**EFFECT OF EXTRACTION METHOD ON CHEMICAL COMPOSITION AND
FUNCTIONAL CHARACTERISTICS OF HIGH DIETARY FIBRE POWDERS
OBTAINED FROM ASPARAGUS BY-PRODUCTS**

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ABSTRACT

Asparagus (*Asparagus officinalis* L.) by-products, which represent around 50% of the processed vegetable, are a potential source of dietary fibre. The way that these by-products are treated affects the composition and functional properties of fibre-rich powders. Factors such as treatment intensity, solvent, and drying system were studied. Only the more soluble components (soluble sugars, uronic acids and proteins) showed significant differences. All the fibre-rich powders had a high concentration of TDF (62-77%). The IF/SF proportion decreased with the severity of treatment, ~~and~~ increasing in this way the physiological quality of the fibre. Functional properties - water holding capacity (WHC), oil holding capacity (OHC), solubility (SOL), and glucose dialysis retardation index (GDRI) - varied according to the obtaining procedure. WHC and GDRI were higher in intensely extracted fibres, due to the effect of thermal processing. WHC had similar values (11-20 mL water/g powder) than those described for other agricultural by-products, but OHC and GDRI were much higher (5-8 mL oil/g powder and 25-45%, respectively). These properties make fibre-rich powders from asparagus by-products a valuable source of dietary fibre to be included in the formulation of fibre-enriched foods.

INTRODUCTION

In developed countries, several gastrointestinal disorders (duodenal ulcer, appendicitis, constipation, hemorrhoids, colon carcinoma), diabetes mellitus, obesity, and cardiovascular diseases, have very low incidence among people consuming high amounts of fibre. Fibre benefits for the gut are widely recognized - a fact that has led to its consideration as a nutrient (FDA, 1993). The key to obtaining the level of fibre intake recommended for adults in western societies is the availability of high quality foods with a high dietary fibre content. The usual sources of dietary fibre added to commercial foods (juices, dairy products, baked goods, etc.) are cereals. Currently however, the demand for by-products from fruits and vegetables as source of dietary fibre has been increasing because these sources present higher nutritional quality, higher amounts of total and soluble fibre, less caloric content, stronger antioxidant capacity, and higher levels of fermentability and water retention (Rodríguez, Jiménez, Fernandez-Bolaños, Guillén, & Heredia, 2006).

Among the vegetables commonly consumed in the United States and Europe, asparagus has been reported as the richest in the total quality and quantity of antioxidants (Vinson, Hao, Su & Zubik, 1998; Pellegrini et al, 2003). Of asparagus producing countries, Spain is in the fifth position after China, Peru, the U.S.A., and Germany. In 2005, about 50,000 tons (including both green and white asparagus) were harvested in Spain, with more than 50% coming from Andalusia (mainly green). During industrial processing, around half of the total length of each spear is discarded, which creates significant waste for producers. Assuming that the by-products have similar composition to the edible part of the spears, these represent a promising source of new value-added compounds (phytochemicals and fibre) (Nindo, Sun, Wang, Tang & Powers, 2003). However, processing and drying may cause irreversible modifications to

the fibre, affecting its original structure. Therefore, its final quality would be determined by the structural and compositional modifications that might have occurred during processing (Garau, Simal, Rosselló & Femenia, 2007).

The objective of this study is to prepare various fibre-rich powders from asparagus by-products using different methods and to evaluate their chemical composition and several functional properties using in vitro tests.

MATERIALS AND METHODS

Asparagus by-products

Asparagus by-products were obtained from Centro Sur S.C.A. (Huétor-Tajar, Granada, Spain). Prior to canning, freshly harvested asparagus spears were cut to obtain the 15 cm-length upper portion (edible part) and the rest of spear (15-18 cm) was considered a by-product. This by-product was sent to our lab within the next 24 hours and held at 4°C until its processing.

