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Effect of Industrial Dehydration on the Soluble Carbohydrates and Dietary Fiber Fractions in Legumes

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The effects of soaking, cooking, and industrial dehydration treatments on soluble carbohydrates, including raffinose family oligosaccharides (RFOs), and also on total dietary fiber (TDF), insoluble dietary fiber (IDF), and soluble (SDF) dietary fiber fractions were studied in legumes (lentil and chickpea). Ciceritol and stachyose were the main α-galactosides for chickpea and lentil, respectively. The processing involved a drastic reduction of soluble carbohydrates of these legumes, 85% in the case of lentil and 57% in the case of chickpea. The processed legume flours presented low residual levels of α-galactosides, which are advisable for people with digestive problems. Processing of legumes involved changes in dietary fiber fractions. A general increase of IDF (27−36%) due to the increase of glucose and Klason lignin was observed. However, a different behavior of SDF was exhibited during thermal dehydration, this fraction increasing in the case of chickpea (32%) and decreasing in the case of lentil (27%). This is probably caused by the different structures and compositions of the cell wall networks of the legumes.

KEYWORDS: Dehydration; legumes; soluble carbohydrates; α-galactosides; dietary fiber

INTRODUCTION

Legume seeds are a good source of protein and calories, and they are widely consumed all over the world (*1*). Legumes are often advocated in Western diets because of their beneficial nutritional effects (*2*); they are considered to be good sources of structural carbohydrates mainly due to their higher dietary fiber (DF) content when compared to other fiber-rich plant foods such as cereals and tubers (*3*, *4*). Their low glycemic index can be considered as beneficial for health and especially for the prevention of diseases related to insulin resistance (*5*). However, in some countries legumes are not utilized sufficiently in the human diet because of their antinutritional factors (*6*).

The presence of α-galactosides in seeds is one of the major reasons why legumes do not play a more major role in animal and human nutrition. These compounds, called also raffinose family oligosaccharides (RFOs), include raffinose, stachyose, and verbascose (*7*) and have important functions in many plant seeds. However, the digestive system of monogastric animals lacks α-galactosidase (EC 3.2.1.22) activity in the small intestine, and the RFOs pass into the large intestine, where the microorganisms present utilize these sugars and lead to flatus formation, which is responsible for digestive discomfort in humans and diarrhea in animals. Besides causing digestive discomfort, flatus production may be a more acute problem in individuals with colonic pathologies such as irritable bowel syndrome. For the above reasons, it would be desirable for most of the population to remove α-galactosides from pulses by technological or genetic means, although α-galactosides may also have a beneficial effect by increasing the bifidobacteria population in the colon (*8*−*10*).

Although research has been done on the effect of processing on the carbohydrate fraction of legumes (*4*, *11*), not much work has been carried out about the industrial process of dehydration after soaking and cooking treatments on the contents of carbohydrate fraction to determine the nutritional improvement. The obtained dehydrated legume flours could be considered ready-to-use for special meals for specific groups of populations.

Hence, in the present study, an attempt has been made to screen oligosaccharides and to assess the effect of soaking, cooking, and dehydration treatment for eliminating oligosaccharides from legumes. In addition, this study has evaluated the effect of this processing on the content of dietary fiber and its fractions in order to obtain legume flours with high nutritive value.

MATERIALS AND METHODS

Samples. The chickpea and lentil cultivars used in the present study were obtained from the agri-food industry through Vegenat S.A. (Badajoz, Spain). From each cultivar there were batches of 250 g of raw and processed samples. The seeds were freeze-dried and then milled to flour and passed through a 250 μm sieve.

