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Chemical composition and dietary fibre of yellow and green commercial soybeans (Glycine max)

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Abstract

Proximate composition and dietary fibre (as non-starch polysaccharides) of yellow soybeans (from conventional, ecological, transgenic and non-transgenic crops) and green soybeans (from conventional and ecological crops) has been studied. Dietary fibre, fat and ash were significantly higher in yellow than in green samples, but moisture and available carbohydrates were significantly lower in yellow soybean than in green ones. Few statistical differences were found for protein between different samples. Soybean seeds were rich in dietary fibre (yellow: 13.7–16.5 g/100 g, green: 9.19–9.45 g/100 g). This component was evaluated as insoluble and soluble fibre, and subsequently, the neutral sugars and uronic acids were determined by gas liquid chromatography and spectrophotometry, respectively. Insoluble fibre became the predominant fibre fraction in yellow and green soybeans (74–78%), and was mainly composed of glucose, uronic acids, galactose, arabinose and xylose. Soluble fibre was between 22% and 26% in both kinds of samples and the principal monomers were uronic acids, galactose and arabinose. The major difference between total dietary fibres of yellow and green commercial samples was the proportion of galactose, which was an important constituent in yellow soybeans (21%) and a minor one in green soybeans (5%).

Keywords: Dietary fibre; Soybean; Crops

1. Introduction

Soybean is one of the most economically important crops in the USA whilst in Europe it is very limited, due to conditions of climate and soil (Bellido, 2002; Liu, 1997a). While conventional cropping practices are destined to increase crop yield by intensifying the use of land with chemical fertilizers, pesticides and growth regulators, ecological agronomic practices are being introduced in order to prevent land and water degradation, to minimize use of agrochemicals and to introduce addition of organic matter to soil (Lampkin, 2001). On the other hand, the use of transgenic crops as food products is becoming more and more widespread due to their agronomic, economic, environmental and social advantages. Herbicide-tolerant soybean is the dominant biotechnological crop (60% of the global area of transgenic crops), with USA, Canada, Argentina, Brazil and China being the most important producers. Reports of the commercialisation of soybean indicate that 56% of it proceeds from crops in which transgenic technology is utilized (James, 2004).

There is an increasing interest of scientists in soybean, which is focussed on the characterisation of its components and the relationship between its consumption and beneficial health effects in humans (Rostagno, Palma, & Barroso, 2005). Soybean contains high amounts of components with health benefits, such as proteins, isoflavones and dietary fibre (Ren, Liu, Endo, Takagi, & Hayashi, 2006). In many studies, soy protein is considered as a possible source of these, in order to prevent cardiovascular

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disease. In fact, the Food and Drug Administration established that inclusion of soy protein in a diet low in saturated fat and low in cholesterol can reduce coronary disease risk (FDA, 1999; Henkel, 2000). Isoflavones have been reported to play essential roles in preventing certain types of cancers and in reducing the risk of cardiovascular disease (Lee, Yan, Ahn, & Chung, 2003). Furthermore, dietary fibre plays an important role in reduction of cholesterol levels in some hiperlipidemic individuals (Anderson, Smith, & Washnock, 1999; Kushi, Meyer, & Jacobs, 1999) and, in diabetes, it can also be used to improve glucose tolerance (Chandalia et al., 2000; Jenkins et al., 2003; Messina, 1999). Dietary fibre also seems to have a positive effect on diarrhoea and constipation and as a treatment for irritable bowel (Bosaeus, 2004; Liu, 1997b). It has anti-inflammatory and anti-carcinogenic effects on the digestive system (Scheppach et al., 2004). Soluble fibre fermentation results in the production of short-chain fatty acids, principally acetate, propionate and butyrate. Butyrate has been found to act as a protective agent against experimental tumorogenesis of these cells. Propionate could be related to hypocholesterolemic effects. Insoluble dietary fibre has a high water-holding capacity, it increases the fecal bulk and reduces the gastrointestinal transit time. This effect may be related to the prevention and treatment of different intestinal disorders, such as constipation, diverticulitis, haemorrhoids and other bowel conditions (Goñi & Martín-Carrón, 1998). Although there have been many advances about dietary fibre properties, there are still many aspects that remain unclear, mainly relationships between fibre and specific pathologies. Further investigations are needed to establish the precise functions of fibre components on human health and nutrition (Rodriguez, Jiménez, Fernández-Bolaños, Guillén, & Heredia, 2006).

Although the effects of dietary fibre are well known, few studies have been found in the literature on the importance and characterisation of dietary fibre in soybean, some of them are very interesting (Huisman, Schols, & Voragen, 1998; Van Laar, Tamminga, Williams, & Verstegen, 2000; Van Laar, Tamminga, Williams, Verstegen, & Engels, 1999).

