676	287	605	182	392
Distilled water 121 °C	709	193	581	236	369
Phosphate buffer 60 °C	146	373	798	123	400
Phosphate buffer 121 °C	654	184	515	261	384

[a] The sum of neutral sugars and uronic acids, determined as defined in Material and Methods section.

to 0.75:1 for amaranth whole grain and products.[25] Saura-Calixto *et al*[26] reported mass ratios of soluble to insoluble dietary fibres from fruits in the range 0.41:1 to 0.71:1, for vegetables between 0.11:1 to 1.9:1, for legumes between 0.14:1 to 0.82:1 and for cereals between 0.28:1 to 4.23:1.

The total monosaccharide and protein contents of the soluble and insoluble freeze-dried fractions from *Rosa rubiginosa* and *Gevuina avellana* are summarized in Table 3. The temperature influenced the monosaccharide and protein content in the soluble fibres from both seeds. The protein contents in the soluble fibres decreased with temperature in the range studied. No clear trend in the content of total monosaccharides in the insoluble fractions after water extraction was observed, whereas for the phosphate buffer insoluble ones the total monosaccharide content was reduced with increasing extraction temperature. The neutral detergent fibre content (NDF) in the insoluble fraction and the protein content in the soluble fraction followed similar trends with the extraction temperature for water and for phosphate buffer. The NDF of the solid residue remaining after extraction from *Gevuina* did not differ significantly among the treatments. An increase in the extraction temperature led to a reduced content of monosaccharides and increase of protein. Two reasons could account for this observed effect, (1) the solubilization of fiber as indicated by lower NDF values, leading to increased protein purity and (2) the insolubilization of protein caused by thermal denaturation.

Water and oil absorption

The water and oil absorption capacities (Table 4) are the most interesting functional properties for insoluble fibres destined for food ingredients. Water absorption is also closely related to swelling and to the satiety effects of fibre-supplemented products. Both composition and structure can influence the water and oil-binding capacity of the fibres. The WAC (water absorption capacity) of *R rubiginosa* soluble fibre recovered by oven-drying was higher than that of freeze-dried fibre (4.16 ± 0.06 compared with 2.89 ± 0.14) for water-extracted fibre, but not significantly different for phosphate buffer-extracted fibre (2.92 ± 0.19 compared with 2.72 ± 0.25). Since the composition of freeze-dried and oven-dried products was similar in terms of protein, total monosaccharides and neutral detergent fibres (data not shown), and the manageability was appreciably improved for freeze-dried samples, the functional properties of these latter were evaluated and are presented in Tables 4 and 5 for the fibres of *R rubiginosa* and *G avellana* respectively.

The WAC and oil absorption capacity (OAC) of the phosphate buffer-insoluble fibre (PIF) and the water-insoluble fibre (WIF) from *R rubiginosa* were

Table 4. Water and oil absorption capacities of freeze-dried fibre from *Rosa rubiginosa* defatted seeds (<0.5 mm). Values are expressed as g of bound liquid g^{-1} fibre (ddb)

Fraction	WAC	OAC	Fraction	WAC	OAC
WIF-60	2.89 ± 0.14	3.01 ± 0.08	WSF-60	8.57 ± 0.43	11.69 ± 0.56
WIF-95	3.22 ± 0.04	3.99 ± 0.24	WSF-95	—	—
WIF-121	2.28 ± 0.12	2.53 ± 0.24	WSF-121	7.27 ± 0.47	12.72 ± 0.84
PIF-60	2.72 ± 0.25	3.49 ± 0.22	PSF-60	11.37 ± 0.4	15.52 ± 0.2
PIF-121	1.99 ± 0.24	1.89 ± 0.07	PSF-121	5.41 ± 0.33	13.21 ± 0.052

ddb: defatted dry basis. WIF: water-insoluble fibre; WSF: water-soluble fibre; PIF: phosphate buffer-insoluble fibre; PSF: phosphate buffer-soluble fibre. Figures after the acronyms indicate the extraction temperature (°C).

