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SMALL GRAIN CEREALS COMPARED FOR DIETARY FIBRE AND PROTEIN CONTENTS

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The content of dietary fibres (cellulose, hemicellulose, lignin, NDF, ADF), tryptophan and proteins, as well as their quality index were determined in whole grains of bread and durum wheat, rye, hull-less barley and hull-less oat, each represented with four genotypes. In addition, content of β-glucans in hull-less barley were determined.

In average, hull-less barley and oat had the lowest content of hemicellulose (22.54 and 13.11% d.m., respectively), cellulose (1.36 and 1.41% d.m., respectively), lignin (0.98 and 0.49% d.m., respectively), as

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well as NDF (24.84 and 15.16% d.m., respectively) and ADF (2.30 and 2.04% d.m., respectively). In average, the highest content of hemicellulose was in durum wheat (33.47% d.m.), followed by rye (29.63% d.m.), and bread wheat (23.24% d.m.). Among tested hull-less barley genotypes the the content of β-glucans ranged from 4.1% d.m. (IWHBON 97-18) to 5.6% d.m. (Apolon). The highest content of proteins (on average 15.65% d.m.) and tryptophan (on average 0.206% d.m.) was in hull-less oat. Hull-less barley had the highest protein quality index (1.48%) followed by bread and durum wheat and hull-less oat (IQ 1.35, 1.34 and 1.31%, respectively), and rye (IQ 0.93%). The results indicate that there is genetic diversity in content of dietary fibres and proteins among tested genotypes and that it should be possible to selectively breed for lines with high nutrition capacities, as well as, to improved diet requirements.

Key words: dietary fibre, protein, small grain cereals, sugar, tryptophan

INTRODUCTION

The grass family *Poaceae* (*Gramineae*) includes major crop plants such as wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), rice (*Oryza sativa* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.) and rye (*Secale cereale* L.). Wheat, barley and rye are related members of the Tribe Triticeae and consequently share many genetic and biochemical characteristics (SHEWRY, 2006). Cultivated wheat, exists in diploid (genome constitution AA, 2*n*=14 chromosomes), tetraploid (AABB, 2*n*=28) and hexaploid (AABBDD, 2*n*=42) forms but the two most important types are hexaploid *Triticum aestivum* var *aestivum* (bread wheat) and tetraploid *T. turgidum* var *durum* (durum or pasta wheat). Other varieties of these two species are still grown in small amounts in some parts of the worldand and with a number of wild diploid species related to the progenitors of the A, B and D genomes of cultivated wheats and wild *T. turgidum* var. *dicoccoides* providing a reservoir of valuable variation for plant breeding (SHEWRY, 2006). In contrast to wheat, cultivated barley comprises only one species, *Hordeum vulgare* L, which is diploid. Cultivated oat, as well wheat, exists in diploid, tetraploid and hexaploid forms with different genome compositions (RABEY, 2008). Whereas wheat, barley and oat are inbreeding, rye (*Secale cereale*) is an out-breeding diploid and has been used as a source of agronomically important genes for wheat improvement (KO *et al.,* 2002).

Wheat, barley, oat and rye have been staples for humans for millennia. Their grains contain the macronutrients (protein, fat and carbohydrate) required by humans for growth and maintenance. The content and nutritional quality of the grain macronutrients is therefore an important consideration. Traditionally, cereal grain fractionation is performed using a dry milling process which leads to the separation of flour and semolina (from the starchy endosperm) and two separate fractions from the germ and bran. However, valuable nutritional constituents including micronutrients, phytochemicals and fibres are particularly concentrated in the germ and bran fractions. For this reason whole grains are ideal foods for human consumption and contribute greatly to long-term health.