Soybean seeds are known to contain different antinutritive factors, such as trypsin inhibitors, phytic acid, raffinose and stachyose, many of which lose their effects after processing (Becker-Ritt, Mulinari, Vasconcelos, & Carlini, 2004; Kumar, Rani, Solanki, & Hussain, 2006)

One of the widely used methods for measuring dietary fibre is the Englyst enzymatic-chemical method (Englyst, Quigley, & Hudson, 1994) for the measurement of plant cell-wall non-starch polysaccharides (NSP). NSP are measured directly as their components (neutral sugars and uronic acids) after isolation and hydrolysis of the polysaccharides. The aim of the present paper was to characterise dietary fibre of yellow and green soybeans from different types of crops, as well as to know their differences in proximate composition.

2. Materials and methods

2.1. Soybean samples

Different samples were selected and grouped into yellow and green soybeans. Yellow seeds were mature harvested samples. Maturation was shown by colour change of pods, from green to brown, and by falling of yellow leaves, leaving only pods. However, green soybeans were harvested before maturation started; therefore no change in colour occurred and they keep their green appearance. The samples came from China, the USA and Brazil. Yellow soybeans were divided into conventional, ecological, transgenic and non-transgenic crops, and green soybeans into conventional and ecological crops according to the labels of each commercial sample. In the European Union, as well as in Spain, genetically modified organisms are subject to adequate labelling requirements, in order to provide clear information (Directive, 2001/18/EC; Ley 9, 2003).

2.2. Proximate composition

Each sample of soybean was blended and homogenised by grinding to a fine powder to pass a 0.4 mm sieve and stored at 4 °C prior to analysis. Moisture was determined by oven-drying at 105 ± 1 °C (AOAC, 1995). Fat content was measured by extraction with diethyl ether in a Soxhlet system (James, 1995). Proteins were analysed as total nitrogen content by the Kjeldahl procedure (AOAC, 1995), and the conversion factor used to transform nitrogen into protein was 5.71. Finally, ash content was determined by incineration of samples at 550 °C in a muffle furnace (AOAC, 1995) and total available carbohydrates were estimated by difference.

2.3. Dietary fibre extraction and quantification

Dietary fibre from soybean was determined according to the method of Englyst et al. (1994). Isolation of fibre 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). Four residues were obtained for each sample. Two of them were destined for total dietary fibre analysis, adding 5 M HCl and acidified ethanol (30 min, 0 °C), and the other two for insoluble fibre analysis, adding phosphate buffer (30 min, 100 °C). The residues obtained were hydrolysed with 12 M H_2SO_4 at 35 °C during 30 min, followed by 2 M H_2SO_4 at 100 °C during 60 min. The released monosaccharides were transformed into alditol acetates with acetic anhydride in the presence of 1-methylimidazole. Quantification was performed in a Perkin–Elmer Autosystem Chromatograph equipped with a hydrogen flame ionisation detector. The column used was a SP-2330 (30 m long, 0.25 mm i.d., and 0.25 μm film thickness) and nitrogen served as carrier gas. Temperatures of injector and detector were 275 °C and oven temperature was 235 °C. Retention times and peak areas were registered in a PE Nelson Computer mod. 1020 and β-D-allose (Fluka) was used as internal standard. Uronic acids were determined in the acid hydrolysates by a colorimetric method using 3,5-dimethylphenol in a Pharmacia mod. LKB Ultrospec Plus at 520 nm, using galacturonic acid as standard (Merck) (Rodriguez, Redondo, & Villanueva, 1992). Soluble fibre was calculated as the difference between total and insoluble fibre.

2.4. Statistical analysis

Data are presented as means and standard deviations. The significant differences among samples were determined by analysis of variance and Duncan's multiple range test ($p \leqslant 0.05$).

3. Results and discussion

3.1. Proximate composition

The proximate composition, expressed in g/100 g of yellow and green soybeans, is shown in Table 1. Yellow soybean's moisture from different crops (conventional: 9.82 g/100 g, ecological: 9.04 g/100 g, transgenic: 7.94 g/100 g and non-transgenic: 8.45 g/100 g) was significantly lower than that of green soybean (conventional: 10.81 g/100 g and ecological: 10.19 g/100 g). As can be seen from the results, the moisture of the transgenic and non-transgenic samples was significantly lower than those of the conventional and ecological ones. The value reported by Souci, Fachmann, and Kraut (1994) corresponded to yellow soybean (8.50 g/100 g).

The content of protein in yellow samples was greater in conventional (40.4 g/100 g) and ecological crops (41.8 g/100 g) than in transgenic (38.9 g/100 g) and non-transgenic crops (39.5 g/100 g), but non-significant differences were found between these samples. However, they were significantly higher ($p \leqslant 0.05$) than those obtained for green soybeans (conventional: 37.1 g/100 g and ecological: 36.8 g/100 g). Results for yellow samples are in agreement with those reported by Liu (1997b) (40 g/100 g), and by Guillon and Champ (2002), which ranged from 38 to 42 g/100 g. Souci et al. (1994) present a protein value of 33.7 g/100 g, which is closer to the amounts of green soybeans. Other legumes present a protein content ranging from 20 to 25 g/100 g (Liu, 1997b); therefore soybean is considered as a good protein source.

