JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Characterization of Nonstarch Polysaccharides Content from Different Edible Organs of Some Vegetables, Determined by GC and HPLC: Comparative Study

M. J. VILLANUEVA-SUÁREZ,* A. REDONDO-CUENCA, M. D. RODRÍGUEZ-SEVILLA, AND M. DE LAS HERAS MARTÍNEZ

Departamento de Nutrición y Bromatología II (Bromatología), Facultad de Farmacia, Universidad Complutense de Madrid, 28040 Madrid, Spain

Content and composition of dietary fiber as nonstarch polysaccharides (NSP) was determined in vegetables belonging to different types of edible organs, using GC and HPLC. Samples analyzed were subterranean organs (radish and leek), leaves (celery, swiss chard, and lettuce), stalks (celery, swiss chard, and asparagus), inflorescence (broccoli), and fruits (tomato, green pepper, and marrow). The results indicate that though the monomeric profile is similar in all these samples quantitative differences were found for neutral sugars and uronic acids among samples of the same type of vegetal organ. The NSP values determined using CG method were in good agreement with HPLC method ($R^2 = 0.9005$). However, arabinose, mannose, and galactose plus rhamnose are more influenced by the analytical method used than the rest of the monomers in nearly all the samples analyzed. Final values of NSP depend on the method used in celery stalks, broccoli, and green pepper.

KEYWORDS: Nonstarch polysaccharides; dietary fiber; gas chromatography; high-performance liquid chromatography; vegetables

INTRODUCTION

In the past few years, the importance of healthy foods and food components (e.g., dietary fiber) has increased enormously (*1*). Research from several sources provides strong evidence that vegetables, fruits, whole grains, and some compounds of the vegetables such as dietary fiber fractions, certain minerals, some fatty acids, and physical activity protect against some cancers (*2*). The role of dietary fiber (DF) in the prevention and treatment of constipation has been recognized for over a century. Dietary fiber is considered an important nutrient in reducing the risk of western world diseases such as cancer, cardiovascular disease, and diabetes (*3*). Jenkins et al. (*4*) have tested the effects of feeding a diet very high in fiber from fruits and vegetables and concluded that very high-vegetable fiber intakes reduce risk factors for cardiovascular diseases and possibly colon cancer.

Due to the chemical and physical complexity of vegetables, the effects of individual nutrients may differ if eaten as whole foods (*5*). Nutrition educators should provide strategies for consumers to increase use of fruits and vegetables in all meals (*6*). Recommendations are for DF from foods, not from supplements. The use of DF supplements may affect the balance of nutrients in an otherwise healthy diet. Limited data exists on the effect of isolated DF, which may differ from the DF naturally present in a food (*7*).

Foods derived from a wide range of vegetables are found in human diets. The vegetal organs consumed include, for example, leaves, stalks, subterranean organs, inflorescences, fruits, and seeds. These different parts of the plants are formed by different types of tissues, each of which has particular types of cell walls. Dietary fiber present in a mixed diet, and even in the majority of foods, is derived from a range of cell wall structures with compositions that can vary depending on the species, the type of vegetable organ, and the quantities of different vegetable foods that are consumed (*8*).

One of the definitions currently used for DF has been proposed by Englyst (*9*). It evolves from Southgate (*10*) and considers DF as nonstarch polysaccharides (NSP). It has been accepted in the United Kingdom in Food Composition Tables (*11*) and also for labeling purposes (*12*). Englyst et al. (*13*) have pointed out that approximately 90% of plant cell wall material in human foods can be defined chemically as NSP, and that its direct measure in plant foods provides a good index of the plant cell wall present in the food. Another definition accepted by scientists is that dietary fiber is the sum of nonstarch polysaccharides and lignin (*14*).

Dietary fiber analysis can be accomplished by many different methods. Gas chromatography was incorporated early to dietary fiber analysis (*15, 16*). Several methods employing this technique have been developed and some of them are the result of important studies and successive modifications (*17*−*21*). At this moment, this technique is widely used for dietary fiber analysis by many researchers (*22*−*24*). High-performance liquid chro-

* To whom corresepondence should be addressed. Tel.: 34-91-394-1799. Fax: 34−91−394−1798. E-mail: mjvilla@farm.ucm.es.

10.1021/jf021010h CCC: $25.00
Published on Web 08/27/2003

matography for analysis of dietary fiber is more recent (*25*, *26*), and related works are very scarcely reported in the literature. Some works such as those of Redondo et al. (*27*, *28*), Marlett (*29*), Jaime et al. (*30*), and Englyst et al. (*19*, *20*) have been published.

Determination of uronic acids is generally performed by spectrophotometric methods (*31*−*33*) due to the difficulties of chromatographic analysis of these compounds.

The aim of this study is the comparison of the dietary fiber content of some vegetables and its composition of neutral sugars analyzed by GC and HPLC methods and uronic acids by a spectrophotometric method and the study of the differences between dietary fiber depending on the origin of the samples in the plant (subterranean organs, leaves, stalks, inflorescence, and fruits).