Asparagus by-product treatment

Three variables were studied (Table 1): extraction treatment (intense - 90 min. at 60° C, or gentle - 1 min. at room temperature-), extraction solvent (water or 96% ethanol), and drying system (freeze-drying or oven treatment at 60°C for 16 hours). Two Kg by-product portions were cut, homogenized and mixed using a professional homogeniser (Sirman Orione, Marsango, Italy) at top speed with each of the extraction solvents in a ratio 1:1 solid:liquid (w/v), and at the programmed temperature (60°C or room temperature) for 1 min. Afterwards, gently extracted samples (G) were directly processed using a industrial juicer (Tecno-Chufa, Valencia, Spain) to separate an asparagus liquid extract and a wet fibrous residue. Intensely extracted samples (I) were treated in an open reactor designed in our lab, with time and temperature controls and

continuous stirring. After 90 min. of extraction, samples were centrifuged as described above. Each treatment was made in duplicate. One batch of wet fibrous residue was freeze-dried (F-D) and the other dried in oven (O-D). Dried fibres were ground in a hammer mill to a particle size lower than 1 mm and stored at 4°C until analysis.

Proximate composition of fibres

Amounts of neutral sugars (NS), uronic acids (UA), proteins (P), and Klason lignin (KL) were determined as described previously (Fernández-Bolaños et al., 2004). For *neutral sugars*, sugar-free fibres (treated with 80% ethanol) were hydrolysed with trifluoroacetic acid (TFA) at 121° C for 1 h (Ruiter & Burns, 1987) and the released sugars were quantified as alditol acetates by gas chromatography (Englyst & Cumming, 1984); *uronic acids* were quantified using the phenyl-phenol method after sulphuric acid hydrolysis (Ahmed & Labavitch, 1977); *proteins* were analysed by the Kjeldahl method, using a Büchi Digestion Unit K-424 and a Büchi Distillation Unit K-314, applying the factor 6.25 to convert total nitrogen into protein content; *Klason lignin* levels were determined gravimetrically as the amount of acid-insoluble material remaining after a two-stage sulphuric acid hydrolysis.

Cellulose (CEL) was quantified from the TFA-insoluble residue after 72% sulphuric acid hydrolysis, and *soluble sugars* (SS) from the ethanol-soluble extract of fibres, both by the anthrone method (Dische, 1962).

Dietary fibre content

The amount of *total dietary fibre* (TDF) was determined using the protocol described by Lee, Prosky & De Vries (1992), with slight modifications. After digestion, insoluble fibre (IF) was recovered by filtration on a sintered glass (no. 2), washed with distilled water and dried overnight at 100° C (ash and protein were corrected during this step). Four volumes of hot ethanol were added to filtrates and the suspensions of soluble

fibre (SF) were left overnight at 4° C to allow SF to precipitate. Afterwards, SF was recovered by centrifugation for 20 min at 2500g, dissolved in distilled water, and freeze-dried.

Functional properties

Water and oil holding capacities and solubility. Water holding capacity (WHC) was determined by centrifugation as described elsewhere (Jiménez et al., 2000). Samples (250 mg x3) were suspended in 15 ml water. After 24 h of stirring at room temperature, the suspension was centrifuged at 14000g for 1 h. Supernatants were carefully discarded and the hydrated fibres were weighed. WHC was expressed as mL water/g fibrous residue. Hydrated pellets were freeze-dried and solubility in water (SOL) was the weight difference between before and after the WHC assay, expressed as a percent. Oil holding capacity (OHC) was determined with the same conditions as WHC using sunflower oil (1.0054 g/mL density), and was expressed as mL oil/g fibrous residue.