Processing Conditions. Legumes were subjected to an industrial dehydration process carried out at Vegenat S.A. The processing

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Table 1. Content of Soluble Carbohydrates in Procesed Legumes (Grams per Kilogram of Dry Matter)[a]

sample	fructose	glucose	galactose	sucrose	maltose	raffinose	ciceritol	stachyose	total RFOs[b]	total sugars
					Chickpea					
raw	2.7 ± 0.3c	1.9 ± 0.2 b	3.0 ± 0.2 b	27.1 ± 2.5 c	1.4 ± 0.1 d	3.9 ± 0.3 c	20.3 ± 1.8 c	14.0 ± 1.1 c	38.2	74.3
S	1.9 ± 0.2 b	1.6 ± 0.1 b	2.6 ± 0.2 b	17.4 ± 1.5 b	0.8 ± 0.08 c	2.8 ± 0.2 b	15.0 ± 1.2 b	10.5 ± 0.9 b	28.3	52.6
S + C	1.6 ± 0.2 b	1.5 ± 0.2 b	2.6 ± 0.2 b	15.1 ± 1.5 b	0.5 ± 0.03 b	2.3 ± 0.2 b	14.0 ± 1.4 b	9.6 ± 0.9 b	25.9	47.2
S + C + D	1.1 ± 0.1 a	1.0 ± 0.1 a	1.5 ± 0.1 a	10.1 ± 0.8 a	0.2 ± 0.01 a	1.3 ± 0.1 a	9.3 ± 0.7 a	7.5 ± 0.6 a	18.1	32.0
					Lentil					
raw	1.1 ± 0.1 c	0.4 ± 0.04 c	tr[c]	9.2 ± 1.0 d	0.5 ± 0.03 c	2.2 ± 0.1 d	10.5 ± 0.9 d	16.4 ± 1.5 c	29.1	40.3
S	0.8 ± 0.07 b	0.3 ± 0.02 b	tr	5.1 ± 0.5 c	0.3 ± 0.01 b	1.5 ± 0.1 c	5.2 ± 0.4 c	11.0 ± 1.0 b	17.7	24.2
S + C	0.4 ± 0.03 a	0.2 ± 0.01 a	tr	3.3 ± 0.2 b	0.2 ± 0.01 a	1.1 ± 0.1 b	3.5 ± 0.2 b	9.4 ± 0.9 b	14.0	18.1
S + C + D	tr	tr	tr	1.1 ± 0.1 a	tr	0.5 ± 0.04 a	1.2 ± 0.1 a	3.3 ± 0.3 a	5.0	6.1

[a] Mean values of each column followed by different letters significantly differ when subjected to Duncan's multiple-range test ($p < 0.05$). Mean ± SD ($n = 4$). [b] Raffinose family oligosaccharides (raffinose + stachyose + ciceritol). [c] Traces.

consisted of the following steps: raw material was soaked in tap water (1:10 w/v) for 16 h at 20 °C. After the soaking water had been drained, the soaked legumes were cooked by boiling for 70 min at 100 °C in the case of chickpea and for 30 min in the case of lentil. The soaked−cooked seeds were dehydrated in a forced-air tunnel at 75 ± 3 °C for 6 h.

Samples were named as follows: S (soaked legumes), S + C (soaked and cooked legumes), and S + C + D (soaked, cooked, and dehydrated legumes).

Determination of Soluble Carbohydrates. The extraction method of soluble carbohydrates was carried out in legume flour according to a procedure described previously by Sánchez-Mata et al. (*12*). The sample extract was vacuum evaporated at 30 °C to dryness; the concentrated sugars were redissolved in deionized water, sonicated for 5 min, filtered using Whatman 41 paper, and made up to 10 mL with Milli-Q water. Samples were passed through a Sep-Pak C_{18} cartridge (Waters, Milford, MA), and 2 mL of filtrate was mixed with 8 mL of acetonitrile and filtered through a 0.54 μm Millex membrane prior to injection. The soluble carbohydrates were determined by HPLC using an amino-bonded column (3.9 × 300 mm column, Waters), an isocrate pump, and a refractive index detector. The mobile phase was acetonitrile/water (65:35 v/v) at a flow rate of 1 mL min^{-1} and room temperature.

Quantification of peaks was performed using the external standard method. An approach to the amount of ciceritol (with no commercial standard available) was made, using the calibration curve of the previous peak (raffinose), corrected by molecular weight. Standard sugars were obtained from Merck (Darmstadt, Germany).