MATERIALS AND METHODS

Materials. Samples are vegetables that have been grouped by their edible organs. All the samples (four of each type) were purchased at local markets. Once in the laboratory, they were cleaned and peeled, and non edible parts were removed. Samples were subsequently cut into pieces for freeze-drying (Freeze-dryer Telstar, mod. Cryodos), at −45 °C and 25 mbar. Freeze-dried samples were homogenized and kept in hermetically closed glass bottles. Tomato samples were homogenized before freeze-drying, due to the lack of consistency of the pulps of these products.

Vegetables analyzed were subterranean organs, radish (*Raphanus sativus* L.) and leek (*Allium porrum* L.); leaves, celery (*Apium graveolens*), swiss chard (*Beta vulgaris* L. var. *cycla*), and lettuce (*Lactuca sativa* L.); stalks, celery (*Apium graveolens*), swiss chard (*Beta vulgaris* L. var. *cycla*), and asparagus (*Asparagus officinalis* L.); inflorescence, broccoli (*Brassica oleracea* L.); fruits, tomato (*Lycopersicum esculentum* Mill.), green pepper (*Capsicum annum*), and marrow pulp and peel (*Cucurbita pepo*).

Methods. The analysis of moisture content was based on weight loss experimented after freeze-drying. Aliquots of samples were freeze-dried in vials at the same time as the rest of the product. It was observed that moisture content in samples determined by this method and by the AOAC procedure of desiccation in air-oven (*34*) gave the same results.

Dietary Fiber by CG was determined following the Englyst et al. method (*20*). Isolation of DF was carried out with termamyl (pH = 5.2, 100 °C, 10 min), followed by treatment with a mixture of pancreatin and pullulanase (pH = 7.0, 50 °C, 30 min The residue of DF obtained was hydrolyzed with H_2SO_4, 12 M, at 35 °C, for 30 min, followed by H_2SO_4, 2 M, at 100 °C, for 1 h. The released monomers were transformed in alditol acetates with acetic anhydride in the presence of 1-methylimidazol. Quantification was performed in a Perkin-Elmer Autosystem Chromatograph with a flame ionization detector and an SP-2330 column (30 m long, 0.25 mm i.d., and 0.25-μm film thickness). The carrier gas was nitrogen at 22 psi, injector and detector temperatures were 275 °C, and the oven temperature was 235 °C. The internal standard was β-D-allose (Fluka). Data were registered in a PE Nelson Computer mod. 1020.

Dietary Fiber analysis by HPLC included isolation of dietary fiber residue following the same enzymatic treatment as in the GC method (*20*). This residue is hydrolyzed with H_2SO_4, 12 M (40 °C, 1h), followed by H_2SO_4, 0.4 M (100 °C, 3h) (*27*). The hydrolysates were neutralized using AG4-X4 resin (Bio-Rad Laboratories, Richmond, CA) (*35*, *36*). The neutral sugar composition of the hydrolysates was determined using chromatographic equipment with an injector (Waters, mod. 717), two isocratic pumps (Waters, mod. 510), microguard column (Waters, Guard-Pak Inserts) in series with a carbohydrate analysis column Aminex HPX-87P, 300 mm × 7.8 mm (BioRad Laboratories, Richmond, CA), oven temperature of 85 °C, and refraction index (Waters, mod. 410). Mobile phase was deionized water at a flow rate of 0.5 mL/min. Erythritol (Sigma) was used as the internal standard. A Millenium 2010 chromatography data system was incorporated.

Uronic acids were determined according to the method of Scott (*33*) in both acid hydrolysates to obtain NSP value by GC and by HPLC. A Pharmacia mod. LKB Ultrospec Plus Spectrophotometer was utilized. Galacturonic acid (Merck) was the standard for calibration purposes.

Statistical Analysis. The data from the different vegetables in each group of edible organs were statistically analyzed by one-way analysis of variance. Duncan's multiple-range test was applied to establish differences between samples ($\alpha = 0.05$). To establish the comparison between results obtained by both methodologies, statistical analysis of Student's t-test was applied ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Samples were analyzed in four replicates, and results are expressed as mg/g dry weight to be able to compare them. To know the polysaccharide profile, results for monomeric components are expressed as polysaccharides multiplying neutral sugars by 0.89 and uronic acids by 0.91.

Analysis by gas chromatography (GC) has allowed the identification of seven sugars in the following elution order: rhamnose, fucose, arabinose, xylose, mannose, galactose, and glucose. Rhamnose and fucose are minor components in all of the analyzed samples. They are difficult to analyze due to the low proportion in which they appear. In HPLC analysis, the order of elution of the detected sugars is cellobiose, glucose, xylose, galactose that coelutes with rhamnose, arabinose, and mannose. Cellobiose results from the incomplete hydrolysis of the crystalline regions of cellulose. Some authors consider that a strong acid treatment should render more glucose and a minor proportion of cellobiose due to a most exhaustive hydrolysis of cellulose. However, this treatment could originate partial degradations of pentoses. Lateral chains that contain arabinose are reported as the more sensible components to acid treatment (*37*).