Glucose dialysis retardation index (GDRI). GDRI was determined as described by Lecumberri et al. (2007), with slight modifications. Samples of 400 mg sugar-free fibres (fibres extracted twice with 80% ethanol) were thoroughly hydrated with 15 mL distilled water containing 30 mg glucose. After 1 h continuous stirring, samples were transferred to 15 cm portions of previously hydrated dialysis bags (12,000 MWCO, Sigma Chemical Co.). Each bag and a control bag (with glucose, but without fibre) were put into a reservoir containing 400 mL distilled water and held in a thermostatic water bath at 37°C for 1 h with constant shaking. At 10 min intervals, 0.5 mL of dialysate was collected and the glucose concentration was determined spectrophotometrically by the anthrone method (Dische, 1962). GDRI was calculated as follows:

$$GDRI = 100 - \left(\frac{\text{Total glucose diffused, sample}}{\text{Total glucose diffused, control}} \times 100 \right)$$

Statistical analysis

Results were expressed as mean values $\pm$ standard deviations. To assess for differences in the composition and functional characteristics between the different treatments, a multiple sample comparison was performed using the Statgraphics Plus program version 2.1. Multivariate analysis of variance (ANOVA) followed by Duncan's multiple comparison test was performed to contrast the groups. The level of significance used was $P < 0.05$.

RESULTS AND DISCUSSION

Asparagus by-products could be considered an interesting source of dietary fibre. By-product processing involves several factors that must be controlled in order to have a dietary fibre with optimised composition and functional characteristics. In this study, three factors have been taken into account (severity of treatment, solvent, and drying system) and their effects on fibre characteristics will be discussed.

Proximate composition.

The composition of major components is presented in Table 2. SS and UA, the more soluble components of cell wall, varied the most - from 7-15% and 9-17%, respectively. In the case of UA, fibres from treatments with water were poorer in UA than those from treatments with ethanol. In ethanol-extracted fibres, the choice of drying system resulted in significant differences; freeze-dried fibres had higher UA level than oven-dried ones. In UA quantification, the three factors considered (severity of treatment, solvent, and drying system) were statistically significant.

NS showed little variation among samples. Neither the drying system nor the solvent affected NS content with only the intensity of treatment leading to significant differences. In fibres that were subjected to intense treatment, NS content was higher than in those with gentle treatment. Hemicelluloses, cell wall polysaccharides mainly composed of NS, are insoluble in both solvents, water and ethanol. Thus, during by-product processing, other components were preferentially solubilized and the resultant fibre was enriched in hemicelluloses. Considering the percentage of individual sugars (rhamnose, fucose, arabinose, xylose, mannose, galactose, and glucose) in the total content of NS (data not shown), it was remarkable that the composition of the fibres from different treatments was very similar: xylose accounted for more than 50% of sugar content, while galactose and arabinose each contributed 10-20%. These results are in concordance with those previously reported for white and green asparagus (Waldron & Selvendran, 1992; Rodríguez, Jiménez, Guillén, Heredia & Fernández-Bolaños, 1999a, 1999b). In white spears, xylose accounted for more than 40% of all sugars while glucose, galactose, and arabinose each accounted for 15-20%. In the basal section of white asparagus (Rodríguez et al., 1999a, 1999b), arabinoxylans and xyloglucans are the main hemicelluloses. This composition above presented for by-products suggests that these polysaccharides are also the major species in the basal section of green asparagus.

Cellulose was the main component in all samples. The intensity of treatments did not affect its amount, but the solvent and drying system did. Freeze-dried samples were richer in cellulose than oven-dried ones. In white asparagus (Rodríguez et al., 1999a, 1999b), the cellulose content was double that of NS, while in this study, it was 3-4 fold higher.

Protein content varied between 12 and 16%. The most important difference was caused by the choice of solvent, with higher protein content in ethanol-treated samples than in those treated with water. In most cases, process intensity did not cause any differences.

KL accounted for 11-18%. It is interesting to note that fibres from gentle aqueous treatment (G/W) had significantly lower lignin content than samples from the other treatments. This could indicate that some additional material or some artefacts resulting from processing were quantified as lignin in fibres from intense treatments or treatments with ethanol.