Dietary Fiber Determination. Mes-Tris AOAC method 991.43 was used for DF determination (*13*). Two replicates of each sample were taken to complete the six-sample analysis method. The principle of the method was based on the use of three enzymes (heat-stable α-amylase, protease, and amyloglucosidase) under different incubation conditions to remove starch and protein components. Dietary fiber fractions were obtained as indigestible residues after enzymatic digestion of nondietary fiber components; the insoluble residues were isolated by filtration, and soluble fiber was precipitated with ethanol. Dried residues correspond to insoluble dietary fiber (IDF) and soluble dietary fiber (SDF), respectively. Determination of residual ashes and proteins (as Kjeldahl N × 6.25) was carried out in the residues for corresponding corrections. Total dietary fiber (TDF) was calculated as the sum of IDF and SDF. Kjeldahl nitrogen and ash contents were assayed according to standard procedures (*13*).

Chemical Analysis of DF Components. Amounts of 100.0 ± 0.1 mg of insoluble fiber residues were subjected to 12 M H_2SO_4 treatment for 3 h at room temperature, followed by dilution to 0.6 M H_2SO_4 hydrolysis at 100 °C for 3 h and also to 0.6 M H_2SO_4 hydrolysis at 100 °C for 3 h. The same amounts (100.0 ± 0.1 mg) of soluble fiber residues were only hydrolyzed with 0.6 M H_2SO_4 at 100 °C for 3 h (*14*). The acid hydrolysis released the different fiber components, neutral sugars and uronic acids. The insoluble residue after 12 + 0.6 M H_2SO_4 hydrolysis was recovered quantitatively over a glass filter (Pyrex no. 4), washed thoroughly with pure water, and dried for 18 h at 105 °C corresponding to Klason lignin residue.

The hydrolysates were neutralized using AG4-X4 resin (Bio-Rad Laboratories, Richmond, CA). The neutral sugar composition of the hydrolysates was determined by HPLC using a microguard column (Aminex Carbo-P, Bio-Rad Laboratories) in series with a carbohydrate analysis column (Aminex HPX-87P, Bio-Rad Laboratories) using a refractive index detector. Galactose and rhamnose coelute from this column. The amounts of sugars present were computed using the System Gold 7.0 version software after calibration with standard sugars (Sigma, St. Louis, MO). Erythritol (Sigma) added just before neutralization was used as the internal standard. Recoveries from the hydrolytic procedure were determined by subjecting standard sugars to the total analytical procedure (*15*).

Uronic acids were determined colorimetrically by adapting the 3-hydroxydiphenyl method of Blumenkrantz and Asboe-Hansen (*16*) with D-galacturonic acid (Sigma).

Statistical Analysis. Results were analyzed using Duncan's multiple-range test (DMRT) (*17*). Differences were considered to be significant at $p \leq 0.05$.

RESULTS AND DISCUSSION

The levels of monosaccharides, disaccharides, and RFOs are presented in **Table 1**. The presence of ciceritol was also considered, although it could not be confirmed due to the lack of a commercial standard available. The chickpea and lentil seeds analyzed differed from each other in different amounts of total soluble sugars. The raw chickpea showed the highest level of total soluble sugars [74.3 g kg^{-1} of dry matter (DM)], sucrose being the main component (≈36% of the total sugar content). The raffinose family sugars accounted for 52% of the total sugar content. The peak of the main α-galactoside appears after raffinose and before stachyose. Its position in the chromatograms and its quantity in the samples suggested that it was ciceritol and other digalactocyclitols. These sugars, which were also detected in earlier studies (*18*−*20*), comprised 27% of the total sugars analyzed in chickpea. Other α-galactosides identified were stachyose and raffinose, the stachyose level (19%) being higher than that of raffinose (5%). Verbascose was not identified in the studied legumes. The contents of RFOs observed in the chickpea were in the same range as reported earlier (*5*, *20*).

Lentil showed a lower content of total soluble sugar (40.3 g $kg^{-1}$of DM) than chickpea, stachyose being the major soluble sugar (41% of the total sugar content), followed by ciceritol (26%) and sucrose (23%). The level of sucrose in the present study was low when compared to the values reported earlier (*21*), which could be due to differences in the environmental conditions, as well as genotypes studied (*22*).