To be able to compare the results obtained for galactose and rhamnose by both techniques, these data were added together when obtained by GC and expressed as one single value. Cellobiose and glucose results obtained by HPLC were also added together and expressed as one single value.

Comparative Study of the Results Obtained by GC and HPLC Methods. In *radish* (**Table 1**), both chromatographic techniques gave similar results for xylose and glucose. Arabinose value, and to a minor extent, mannose value were higher when determined by HPLC method ($p < 0.001$). On the other hand, the estimation of galactose plus rhamnose by HPLC was statistically different ($p < 0.01$) from the sum of both monomers determined by GC. In *leek* there were no significant differences between HPLC and GC results for any individual neutral sugar, except for arabinose ($p < 0.05$), in which the values obtained by HPLC were larger than those measured by GC.

Data from the leaves group show that the HPLC procedure provided more amounts of arabinose ($p < 0.05$) and xylose ($p < 0.01$) than GC in *celery*. The same occurs with arabinose ($p < 0.001$) in *swiss chard* and with arabinose ($p < 0.001$) and mannose ($p < 0.05$) in *lettuce*. Statistically significant differences have been found only for galactose plus rhamnose in lettuce samples ($p < 0.01$). No statistically significant differences have been found for glucose in any vegetable of this group.

In *celery stalks*, differences have been observed only for galactose plus rhamnose ($p < 0.001$). In *swiss chard stalks*, arabinose ($p < 0.05$) is statistically higher by HPLC than by GC, mannose values were lower ($p < 0.001$) by HPLC, and consistent differences have also been detected for galactose plus rhamnose ($p < 0.01$). In *asparagus*, no statistical differences between these two methods have been found for any neutral

Table 1. Dietary Fiber Composition of Neutral Sugars Analyzed by GC and HPLC Methods (mg/g dry weight)

		rhamnose	fucose	arabinose			xylose			mannose			galactose[f]			glucose[g]		
		GC	GC	GC	HPLC	sign	GC	HPLC	sign	GC	HPLC	sign	GC	HPLC	sign	GC	HPLC	sign
radish	subterranean	5.7[a]	0.7[b]	9.7[b]	14.4[b]	***	11.2[a]	11.1[a]	ns	6.4[a]	7.5[a]	***	10.0[b]	13.5[b]	**	84.2[a]	84.5[a]	ns
leek	organs	5.0[b]	1.3[a]	12.5[a]	17.8[a]	*	11.5[a]	11.2[a]	ns	5.1[b]	6.3[b]	ns	46.9[a]	48.8[a]	ns	48.7[b]	49.7[b]	ns
celery		7.7[a]	3.0[a]	17.1[a]	21.6[a]	*	10.8[a]	13.4[a]	**	5.4[a]	6.0[a]	ns	15.4[a]	23.9[a]	ns	55.3[a]	53.9[a]	ns
swiss chard	leaves	3.2[c]		11.9[b]	16.3[b]	***	7.8[b]	7.6[c]	ns	3.8[b]	3.8[b]	ns	9.4[c]	11.5[c]	ns	47.6[b]	50.6[a]	ns
lettuce		6.4[b]	2.6[b]	9.8[c]	14.7[b]	***	10.6[a]	11.2[b]	ns	5.1[a]	6.2[a]	*	10.5[b]	15.2[b]	**	55.4[a]	52.3[a]	ns
celery		6.6[a]	3.2[a]	24.5[a]	24.0[a]	ns	9.0[c]	8.6[c]	ns	6.5[c]	6.8[b]	ns	28.2[a]	29.0[a]	***	90.0[b]	80.8[b]	ns
swiss chard	stalks	5.0[b]		21.6[ba]	25.4[a]	*	16.0[b]	13.4[b]	ns	7.3[b]	4.5[c]	***	14.9[b]	15.4[b]	**	104.9[a]	97.6[a]	ns
asparagus		4.5[c]	1.9[b]	16.8[b]	23.5[a]	**	31.7[a]	33.3[a]	ns	8.0[a]	7.9[a]	ns	27.6[a]	30.9[a]	ns	75.2c	72.8[b]	ns
broccoli	inflorescence	7.6	3.7	36.2	35.8	ns	15.4	12.9	*	7.0	6.5	*	26.8	29.8	*	86.0	80.9	ns
tomato		1.0[c]	0.4[b]	6.2[c]	10.0[b]	*	7.9[c]	9.2[b]	ns	15.1[a]	14.1[a]	ns	9.7[c]	11.7[c]	*	54.4[d]	56.8[b]	ns
green pepper	fruits	1.5[b]		6.3[c]	10.5[b]	***	8.3[c]	11.1[a]	**	5.3[b]	4.0[b]	**	18.9[a]	19.2[a]	ns	60.4[b]	74.7[a]	*
marrow (pulp)		2.5[a]		7.3[b]	11.4[b]	**	9.9[b]	11.0[a]	ns	3.0[d]	4.9[b]	ns	14.4[b]	14.9[b]	ns	58.0[c]	53.0[b]	*
marrow (peel)			1.5[a]	13.7[a]	14.2[a]	ns	10.8[a]	11.7[a]	ns	3.5[c]	2.3[c]	**	14.9[b]	15.4[b]	ns	62.5[a]	66.7[a]	ns