Fat mean values for conventional yellow soybean samples were 18.56 g/100 g, ecological 19.22 g/100 g, transgenic 20.74 g/100 g and non-transgenic 21.66 g/100 g. However, green soybeans present very low concentration (conventional: 0.93 g/100 g and ecological: 0.98 g/100 g). Most legumes are very poor in lipids, soybean being an exception. As much as 47% of its energy value is derived from fat content (Liu, 1997b; Messina, 1999). Guillon and Champ (2002) reported percentages of fat between 18 and 22 g/100 g. Anderson et al. (1999) found results around 19 g/100 g, while Souci et al. (1994) obtained a value of 18.10 g/100 g.

Dietary fibre, as the sum of its monomeric constituents, was 16.5 g/100g in conventional yellow soybean samples and 16.3 g/100 g in ecological ones, both of which were significantly higher ($p \leqslant 0.05$) than values obtained in transgenic 13.9 g/100 g and in non-transgenic 13.7 g/100 g. Furthermore, the results for yellow samples were higher ($p \leqslant 0.05$) than those for green samples (conventional: 9.19 g/100 g and ecological: 9.45 g/100 g). Values for yellow soybeans in this work are similar to those of Irish and Balnave (1993) who used the method of Englyst and Cummings (1984). However, Souci et al. (1994) reported higher content, 22.0 g/100 g, using the gravimetric method from AOAC, that includes fibre-associated compounds.

Values for available carbohydrates were calculated by difference with regard to the rest of the components. Results for green soybeans were significantly higher ($p \leqslant 0.05$) than those for yellow soybean samples because of the presence of important proportions of starch. Available carbohydrates of soybean include galactose, raffinose, stachyose, verbascose, fructose and traces of glucose and arabinose (Guillon & Champ, 2002; Huisman, 2000; Liu, 1997b; Sosulski, Elkowicz, & Reichert, 1982). Starch, which is present in cotyledons, is predominant when maturation begins and represents between 13%

Table 1
Proximate composition of yellow and green soybeans (g/100 g)

Soybean crops	Moisture	Protein	Fat	Dietary fibre[a]	Available carbohydrates[b]	Ash
Yellow soybeans						
Conventional	9.82 ± 0.21b	40.4 ± 1.82ab	18.56 ± 0.35d	16.5 ± 0.63a	9.94 ± 1.94c	4.81 ± 0.08b
Ecological	9.04 ± 0.49c	41.8 ± 0.78a	19.22 ± 0.37c	16.3 ± 2.05a	8.92 ± 0.98c	4.72 ± 0.07b
Transgenic	7.94 ± 0.33d	38.9 ± 0.67b	20.74 ± 0.61b	13.9 ± 0.55b	13.3 ± 0.50b	5.28 ± 0.15a
Non-transgenic	8.45 ± 0.43d	39.5 ± 0.53b	21.66 ± 0.37a	13.7 ± 0.34b	11.9 ± 0.74b	4.81 ± 0.15b
Green soybeans						
Conventional	10.81 ± 0.34a	37.1± 0.74c	0.93 ± 0.02e	9.19 ± 0.42c	38.6 ± 0.90a	3.39 ± 0.25c
Ecological	10.19 ± 0.27a	36.8 ± 0.73c	0.98 ± 0.10e	9.45 ± 0.46c	38.5 ± 1.06a	3.08 ± 0.17d

Different letters with the same column mean significant differences according to Duncan's multiple range test ($p \leqslant 0.05$).

[a] Expressed as sum of monomers.

[b] Calculated as (100% − (% moisture + % protein + % fat + % fibre + % ash)).

and 50% of the total carbohydrate fraction (Macrae, Robinson, & Sadler, 1993). However, in mature soybean, starch content falls to approximately 1% (Huisman, 2000; Huisman et al., 1998).

Mineral level in yellow soybeans (conventional: 4.81 g/100 g, ecological: 4.72 g/100 g, transgenic: 5.28 g/100 g, non-transgenic 4.81: g/100 g) was higher ($p \leqslant 0.05$) than that in green soybeans (conventional: 3.39 g/100 g, ecological: 3.08 g/100 g). Souci et al. (1994) reported a total mineral value of 4.70 g/100 g, and Liu (1997b) an ash of 5 g/100 g. These results agree with those obtained for the yellow samples in this study.

Differences in fat and in available carbohydrates between yellow and green soybeans may be due to the different stage of maturation in which they were harvested. In the first stages of development of oleaginous seeds, carbohydrates, especially saccharose, are used to synthesize lipids, which will act as an energy reserve. Lipids content is, therefore, higher in yellow soybeans whereas, in green ones, lipid synthesis has not yet occurred, and available carbohydrates are in a high proportion (Guardiola & García, 1990).