In both legumes the monosaccharides appeared in minor amounts in the soluble sugar fraction, and in some legumes they

are not even present (*19*, *20*). In this study, the sum of fructose, glucose, and galactose represented 10 and 4% of the total sugar content in chickpea and lentil, respectively.

In general terms, the industrial process of soaking, cooking, and dehydration involved a drastic reduction of the soluble carbohydrates of these legumes. It has been observed that the decrease was more accentuated in the case of lentil (85%) than in the case of chickpea (57%) at the end of the industrial process.

During soaking treatment (S), a significant decrease of sugars was shown, especially of sucrose and ciceritol (44 and 51%, respectively) in lentil and of sucrose and total RFOs (36 and 25%, respectively) in chickpea. Therefore, the possible metabolic processes that take place during this treatment would solubilize sugars from the cell to the soaking solution, which was drained off (*20*, *23*, *24*). Price et al. (*25*) have reported that soaking of legumes decreased the levels of RFOs, and the different percentage of sugar reduction could be attributed to the differential solubilities of individual sugars and their diffusion rates. Nevertheless, an increase of soluble carbohydrates of legumes has also been reported after soaking (*23*). The cooking after soaking treatment (S + C) also facilitated the solubilization of sugars that represented a reduction of total soluble sugars of ≈36% in chickpea and ≈55% in lentil. The content of α-galactosides suffered a reduction ranging from 31 to 49% in chickpea and from 43 to 67% in lentil. The major soluble sugars in the processed (soaked and cooked) samples were sucrose and ciceritol in chickpea and stachyose in lentil, as in the raw samples. Data regarding the effect of soaking and cooking on the α-galactoside content in some legumes have been reported (*23*, *26*, *27*), and authors agree that domestic treatments, the fermentation and germination processes, and also the α-galactosidase treatment (*28*) reduce the flatulence compounds, although, once again, reduction varies not only with the conditions of the procedure such as cooking time and temperature but also with the type of legume. However, in some cases increases in stachyose, raffinose, and verbascose contents have been detected in cooked legumes, probably due to the interaction with macromolecules (*29*). In addition, mono- and disaccharides increased after processing, due to the hydrolysis of oligo- and polysaccharides in the samples or the formation of other compounds during the cooking process (*27*, *28*).

Industrial dehydration was the process that produced the greatest reductions of these soluble compounds. Dehydration after soaking and cooking processing (S + C + D) was an efficient process to reduce the levels of RFOs in legumes, by 53% in chickpea and by 83% in lentil. Comparing individual α-galactosides in chickpea, raffinose was the oligosaccharide that experienced the largest reduction (67%), followed by ciceritol (54%) and stachyose (46%). In the case of lentil, the decreases were greater for ciceritol (89%), followed by stachyose (80%) and raffinose (77%). The reduction detected after the industrial dehydration in stachyose and raffinose, as flatulence-inducing sugars, was 56% in chickpea and 79% in lentil. The results showed larger reductions than those obtained by other processing reported previously (*20*, *23*, *24*). Therefore, the flours obtained from these processed legumes present low residual levels of α-galactosides and may be advisable for people with digestive problems.

Different studies have been carried out on the effect of different thermal methods and chemical and mechanical processes upon DF components (*30*−*32*); however, the effect of the industrial dehydration process upon DF fractions of legumes has not been well documented. This industrial process had a significant impact on these values (**Table 2**), showing the largest changes in dehydrated legumes. The levels of IDF were important in these legumes, which are higher than in other important legumes and cereals (*31*, *34*, *35*). This fraction represented 89 and 93% of the TDF for lentil and chickpea, respectively. The remaining percentage of these values was composed of soluble fiber, representing a small part (11−7%) of the total DF of these legumes. These results are in accordance with those found in the literature (*35*, *36*).