[a–d] Duncan's test: values in the same column of the same group of samples with the same superscript letter are not significantly different ($\alpha = 0.05$). [e] Student's t-test: ns = non significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. [f] HPLC data for galactose correspond with galactose + rhamnose. To compare both methods GC data for galactose and rhamnose are added up. [g] HPLC data for cellobiose and glucose have been added up.

Table 2. Neutral Sugars, Uronic Acids and Nonstarch Polysaccharides (mg/g dry weight)

		Neutral sugars			Uronic acids			NSP		
		GC	HPLC	sign	GC	HPLC	sign	GC	HPLC	sign
radish	subterranean	113.8[a]	116.6[a]	ns	100.9[a]	98.2[a]	ns	214.7[a]	214.8[a]	ns
leek	organs	116.6[a]	119.1[a]	ns	50.4[b]	58.2[b]	ns	167.0[b]	177.3[b]	ns
celery		102.1[a]	105.7[a]	ns	71.4[a]	69.1[a]	ns	173.5[a]	174.8[a]	ns
swiss chard	leaves	74.5[c]	79.9[c]	ns	54.8[b]	48.8[c]	ns	129.3[c]	128.7[c]	ns
lettuce		89.4[b]	88.6[b]	ns	48.4[c]	53.6[b]	ns	137.8[b]	142.4[b]	ns
celery		149.5[a]	132.8[b]	ns	57.8[b]	50.1[b]	**	207.3[b]	182.9[b]	*
swiss chard	stalks	151.0[a]	139.1[ba]	ns	86.2[a]	84.5[a]	ns	237.2[a]	223.6[a]	ns
asparagus		147.5[a]	149.9[a]	ns	47.3[c]	45.3[c]	ns	194.8[c]	195.2[b]	ns
broccoli	inflorescence	162.6	147.7	*	54.9	51.8	ns	217.5	199.5	***
tomato		84.3[c]	90.6[cb]	ns	55.5[c]	60.8[b]	ns	139.8[c]	151.4[b]	ns
green pepper	fruits	89.6[b]	106.4[a]	**	58.3[cb]	61.2[b]	*	147.9[b]	167.6[a]	**
marrow (pulp)		84.6[c]	84.7[c]	ns	67.9[a]	68.3[a]	ns	152.5[a]	153.0[b]	ns
marrow (peel)		95.1[a]	98.2[b]	ns	61.9[b]	52.6[c]	**	157.0[a]	150.8[b]	ns

[a–d] Duncan's test: values in the same column of the same group of samples with the same superscript letter are not significantly different ($\alpha = 0.05$). [e] Student's t-test: ns = non significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

sugar, except for arabinose, with HPLC results being higher than those of GC ($p < 0.01$).

Differences between methods have been significant ($p < 0.05$) in *broccoli* for xylose, mannose, and galactose plus rhamnose. No statistical differences were appreciated for arabinose and glucose.

In *tomato*, statistical differences ($p < 0.05$) affected the contents of arabinose and galactose plus rhamnose. In *green pepper*, arabinose ($p < 0.001$), xylose ($p < 0.01$), and glucose ($p < 0.05$) were in greater amount when measured by the HPLC method; however, the mannose value was lower than that obtained by GC ($p < 0.01$).

In *marrow*, both *pulp* and *peel* have been analyzed separately. In *pulp*, differences were only significant for arabinose ($p < 0.01$) and glucose ($p < 0.05$). In *peel*, statistically significant differences were found only in mannose ($p < 0.01$).

From the results obtained, it could be concluded that arabinose, mannose, and galactose plus rhamnose were more influenced by the analytical method used than the rest of the individual components in nearly all of the samples analyzed.

The value for total neutral sugars (**Table 2**) depended on the analytical procedure used only in *broccoli* ($p < 0.05$) and in *green pepper* ($p < 0.01$). Uronic acids results depended on the different hydrolysates analyzed in *celery stalks* ($p < 0.01$), *green pepper* ($p < 0.05$), and *marrow peel* ($p < 0.01$). Finally, values of NSP depended on the method used in *celery stalks* ($p < 0.05$), *broccoli* ($p < 0.001$), and *green pepper* ($p < 0.01$).