3.2. Dietary fibre

3.2.1. Insoluble dietary fibre

Table 2 shows values of the monomers (neutral sugars and uronic acids) for the insoluble fibre fraction expressed in g/100 g. The amounts of insoluble fibre were significantly lower in green soybeans (conventional: 6.80 g/100 g and ecological: 7.34 g/100 g) than in yellow samples (conventional: 12.3 g/100 g, ecological: 12.5 g/100 g, transgenic: 10.6 g/100 g, non-transgenic: 10.5 g/100 g). In yellow seeds, amounts from conventional and ecological crops were statistically higher than from transgenic and non-transgenic crops.

The major component of insoluble fibre in all the samples analysed was glucose, 30–32% in yellow and 39–40% in green soybeans, indicating that cellulose was the predominant polysaccharide. However, significant differences were found for this monomer among the samples analysed. Glucose was higher ($p \leqslant 0.05$) in two crops of yellow samples, conventional (3.94 g/100 g) and ecological (3.77 g/100 g), than in the other two, transgenic (3.34 g/100 g) and non-transgenic (3.19 g/100 g). The lowest values occurred in the green samples, conventional (2.65 g/100 g) and ecological (2.93 g/100 g).

There were also important amounts of uronic acids (17–20% in yellow and 15–17% in green soybeans) and galactose (18–20% in yellow and 3–4% in green soybeans). In yellow soybeans, uronic acids (conventional: 2.51 g/100 g, ecological: 2.47 g/100 g, transgenic: 1.80 g/100 g, and non-transgenic: 1.90 g/100 g) were significantly higher ($p \leqslant 0.05$) than in green soybeans (conventional: 1.03 g/100 g and ecological: 1.22 g/100 g). The most significant differences between yellow and green samples were found for galactose which was much higher ($p \leqslant 0.05$) in all types of yellow soybeans (conventional: 2.23 g/100 g, ecological: 2.33 g/100 g, transgenic: 1.98 g/100 g and non-transgenic: 2.06 g/100 g) than in both crops of green soybeans (conventional: 0.23 g/100 g and ecological: 0.27 g/100).

There were moderate contents of arabinose and xylose and low contents of mannose, rhamnose and fucose. Arabinose represented 11–14% in yellow and 19–20% in green soybeans, and xylose ranged from 12 to 14% in yellow and 19–21% in green soybeans. Values for arabinose in yellow seeds were 1.40 g/100 g (conventional), 1.66 g/100 g (ecological), 1.52 g/100 g (transgenic), and 1.41 g/100 g (non-transgenic), and in green seeds they were 1.34 g/100 g (conventional) and 1.43 g/100 g (ecological). Contents of xylose in yellow soybeans were 1.43 g/100 g in conventional, 1.51 g/100 g in ecological, 1.40 g/100 g in transgenic and 1.47 g/100 g in non-transgenic, and in green soybeans were 1.43 g/100 g in conventional and 1.40 g/100 g in ecological crops. No statistical differences could be found for arabinose and xylose between yellow and green samples. According to the literature, the high percentages of xylose could be due to the presence of xyloglucans as the main hemicellulosic polysaccharides in soybean cell walls, frequently bound to other sugars, such as galactose, fucose and arabinose (Huisman, 2000).

Mannose was in a minor amount in all of the samples analysed: 2–4% in yellow and 1–2% in green soybeans. In yellow seeds, mannose values from conventional and ecological samples were significantly higher ($p \leqslant 0.05$) than those of transgenic and non-transgenic crops. Very low values were found for rhamnose and fucose, only detected in crops of yellow samples. Irish and Balnave (1993) reported levels of insoluble fibre monomers similar to those of yellow soybeans found in this paper.

Table 2
Sugar compositions of insoluble dietary fibre (g/100 g)

Soybean crops	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic Ac.	Total
Yellow soybeans									
Conventional	0.17 ± 0.02a	0.19 ± 0.04a	1.40 ± 0.10b	1.43 ± 0.06a	0.43 ± 0.07a	2.23 ± 0.22a	3.94 ± 0.27a	2.51 ± 0.36a	12.29 ± 0.42a
Ecological	0.16 ± 0.01ab	0.18 ± 0.03a	1.66 ± 0.28a	1.51 ± 0.26a	0.44 ± 0.07a	2.33 ± 0.75a	3.77 ± 0.12a	2.47 ± 0.30a	12.51 ± 1.71a
Transgenic	0.14 ± 0.02b	0.19 ± 0.01a	1.52 ± 0.04ab	1.40 ± 0.03a	0.26 ± 0.01b	1.98 ± 0.05a	3.34 ± 0.16b	1.81 ± 0.24b	10.64 ± 0.38b
Non-transgenic	0.10 ± 0.02c	0.14 ± 0.01b	1.41 ± 0.04b	1.47 ± 0.02a	0.21 ± 0.01b	2.06 ± 0.09a	3.19 ± 0.21bc	1.90 ± 0.26b	10.47 ± 0.44b
Green soybeans									
Conventional	–	–	1.34 ± 0.03b	1.43 ± 0.07a	0.13 ± 0.01c	0.23 ± 0.03b	2.65 ± 0.31d	1.03 ± 0.13c	6.80 ± 0.43c
Ecological	–	–	1.43 ± 0.07b	1.40 ± 0.04a	0.11 ± 0.00c	0.27 ± 0.01b	2.93 ± 0.21cd	1.22 ± 0.20c	7.34 ± 0.40c

Different letters within the same column mean significant differences according to Duncan's multiple range test ($p \leqslant 0.05$).