Table 5. Water and oil absorption capacities of freeze-dried fiber from the fraction obtained after oil and protein extraction from *Gevuina avellana* dehulled seeds. Values are expressed as g of bound liquid g^{-1} fibre (ddb)

Fraction	WAC	OAC	Fraction	WAC	OAC
WIF-60	10.0 ± 0.1	—	WSF-60	11.5 ± 0.3	16.3 ± 0.8
WIF-95	11.0 ± 0.2	14.7 ± 0.2	WSF-95	10.2 ± 0.1	—
WIF-121	12.8 ± 0.1	12.8 ± 1.0	WSF-121	11.0 ± 0.2	14.6 ± 0.2
PIF-60	11.5 ± 0.3	16.3 ± 0.8	PSF-60	12.8 ± 0.1	12.8 ± 0.1
PIF-121	12.9 ± 0.1	11.9 ± 0.7	PSF-121	12.9 ± 0.1	11.9 ± 0.6

ddb: defatted dry basis. WIF: water-insoluble fibre; WSF: water-soluble fibre; PIF: phosphate buffer-insoluble fibre; PSF: phosphate buffer-soluble fibre. Figures after the acronyms indicate the extraction temperature.

comparable. The phosphate buffer-soluble fractions (PSF) extracted at 60 °C showed higher capacity to bind both water and oil than the water-soluble fractions (WSF). No significant differences were noticed for the WAC of soluble fibres extracted with water and with phosphate buffer, although improved WBC (water binding capacity) of fibres extracted in the presence of salts with respect to those extracted with deionized water was observed for artichoke.[12]

The oil absorption of the soluble fractions was five to six times higher than that of the insoluble fractions. Similar behaviour was reported by Fleury and Lahaye.[27] In contrast, López *et al*[12] reported higher OAC for the insoluble fraction of artichoke fibre and found that the nature of the surface, the lignin content, the density, and the size of particles affected the OAC.

The WAC of the insoluble fraction from *G avellana* fibre increased slighlty with extraction temperature. For the soluble fractions, the WAC was higher for the phosphate buffer-extracted fibres than for the water extracted ones. Temperature did not influence the WAC of water or phosphate buffer-soluble fibres. The OACs of both soluble and insoluble fibres decreased when the extraction was performed at higher temperature regardless of the extraction method.

Values for the water and oil binding capacities of the fibre from *R rubiginosa* seeds were comparable with those obtained for other fibre sources, either natural or commercial ones, with values of 2.6 g g^{-1}[28] and 3.1 g g^{-1}[29] for wheat, and up to 6.9 g g^{-1} for oats.[30] For rice bran a water holding capacity of 4.89 g g^{-1} was reported,[7] between 132.8 and 599 g g^{-1} for amaranth whole grains and high fibre fractions.[25] Values for commercial products ranged from 4.6 g g^{-1} to 332.6 g g^{-1}.[25] The WAC of the fibre from *G avellana* was in the range of those reported for peach fibre (9.2–12.1 g g^{-1})[6] and cauliflower (12.8–13.4 g g^{-1}).[31] The oil-binding capacities reported in literature ranged from 4.54 g g^{-1} for rice bran,[7] 5.7 g g^{-1} for artichoke,[12] 6.7 g g^{-1} for grapefruit[32] and 332.6 g g^{-1} for amaranth grains and high-fibre fractions.[25]

Monosaccharide composition

Tables 6 and 7 summarize the monosaccharide compositions of the fibre fractions from *R rubiginosa* and *G avellana* respectively, which was influenced by temperature. The total monosaccharides solubilized increased significantly in the WSF with respect to the values for the PSF. The WSF-95 fraction contained polysaccharides rich in glucose, possibly glucans. It is unlikely that these polysaccharides arose from starch since, as evidenced by Pas-amido black staining, starch was not detected in the embryo of *R rubiginosa* seeds.[13] For *R rubiginosa* an increase of HexA and Ara in the soluble fractions with extraction temperature was

Table 6. Monosaccharide composition of the freeze-dried fractions from *Rosa rubiginosa* expressed as molar percentage of total monosaccharides