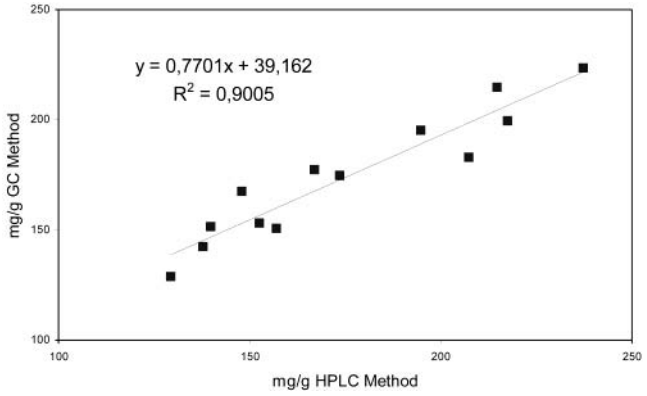

Figure 1. Regression analysis of NSP content by GC and HPLC.

Linear regression for NSP results obtained by GC and by HPLC is represented in **Figure 1**. The coefficient $R^2 = 0.9005$ suggests that both methodologies are in good agreement.

Comparative Study of the Composition and Content of Dietary Fiber of the Different Vegetables Analyzed. *Subter-*

Table 3. Comparative Dietary Fiber Composition of Neutral Sugars, Uronic Acids, and Nonstarch Polysaccharides among Groups of Edible Organs (mg/g dry weight)

	rhamnose	fucose	arabinose	xylose	mannose	galactose	glucose	neutral sugars	uronic acids	nsp
subterranean organs	5.4^{b}	1.0^{bc}	11.1^{cd}	11.3^{cb}	5.8^{a}	28.5^{a}	66.5^{b}	115.2^{c}	75.6^{a}	190.9^{b}
leaves	5.8^{b}	1.9^{b}	12.9^{c}	9.7^{c}	4.8^{a}	11.8^{b}	52.8^{c}	88.7^{d}	58.2^{a}	146.8^{c}
stalks	5.4^{b}	1.7^{b}	21.0^{b}	18.9^{a}	7.3^{a}	23.6^{a}	90.0^{a}	149.3^{b}	63.8^{a}	213.1^{a}
inflorescence	7.6^{a}	3.7^{a}	36.2^{a}	15.4^{ba}	7.0^{a}	26.8^{a}	86.0^{a}	162.6^{a}	54.9^{a}	217.5^{a}
fruits	1.2^{c}	0.5^{c}	8.4^{d}	9.2^{c}	6.7^{a}	14.5^{b}	58.8^{bc}	88.4^{d}	65.4^{a}	153.8^{c}

$^{a-d}$ Duncan's test: values in the same column with the same superscript letter are not significantly different ($\alpha = 0.05$).

ranean organs. In *radish*, the major neutral sugar was glucose, followed by arabinose, galactose, and xylose, which were in similar proportion, and in a minor amount, fucose (**Table 1**). In *leek*, glucose and galactose were the major monomers, followed by arabinose and xylose. Therefore, although these two samples have the same origin in the plant, they have different monomeric profiles, with only xylose content being statistically similar in both vegetables (Duncan's test). Dietary fiber, expressed as NSP (**Table 2**) was higher in *radish* than in *leek*, with the difference being statistically significant (Duncan's test). This difference was mainly due to the uronic acids content.

Leaves. Major sugars for *celery leaves* and *swiss chard leaves* were glucose, arabinose, and galactose (**Table 1**). However in *lettuce*, glucose, xylose, and galactose were the more important components. The larger percentage of uronic acids in the leaves group proceeds from *celery* (**Table 2**). Contents of NSP were statistically different between these samples, with values for *swiss chard* and *lettuce* being lower than the values for *celery* (Duncan's test).

Stalks. In *celery stalks*, major sugars were glucose, galactose, and arabinose, the same as in the leaves of these vegetables (**Table 1**). Stalks from *swiss chard* have as main neutral monomers, glucose, arabinose, and xylose. In *asparagus*, the main neutral monomers were glucose, galactose, and xylose, with this last one present in larger levels than those in the rest of the samples of this group. Among the analyzed stalks (**Table 2**), the ratio between neutral sugars and uronic acids (NS/UA) differed in each sample because of the varying amounts of uronic acids. *Swiss chard* supplied larger amounts of NSP than *celery* and *asparagus*, due to the predominant proportion of uronic acids.

Inflorescence. In *broccoli*, glucose, arabinose, and galactose were the more important neutral monomers (**Table 1**). The ratio of NS/UA reveals that the uronic acids fraction is slightly more represented than that of the neutral sugars (**Table 2**).