In order to compare these fibre-rich powders with those obtained from other fruit and vegetable by-products, the composition of different fibres obtained from asparagus by-products is summarised as follows: SS 7.18-15.11%, NS 5.27-6.62%, UA 9.06-17.43%, cellulose 18.65-25.25%, protein 12.32-16.30%, and KL 10.97-18.06%. The content of SS in asparagus fibres was slightly higher than that found for other fruit or vegetable by-products. The percentage of SS was around 3% for mango peel (Larrauri, Rupérez, Borroto & Saura-Calixto, 1996) and red grape pomace (Llobera & Cañellas, 2007), although content of around 10% can be found in some citrus by-products (Marín, Soler-Rivas, Benavente-García, Castillo & Pérez-Alvarez, 2007). The content of hemicelluloses (NS) among all fruit and vegetable by-products varies between 5 and 30%. In guava pulp (Jiménez-Escrig, Rincón, Pulido & Saura-Calixto, 2001), hemicelluloses accounted for about 16%, but lower levels (5-7%) were found in cocoa bean husks (Lecumberri et al., 2007) and some citrus by-products (Marín et al., 2007). UA contents also showed high variability depending on the by-product studied. The lowest level was found in guava pulp (Jiménez-Escrig et al., 2001), which was 2%. Lime peels had the highest level, around 25% (Ubando-Rivera, Navarro-Ocaña &

Valdivia-López, 2005). UA levels similar to those in asparagus were found in peach pulp (Grigelmo-Miguel, Gorinstein & Martín-Belloso, 1999). The cellulose content of fibre-rich powder from asparagus by-product was also in the range of the other products, with the lowest level, found in cocoa bean husks, being around 10% (Lecumberri et al., 2007), and the highest, found in citrus, being 36-40% (Marín et al., 2007). The content of protein in the fibre generated from asparagus (12.32-16.30%) was around the highest values reported for agricultural by-products, e.g. 16% for rice bran (Abdul-Hamid & Luan, 2000). The range of lignin content from other by-products was wide, varying from 6% for peach pulp (Grigelmo-Miguel et al., 1999) to 32% for cocoa bean husks (Lecumberri et al., 2007). The lignin content in fibres from asparagus by-product was similar to those reported by Jiménez-Escrig et al. (2001) for guava pulp.

Dietary fibre content

Table 3 shows the content of total dietary fibre (TDF), insoluble fibre (IF), soluble fibre (SF) and the ratio between IF and SF in fibre-rich powder from asparagus by-product. The varying extraction methods resulted in three levels of TDF content. The highest of these was found in fibres from intense treatment in water (I/W), and it was greater than 75%, probably as a consequence of the depletion of soluble components during processing, as was commented upon above. There was another group with medium content (around 69%) that included fibre from intense extraction with ethanol (I/E) and gentle extraction in water (G/W). The lowest TDF content (less than 65%) was found in fibres gently extracted in ethanol (G/E). TDF values in samples ranged from 62.09 to 77.53%, which is greater than the 49.0% previously reported by Grigelmo-Miguel & Martín-Belloso (1999) for asparagus by-product. The difference may be due to the processing that these authors used as they only washed their samples with water

and dried them in an oven. In this case, there was no depletion of soluble components at all, so the percentage of TDF decreased in the total composition.

In the literature there are many by-products that are valuable TDF sources with content varying between 30 and 90%. Three different groups could be established: low-TDF sources (30-50%), such as banana (Rodríguez-Ambriz, Islas-Hernández, Agama-Acevedo, Tovar & Bello-Pérez, 2008), Marsh grapefruit (Figueroa, Hurtado, Estévez, Chiffelle & Asenjo, 2005), and guava (Jiménez-Escrig et al., 2001); medium-TDF sources (50-70%), such as Eureka lemon (Figueroa et al., 2005) and mango peel (Larrauri et al., 1996); and high-TDF sources (70-90%), such as red grape pomace (Llobera & Cañellas, 2007) and lime peel (Ubando-Rivera et al., 2005). Asparagus by-product fibre falls into the medium-TDF content group.