	Monosaccharides (mol %)								Total monosaccharides
Sample	Rha	Fuc	Ara	Xyl	Man	Gal	Glc	HexA	(mg g^{-1})
WIF-60	9		2	32		1	48	8	693
WIF-95	13		7	30	3	3	34	11	1077
WIF-121	6		2	37	t	1	46	9	805
PIF-60	13		2	33		1	43	8	747
PIF-121	5	6	22	20	4	11	25	9	721
IDF	9		1	31	1	1	47	10	501
WSF-60	9		5	2	3	4	60	18	399
WSF-95	15		8	1	2	5	47	23	479
WSF-121	14		15	3		7	6	55	560
PSF-60	60		8	1		4	2	24	204
PSF-121	16		15	3		7	4	55	459
SDF	26		7	1	4	6	11	45	253

IDF: insoluble dietary fibre; SDF: soluble dietary fibre; WIF: water-insoluble fibre; WSF: water-soluble fibre; PIF: phosphate buffer-insoluble fibre; PSF: phosphate buffer-soluble fibre. Figures after the acronyms indicate the extraction temperature (°C). Blank spaces: not detected; t: trace amounts.

Table 7. Monosaccharide composition of freeze-dried fraction from *G avellana* expressed as molar percentage of total monosaccharides

Sample	Monosaccharides (mol %)								Total monosaccharides (mg g^{-1})
	Rha	Fuc	Ara	Xyl	Man	Gal	Glc	HexA	
WIF-60	8	2	10	28		5	34	14	892
WIF-95	9	1	19	10	1	11	38	10	605
WIF-121	11	1	11	9	1	9	49	8	581
PIF-60	8	2	20	10	2	11	35	13	798
PIF-121	12	2	11	10	1	9	50	6	515
WSF-60	48	nd	14	3	4	15	7	8	97
WSF-95	14	nd	4	1	5	4	64	9	676
WSF-121	16	1	28	4	t	16	10	24	709
PSF-60	39	nd	8	12	9	11	10	12	146
PSF-121	11	nd	33	3	nd	17	9	28	654

WIF: water-insoluble fibre; WSF: water-soluble fibre; PIF: phosphate buffer-insoluble fibre; PSF: phosphate buffer-soluble fibre. Figures after the acronyms indicate the extraction temperature (°C). nd: not detected; t: trace amounts.

observed. Similar behaviour was observed for *G avellana* fibres obtained by water and by phosphate buffer extraction (Table 7). Unbranched pectins and possibly glucans may enter the composition of SDF from *R rubiginosa*. Pectic polysaccharides, xyloglucan and cellulose are the main components of *G avellana* cell walls.[14] Xylose in *G avellana* could come from xyloglucan, which was shown to be the major non-cellulosic polysaccharide of the cell walls. The seed coat from *R rubiginosa* seeds was shown to contain significant amounts of glucuronoxylans, a polysaccharide characteristic of heavily lignified tissues.[13] However, as also observed by these authors, glucuronoxylans were also present in the cell walls of the embryo, although in smaller amounts. Furthermore, since the seeds were dehulled prior to aqueous extraction of the fibres, it seems unlikely that the xyloglucan would arise from the highly lignified tissues of the seed coat (or hull). Some non-cellulosic glucans may be present in the water and phosphate soluble fractions. Much of the arabinose and galactose may be derived from neutral side-chains attached to rhamnogalacturonan molecules.

Colour

Colour values of fibre from *R rubiginosa* and *G avellana* are shown in Table 8. As a general trend, fibres from *G avellana* showed higher L^* values and lower a^* values than those from *R rubiginosa* for the various conditions, indicating that *R rubiginosa* fibres were darker and more reddish than those from *G avellana*. Only for fibres extracted at 121 °C were the b^* values for *R rubiginosa* lower than for *G avellana*, indicating a stronger yellowish colour for this latter. Probably the compounds imparting this colour could be removed from *R rubiginosa* at 95–121 °C. As a general trend, the soluble fibres from both seeds showed higher L^* values, and lower a^* and b^* values than the insoluble fractions.