3.2.2. Soluble dietary fibre

Soluble fibre (Table 3) was less than insoluble fibre in yellow and in green soybeans. Statistical differences were found between yellow soybean crops (conventional: 4.20 g/100 g, ecological: 3.79 g/ 100 g, transgenic: 3.27 g/ 100 g and non-transgenic: 3.19 g/100 g) and green soybean crops (conventional: 2.40 g/100 g and ecological: 2.11 g/ 100 g). In yellow samples, conventional and ecological presented higher amounts than the other two crops.

Soluble fibre contained large proportions of uronic acids (31–38% in yellow and 41–50% in green soybeans) and galactose (27–29% in yellow and 9–11% in green samples) and a moderate level of arabinose (13–17% in yellow crops and 11–22% in green ones). The same monomers were found to be the major components in soluble soybean fibre by Maeda (2000). Levels of soluble fibre monomers are also very similar to those obtained by Irish and Balnave (1993).

Uronic acid values presented little differences between yellow soybeans (conventional: 1.35 g/100 g, ecological: 1.17 g/100 g, transgenic: 1.20 g/100 g, and non-transgenic: 1.22 g/100 g) and green soybeans (conventional: 0.98 g/ 100 g and ecological: 1.06). Data for galactose in yellow soybeans showed no statistical differences between different types of crops (conventional: 1.13 g/100 g, ecological: 1.04 g/100 g, transgenic: 0.93 g/100 g and non-transgenic: 0.91 g/100 g), while they were significantly higher ($p \leqslant 0.05$) than those of green soybean (conventional: 0.22 g/100 g and ecological: 0.24 g/100 g). The amounts of arabinose and glucose were found to be very similar in all the samples analysed. However, in yellow soybeans, arabinose was lower ($p \leqslant 0.05$) in transgenic (0.44 g/ 100 g) and non-transgenic (0.59 g/100 g) than in conventional (0.72 g/100 g) and ecological crops (0.66 g/100 g). Between yellow and green commercial samples, no significant differences were found. For green soybeans results of conventional (0.53 g/100 g) were higher ($p \leqslant 0.05$) than results for ecological (0.24 g/100 g). Small differences were detected between groups for glucose values, where yellow soybean results were, conventional: 0.51 g/100 g, ecological: 0.40 g/100 g, transgenic: 0.24 g/100 g and non-transgenic: 0.10 g/100 g, and in green soybeans, conventional: 0.43 g/100 g and ecological: 0.30 g/100 g.

The proportions of xylose (1–4% in yellow and 5% in green soybeans) and mannose (6–8% in yellow and 5–7% green soybeans) were lower in soluble than in insoluble fibre. For yellow soybeans, values obtained were 0.12 g/ 100 g in conventional, 0.17 g/100 g in ecological, 0.10 g/ 100g in transgenic, and 0.04 g/100 g in non-transgenic crops and for green soybeans, 0.13 g/100 g in conventional and 0.11 g/100 g in ecological crops. Mannose amounts were similar among yellow soybean crops (conventional: 0.26 g/100 g, ecological: 0.26 g/100 g, transgenic: 0.26 g/ 100 g and non-transgenic: 0.25 g/100 g). These values were a bit higher ($p \leqslant 0.05$) than those in green soybean (conventional: 0.12 g/100 g and ecological: 0.15 g/100 g). Rhamnose is a characteristic monosaccharide of soluble fibre; it was 3% in yellow soybeans, and it was not detected in green soybeans. Though this monosaccharide was found in slightly higher amounts in insoluble fibre, the proportion was lower (1%).

3.2.3. Total dietary fibre

The amount of total dietary fibre, as the sum of its monomeric constituents (Table 4), was greater ($p \leqslant 0.05$) in yellow soybeans (conventional: 16.5 g/100 g, ecological: 16.3 g/100 g, transgenic: 13.9 g/100 g and non-transgenic: 13.7 g/100 g) than in green soybeans (conventional: 9.19 g/100 g and ecological: 9.45 g/100 g). The monomeric compositions (Table 4) were in good agreement with the results reported by Irish and Balnave (1993), Huisman et al. (1998), Guillon, Champ, and Thibault, 2000, Huisman (2000) and Guillon and Champ (2002).