The IF/SF ratio varied from 4.6-7.2 (Table 3). The range to obtain the physiological effects associated with both the soluble and insoluble fractions was 1-2.3 (Spiller, 1986). The lowest value for the IF/SF ratio for asparagus by-product (4.6) was obtained with the G/E treatment. A decrease in this ratio was observed to be linked to the severity of the treatment and the solvent used. The decrease was due to a reduction in the percentage of IF in gently extracted samples. Most fibre from agricultural by-products also had values higher than 4, e.g. cocoa bean husks - 5 (Lecumberri et al., 2007), red grape pomace - 6.4 (Llobera & Cañellas, 2007), banana - 7.6 (Rodríguez-Ambriz et al., 2008), rice bran - 11 (Abdul-Hamid & Luan, 2000), and guava pulp - 27 (Jiménez-Escrig et al., 2001).

Functional properties

Water and oil holding capacities and solubility. The results obtained for WHC, SOL, and OHC are presented in Table 4. WHC is an important property of dietary fibre from both a physiological and technological point of view. WHC showed significant

differences depending on the severity of processing: fibre obtained with thermal treatment had higher WHC. Heating might modify the structural characteristics of the fibre, hence facilitating its water uptake (Figuerola et al., 2005). The choice of drying system did not lead to significant differences, although in other agronomical by-products, drying at high temperatures (40-90° C) causes a reduction in this capacity (Garau et al., 2007). WHC is related to soluble dietary fibre content. As was commented upon above, fibres undergoing gentle treatment had a lower IF/SF ratio, but a higher WHC. So, the effect of heating on fibre structure seems to be greater than the influence of a higher percentage of soluble fibre. It is probably that the high solubility of asparagus fibre, between 22-34% (Table 4), could improve this functional property. SOL was significantly influenced by the choice of drying system, with the lowest value being in I/W samples.

Fibre-rich asparagus powder generated by gentle processing had a WHC similar to what was previously reported (Grigelmo-Miguel & Martín –Belloso, 1999). These results are in the range of most described fibres, e.g. 12.6 mL water/g for peach pulp fibre (Grigelmo-Miguel et al., 1999) and more than 11 mL water/g for lemon fibre (Lario et al., 2004). Other agricultural by-products had lower values than those commented upon above, e.g. rice bran (Abdul-Hamid & Luan, 2000) and cocoa husks (Lecumberri et al., 2007), both with a WHC value of 5 mL water/g fibre. On the basis of these values, this product could be promoted as a modifier of viscosity and texture of formulated products in addition to promoting the decrease in calories that this addition could imply.

Results for OHC are presented in Table 4. Except for G/E samples, freeze-drying resulted in an increase of this property, ranging between 7.5-8.5 mL oil/g powder. G/E samples had lower capacities. Values found in the literature were much

lower than those for asparagus by-products, e.g. 0.6-1.8 mL oil/g for apple pomace and citrus peel (Figuerola et al., 2005), and around 2 mL oil/g for unripe banana flour (Rodríguez-Ambriz et al., 2008). The highest reported level was around 6 mL oil/g described for carrot pulp dried at 50° C (Garau et al., 2007). Fibre-rich asparagus powder had even higher values, so the use of this fibre may be appropriate in products where emulsifying properties are required.

Glucose dialysis retardation index. In Figure 1 the graphs for GDRI are presented. Except for control and I/W O-D, the retardation curves of all the other samples were adjusted at a “square root x” model ($y = a + bx^2$) with $R > 0.92$. Using the regression equation for each sample, the different GDRI's at 60 min. were calculated and the results are presented in Figure 2. Values ranged between 18-48%. Intense treatments led to higher GDRI than gentle ones, although differences were stronger in samples extracted with water than in those extracted with ethanol. Fibre treated with ethanol had higher values than corresponding with water, and those freeze-dried were higher than those that were oven-dried. The GDRI phenomenon seems to be related to the soluble dietary fibre and uronic acid content of insoluble fibre (Edwards et al., 1987; Wolever, 1990), although other authors pointed to the relationship between the internal structure and surface properties of fibres and glucose diffusion (López et al., 1996). Both factors could probably modulate this functional property to different degrees depending on the studied fibre. For asparagus fibre, the surface characteristics must have some influence on GDRI because freeze-dried samples presented a longer delay of glucose dialysis. After regression analysis between chemical composition and the GDRI, uronic acids were the components that showed the highest correlation ($R = 0.72$), in agreement with above comments.