Table 8. Colour of fractions from *Rosa rubiginosa* and *Gevuina avellana*

	L^*	a^*	b^*
Rosa rubiginosa			
WIF-60	73.86 ± 0.42	4.94 ± 0.04	14.81 ± 0.20
WIF-95	61.92 ± 0.15	9.68 ± 0.09	13.64 ± 0.26
WIF-121	58.98 ± 0.14	7.11 ± 0.06	11.87 ± 0.04
PIF-60	65.13 ± 0.20	5.19 ± 0.18	13.79 ± 0.13
PIF-121	56.94 ± 1.17	7.41 ± 0.25	12.26 ± 0.63
IDF	62.90 ± 0.72	5.30 ± 0.13	12.92 ± 0.38
WSF-60	91.87 ± 0.05	1.91 ± 0.02	8.00 ± 0.05
WSF-121	77.72 ± 0.09	5.16 ± 0.04	8.34 ± 0.12
PSF-121	82.80 ± 0.22	5.19 ± 0.07	10.67 ± 0.13
SDF	52.32 ± 0.14	4.95 ± 0.03	8.31 ± 0.13
Gevuina avellana			
WIF-60	89.66 ± 0.37	0.22 ± 0.10	5.97 ± 0.34
WIF-121	76.76 ± 0.15	3.48 ± 0.04	14.82 ± 0.14
PIF-60	86.60 ± 0.25	1.56 ± 0.05	6.61 ± 0.01
PIF-121	77.00 ± 0.23	4.15 ± 0.08	16.53 ± 0.17
WSF-95	82.14 ± 0.39	1.77 ± 0.11	6.98 ± 0.25
WSF-121	91.97 ± 0.13	1.05 ± 0.07	8.76 ± 0.08
PSF-60	64.17 ± 0.01	3.78 ± 0.26	14.79 ± 0.49
PSF-121	86.73 ± 0.10	2.02 ± 0.08	12.31 ± 0.06

IDF: insoluble dietary fibre; SDF: soluble dietary fibre; WIF: water-insoluble fibre; WSF: water-soluble fibre; PIF: phosphate buffer-insoluble fibre; PSF: phosphate buffer-soluble fibre. Figures after the acronyms indicate the extraction temperature (°C).

Microstructural features of freeze-dried fibres from *R rubiginosa* and *G avellana*

Since the functional properties of fibres are related to their structure, scanning electron observations were done in order to compare the morphology of both soluble and insoluble fractions. Figure 1 shows the microstructural features of soluble fibres extracted with water and phosphate buffer from *R rubiginosa* defatted seeds and from the solid obtained after protein extraction from *G avellana* defatted seeds. The soluble fibres showed a regular porous structure regardless of the solvent utilized during fibre extraction, although the soluble fibres extracted from *R rubiginosa* with phosphate buffer (b) and