Fruits. In *tomato*, glucose and mannose were present in more representative percentages (**Table 1**). In the rest of the fruits, *green pepper* and *marrow* (pulp and peel), glucose is the predominant neutral monomer, followed by galactose. The ratio of NS/UA was similar for all of the samples of this group and suggests a slightly higher contribution of neutral sugars than uronic acids. NSP data have been found statistically different for these samples (Duncan's test) (**Table 2**).

Comparison between different organs of the same vegetable (**Table 2**) indicates for *celery* that neutral sugars were in greater proportion in stalks than in leaves; however, uronic acids in leaves exceeded that of stalks. In *swiss chard*, NSP was higher in stalks than in leaves, due to both neutral sugars and uronic acids; in this case, glucose and arabinose were present in double the amount in stalks with respect to leaves. In *marrow*, the values of NSP, uronic acids, and neutral sugars in pulp and peel were similar. The proportion of neutral monomers (**Table 1**) was very similar between these tissues, except for arabinose, which was found in greater amount in peel than in pulp.

In **Table 3**, data have been compared between groups defined by the location of the edible organ in the plant (subterranean organs, leaves, stalks, inflorescence, and fruits). Each result is the mean corresponding to all the samples of the same type of organ.

Subterranean organs differed significantly from stalks in arabinose and in xylose contents, from the inflorescence in arabinose, and from leaves and fruits in galactose. The value of glucose was different from the rest of the groups, except for fruits.

Leaves differed in arabinose levels from all of the groups except subterranean organs, in xylose content from inflorescence and stalks, and in galactose and glucose from all of the groups except fruits.

Stalks differed from all the groups in arabinose amount, from leaves and fruits in galactose contents, and their glucose value was only similar to that found in the inflorescence.

The inflorescence group shows a significant differentiation from the rest of groups in arabinose content. Xylose, galactose, and glucose contents were different from leaves and from fruits; the last monomer is also different from subterranean organs.

In fruits, significant differences were found for galactose when compared with all of the groups except leaves. Glucose content was found to be different from that for inflorescence and leaves.

Data for mannose and uronic acids corresponding to the grouped vegetables were not affected by statistically significant differences among the compared groups ($p > 0.05$).

NSP value in the subterranean organs group was significatively different from all other groups. In leaves, NSP content was similar only to that of fruits. In stalks, NSP levels differed from subterranean organs, leaves, and fruits. In the inflorescence, NSP content was found to be similar to stalks and different from the rest of the groups. Finally, NSP in fruits was statistically similar only to leaves.

In **Table 4** moisture is expressed in g/ 100 g, and NSP is also expressed in g/100 g on a dry and on a fresh weight basis to have a real knowledge of the dietary fiber supply of each sample to the diet. Moisture content is very high in all of the samples. Values ranged from 73.9g/100 g in broccoli to 96.9g/ 100 g in swiss chard stalks. In celery and in swiss chard, moisture content was found to be higher in stalks than in leaves, and similarily, marrow pulp resulted in a higher water content than marrow peel.

When supplies of NSP are considered in g/100 g dry weight, the larger amounts corresponded to swiss chard stalks, radish, broccoli, asparagus, and celery stalks. However, if values are considered in g/100 g fresh weight, broccoli supplies are the highest, followed by celery leaves, asparagus, leek, and green pepper.

ACKNOWLEDGMENT

We are very grateful to Ricardo García Mata for the statistical assistance.

Table 4. Moisture and Total Dietary Fiber Expressed as NSP (g/100 g)

		moisture	NSP			
			dry weight		fresh weight	
			GC	HPLC	GC	HPLC
radish	subterranean	95.4	21.5^{a}	21.5^{a}	1.0^{b}	1.0^{b}
leek	organs	86.9	16.7^{b}	17.7^{b}	2.2^{a}	2.3^{a}
celery		86.3	17.4^{a}	17.5^{a}	2.4^{a}	2.4^{a}
swiss chard	leaves	92.8	12.9^{c}	12.9^{c}	0.9^{b}	0.9^{b}
lettuce		94.0	13.8^{b}	14.2^{b}	0.8^{c}	0.8^{c}
celery		94.1	20.7^{b}	18.3^{b}	1.2^{b}	1.1^{b}
swiss chard	stalks	96.9	23.7^{a}	22.4^{a}	0.7^{c}	0.7^{c}
asparagus		88.9	19.5^{c}	19.5^{b}	2.2^{a}	2.2^{a}
broccoli	inflorescence	73.9	21.8	20.0	5.7	5.2
tomato		90.7	14.0^{c}	15.1^{b}	1.3^{b}	1.4^{b}
green pepper	fruits	86.9	14.8^{b}	16.8^{a}	1.9^{a}	2.2^{a}
marrow (pulp)		95.4	15.3^{ba}	15.3^{b}	0.7^{d}	0.7^{d}
marrow (peel)		92.1	15.7^{a}	15.1^{b}	1.2^{c}	1.2^{c}

$^{a-d}$ Duncan's test: values in the same column with the same superscript letter are not significantly different ($\alpha = 0.05$).