The prime focus of this paper will be on cereal dietary fibers and proteins. Complex polysaccharides, indigestible fraction in foods (IF), is defined as the part of vegetable foods that is not digested nor absorbed in the small intestine, reaching the colon where it is a substrate for the fermentative microflora. As such, it comprises not only dietary fiber (DF), but also other compounds of proven resistance to the action of digestive enzymes such as a fraction of dietary starch, protein, certain polyphenols, and other associated compounds (SAURA-CALIXTO *et al.,* 2000). Dietary fiber is classified into two basic types: soluble fibre and insoluble fibre with different effects on the human and animal body. The role of DF in nutrition and health is well established (OU *et al.,* 2001). Soluble fibre has also been thought to slow down the digestion of carbohydrate in sugars and starches, which results in better glucose metabolism, while insoluble dietary fibre binds with water in the intestine and helps remove waste from the body. This type of dietary fibre is known to help prevent constipation. Some researchers suggest it may also help prevent hemorrhoids (piles), diverticular disease, polyps and cancer of the colon or large intestine (LUI, 2007). β-Glucan is one of the major cell wall carbohydrate which is isolated from cereal grains, notably oats and barley. β-Glucan, content of cereals ranges from 1% in wheat grains, to 3–7% in oats, and 5–11% in barley (SKENDI *et al.,* 2003). Human clinical trials have shown that β-glucan from barley gives on average 7-10% reductions in total and LDL-cholesterol over a dose range of 3-8 g per day (BEHALL *et al.,* 2044a,b).

Cereals protein are deficient in certain essential amino acids when used as food for monogastic animals. In particular, they contain low levels of lysine (the first limiting amino acid) and to a lesser extent, threonine and tryptophan resulting from deficiencies of these amino acids in the prolamin storage proteins, which account for about half of the total nitrogen in the mature grains. In all cereals the predomonant proteins are prolamins, except oats and rice in which the major storage proteins are related to the 11S globulins (''legumins'') of legumes (SHEWRY, 2007). The prolamin fractions of wheat, rye and barley are complex mixtures of proteins, which vary in their composition between different genotypes of the same species. The individual components are classically divided into groups based on their solubility and electrophoretic properties, the groups being given different names in the three species (hordeins, secalins and gliadins + glutenins in barley, rye and wheat, respectively). In the oat grains prolamin fractions (avenin) is the minor protein. The total protein content of the grain can be manipulated by adding fertilizer nitrogen but genes conferring high grain protein have been identified in wild tetraploid wheats (BREVIS *et al*., 2010) or in mutant baley lines (ROESLER and RAO, 2000). High density genetic maps of wheat (BOEUF *et al.,* 2002) and barley (SERIZAWA *et al.,* 2001) helped breeders to locate precisely the position of these genes on individual chromosome. However, these genes have either not yet been exploited to increase the protein content of cultivated wheat or have not been successful when incorporated into cultivated lines.

More data are needed regarding carbohydrates and protein in cereal genotypes, as this could lead to new opportunities for breeding and eventual

commercial production of value-added varieties rich in health-beneficial components for making nutraceuticals and other functional foods. For this reason the objective of the present study was to identify and quantify carbohydrates compounds, proteins and tryptophan in durum and bread wheat, hull less barley, rye and hull less oat samples, as well as, to compare their contents according to obtained results.

MATERIALS AND METHODS

Plant materials

A collection of 20 genotypes (cultivars and breeding lines) of small grain cereals, including bread wheat (*Triticum aestivum* L.), durum wheat (*Triticum durum* Desf.), rye (*Secale cereale*), hull-less barley (*Hordeum vulgare* L. var. *nudum* Hook. f.) and hull-less oat (*Avena nuda* L.), were evaluated for antioxidants concentration over one year (2010). The genotypes were chosen on the basis of their differences in agronomic traits such as yield and its components. Their names, origin and growth type are given in Table 1.

