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PHYSICO-CHEMICAL CHARACTERISTICS OF DIETARY FIBRE FRACTIONS IN THE GRAINS OF TETRAPLOID AND HEXAPLOID TRITICALES: A COMPARISON WITH WHEAT AND RYE

ABSTRACT

The contents of water-soluble (SDF) and insoluble dietary fibre (IDF) and DF-associated protein, sugar composition of noncellulosic polysaccharides (NCP) as well as viscosity of cereal slurries were investigated in tetraploid (4x) and hexaploid (6x) triticales compared to wheat and rye. The SDF content found in 4x triticale (3.3% of dry matter) was significantly higher ($P<0.05$) than those in 6x triticale and wheat (1.7 and 1.9%, respectively), but lower than that in rye (4.8%). Consequently, the level of soluble arabinoxylans was significantly higher ($P<0.05$) in 4x triticale (1.53%) than in 6x triticale (0.91%). However, it was intermediate when compared to wheat and rye (0.85% and 2.78%, respectively). In rye 33% of arabinoxylans was soluble in water, 22% in 4x triticale while only 15% in 6x triticale and wheat. The differences in sugar content and composition between 6x and 4x triticales were evident mainly in the SDF fraction, which may be attributed to higher proportion of rye to wheat genomes in 4x triticale (2:2) than in 6x triticale (2:4). Nevertheless, the water-soluble arabinoxylans from grains of 4x and 6x triticales were characterized by extremely high degrees of substitution, as evidenced by their arabinose-to-xylose ratio (Ara/Xyl), exceeding those of parent wheat and rye. The viscosity of 4x triticale slurry had a significant, positive correlation with total content of arabinoxylans ($r=0.82$, $P<0.05$). The DF-associated protein represented 16–24% of total amount of protein in the grain.

Key words: arabinoxylans, cereal grains, dietary fibre, nonstarch polysaccharides, viscosity

INTRODUCTION

Owing to current progress in food and feed technology, today more attention is paid to the dietary fibre (DF). This food and feed constituent comprises a mixture of nonstarch polysaccharides (mostly arabinoxylans, and to some extent, β-glucans and cellulose), which is partly associated with lignin in plant cell walls (Southgate, 1969). Unlike the starch polymers with α-glycosidic linkages, polysaccharides present in the cell walls, in general, consist of sugar residues held together by β-linkages. It makes a substantial difference for human physiology, since polysaccharides with latter type of linkages are not hydrolyzed by enzymes of human digestive tract. However, they are utilized by microflora in the lower part of the gut. The products of their bacterial degradation as well as the specific properties of dietary fiber affect the human physiology,

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providing benefits for health maintenance and preventing a wide range of diseases common in Western civilizations (heart diseases, diabetes, colon cancer, obesity) (Kay, 1982; Vahouny, 1987; Madar and Thorne, 1987).

On the other hand, arabinoxylans, the major polysaccharides of DF fractions, especially these soluble in water, negatively affect feed utilization in broiler chickens fed rye-based diets (Antoniou et a., 1981; Boros *et al.*, 1985). This is mostly ascribed to their viscosity-enhancing properties. Whereas, 6x triticale shows no such effect (Rakowska *et al.*, 1992), despite the complete of rye genome in Polish cultivars. The explanation of this fact must be related to the content and composition of cell wall polysaccharides, which in addition to starch, control the swelling and viscous potential of cereal-based diet.

The aim of present paper, therefore, was to estimate the content and composition of soluble and insoluble DF fractions in 6x and 4x triticales compared to their parent species; wheat and rye. Also, the viscosity of whole meal slurry was monitored, as an indirect method for evaluation of differences between cereals studied in the level of DF-polysaccharides and their structural variations. 4x triticale, with higher proportion of rye genome and different chromosome composition seems an interesting material for such research.