Table 2. Content of Insoluble, Soluble, and Total Dietary Fiber and Its Distribution in Raw and Processed Legume Flours (Grams per Kilogram of Dry Matter)[a]

sample	IDF	SDF	TDF	IDF:SDF
		Chickpea		
raw	195.4 ± 9.8a	15.1 ± 1.1a	210.5	13:1
S	215.1 ± 12.9 a	15.4 ± 1.3a	230.5	14:1
S + C	233.1 ± 11.7 b	14.6 ± 0.9 a	247.7	16:1
S + C + D	265.8 ± 15.3 c	19.9 ± 1.8b	285.7	13:1
		Lentil		
raw	216.3 ± 12.7 a	26.8 ± 2.1 c	243.1	8:1
S	217.3 ± 12.0 a	17.6 ± 1.6 a	234.9	12:1
S + C	282.5 ± 16.7 b	21.8 ± 1.9 b	304.3	13:1
S + C + D	274.0 ± 17.3 b	19.6 ± 1.8 b	293.6	14:1

[a] Mean values of each column followed by different letters significantly differ when subjected to Duncan's multiple-range test ($p < 0.05$). Mean ± SD ($n = 6$).

Processing of legumes caused some changes in dietary fiber fractions (**Table 2**). The soaking process (S) had a different impact on the IDF fraction in the studied legumes, showing an increase in chickpea (10%), whereas lentil did not show changes compared to raw samples. Pérez-Hidalgo et al. (*30*) obtained slight increases of insoluble dietary fiber content in soaked chickpeas. Rehinan et al. (*31*) reported no changes in neutral detergent fiber content of legumes soaked in tap water, whereas fiber increased in legumes soaked in sodium bicarbonate solution. The cooking process (S + C) showed a further increase of IDF in both legumes (19% in chickpea and 31% in lentil), and the dehydration (S + C + D) raised the level of IDF in chickpea (36%). The increases of IDF values are mainly due to higher gravimetric residues found in processed legumes, accompanied in the case of lentil by a lower protein content (7 versus 9%) associated with the fiber matrix.

With regard to SDF, the results were different depending on the type of legume. The industrial dehydration process (S + C + D) exhibited an increase of this fraction in chickpea (32%), whereas lentil showed a general decrease in processed samples (27%). The studied legumes had different behaviors during processing due to the different structures and compositions of the cell wall network. These results agree with data presented in studies by Kutos et al. (*36*) and Almeida et al. (*37*), which indicated increases of SDF in pea and common bean. However, Vidal-Valverde et al. (*38*, *39*) suggested that a softening of soluble fibers occurs with the cooking process, reducing its content.

The result of these processing methods could influence the physiological effects of DF. The ratio of insoluble to soluble fiber is important from both dietary and functional perspectives. To be acceptable, a dietary fiber ingredient must perform in a satisfactory manner as a food ingredient (*40*). The ratio of insoluble to soluble fiber is an important variant related to structural and also sensorial properties. The changes promoted by the dehydration process are reflected in the IDF:SDF ratio. This suggests that the industrial procedure might be used to alter the dietary and functional characteristics of the fiber.

The profile of the sugar composition of IDF indicated clear differences between IDF constituents of these legumes (**Table**

Table 3. Composition of Insoluble Dietary Fiber in Raw and Processed Legume Flours (Grams per Kilograms of Dry Matter)[a]