Table 1. Name, country of origin and growth type of the 20 small grain genotypes

Name	Type of line	Origin	Growth type	Name	Type of line	Origin	Growth type
Bread wheat				**Rye**			
ZP 87/I	breeding line	Serbia	winter	Raša	cultivar	Serbia	winter
ZP Zemunska rosa	cultivar	Serbia	winter	Šampion	cultivar	Serbia	winter
ZP Zlatna	cultivar	Serbia	winter	DK-R	breeding line	Serbia	winter
Apache	cultivar	France	winter	DK-R1/08	breeding line	Serbia	winter
Durum wheat				**Hull-less barley**			
ZP 10/I	breeding line	Serbia	winter	Apolon	cultivar	Serbia	spring
DSP/01-66	breeding line	ICARDA	facultative	Golijat	cultivar	Serbia	spring
ZP 34/I	breeding line	Serbia	winter	IWHBON 97-18	breeding line	ICARDA	spring
Varano	cultivar	Italy	facultative	Balša	cultivar	Serbia	spring
Hull-less oat							
Novosadski ovas	cultivar	Serbia					
NSO 217/201	breeding line	Serbia					
NS JOGO 902	breeding line	Serbia	spring				
NS 049/2010	breeding line	Serbia	spring				

ICARDA = International Centre for Agricultural Research in the Dry Areas.

The small grain cereals collection were grown in the field at the Maize Research Institute (Belgrade, Serbia), in a randomized complete block design (RCB) with two replications. Each plot (5 rows, 1.0 m long) was sown with 250 seeds, with rows and plots spaced 0.2 m apart. Winter and facultative genotypes were sown in October while spring ones in March. Standard cropping practices were applied to provide adequate nutrition and to keep the disease-free plots.

The wholemeal (particle size < 500 μm) obtained by grinding cereals grains on a Perten 120 lab mill (Perten, Sweden) was used for the analyses.

Analytical procedures

Dietary fibre contents

The content of dietary fibres, hemicellulose, cellulose, neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin (ADL) was determined by the Van Soest detergent method modified by MERTENS (1992) using Fibertec system 2010 (Foos, Sweden). The method is based on the fibres solubility in neutral, acid and alkali reagents. NDF was measured by boiling cereals flour sample (1 g) in 100 ml of a special detergent under a neutral (pH 7) condition during 60 min and filtering the boiled sample. Solution for hydrolysis contained sodium tetraborate 10-hydrate (6.81 g), sodium salt dihydrate (18.61 g), dodecyl sulfate (30 g), disodium hydrogenphosphate-12-hydrate (7.77 g) and methil celosol (10 ml) dissolved in 1000 ml of distilled water. The liquid that passes through the sintered disc filter contained starch, sugar, protein and other compounds that were dissolved. The residue of the sample that was not dissolved remained on the sintered disc filter is called NDF. After drying, NDF was calculated as a percentage of the original sample. ADF was determined in much the same way, except that a different detergent was used under acid (pH 2) conditions. Cetyl trimethim ammonium bromide and 0.5 M H_2SO_4 were used for hydrolysis. The sample was boiled and filtered as in the NDF procedure. Because of the different detergent and acid conditions, hemicellulose and cell solubles dissolve and were filtered away. The residue left was ADF and consisted mainly of cellulose and lignin. ADF was related to dry matter digestibility and was used to predict net energy content. ADL was measured by further treating ADF with strong acid (72% H_2SO_4) which dissolves cellulose. After filtering and drying, the ADL was calculated as a percentage of the original sample. All the results are given as the percentage of dry matter (d.m.). Content of hemicellulose was obtained as the difference between NDF and ADF content, while the cellulose content was calculated as the difference between ADF and lignin content.

β-glucan was determined by the MEGAZYME (2006) method. Brefly, samples (0.5 g) were suspended and hydrated in ethanol (1 ml, 50% v/v) and sodium phosphate buffer solution (5 ml, 20 mM, pH 6.5) and then incubated at 40^{o}C for 1 h with purified lichenase enzyme (0.2 ml, 10 U) and filtered. An aliquot of the filtrate was then hydrolysed to completion with purified β-glucosidase (0.1 ml, 0.2 U in 50 mM acetate buffer pH 4.0). The D-glucose produced was assayed using a glucose oxidase/peroxidase reagent (GOPOD) (3 ml). The absorbance was measured at 510 nm. β-glucan content is expressed as a percentage of d.m.