MATERIAL AND METHODS

Four 6x triticale cultivars, six 4x triticale lines, wheat (cv. Grana) and rye (cv. Dańkowskie Złote) were used in this study. All grains were harvested in 1991 from plants grown under the same soil and climatic conditions. Prior to chemical analyses the samples were ground in a Tecator mill to pass 0.5 mm screen. Dry matter content was determined by oven-drying to constant weight at 105°C. Protein (N × 6.25) was determined by the Kjeldahl method using a Kjeltec Auto analyser (Tecator, Sweden). Minerals were determined gravimetrically after combustion at 550°C for 6h. Viscosity of whole meal slurry (1: 3 w/v) in 0.2 M sodium phosphate buffer (pH 5.6) was measured with Rheotest-2 (Germany) at constant temperature (30°C). The insoluble (IDF) and soluble (SDF) dietary fiber fractions were isolated by method of Asp *et al.* (1983). Total dietary fiber (TDF) was calculated from the sum of IDF and SDF. Hydrolysis of IDF and SDF fractions was performed in 1N TFA for 1h at 125°C according to the method of Theander and Westerlund (1986). Neutral sugars composition of DF fractions was determined by gas chromatography of their aldononitrile acetate derivatives prepared by method of McGinnis (1982), using N-methylimidazole as catalyst and solvent. Allose was used as internal standard. The samples were analysed using a Varian 3700 gas chromatograph equipped with flame-ionization detector and wide-bore capillary column (DB-WAX, 30 m × 0.53 mm i.d.) at 190–220°C (5°C/min) and 220°C for 8 min. All constituent sugar values were corrected for losses during hydrolysis and derivatisation, and expressed as polysaccharides by using factor of 0.9. All analyses were carried out at least in duplicate and are reported on a dry matter basis. The data were subjected to a one-way analysis of variance and Tukey's multiple range test. The minimum level of statistical significance was $p<0.05$.

RESULTS AND DISCUSSION

The SDF content found in 4x triticale was almost two times higher than those in 6x triticale and wheat. However, it was lower than that of rye (Table 1). There were no significant differences in IDF content between triticale samples. With regard to TDF content, the significant differences (P<0.05) were found between both types of triticale and rye, as tested by analysis of variance.

Table 1

Contents of dietary fibre fractions, buffer suspension viscosity of cereal meals and ratio of viscosity to total content of arabinoxylans

Sample	DF fractions [% of dry matter]			Viscosity [mPa×s]	Viscosity : TAX
	IDF	SDF	TDF		
Wheat (Emika)	10.9±0.1	1.9±0.2	12.8±0.2	27±0.5	5:1
6x Triticale (n=4)	11.2±0.5	1.7±0.5	12.9±0.6	43±3	7:1
4x Triticale (n=6)	12.4±0.8	3.3±0.9	15.7±0.7	120±10	18:1
Rye (Dańkowskie Złote)	12.8±0.2	4.8±0.2	17.6±0.2	1465±13	172:1

IDF–insoluble dietary fibre, SDF–soluble dietary fibre, TDF–total dietary fibre, TAX –total content of arabinoxylans. The values are expressed as mean ± standard deviation

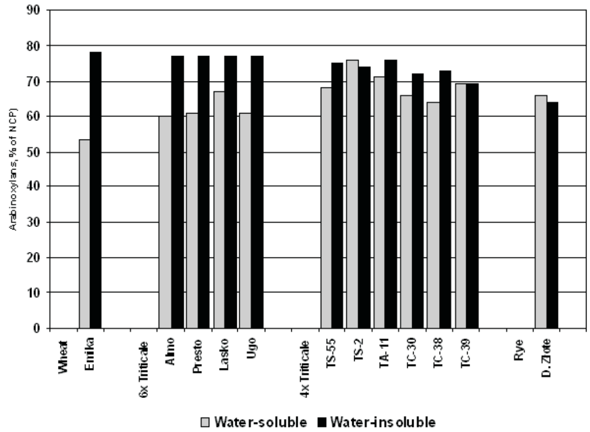

Fig.1. Proportion of arabinoxylans in noncellulosic polysaccharide fractions of wheat, 6x- and 4x triticales and rye