sample	H_2SO_4 hydrolysis	carbohydrates						total sugars	Klason lignin	total
		Glc	Xyl	Gal/Rha	Ara	Man	UA			
					Chickpea					
raw	12 + 0.6 M	40.6 ± 4.1a	1.5 ± 0.2 a	1.7 ± 0.1 b	48.4 ± 3.3 a	nd[b]	12.9 ± 1.1 b	105.1	22.4 ± 2.1 a	127.5
	0.6 M	14.7 ± 1.2	1.1 ± 0.1	1.8 ± 0.2	56.6 ± 4.5	0.6 ± 0.1	16.0 ± 1.6	90.8		90.8
S	12 + 0.6 M	36.1 ± 2.1 a	2.6 ± 0.2 b	1.8 ± 0.1 b	55.3 ± 4.7 a	nd	11.6 ± 1.1 b	107.4	20.2 ± 2.0 a	127.6
	0.6 M	11.9 ± 0.9	1.8 ± 0.1	1.9 ± 0.1	62.9 ± 5.8	0.4 ± 0.1	12.0 ± 0.8	90.9		90.9
S + C	12 + 0.6 M	55.3 ± 4.9 b	3.2 ± 0.3 c	4.0 ± 0.3 c	59.5 ± 4.1 b	nd	8.0 ± 0.8 a	130.0	67.8 ± 5.9 b	197.8
	0.6 M	12.4 ± 1.3	1.3 ± 0.1	3.5 ± 0.3	64.2 ± 5.9	nd	7.8 ± 0.5	89.2		89.2
S + C + D	12 + 0.6 M	54.2 ± 5.1 b	1.1 ± 0.2 a	0.5 ± 0.1 a	52.8 ± 4.2 a	0.3 ± 0.0	12.9 ± 1.2 b	121.8	87.8 ± 7.3 c	209.6
	0.6 M	22.1 ± 2.1	nd	1.6 ± 0.2	62.0 ± 5.6	2.2 ± 0.2	14.8 ± 1.4	102.7		102.7
					Lentil					
raw	12 + 0.6 M	77.7 ± 6.3 b	12.7 ± 1.1 b	1.0 ± 0.1 c	26.0 ± 2.4 a	1.3 ± 0.1	9.7 ± 0.9 b	128.4	41.2 ± 3.8 a	169.6
	0.6 M	35.1 ± 3.3	5.8 ± 0.3	1.4 ± 0.1	27.9 ± 2.5	4.7 ± 0.4	6.8 ± 0.6	81.7		81.7
S	12 + 0.6 M	67.9 ± 1.5 a	8.1 ± 0.7 a	0.2 ± 0.01 a	31.1 ± 2.8 a	nd	7.2 ± 0.6 a	114.5	51.4 ± 4.8 b	165.9
	0.6 M	27.2 ± 0.6	8.0 ± 0.7	1.1 ± 0.1	36.2 ± 3.1	0.9 ± 0.1	8.9 ± 0.8	82.3		82.3
S + C	12 + 0.6 M	85.0 ± 7.1 b	12.8 ± 1.2 b	nd	31.4 ± 2.9 b	nd	9.3 ± 1.0 b	138.5	58.2 ± 5.1 b	196.7
	0.6 M	20.6 ± 1.9	6.5 ± 0.5	0.3 ± 0.02	32.8 ± 2.9	1.0 ± 0.1	8.9 ± 0.8	70.1		70.1
S + C + D	12 + 0.6 M	89.7 ± 7.2 b	15.0 ± 1.3 b	0.6 ± 0.02 b	29.2 ± 2.5 a	nd	13.5 ± 1.2 c	148.0	67.7 ± 5.4 b	215.7
	0.6 M	14.3 ± 1.3	9.1 ± 0.8	0.7 ± 0.03	31.7 ± 2.8	nd	12.5 ± 0.8	68.3		68.3

[a] Mean values of each column followed by different letters significantly differ when subjected to Duncan's multiple-range test ($p < 0.05$). Mean ± SD ($n = 6$). [b] Not detected.

3). The bulk of the IDF of raw chickpea mainly comprised carbohydrates, arabinose (46%), glucose (39%), and uronic acid (12%) being the main sugar constituents, followed by galactose and xylose, which appeared in minor amounts. The arabinose component was from pectic polysaccharide, because its concentration was higher in 0.6 M H_2SO_4 hydrolysis. The glucose was mainly cellulosic in origin, although the 0.6 M H_2SO_4 hydrolysis (release of ≈10% of cellulose) showed the existence of a certain amount of resistant starch which remained during DF preparation (10.6 mg/g of DM). From these results, arabinans and cellulose were inferred to be the main polysaccharides of IDF in chickpea. However, raw lentil showed a different sugar pattern: a predominance of glucose (60%) followed by arabinose (20%), xylose (10%), and uronic acid, whereas mannose and galactose were found in minor amounts. Only half of the glucose can be inferred to be of cellulosic origin, because 46% of glucose (35.1 mg/g of DM) was released by 0.6 M H_2SO_4. The levels of cell wall xylose and mannose were much lower than those of the noncellulosic glucose, which indicated that most of the glucose released by the mild conditions was from resistant starch in the IDF fraction (**Table 3**). In addition, 100% of arabinose was solubilized by mild conditions, probably due to arabinans not linked to cellulose matrix. Uronic acids displayed a different behavior; they were only solubilized 70% in mild conditions. This could be due to the occurrence of some homogalacturonans linked to cellulose. Comparing mild and strong hydrolysis, the different behaviors between legumes could be due to their different structures and compositions of cell wall.