Tryptophan content

Tryptophan content was determined according to NURIT *et al.* (2009) from defatted cereals flour. Shortly, flour hydrolysate (obtained by overnight digestion with papain solution at 65°C) was added to 3 ml reagent containing Fe^{3+} (1 g $FeCl_3$ dissolved in 50 mL 3.5 M H_2SO_4), 15 M H_2SO_4 and 0.1 M glyoxilic acid. After incubation at 65°C for 30 min, absorption was read at 560 nm. Tryptophan content was calculated using a standard (calibration) curve, developed with known amounts of tryptophan, ranging from 0 to 30 μg ml^{-1}. The standard chemical methods were applied to determine the content of total proteins. Besides tryptophan content quality index (QI), defined as tryptophan to protein ratio in the sample, was also calculated.

Statistical analysis

All chemical analyses were performed in two replicates per plot and the results were statistically analysed. For each trait mean and the coefficient of variation (CV) were determined. Significant differences between genotype means and species means were assessed by the Fisher´s least significant differences (LSD) test, after the analysis of variance (ANOVA) for trials set up according to the RCB design. Differences with $P<0.05$ were considered significant.

RESULTS AND DISCUSSION

Content of dietary fibre in small grain cereals

Fibre components are one of the most important nutritional and technological factors of the cereals grain. The content of cellulose, hemicellulose, NDF, ADF and lignin in grains of the investigated genotypes is presented in Table 2.

In average, hemicellulose was the most abundant dietary fibres in all cereal species. The highest content was detected in durum wheat. The hemicellulose of durum wheat samples ranged from 26.74% d.m. (Varano) to 40.01% d.m. (ZP 10/I), with an average of 33.47% d.m. On average, durum wheat had 2.55-fold higher hemicellulose than hull-less oat, 1.48-fold than hull-less barley, 1.44-fold higher than bread wheat and 1.13-fold higher than rye samples. However, among all tested genotypes the highest content of hemicellulose (42.37% d.m.) was in rye genotype DK-R. In addition, the highest variation for the hemicellulose content was found within rye genotypes (CV = 30.48%) followed by bread wheat (CV = 24.48%), hull-less oat (CV = 24.38%), durum wheat (CV = 15.02%) and hull-less barley (CV = 17.24%) genotypes (Table 2). In average, similarly to hemicellulose, NDF content was far highest in durum wheat (37.22% d.m.) followed by rye (33.49% d.m.), bread wheat (28.99% d.m.), hull-less barley (24.84% d.m.) and and the lowest in oat (15.16% d.m.) (Table 2a). However, obtained ranges for NDF in our hull-less oat genotypes (10.67 to 19.04% d.m.) were rather higher to those reported by NYACHOTI *et al.* (2010) for hull-less oat genotypes (7.73 to 12.00% d.m.) originating from Canada. Also, values and ranges for NDF content in our bread wheat genotypes were higher than those reported by AUGUSTYN and BARTECZKO (2006) for bread wheat cultivars grown in Poland (10.9 to 20.11% d.m.) but lower than that in our previous studies (ŽILIĆ *et al.,* 2009).

Table 2. Content of dietary fibre in genotypes of small grain cereals (%)