The GDRI is a useful in vitro index to predict the effect that fibre has on the delay of glucose absorption in the gastrointestinal tract (López et al., 1996). In the literature there are a wide range of values, from wheat bran at 5.3% (Adiotomre, Eastwood, Edwards & Brydon, 1990) to guar gum at 43% (Larrauri, Goñi, Martín-Carrón, Rupérez & Saura-Calixto, 1996). Most of the by-products have intermediate values, e.g., artichoke fibre - 27% (López et al., 1996), mango peel - 21% (Larrauri et al., 1996), and carambola pomace - 25% (Chau, Chen & Lin, 2004). The results obtained for fibre-rich powders from asparagus by-product were similar to those reported above, with two of the treatments (I/E F-D and G/E F-D) leading to higher values.

Conclusions

The treatments applied for obtaining the fibre-rich powders from asparagus by-products caused little variability in the chemical composition of the powder. Only the components with high solubility (soluble sugars, uronic acids and proteins) showed significant differences. With gentle treatments, especially those with ethanol, powders with lower IF/SF ratios could be obtained. Therefore, the degree of treatment severity became the key in determining the physiological quality of asparagus by-product fibre. The average composition of fibre obtained under different conditions for asparagus was very similar to other good sources of food fibre suggested in the literature.

The drying systems studied affected fibre surface differently. This factor had a sizeable influence on the functional properties of the fibre. Solubility and oil holding capacity were higher in freeze-dried fibres than in oven-dried fibres. However, water holding capacity was more influenced by thermal treatment. The functionality of thermally treated fibre makes it suitable for addition to fibre-enriched food as a modifier of viscosity and texture, and could also cause a decrease in calories. Some of the fibres

examined in this study have been added to plain yoghurt and were compatible with its manufacturing process (Sanz, Salvador, Jiménez & Fiszman, in press). Especially considering their oil holding capacities, the high-fibre powers from asparagus by-products may be appropriate in products where emulsifying properties are required. This study also revealed that they could effectively retard the diffusion of glucose; this capacity was highly affected by the process by which it was obtained. The potential hypoglycaemic effects of these fibres suggested that they could be incorporated as low-calorie bulk ingredients in high-fibre foods to lower postprandial serum glucose levels. Studies to identify bioactive compounds in these fibres and their in vitro antioxidant activities have been undertaken in order to evaluate the properties of these compounds that may be beneficial for health. These studies are almost ready to be published. Further investigations on the in vivo hypoglycaemic effect and other physiological effects using animal feeding experiments are needed to establish the possibility of the use of asparagus-derived fibres as food ingredients, and for nutritional and technological applications, while making use of asparagus-processing waste. All these studies are thus of economic interest to producers.

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470

471 Table 1.- Different conditions for obtaining a fibre-rich powder from asparagus by-
 472 product.

Description	
I/W O-D	Intense treatment (90 min at 60° C) with water and oven-drying
I/W F-D	Intense treatment (90 min at 60° C) with water and freeze-drying
I/E O-D	Intense treatment (90 min at 60° C) with ethanol and oven-drying
I/E F-D	Intense treatment (90 min at 60° C) with ethanol and freeze-drying
G/W O-D	Gentle treatment (1 min at room temperature) with water and oven-drying
G/W F-D	Gentle treatment (1 min at room temperature) with water and freeze-drying
G/E O-D	Gentle treatment (1 min at room temperature) with ethanol and oven-drying
G/E F-D	Gentle treatment (1 min at room temperature) with ethanol and freeze-drying