In the processed legumes, the acid hydrolysis of insoluble residues and the chemical analysis of its components as the sum of total sugars (neutral sugars + uronic acids) showed a trend similar to that of the enzymatic−gravimetric AOAC method.

The studied processing induced different changes in the cell wall components. No important changes were exhibited by soaked legume samples (S). However, processed legumes (cooked and dehydrated) exhibited increases of the total sugar content compared to raw legumes. In the case of cooked legume samples (S + C), significant increases of total sugar were exhibited, being more relevant in chickpea (24%), which was caused by the higher levels of glucose (36%) and arabinose (23%). A similar trend was observed in dehydrated samples (S + C + D), which exhibited increases of total sugars of 16 and 15% in chickpea and lentil, respectively. Glucose (33%) and arabinose (9%) were the sugars responsible for the IDF increase in the case of processed chickpea and uronic acid (39%) and glucose (15%) in the case of processed lentil. Thus, thermal treatments (cooking and dehydratation) would produce the insolubilization of glucose-containing compounds. These results are in agreement with previously published data on processed legumes (*31*, *33*). Changes in the dietary fiber (resistant starch and nonstarch polysaccharides) content of cooked flours prepared from legumes were reported (*41*). Cooking increased the contents of IDF, and the increase was higher with pressure and steam cooking (*42*, *43*). However, reductions in IDF content in food legumes have also been reported by earlier workers (*38*), but the different data could be attributed to the different methodology used.

In relation to the Klason lignin level, raw material showed relatively high values, especially lentil (41.2 g kg^{-1} of DM) compared to other legumes (*33*, *44*, *45*), possibly due to the present cell wall or coprecipitated intracellular protein residues (*14*). However, the acid hydrolysis insoluble residues exhibited differences depending on the different processing. A general increase of the Klason lignin residues was detected during the processing, showing the dehydrated samples to have the highest values (87.8 and 67.7 g kg^{-1} of DM in chickpea and lentil, respectively). Probably, this is due to the formation of new insoluble products (Maillard components). These results were in agreement with previously published data on processed food (*31*, *32*).

Similar to IDF, the carbohydrate composition of total SDF of processed samples showed differences between both legumes (**Table 4**). The composition of SDF exhibited significant contents of mannose in both legumes, probably due to the presence of fructose, which elutes at the same time to mannose. The SDF content was 2 times higher in lentil than in chickpea. The main sugar component for raw lentil was arabinose (57%), which had a low content of pectic polysaccharides (20% of uronic acid). Nevertheless, raw chickpea showed a clear predominance of uronic acid (34%) (**Table 4**); this pattern was similar to that shown by other legumes (peas and beans) (*30*,

Table 4. Composition of Soluble Dietary Fiber in Raw and Processed Legume Flours (Grams per Kilogram of Dry Matter)[a]