Genotypes	Hemicellulose	Cellulose	NDF	ADF	Lignin
Bread wheat					
ZP 87/I	27.46^{a}	2.96^{c}	31.53^{a}	4.07^{ab}	1.31^{a}
Apache	26.88^{a}	2.30^{d}	30.62^{ab}	3.73^{b}	1.49^{a}
ZP Zemunska rosa	18.97^{b}	3.13^{b}	29.63^{b}	4.16^{ab}	1.62^{a}
ZP Zlatna	19.65^{c}	3.29^{a}	24.16^{c}	4.51^{a}	1.37^{a}
F test	**	**	**	n.s.	n.s.
CV (%)	24.48	13.72	10.61	8.11	16.93
Durum wheat					
ZP 34/I	33.85^{b}	2.97^{a}	37.67^{b}	3.82^{a}	1.06^{a}
ZP 10/I	40.01^{a}	3.12^{a}	43.89^{a}	3.88^{a}	0.98^{a}
ZP DSP/01-66	33.29^{b}	3.15^{a}	37.13^{b}	3.84^{a}	1.05^{a}
Varano	26.74^{c}	2.73^{a}	30.19^{c}	3.45^{a}	1.07^{a}
F test	***	n.s.	***	n.s.	*
CV (%)	15.02	6.82	13.94	5.99	9.03
Rye					
Raša	29.45^{b}	2.85^{a}	33.66^{b}	4.21^{a}	1.31^{a}
DK-R	42.37^{a}	2.52^{b}	46.10^{a}	3.73^{ab}	1.29^{a}
Šampion	18.67^{d}	2.30^{b}	22.01^{d}	3.34^{b}	1.06^{a}
DK-R1/08	28.03^{c}	2.46^{b}	32.18^{c}	4.15^{a}	1.38^{a}
F test	***	*	***	*	n.s.
CV (%)	30.48	9.01	27.32	10.10	11.47
Hull-less barley					
Apolon	25.20^{a}	1.58^{a}	27.81^{a}	2.61^{a}	0.77^{a}
Golijat	23.43^{b}	1.43^{a}	25.63^{b}	2.20^{a}	0.38^{b}
IWHBON 97-18	25.14^{a}	1.41^{a}	27.35^{a}	2.21^{a}	0.54^{ab}
Balša	16.39^{c}	1.01^{b}	18.58^{c}	2.18^{a}	0.28^{b}
F test	**	*	**	n.s.	*
CV (%)	17.24	17.24	15.98	9.26	43.02

Table 2. Content of dietary fibre in genotypes of small grain cereals (%) con..

Hull-less oat					
NSO 217/201	8.89[d]	1.28[a]	10.67[d]	1.78[d]	0.76[b]
Novosadski golozrni	11.94[c]	1.53[a]	13.93[c]	1.99[c]	0.91[b]
NS 049/2010	14.82[b]	1.30[a]	17.01[b]	2.18[b]	0.91[b]
NS JOGO 902	16.80[a]	1.52[a]	19.04[a]	2.24[a]	1.33[a]
F test	***	n.s.	***	***	*
CV (%)	24.38	10.35	22.36	9.83	24.81

Mean of genotypes followed by the same letter within the same column are not significantly different ($P < 0.05$); *** = significant at $P < 0.001$; ** = significant at $P < 0.01$; * = significant at $P < 0.05$; n.s. = no significant; CV = coefficient of variation.

Table 2a. Average value of dietary fibre in small grain cereals (%)

Species	Hemicellulose	Cellulose	NDF	ADF	Lignin
Mean (bread wheat)	23.24[b]	2.92[ab]	28.99[ab]	4.11[a]	1.45[a]
Mean (durum wheat)	33.47[a]	2.99[a]	37.22[a]	3.75[a]	1.04[b]
Mean (rye)	29.63[ab]	2.53[b]	33.49[a]	3.86[a]	1.26[a]
Mean (hull-less barley)	22.54[b]	1.36[c]	24.84[b]	2.30[b]	0.49[c]
Mean (hull-less oat)	13.11[c]	1.41[c]	15.16[c]	2.04[b]	0.98[b]
F test	**	***	**	***	***

Mean of species followed by the same letter within the same column are not significantly different ($P < 0.05$); *** = significant at $P < 0.001$; ** = significant at $P < 0.01$.

Hull-less barley showed more than two fold lower lignig content than rye, durum and bread wheat. The similar was for ADF content. The variation of lignin among hull-less oat, hull-less barley and bread genotypes was a high (43.02, 24.81 and 16.93% d.m., respectively), which can be exploited (Table 2). Lignin is one of the most chemically active components of the cell walls, being responsible for interactions with other dietary components and for decreasing bioavailability of nutrients (PROSKY, 2000). ŽILIĆ *et al.* (2011) reported that the grain dry matter digestion was negatively correlated to the lignin content ($r = -0.53$), and positively correlated to the hemicellulose and NDF ($r = 0.80$ and 0.71, respectively). This suggests that hull-less forms of barley and oat is of particular interest in human and animal diet. Also, studies have shown that high dietary fibre reduces feed intake and

nutrient utilization in pigs (NOBLET and LE-GOFF, 2001). Thus, with lower fibre content, it can be expected that hull-less oat and barley could be used in larger amounts as a feedstuff for pig, particularly young pig.