LITERATURE CITED

(1) Vetter, S.; Kunzek, H. Material properties of processed fruit and vegetables. II. Water hydration properties of cell wall materials from apples. *Eur. Food Res. Technol*. **2001**, DOI 10.1007/s002170 100414.

(2) Greenwald, P.; Clifford, C. K.; Milner, J. A. Diet and cancer prevention. *Eur. J. Cancer.* **2001**, *37*, 948−965.

(3) O'Sullivan, K. R. O.; Cho, S. S. Fibre recommendations throughout the world. *J. Food Sci. Nutr.* **1998**, *49*, 3-S21.

(4) Jenkins, D. J. A.; Kendall, C. W. C.; Popovich, D. G.; Vidgen, E.; Mehling, C. C.; Vuksan, V.; Ransom, T. P. P.; Rao, A. V.; Rosenberg, Z. R.; Tariq, N.; Corey, P.; Jones, P. J. H.; Raeini, M.; Story, J. A.; Furumoto, E. J.; Illingworth, D. R.; Pappu, A. S.; Connelly, P. W. Effect of a very-high-fiber vegetable, fruit, and nut diet on serum lipids and colonic function. *Metab., Clin. Exp*. **2001**, *50*, 494−503.

(5) Liu, S. M.; Lee, I. M.; Ajani, U.; Cole, S. R.; Buring, J. E.; Manson, J. E. Intake of vegetables rich in carotenoids and risk of coronary heart disease in men: The physicians' health study. *Int. J. Epidemiol.* **2001**, *30*, 130−135.

(6) Auld, G. W.; Bruhn, C. M.; McNulty. J.; Bock, M. A.; Gabel, K.; Lauritzen, G.; Medeiros, D.; Newman, R.; Nitzke, S.; Ortiz, M.; Read, M.; Schutz, H.; Sheehan, E. T. Reported adoption of dietary fat and fiber recommendations among consumers. *J. Am. Diet. Assoc*. **2000**, *100*, 52−58

(7) Bal, D. G.; Foerster, S. B. Dietary stratergies for cancer prevention. *Cancer*. **1993**, *72*, 1005−1010.

(8) Johnson, I. T.; Southgate, D. A. T. In *Fibra Dietética y Substancias Relacionadas*; SG Editores, Instituto Español de la Nutrición: Barcelona, Spain, 1995.

(9) Englyst, H. N. Determination of carbohydrate and its composition in plant materials. In *The Analysis of Dietary Fiber in Foods*; James, W. T. P., Theander, O., Eds.; Marcel Dekker: New York, 1981; pp 71−93.

(10) Southgate, D. A. T. Determination of carbohydrates in foods II.- Unavailable carbohydrates. *J. Sci. Food Agric*. **1969**, *20*, 331−335.

(11) McCance and Widdowson's *The Composition of Foods*, 5th ed.; Holland, B., Welch, A. A., Unwin, I. D., Buss, D. H., Paul, A. A., Southgate, D. A. T., Eds.; The Royal Society of Chemistry, Ministry of Agriculture Fisheries and Food: Cambridge, UK, 1994.

(12) Englyst, H. N.; Cummings, J. H. *Analyse der polysaccharide pflanzlicher lebensmittel*. In 22nd Congress proceedings DGQ, Kiel, 1987; pp 21−50.

(13) Englyst, H. N.; Hudson, G. J. The classification and measurement of dietary carbohydrates. *Food Chem*. **1996**, *57*, 15−21.

(14) Theander, O.; Aman, P.; Westerlund, E.; Graham, H. Enzymatic/chemical analysis of dietary fiber. *J. AOAC Inte*r. **1994**, *77*, 703−709.

(15) Sawardeker, J. F.; Sloneker, J. H.; Jeanes, A. Quantitative determination of monosaccharides as their alditol acetates by gas−liquid chromatography. *Anal. Chem.* **1965**, *37*, 1602−1604.

(16) Oades, J. M. Gas−liquid chromatography of alditol acetates and its application to the analysis of sugars in complex hydrolysates. *J. Chromatog*. **1967**, *28*, 246−250.

(17) Theander, O.; Aman, P.; Westerlund, E.; Graham, H. The Uppsala method for rapid analysis of total dietary fiber. In *New Developments in Dietary Fiber*; Furda, I.; Brine, C. J., Eds.; Plenum Press: New York, 1990; pp 273−281.

(18) Theander, O.: Aman, P.; Westerlund, E.; Anderson, R.; Petterson, D. Total dietary fiber determined as neutral sugars residues, uronic acid residues, and Klason lignin (The Uppsala Method): Collaborative study. *J. AOAC Int*. **1995**, *78*, 1030−1044.

(19) Englyst, H. N.; Quigley, M. E.; Hudson, G. J.; Cummings, J. H. Determination of dietary fibre as nonstarch polysaccharides by gas−liquid chromatography. *Analyst*. **1992**, *117*, 1707−1714.