The viscosity of whole meal slurry was the lowest for wheat and the highest for rye. On average, viscosity of 4x triticale was 120 mP·s with the range from 81 to 343 mP·s, while it was almost three times lower in 6x triticale - 43 mP·s with the range from 35 to 50 mP·s. It should be stressed that unlike the water extract viscosity, which is highly correlated with content of soluble arabinoxylans in rye and wheat (Boros *et al.*, 1993, Saulnier *et al.*, 1995), the viscosity of whole meal slurry reflects both the viscous nature of soluble arabinoxylans and swelling capacity (water holding capacity) of insoluble counterparts. This is partly evidenced by the fact that only content of total arabinoxylans significantly influenced the buffer suspension viscosity in 4x triticale (r=0.82, P<0.05) (results not shown). However, a high variation observed in the content of soluble arabinoxylans in 4x triticale (Fig. 1) most probably reinforced this relationship as well. This was much obvious when both 4x and 6x sets of triticale were considered, due to extended range of variation for parameters studied. In this case, the amounts of total and soluble arabinoxylans were significantly correlated with viscosity (r= 0.85 and r=0.77, respectively, P<0.01). Furthermore, the content of soluble polymers was positively correlated with total arabinoxylans content in the grain (r=0.76, P<0.01) (data not shown). It is well known that viscosity of polymer solution or slurry is mostly related to its concentration. However, other factors, such as molecular size, conformation of the polymer or interaction with solvent, also have an important effect on viscosity. The ratios of viscosity to total arabinoxylan content (Table 1) calculated for wheat and 6x triticale were similar. A much higher value of this parameter obtained for 4x triticale, whereas that for rye was exceptionally high. In other words, one unit of weight of arabinoxylans present in wheat, 6x and 4x triticale and rye grains, was related to different viscosity values, indicating that not only level of arabinoxylans, but also their structural features influenced viscosity. Furthermore, this parameter reflects the differences in the structure of arabinoxylans, which are evident between both triticales as well as between wheat and rye.

Table 2

Sugar content and composition of dietary fiber fractions in cereal grains

Sample	Constituent sugars [% of dry matter]						Total NCP	Ara/Xyl
	DF fractions	Ara	Xyl	Man	Gal	Glc		
1	2	3	4	5	6	7	8	9
				Wheat				
Emika	IDF	1.85	2.86	0.12	0.17	1.03	6.03	0.65
	SDF	0.33	0.52	0.05	0.23	0.47	1.60	0.63
	TDF	2.18	3.38	0.17	0.40	1.50	7.63	
				6x Triticale:				
Almo	IDF	2.14	3.24	0.13	0.18	1.30	6.99	0.66
	SDF	0.33	0.47	0.04	0.14	0.37	1.35	0.70
	TDF	2.47	3.71	0.17	0.32	1.67	8.34	
Presto	IDF	1.98	2.93	0.13	0.19	1.15	6.38	0.68
	SDF	0.38	0.52	0.04	0.18	0.36	1.48	0.73
	TDF	2.36	3.45	0.17	0.37	1.51	7.86	
Lasko	IDF	2.17	3.20	0.15	0.19	1.26	6.97	0.68
	SDF	0.41	0.55	0.06	0.15	0.27	1.44	0.75
	TDF	2.58	3.75	0.21	0.34	1.53	8.41	
Ugo	IDF	2.05	2.94	0.15	0.18	1.12	6.44	0.70
	SDF	0.40	0.58	0.06	0.15	0.41	1.60	0.69
	TDF	2.45	3.52	0.21	0.33	1.53	8.04	

IDF–insoluble dietary fibre; SDF–soluble dietary fibre; TDF–total dietary fibre; Ara–arabinose; Xyl–xylose; Man–mannose; Gal–galactose; Glc–glucose; NCP–noncellulosic polysaccharides; Ara/Xyl–arabinose to xylose ratio

Table 2

Sugar content and composition of dietary fiber fractions in cereal grains (continued)