Barley along with oat, particularly their hull less forms, represent the main cereal grain for the development of functional foods, as it contains several classes of compounds of strong nutritional effect such as β-glucans (PANFILI *et al.,* 2008). The content of β-glucans in hull-less barley genotypes is presented in Fig 1. β-Glucans of hull-less barley samples ranged from 4.1% d.m. to 5.6% d.m. in IWHBON 97-18 and Apolon, respectively, with an average value of 5.07% d.m. The amount of β-glucan in hull-less barley normally varies from 4% to 8% (IZYDORCZYK *et al.*, 2003). According to HELM and DE FRANCISCO (2004) β-glucan content in six Brazilian hull-less barley varieties (3.70 to 5.77% d.m.) was similar with content in our hull-less barley genotypes. IZYDORCZYK *et al.* (2005) observed significant differences in β-glucan content among barley types with various starch amylose contents and reported that the average β-glucan content was 7.5% in high amylose, 6.9% in waxy, 6.3% in zero amylose waxy and 4.4% in normal starch types. It was estimated that a 300-gram daily portion of breads supplemented with hull-less barley could meet up to 40% of dietary recommended intakes for selenium and 70–75% of recommended daily values for β-glucan (ŠKRBIĆ *et al.,* 2009). The effectiveness of barley β-glucans in barley food products in lowering blood cholesterol, and glycemic index has been reported in numerous publications and is widely accepted (CAVALLERO *et al.,* 2002; PINS and KAUR, 2006).

Content of proteins in small grain cereals

In average, hull-less oat (15.65% d.m.) and hull-less barley (14.11% d.m.) wholemeal had a significantly higher ($P < 0.05$) content of total proteins than durum wheat (11.66% d.m.), rye (11.38% d.m.) and bread wheat (10.90% d.m.) (Table 3a). Generaly, hull-less barley and hull-less oat usually has higher total protein and amino acid contents than hulled, as well as other cereals (HELM *et al.,* 2004; KANDIĆ *et al.,* 2010). Hull-less oat had significantly higher protein content than hull-less barley, but coefficient of variation for hull less barley is much higher than for hull-less oat (15.92 and 1.49%, respectively). Among the tested cereal genotypes, the highest content of protein (16.91% d.m.) was detected in hull-less barley Apolon (Table 3). According to HELM and DE FRANCISCO (2004) protein contents in six Brazilian hull-less barley varieties (12.55 to 15.92% d.m.) was rather similar with presented hull-less barley genotypes (12.59 to 16.91% d.m.). On the other hand, the total proteins content of hull-less oat was lower than that grown in Canada (15.3 to 18.4% d.m.) (NYACHOTI *et al.,* 2010). Durum wheat, bread wheat and rye showed no significant differences total protein content between them. Coefficients of variation for total protein among durum wheat genotypes were low (5.83%) but relatively a high among bread wheat (15.80%) and rye (15.10%). According to (ŽILIĆ *et al.*, 2010), ranges of 10.9 to13.0% d.m. and 11.5 to 16.5% d.m. of protein on a dry matter basis have been quoted for bread and durum wheat, respectively, 10 to 17% d.m. for barley (QUINDE, 2004) and 7.9 to 11.7% for rye (NOWOTNA *et al.,* 2006).