Therefore, in all the commercial samples of the different crops analyzed, both for the yellow and green soybeans, glucose was the main component of total dietary fibre, which also contained significant amounts of uronic acids, arabinose and xylose. The major difference between yellow and green seeds was found to be the proportion of galactose, which was one of the main constituents of fibre for yellow soybeans while, in green soybeans it was among the minor ones. High amounts of uronic acids, galactose (in the case of yellow soybeans) and arabinose may correspond to arabinogalactan, in whose structure the main chain consisted of D-galacturonic acid and L-rhamnose residues and side chains consisted of galactose and arabinose. Arabinogalactans are pectic substances of the soluble fraction of dietary fibre (Huisman, 2000; Huisman et al., 1998; Van de Vis, 1994).

Table 3
Sugar compositions of soluble dietary fibre (g/100 g)

Soybean crops	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic Ac.	Total
Yellow soybeans									
Conventional	0.12 ± 0.02a	–	0.72 ± 0.13a	0.12 ± 0.03b	0.26 ± 0.03a	1.13 ± 0.18a	0.51 ± 0.13a	1.35 ± 0.13a	4.20 ± 0.32a
Ecological	0.10 ± 0.03ab	–	0.66 ± 0.17ab	0.17 ± 0.02a	0.26 ± 0.08a	1.04 ± 0.14ab	0.40 ± 0.19ab	1.17 ± 0.15a	3.79 ± 0.38b
Transgenic	0.09 ± 0.02ab	–	0.44 ± 0.05c	0.10 ± 0.02b	0.26 ± 0.02a	0.93 ± 0.12b	0.24 ± 0.06bc	1.20 ± 0.13b	3.27 ± 0.24c
Non-transgenic	0.09 ± 0.02b	–	0.59 ± 0.08abc	0.04 ± 0.01c	0.25 ± 0.02a	0.91 ± 0.08b	0.10 ± 0.03c	1.22 ± 0.16b	3.19 ± 0.19c
Green soybeans									
Conventional	–	–	0.53 ± 0.02bc	0.13 ± 0.02b	0.12 ± 0.01b	0.22 ± 0.02c	0.43 ± 0.07ab	0.98 ± 0.09c	2.40 ± 0.12d
Ecological	–	–	0.24 ± 0.03d	0.11 ± 0.06b	0.15 ± 0.02b	0.24 ± 0.05c	0.30 ± 0.14b	1.06 ± 0.12c	2.11 ± 0.22d

Different letters within the same column mean significant differences according to Duncan's multiple range test ($p \leqslant 0.05$).

Table 4
Sugar compositions of total dietary fibre (g/100 g)

Soybean crops	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic Ac.	Total
Yellow soybeans									
Conventional	0.29 ± 0.03a	0.19 ± 0.04a	2.12 ± 0.20ab	1.55 ± 0.05a	0.69 ± 0.08a	3.35 ± 0.29a	4.44 ± 0.15a	3.86 ± 0.26a	16.49 ± 0.63a
Ecological	0.25 ± 0.03ab	0.18 ± 0.03a	2.32 ± 0.44a	1.69 ± 0.27a	0.70 ± 0.03a	3.36 ± 0.84a	4.16 ± 0.29a	3.64 ± 0.34a	16.31 ± 2.05a
Transgenic	0.23 ± 0.02b	0.19 ± 0.01a	1.96 ± 0.03abc	1.50 ± 0.04a	0.52 ± 0.02b	2.91 ± 0.14a	3.58 ± 0.11b	3.01 ± 0.36b	13.90 ± 0.55b
Non-transgenic	0.19 ± 0.04c	0.14 ± 0.01b	1.99 ± 0.09abc	1.51 ± 0.03a	0.46 ± 0.02b	2.97 ± 0.04a	3.29 ± 0.18bc	3.11 ± 0.17b	13.66 ± 0.34b
Green soybeans									
Conventional	–	–	1.87 ± 0.05bc	1.56 ± 0.09a	0.24 ± 0.01c	0.45 ± 0.04b	3.08 ± 0.19d	2.00 ± 0.17c	9.19 ± 0.42c
Ecological	–	–	1.67 ± 0.09c	1.51 ± 0.08a	0.26 ± 0.02c	0.51 ± 0.06b	3.22 ± 0.27cd	2.28 ± 0.12c	9.45 ± 0.46c

Different letters within the same column mean significant differences according to Duncan's multiple range test ($p \leqslant 0.05$).