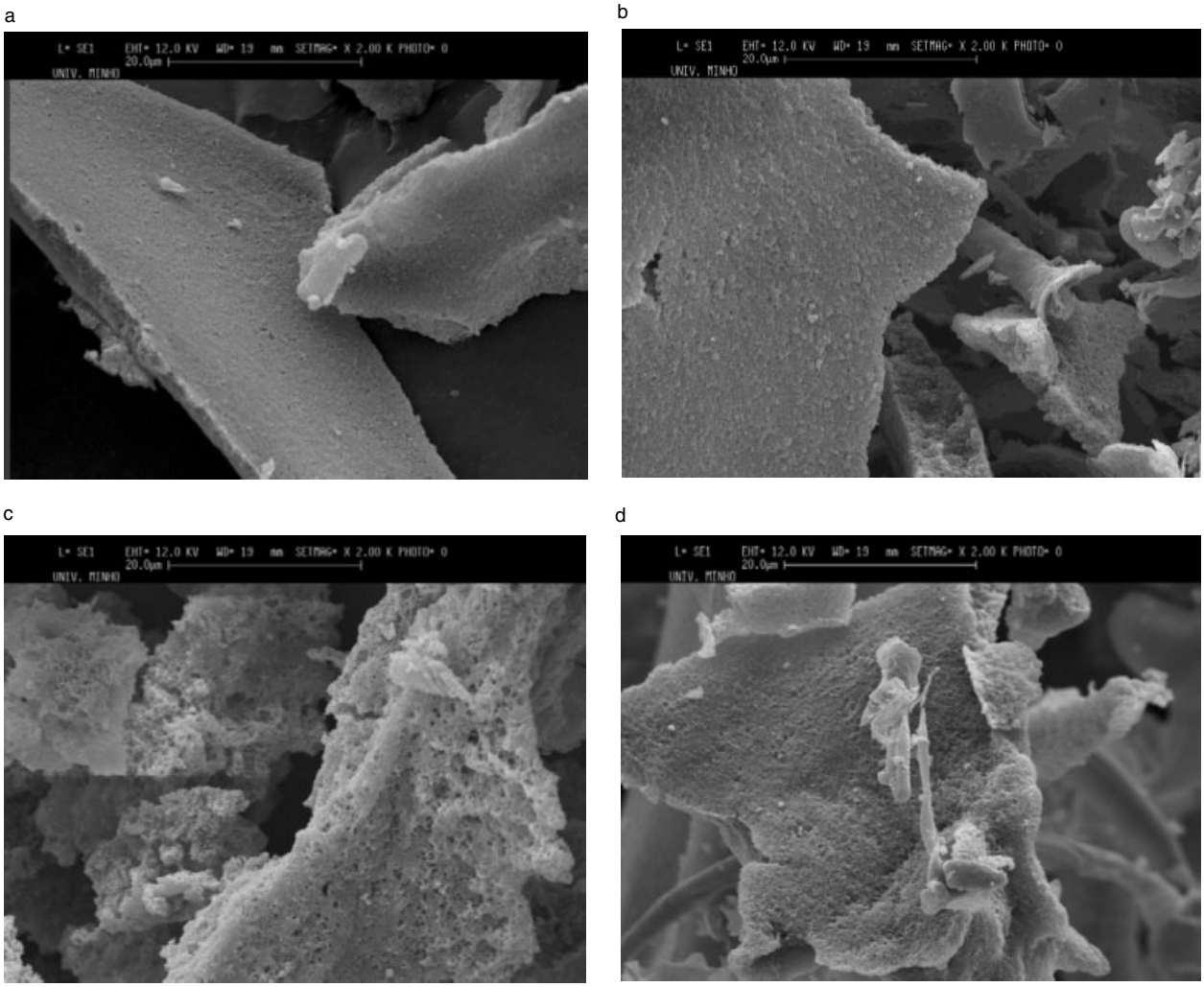

Figure 1. Soluble fibre extracted at 121 °C from *Rosa rubiginosa* defatted seeds with water (a) and with phosphate buffer (b) and from the solid after protein extraction from *Gevuina avellana* defatted seeds with water (c) and with phosphate buffer (d).

from *G avellana* with water (c) were apparently more porous.

The structural differences between soluble fibre extracted with water and with phosphate buffer have been reported for fibres containing pectic substances, such as those from artichoke, the higher degree of organization corresponding to the phosphate buffer extracted samples.[33]

Figure 2 shows the microstructural features of insoluble fractions after extraction of defatted *R rubiginosa* seeds at 60 °C with water (a) and with phosphate buffer (b). The structures of the insoluble fraction resulting after water extraction and that after phosphate extraction were similar. Mechanical disruption of the cell wall was apparent and was the most significant noticeable feature in both samples. The effect of temperature on the cell walls was noticeable, with a more intense disruption of the cell walls at 121 °C. The greater disruption of the cell walls at higher temperatures may explain the higher amount of solubilized fibres found (see Table 3).

Figure 3 shows the microstructure of dietary fiber from *R rubiginosa*. Figure 3b, c and d, at higher magnifications than Fig 3a, show the existence of areas with differing porosities, and the presence of features common to both insoluble and soluble fibre.

In conclusion, the fibre fractions from *R rubiginosa* and from *G avellana* seeds remaining after oil and protein extraction yielded soluble to insoluble ratios which depended on the solvent and the extraction conditions. Colour and microstructure were also influenced by the operational conditions used during the extraction of soluble fibre. The water and oil absorption capacities of the soluble fractions from *R rubiginosa* and both fractions from *G avellana* were higher than $10\,g\,g^{-1}$.

ACKNOWLEDGEMENTS

This work was funded by the INCO-DC Programme of European Commission (ERBIC 18 CT 970206) and co-funded by Xunta Galicia, University of Vigo and by MEC (ALI98-1641-CE). The authors are also grateful to Pedro Vasco and Dr António Coimbra (Departamento de Química, Universidade de Aveiro, Portugal) for the carbohydrate analysis.