(20) Englyst, H. N.; Quigley, M. E.; Hudson, G. J. Determination of dietary fibre as nonstarch polysaccharides with gas−liquid chromatographic, high-performance liquid chromatographic or spectrophotometric measurement of constituent sugars. *Analyst*. **1994**, *119*, 1497−1509.

(21) Englyst, H. N.; Cummings, J. H. Improved method for measurement of dietary fiber as nonstarch polysaccharides in plant food. *J. Assoc. Food Chem*. **1988**, *71*, 808−814

(22) Redondo-Cuenca, A.; Villanueva-Suárez, M. J.; Rodríguez-Sevilla, M. D.; Heredia-Moreno, A. Changes in insoluble and soluble dietary fiber of white asparagus (*Asparagus officinalis*, L.) during different conditions of storage. *J. Agric. Food Chem*. **1997**, *45*, 3228−3232.

(23) Villanueva-Suárez, M. J.; Redondo-Cuenca, A.; Rodríguez-Sevilla, M. D.; Heredia-Moreno, A. Postharvest storage of white asparagus (*Asparagus officinalis*, L.): Changes in Dietary Fiber (Nonstarch Polysaccharides). *J. Agric. Food Chem*. **1999**, *47*, 3832−3836.

(24) Mongeau, R.; Brassard, R.; Deeks, J. R.; Laffey, P. J.; Nguyen, L.; Brooks, P. J. Comparison of dietary fiber contents of selected baby foods from two major brands in Canada using three methods. *J. Agric. Food Chem*. **2001**, *49*, 3782−3786.

(25) Conrad, E. C.; Palmer, J. K. Rapid analysis of carbohydrates by high-pressure liquid chromatography. *Food Technol*. **1976**, *10*, 84−92.

(26) Barton, F. E.; Windham, W. R.; Himmelsbach, D. S. Analysis of neutral sugar hydrolysates of forage cell walls by high-pressure liquid chromatography. *J. Agric. Food Chem*. **1982**, *30*, 1119−1123.

(27) Redondo, A.; Villanueva, M. J.; Rodríguez, M. D. High-performance liquid chromatography determinationn of dietary fibre in raw and processed carrots. *J. Chromatogr. A.* **1994**, *677*, 273−278.

(28) Redondo-Cuenca, A.; Villanueva-Suárez, M. J.; Rodríguez-Sevilla, M. D. Influence of thermal processes on dietary fibre: a study on turnip (*Brassica napus*). *Eur. J. Clin. Nutr*. **1995**, *49*, s271−s273.

(29) Marlett, J. A. Changes in content and composition of dietary fiber in yellow onions and red delicious apples during commercial storage. *J. AOAC Int*. **2000**, *83*, 992−996.

(30) Jaime, L.; Mollá, E.; Fernández, A.; Martín-Cabrejas, M. A.; López-Andreu, F. J.; Esteban, R. M. Structural carbohydrate differences and potential source of dietary fiber of onion (*Allium cepa*, L.) tissues. *J. Agric. Food Chem*. **2002**, *50*, 122−128.

(31) Bitter, T.; Muir, H. M. A modified uronic acid carbazole reaction. *Anal. Biochem.* **1962**, 330−334.
(32) Blumenkranzt, N.; Asboe-Hansen, G. New method for quantitative determination of uronic acids. *Anal. Biochem.* **1973**, *54*, 484−489.
(33) Scott, R. W. Colorimetric determination of hexuronic acids in plant materials. *Anal. Chem.* **1979**, *51*, 936−941.
(34) AOAC. Moisture in animal feed. Drying in vacum at 95−100 °C. Final Action (934.01). In *AOAC Official Methods of Analysis*, 15th ed.; Helrich, K., Ed.; Association of Official Analytical Chemists: Arlington, VA, 1990; p 69.
(35) Garleb, K. A.; Bourquin, L. D.; Fahey, G. C. Neutral monosaccharide composition of various fibrous substrates: a comparison of hydrolytic procedures and use of anion exchange high-performance liquid chromatography with pulsed amperometric detection of monosaccharides. *J. Agric. Food Chem.* **1989**, *37*, 1287−1293.
(36) Villanueva, M. J.; Rodríguez, M. D.; Redondo, A.; Saco, M. D. Effect of autoclaving on dietary fibre content of beetroot (*Beta vulgaris*). Evaluation by different methods. *Z. Lebensm. Unters Forsch.* **1996**, *203*, 345−350.
(37) Theander, O.; Westerlund, E. A. Studies on dietary fiber. 3. Improved procedures for analysis of dietary fiber. *J. Agric. Food Chem.* **1986**, *34*, 2, 330−336.

Received for review October 1, 2002. Revised manuscript received April 24, 2003. Accepted May 15, 2003.

JF021010H