	carbohydrates						
sample	Glc	Xyl	Gal/Rha	Ara	Man/Fruc	UA	total sugars
			Chickpea				
raw	0.1 ± 0.01 a	nd[b]	0.6 ± 0.03 b	0.9 ± 0.10 a	2.8 ± 0.20 d	2.2 ± 0.1 a	6.6
S	0.4 ± 0.02 d	nd	1.2 ± 0.01 c	2.4 ± 0.40 b	1.0 ± 0.10 b	2.9 ± 0.2 a	7.9
S + C	0.2 ± 0.01 b	nd	0.5 ± 0.04 a	2.2 ± 0.20 b	0.5 ± 0.04 a	4.7 ± 0.4 b	8.1
S + C + D	0.3 ± 0.01 c	nd	0.6 ± 0.04 b	1.9 ± 0.10 b	2.5 ± 0.20 c	2.5 ± 0.2 a	7.8
			Lentil				
raw	0.5 ± 0.02 b	0.3 ± 0.02 b	0.9 ± 0.05 d	7.5 ± 0.6 c	1.7 ± 0.1 b	2.8 ± 0.2 b	13.7
S	0.4 ± 0.02 a	nd	0.5 ± 0.02 a	5.7 ± 0.4 b	0.9 ± 0.1 a	2.9 ± 0.1 b	10.4
S + C	0.7 ± 0.03 c	0.2 ± 0.01 a	0.8 ± 0.03 c	4.8 ± 0.4 a	4.3 ± 0.4 c	0.9 ± 0.1 a	11.7
S + C + D	0.8 ± 0.03 d	0.2 ± 0.01 a	0.7 ± 0.02 b	4.2 ± 0.3 a	4.5 ± 0.6 c	0.8 ± 0.1 a	11.2

[a] Mean values of each column followed by different letters significantly differ when subjected to Duncan's multiple-range test ($p < 0.05$). Mean ± SD ($n = 6$). [b] Not detected.

Table 5. Composition of Total Dietary Fiber in Raw and Processed Legume Flours (Grams per Kilogram of Dry Matter)

	carbohydrates								
sample	Glc	Xyl	Gal/Rha	Ara	Man/Fruc	UA	total sugars	lignin	total sugars + lignin
					Chickpea				
raw	40.7	1.5	2.3	49.3	2.8	15.1	111.7	22.4	134.1
S	36.5	2.6	3.0	57.7	1.0	14.5	115.3	20.2	135.5
S + C	55.5	3.2	4.5	61.7	0.5	12.7	138.1	67.8	205.9
S + C + D	54.5	1.1	1.1	54.7	2.8	15.4	129.6	87.8	217.4
					Lentil				
raw	78.2	13.0	1.9	33.5	3.0	12.5	142.1	41.2	183.3
S	68.3	8.1	0.7	36.8	0.9	10.1	124.9	51.4	176.3
S + C	85.7	13.0	0.8	36.2	4.3	10.2	150.2	58.2	208.4
S + C + D	90.5	15.2	1.3	33.4	4.5	14.3	159.2	67.7	226.9

33). Soaking, cooking, and dehydration processes produced in chickpea a slight increase of sugar content, arabinose and uronic acid being the sugars responsible for these increases. However, lentil showed a different pattern, because the processing involved a decrease of arabinose (44%) and a marked decrease in uronic acid, consistent with a clear loss of pectic polysaccharides during this process. Thus, the dehydration processing caused slight changes in the SDF fraction, and its effects were different depending on legume type.

Differences were detected in the carbohydrate composition of TDF from the processes of soaking, cooking, and dehydration (**Table 5**). In keeping with IDF trends, the TDF of processed samples showed important increases of 62 and 24% in chickpea and lentil, respectively. These increases were mainly due to the increase of Klason lignin and glucose in both legumes, and to a lesser extent to arabinose in chickpea and mannose in lentil. In the present study, it was observed that thermal dehydration produced new insoluble products and therefore caused changes in the cell wall network. The significant increase of IDF contents compared to raw samples should promote changes in the properties of DF that will influence their technofunctionality such as the fiber dimension, porosity, hydration, rheological, and fat-binding properties.

In conclusion, the above work has demonstrated that the dehydration process in legumes decreases efficiently the α-galactosides content, responsible for the digestive discomfort related to pulse consumption. Furthermore, the dehydration process exhibited changes in DF fractions, especially in insoluble fiber, which will provide positive effects, both physiological and metabolic, at least in subjects suffering from disorders. Fundamental knowledge of the behavior of fiber fractions in complex food systems is still required in order to be able to propose ingredients and adaptations to formulations for appetizing foods with good nutritional properties.

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