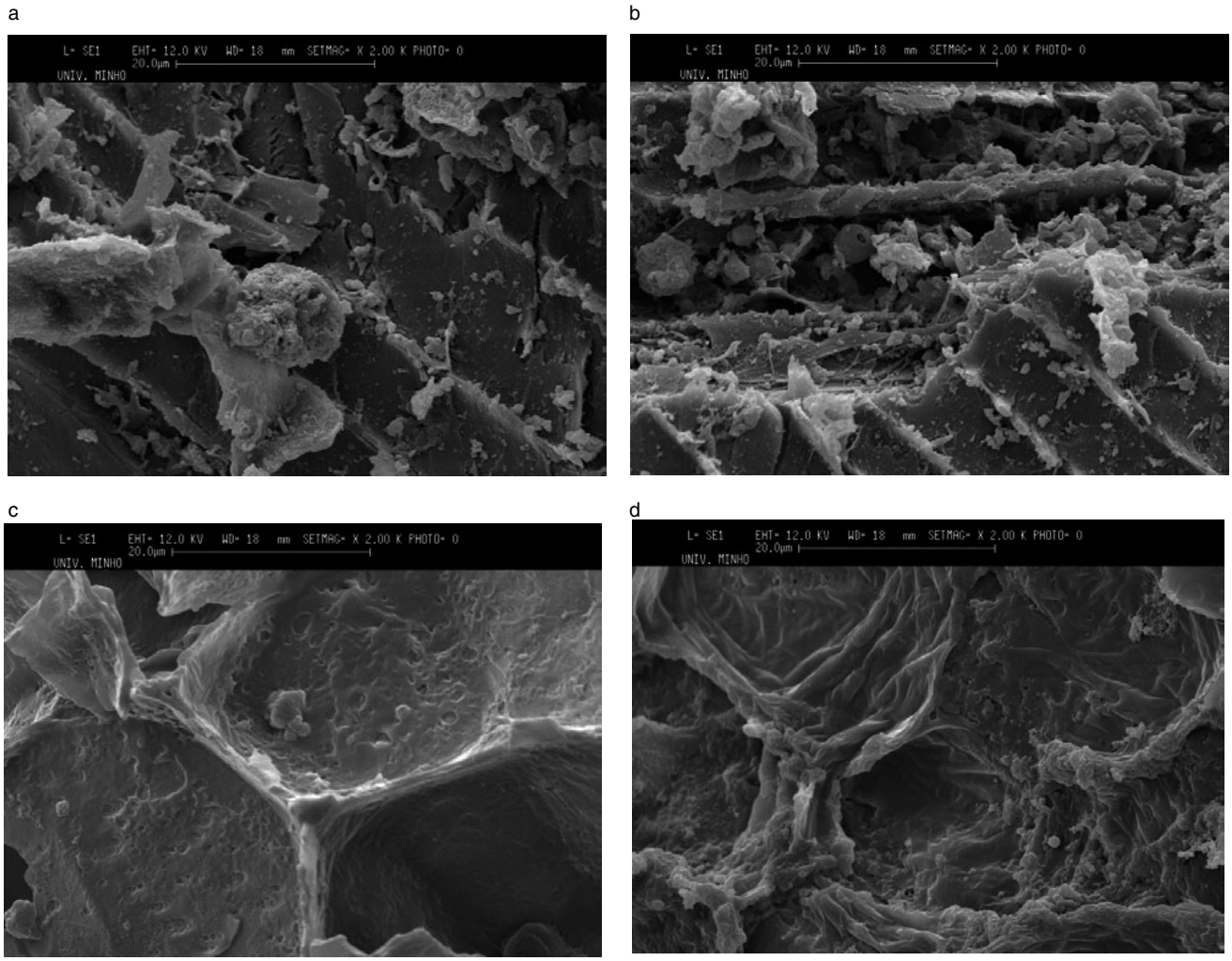

Figure 2. Insoluble fractions after extraction with water (a) and with phosphate buffer (b) from *Rosa rubiginosa* defatted seeds and insoluble residue after extraction with water at 60 °C (c) and at 121 °C (d) from the solid after protein extraction from *Gevuina avellana* defatted seeds.