Table 5
Polysaccharide compositions of total dietary fibre (g/100 g)

Soybean crops	Neutral NCP	Acid NCP	CP	NSP
Yellow soybeans				
Conventional	7.37 ± 0.42ab	3.51 ± 0.24a	3.96 ± 0.13a	14.75 ± 0.56a
Ecological	7.66 ± 1.38a	3.32 ± 0.31a	3.70 ± 0.26a	14.59 ± 1.84a
Transgenic	6.60 ± 0.11b	2.74 ± 0.33b	3.18 ± 0.10b	12.43 ± 0.50b
Non-transgenic	6.55 ± 0.09b	2.83 ± 0.15b	2.92 ± 0.17bc	12.22 ± 0.31b
Green soybeans				
Conventional	3.84 ± 0.10c	1.82 ± 0.15c	2.74 ± 0.31c	8.22 ± 0.38c
Ecological	3.69 ± 0.17c	2.08 ± 0.10c	2.87 ± 0.24c	8.46 ± 0.41c

NCP: non-cellulosic polysaccharides; CP: cellulosic polysaccharides; NSP: non-starch polysacharides.
Different letters within the same column mean significant differences according to Duncan's multiple range test ($p \leqslant 0.05$).

Table 5 shows values of non-starch polysaccharides (NSP) and polymeric components, grouped into non-cellulosic neutral polysaccharides (neutral NCP), non-cellulosic acid polysaccharides (acid NCP) and cellulosic polysaccharides (CP). Monomeric residues were corrected by a factor to anhydrosugars, as present in polysaccharides. The polymeric composition of NSP of commercial soybeans, expressed as a percentage, suggested a large proportion of neutral NCP (yellow: 50–54%, green: 44–47%), followed by CP (yellow: 24–27%, green: 33–34%) and acid NSP (yellow: 23–24%, green: 22–25%).

Results on monomeric and polymeric constituents, that characterize the dietary fibre of the soybean seeds, showed the most significant differences between green and yellow soybeans, although the variability found between different crops can be influenced by the different agricultural practices and climate conditions.

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References

Anderson, J. W., Smith, B. M., & Washnock, C. S. (1999). Cardiovascular and renal benefits of dry bean and soybean intake. *American Journal of Clinical Nutrition, 70*, 464–474.

AOAC (1995). *Official methods of analysis* (16th ed.). Washington, DC: Association of Official Analytical Chemists.

Bellido, L. L. (2002). *Cultivos industriales*. Madrid: Mundi-Prensa.

Becker-Ritt, A. B., Mulinari, F., Vasconcelos, I. M., & Carlini, C. R. (2004). Antinutritional and/or toxic factors in soybean (Glycine max (L)) Merril seeds: comparison of different cultivars adapted to the souther region od Brazil. *Journal of the Science of Food and Agriculture, 84*, 263–270.

Bosaeus, I. (2004). Fibre effects on intestinal functions (diarrhoea, constipation and irritable bowel syndrome). *Clinical Nutrition Supplements, 1*, 33–38.

Chandalia, M., Garg, A., Lutjohann, D., Von Bergmann, K., Grundy, S. M., & Brinkley, L. J. (2000). Beneficial effects of high dietary fiber intake in patients with type 2 diabetes mellitus. *The New England Journal of Medicine, 342*, 1392–1398.

Directive 2001/18/EC of the European Parliament and of the Council of 12 March of 2001 on the deliberate release into the environment of genetically modified organism. OJL 106, 17.4.2001 (pp. 1–39).

Englyst, H. N., & Cummings, J. H. (1984). Simplified method for the measurement of total non-starch polysaccharides by gas-liquid chromatography of constituent sugars as alditol acetates. *Analyst, 109*, 937–942.

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

Food and Drug Administration (FDA) (1999). FDA approves new health claim for soy protein and coronary heart disease. FDA Talk Paper in www.fda.gov.

Guardiola, J. L., & García, A. (1990). Acumulación y movilización de las reservas. In J. L. Guardiola Bárcena & A. García Luis (Eds.), *Fisiología vegetal I: Nutrición y transporte* (pp. 379–394). Madrid: Síntesis.

Goñi, I., & Martín-Carrón, N. (1998). In vitro fermentation and hydratation properties of comercial dietary fiber-rich supplements. *Nutrition Research, 8*, 1077–1089.

Guillon, F., & Champ, M. M. J. (2002). Carbohydrate fractions of legumes: uses in human nutrition and potential for health. *British Journal of Nutrition, 8*(3), 293–306.

Guillon, F., Champ, M., & Thibault, J. F. (2000). Dietary fibre functional products. In G. R. Gibson & C. M. Williams (Eds.), *Functional foods* (pp. 315–355). Cambridge: Woodhead Publishing.

Henkel, J. (2000). Soy: Health claims for soy protein, questions about other components. FDA Consumer in www.cfsan.fda.gov.

Huisman, M. M. H. (2000). Elucidation of the chemical fine structure of polysaccharides from soybean and maize kernel cell walls. Ph.D. thesis, Wageningen University, Netherlands.

Huisman, M. M. H., Schols, H. A., & Voragen, A. G. J. (1998). Cell wall polysaccharides from soybean (Glycine max.) meal. Isolation and characterisation. *Carbohydrate Polymers, 37*, 87–95.

Irish, G. G., & Balnave, D. (1993). Non-starch polysaccharides and broiler performance on diets containing soybean meal as the sole protein concentrate. *Australian Journal of Agricultural Research, 44*, 1483–1499.