1	2	3	4	5	6	7	8	9
				4x Triticale:				
TS-55	IDF	2.04	3.36	0.25	0.32	1.26	7.23	0.61
	SDF	0.54	0.84	0.12	0.18	0.34	2.02	0.64
	TDF	2.58	4.20	0.37	0.50	1.60	9.25	
TS-2	IDF	2.08	3.18	0.29	0.29	1.31	7.15	0.65
	SDF	0.77	1.09	0.15	0.15	0.30	2.46	0.71
	TDF	2.85	4.27	0.44	0.44	1.61	9.61	
TA-11	IDF	2.16	3.54	0.23	0.25	1.33	7.51	0.61
	SDF	0.51	0.62	0.09	0.11	0.27	1.60	0.82
	TDF	2.67	4.16	0.32	0.36	1.60	9.11	
TC-30	IDF	2.01	3.56	0.32	0.32	1.51	7.72	0.56
	SDF	0.67	0.86	0.11	0.24	0.44	2.32	0.78
	TDF	2.68	4.42	0.43	0.56	1.95	10.04	
TC-38	IDF	1.82	2.90	0.23	0.26	1.24	6.45	0.63
	SDF	0.83	0.92	0.14	0.24	0.60	2.73	0.90
	TDF	2.65	3.82	0.37	0.50	1.84	9.18	
TC-39	IDF	1.90	3.37	0.31	0.32	1.72	7.62	0.56
	SDF	0.64	0.91	0.09	0.23	0.37	2.24	0.70
	TDF	2.54	4.28	0.40	0.55	2.09	9.86	
				Rye				
Dańkow-skie Złote	IDF	2.08	3.66	0.22	0.30	2.71	8.97	0.57
	SDF	1.13	1.65	0.16	0.18	1.17	4.24	0.68
	TDF	3.21	5.31	0.38	0.48	3.88	13.26	

IDF–insoluble dietary fibre; SDF–soluble dietary fibre; TDF–total dietary fibre; Ara–arabinose; Xyl–xylose; Man–mannose; Gal–galactose; Glc–glucose; NCP–noncellulosic polysaccharides; Ara/Xyl–arabinose to xylose ratio

Sugar compositions of DF fractions are summarised in Table 2. On average, an arabinose, xylose and glucose together constituted over 90% of insoluble polysaccharide fraction and over 80% of soluble fraction. The mannose and galactose were present in small amounts. Generally, sugar compositions of polysaccharide fractions in wheat and 6x triticale were similar, no significant differences were found. The interspecies differences in sugar composition occurred mainly in the soluble fraction. A high content of arabinose was found in rye soluble fraction whereas in wheat and 6x triticale it was three times lower and almost two times lower in 4x triticale. The content of xylose in soluble fraction was highest in rye and significantly lower in the other species. Similarly, glucose content in soluble fraction of rye was three times higher than those of wheat and both types of triticale. However, three samples of 4x triticale (TS-55, TS-2, TA-11) had the same, constant glucose content in both DF fractions (on average, total 1.60%), it was close to glucose level found in 6x triticale (1.56%), while three remaining samples (TC-30, TC-38, TC-39) had evidently higher total glucose content (1.95, 1.84 and 2.09%, respectively). Practically the same level of galactose was found in wheat, 4x triticale and rye, except for 6x triticale where it was somewhat lower. The mannose contents in rye and 4x triticale were two times higher than those in wheat and 6x triticale.

It should be borne in mind that generally arabinose and xylose are building units of arabinoxylans, the principal DF-polysaccharides in wheat, triticale and rye. They represented 78 and 64% of insoluble polysaccharide fractions and 53 and 66% of soluble polysaccharide fractions in wheat and rye, respectively (Fig. 1). The proportions of arabinoxylans in insoluble polysaccharides of both triticales were intermediate when compared to these in parent wheat and rye. A wide range of this parameter was observed in water-soluble polysaccharide fractions of 4x triticale (64–76%). On average, the proportion of arabinoxylans in this fraction (69%) was somewhat higher than that in rye.

The mean, total content of arabinoxylans varied from 5.56% of dry matter in wheat, 6.07% and 6.85% in 6x and 4x triticales, respectively, to 8.52% in rye (Fig. 2). Interestingly, the proportion of soluble arabinoxylans increased from 15% in 6x triticale and wheat to 22 and 33% in 4x triticale and rye, respectively.