473

474

475 Table 2.- Composition of fibre-rich powder obtained under different conditions from
 476 asparagus by-products (% dry matter)^a

		Soluble sugars ^b	Neutral sugars	Uronic acids	Cellulose	Protein	Klason lignin
I/W	O-D	10.99±0.15ab	6.56±0.03a	9.65±0.58ab	22.10±1.16a	12.32±0.14a	16.57±0.64ab
	F-D	12.11±0.49c	6.62±0.13a	9.06±1.04a	25.25±1.46b	12.43±0.08a	18.06±1.78b
I/E	O-D	9.33±0.66d	5.87±0.15b	16.37±1.01c	19.09±2.38c	16.30±0.12b	15.23±0.36a
	F-D	13.70±0.83e	6.14±0.09ab	17.43±0.84d	21.91±0.26a	15.18±0.01c	16.61±0.10ab
G/W	O-D	10.36±0.10a	5.91±0.38b	10.22±0.45b	22.50±1.31a	13.95±0.05d	11.60±0.69c
	F-D	11.25±0.26b	5.77±0.08bc	9.89±1.11ab	22.00±1.05a	13.47±0.25e	10.97±1.52c
G/E	O-D	7.18±0.36f	5.73±0.25bc	11.99±0.58e	18.65±0.99c	16.08±0.01b	16.22±1.91ab
	F-D	15.11±0.14g	5.27±0.30c	15.11±0.52f	22.21±1.40a	15.08±0.09c	14.79±2.02a

477

478 ^a All analyses are done at least in duplicate.

479 ^b Means within a column bearing the same letter are not significantly different at 5%

480 level as determined by the Duncan multiple range test.

Table 3.- Dietary fibre fractions of different fibre-rich powder from asparagus by-products (% dry matter)^a

		IF	SF	TDF ^b	IF/SF
I/W	O-D	66.84±2.56	10.69±0.38	77.53±2.94a	6.2
	F-D	65.15±1.12	10.27±0.35	75.42±1.47a	6.3
I/E	O-D	60.62±1.99	9.79±0.07	70.41±2.05b	6.2
	F-D	60.09±2.11	8.26±0.48	68.35±2.59b	7.2
G/W	O-D	58.22±1.89	9.90±1.69	68.11±3.58b	5.9
	F-D	58.65±1.39	10.52±0.38	69.18±1.77b	5.6
G/E	O-D	54.88±1.50	9.58±0.83	64.45±2.32c	5.7
	F-D	51.02±0.32	11.07±0.32	62.09±0.64c	4.6

^a Values are means of triplicate assays.

^b Means bearing the same letter are not significantly different at 5% level as determined by the Duncan multiple range test.

Table 4.- Functional properties of different fibre-rich powder from asparagus by-products^a.

		WHC ^b	SOL	OHC
		mL water/g powder	%	mL oil/g powder
I/W	O-D	20.34±0.54a	23.39±1.20a	7.61±0.27ab
	F-D	18.84±1.01a	22.58±0.57a	8.19±0.16c
I/E	O-D	19.65±2.08a	27.72±1.75b	7.52±0.27a
	F-D	19.69±1.54a	34.37±2.75c	8.27±0.68c
G/W	O-D	11.40±0.38b	26.53±0.53b	7.69±0.17ab
	F-D	12.58±0.77b	34.15±0.61c	8.53±0.30c
G/E	O-D	12.06±1.26b	28.91±0.96b	5.28±0.34d
	F-D	12.15±0.92b	34.73±0.76c	5.53±0.54d

^a Values are means of triplicate assays.

^b Means within a column bearing the same letter are not significantly different at 5% level as determined by the Duncan multiple range test.

Figure 1

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Figure 2

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553 **FIGURE CAPTIONS**

554

555 Figure 1. Time-related effects of the different fibre-rich powders obtained from
556 asparagus by-products on glucose diffusion.

557

558 Figure 2. Glucose dialysis retardation index (%) of the different fibre-rich powders
559 obtained from asparagus by-products.

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