James, C. S. (1995). Determination of fat by the Soxhlet methods. In C. S. James (Ed.), *Analytical chemistry of foods* (pp. 91–92). London: Blackie Academic & Professional.

James, C. (2004). Preview: global status of commercialized biotech/GM crops in 2004. ISAAA Briefs no. 32. New york.

Jenkins, D. J. A., Kendall, C. W. C., Augustin, L. S. A., Franceschi, S., Hamidi, M., Marchie, A., et al. (2003). Glycemic index: overview of implications in health and disease. *American Journal of Clinical Nutrition, 76*, 266–273.

Kumar, V., Rani, A., Solanki, S., & Hussain, S. M. (2006). Influence of growing environment on the biochemical composition and physical characteristics of soybean seed. *Journal of Food Composition and Analysis, 19*, 188–195.

Kushi, L. H., Meyer, K. M., & Jacobs, D. R. (1999). Cereals, legumes, and chronic disease risk reduction: evidence from epidemiologic studies. *American Journal of Clinical Nutrition, 70*, 451–458.

Lampkin, N. (2001). *La agricultura ecológica*. Madrid: Mundi-Prensa.

Lee, S. J., Yan, W., Ahn, J. K., & Chung, I. M. (2003). Effects of year, site, genotype and their interactions on various soybean isoflavones. *Field Crops Research, 81*, 181–192.

Ley 9/2003 del 25 de abril de (2003), por la que se establece el régimen jurídico de la utilización confinada, liberación voluntaria y comercialización de organismos modificados genéticamente. BOE, núm. 100, 26.4.2003 (pp. 16214–16223). Madrid.

Liu, K. (1997a). Agronomic characteristics, production, and marketing. In K. Liu (Ed.), *Soybeans: Chemistry, technology and utilization* (pp. 1–10). New York: Chapman & Hall.

Liu, K. (1997b). Chemistry and nutritional value of soybean components. In K. Liu (Ed.), *Soybeans: Chemistry, technology and utilization* (pp. 25–113). New York: Chapman & Hall.

Macrae, R., Robinson, R. K., & Sadler, M. J. (1993). *Encyclopaedia of food science, food technology and nutrition*. London: Academic Press.

Maeda, H. (2000). Soluble soybean polysaccharide. In G. O. Phillips & P. A. Williams (Eds.), *Handbook of hydrocolloids*. Cambridge: Woodhead Publishing.

Messina, M. J. (1999). Legumes and soybeans: overview of their nutritional profiles and health effects. *American Journal of Clinical Nutrition, 70*, 439–450.

Ren, H., Liu, H., Endo, H., Takagi, Y., & Hayashi, T. (2006). Anti-mutagenic and anti-oxidative activities found in Chinese traditional soybean fermented products furu. *Food Chemistry, 95*, 71–76.

Rodriguez, R., Jiménez, A., Fernández-Bolaños, J., Guillén, R., & Heredia, A. (2006). Dietary fibre from vegetable products as source of functional ingredients. *Trends in Food Science & Technology, 17*, 3–15.

Rodriguez, M. D., Redondo, A., & Villanueva, M. J. (1992). Estudio comparativo de los métodos m-hidroxifenilfenol y 3,5-dimetilfenol para determinar sustancias pécticas en nabo (*Brassica napus*). *Alimentaria, 232*, 79–83.

Rostagno, M. A., Palma, M., & Barroso, C. G. (2005). Short-term stability of soy isoflavones extracts: sample conservation aspects. *Food Chemistry, 93*, 557–564.

Scheppach, W., Luethrs, H., Melcher, R., Gostner, A., Schauber, J., Kudlich, T., et al. (2004). Antiinflammatory and anticarcinogenic effects of dietary fibre. *Clinical Nutrition Supplements, 1*(2), 51–58.

Sosulski, F. W., Elkowicz, L., & Reichert, R. D. (1982). Oligosaccharides in eleven legumes and their air-classified protein and starch fractions. *Journal Food Science, 47*, 498–502.

Souci, S. W., Fachmann, W., & Kraut, H. (1994). *Food composition and nutrition tables*. Stuttgart: Scientific Publishers.

Van Laar, H., Tamminga, S., Williams, B. A., & Verstegen, M. W. A. (2000). Fermentation of the endosperm cell walls of monocotyledon and dicotyledon plant species by faecal microbes from pigs. The relationship between cell wall characteristics and fermentability. *Animal Feed Science and Technology, 88*, 13–30.

Van Laar, H., Tamminga, S., Williams, B. A., Verstegen, M. W. A., & Engels, F. M. (1999). Fermentation characteristics of cell-wall sugars from soya bean meal, and from separated endosperm and hulls soya beans. *Animal Feed Science and Technology, 79*, 179–193.

Van de Vis, J. W. (1994). Characterization and mode of action of enzymes degrading galactan structures of arabinogalactans. Ph.D. thesis, Wageningen University, Netherlands.