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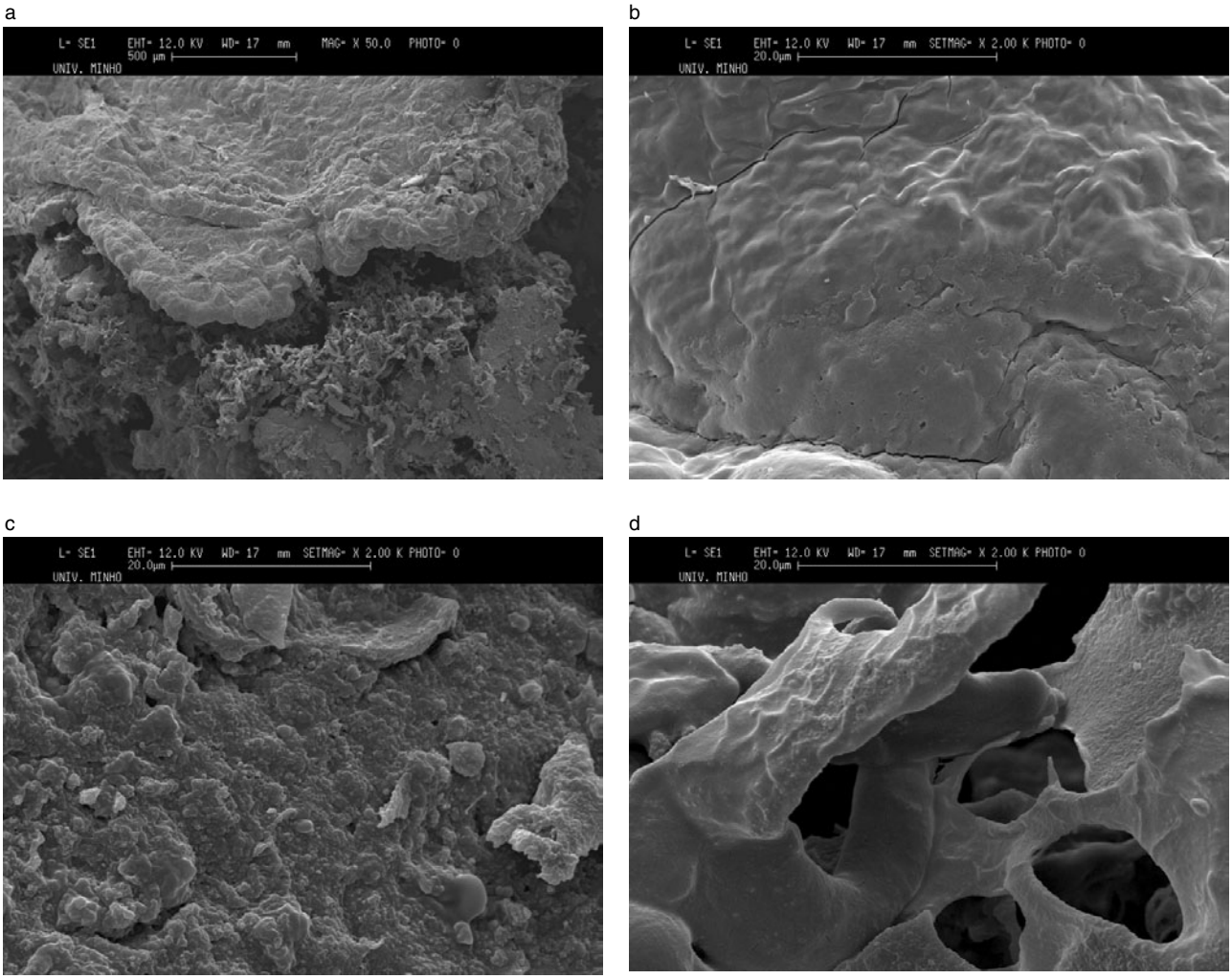

Figure 3. Dietary fibre from *Rosa rubiginosa* extracted following the procedure described by Prosky *et al*[15].

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