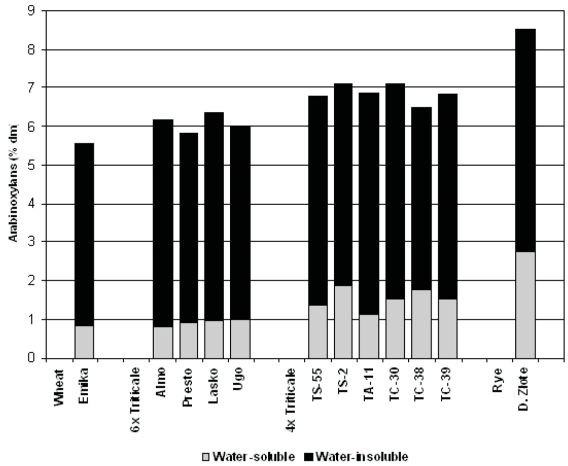

Fig.2. Content of total arabinoxylans in wheat, 6x- and 4x triticales and rye

Since xylose residues form a linear backbone of arabinoxylans, and some of them are substituted with one or two arabinose residues, the Ara/Xyl ratio represents the overall degree of substitution of arabinoxylan chain. Unexpectedly, the Ara/Xyl ratios calculated for soluble polysaccharides of both triticales were higher that those in wheat and rye (Table 2). Also, the degree of substitution of insoluble arabinoxylans in 6x triticale was higher than in the parent species. An increased level of short side chains built of 2–3 arabinose residues, known as a minor element of arabinoxylans structure, instead of terminal arabinose residues, might be one of the possible explanations. The increased level of disubstituted xylose residues with terminal arabinose units, can be considered as well. However, this must be experimentally confirmed in the future study. Up to date, there is no information available on the substructures present in the triticale arabinoxylans. Undoubtedly, much like in wheat and rye (Dervilly *et al.*, 2000, Cyran and Saulnier, 2005), the entire arabinoxylan population in triticale consists of substructures with low, intermediate and high degrees of substitution, and some of them control functionality, and consequently, the quality of end-products. Their proportions in the overall fraction and the importance for triticale functionality still need to be revealed in the future.

A level of DF-associated protein (Table 3) was similar in wheat, 6x triticale and rye (on average, 2.3% of dry matter), whereas in 4x triticale it was almost two times higher. Generally, DF-associated protein constituted about 20% of the total grain protein, which ranged from 16% in wheat to 24% in rye. Significantly more protein was associated with IDF. Despite the high protein content in 4x triticale, SDF-associated protein accounted for only 3.6% of the grain protein. Whereas, a somewhat higher proportion of this component was observed in 6x triticale and wheat and much higher in rye. On average, lysine content in 4x triticale (4.03 g/16g N with range from 3.79 to 4.49) was slightly higher than that of rye (3.99) and significantly higher than those of 6x triticale (3.33 g/16g N with range from 3.03 to 3.67) and wheat (2.94 g/16g N) (results not shown). This high lysine content in 4x triticale was connected with high protein content, whereas usually opposite relationship is observed.

Table 3

Grain protein and DF-associated protein of wheat, rye, 6x and 4x triticales

Sample	Grain protein [% of dry matter]	DF fractions	DF- associated protein	
			[% of dry matter]	[% of grain protein]
Wheat (Emika)	13.3±0.1	IDF	1.4	10.4±0.1
		SDF	0.8	5.9±0.2
		TDF	2.2	16.3±0.2
6x Triticale (n=4)	12.7±0.5	IDF	1.5	12.1±1.5
		SDF	0.7	5.6±0.6
		TDF	2.2	17.7±1.4
4x Triticale (n=6)	22.2±1.1	IDF	3.6	16.4±1.4
		SDF	0.8	3.6±0.7
		TDF	4.4	20.0±1.4
Rye (Dańkowskie Złote)	10.6±0.2	IDF	1.6	15.4±0.1
		SDF	0.9	8.4±0.2
		TDF	2.5	23.8±0.2

IDF–insoluble dietary fibre, SDF–soluble dietary fibre, TDF–total dietary fibre. The values are expressed as mean ± standard deviation

Our results indicate that higher proportion of rye to wheat genomes in 4x triticale (2:2) in comparison to that in 6x triticale (2:4) significantly affected the content and composition of DF polysaccharides, especially their water-soluble fraction. In this respect sugar spectrum of 6x triticale showed close resemblance to that of wheat, whereas in 4x triticale it was moved towards rye sugar profiles. However, more advanced study should be carried out to elucidate the high degrees of substitution observed in soluble arabinoxylans of both triticales, going beyond those of parent wheat and rye.

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