Table 3. Content of tryptophan, proteins and their quality index in genotypes of small grain cereals

	Total protein (%)	Triptophan (%)	QI (%)		Total protein (%)	Triptophan (%)	QI (%)
Bread wheat				**Hull-less barley**			
ZP 87/I	9.50^{b}	0.138^{c}	1.44^{ab}	Apolon	16.91^{a}	0.245^{a}	1.49^{a}
Apache	9.25^{b}	0.150^{a}	1.62^{a}	Golijat	12.59^{d}	0.185^{d}	1.47^{a}
ZP Zemunska rosa	12.64^{a}	0.148^{a}	1.17^{b}	IWHBON 97-18	13.92^{b}	0.205^{b}	1.50^{a}
ZP Zlatna	12.21^{a}	0.141^{b}	1.15^{b}	Balša	13.03^{c}	0.190^{c}	1.46^{a}
F test	**	n.s.	*	F test	***	**	*
CV (%)	15.10	6.09	16.31	CV (%)	15.92	19.93	2.89
Durum wheat				**Hull-less oat**			
ZP 34/I	12.14^{ab}	0.154^{c}	1.27^{b}	NSO 217/201	15.62^{b}	0.197^{b}	1.26^{b}
ZP 10/I	11.12^{b}	0.138^{d}	1.24^{b}	Novosadski golozrni	15.99^{a}	0.239^{a}	1.49^{a}
ZP DSP/01-66	11.04^{b}	0.172^{a}	1.55^{a}	NS 049/2010	15.50^{b}	0.190^{c}	1.22^{b}
Varano	12.35^{a}	0.162^{b}	1.32^{b}	NS JOGO 902	15.47^{b}	0.198^{b}	1.27^{b}
F test	n.s.	*	**	F test	n.s.	*	*
CV (%)	5.83	8.48	9.84	CV (%)	1.49	10.19	8.80
Rye							
Raša	10.83^{c}	0.096^{c}	0.88^{b}				
DK-R	9.29^{d}	0.096^{c}	1.03^{a}				
Šampion	11.43^{b}	0.109^{b}	0.95^{ab}				
DK-R1/08	13.96^{a}	0.120^{a}	0.86^{b}				
F test	***	*	*				
CV (%)	15.80	10.40	7.93				

Mean of genotypes followed by the same letter within the same column are not significantly different ($P < 0.05$); *** = significant at $P < 0.001$; ** = significant at $P < 0.01$; * = significant at $P < 0.05$; n.s. = no significant; CV = coefficient of variation.

Table 3a. Average value of tryptophan, proteins and their quality index in small grain cereals

Species	Total protein (%)	Triptophan (%)	QI (%)
Mean (bread wheat)	10.90^{c}	0.144^{bc}	1.35^{a}
Mean (durum wheat)	11.66^{c}	0.157^{b}	1.34^{a}
Mean (rye)	11.38^{c}	0.105^{c}	0.93^{b}
Mean (hull-less barley)	14.11^{b}	0.201^{a}	1.48^{a}
Mean (hull-less oat)	15.65^{a}	0.206^{a}	1.31^{a}
F test	**	**	**

Mean of species followed by the same letter within the same column are not significantly different ($P < 0.05$); *** = significant at $P < 0.001$; ** = significant at $P < 0.01$.

However, initial screening of the USDA World Wheat Collection showed that the protein content of 12,600 wheat lines varied even more, from about 7% to 22% d.m. (VOGEL *et al.,* 1978), with the genetic component accounting for about a third of this (i.e. about 5%). Hence, the greater part of the variation was due to non-genetic factors and this strong environmental impact has made breeding for high protein difficult. For example, HENDAWEY (2009) showed that content of total protein, as well as gluten, varied from 10.84 to 12.21% d.m., and from 63.02 to 74.22% d.m., in wheat cultivar grown under different salinity levels (512 to 8614 ppm).

Content of tryptophan in small grain cereals

The tryptophan contents and QI values of the tested wheat, rye, barley and oat genotypes are presented in Table 3 and 3a. Because the essential amino acids composition of cereal grains is determined by their low levels in the prolamin storage proteins, the quality of the grain is influenced by factors which affect the proportions of these proteins in the grain. The contents of lysine and tryptophan are higher in the legumin-type storage proteins of oats, accounting for the higher contents of these amino acids in these cereals (SHEWRY, 2007). This is confirmed by our study as hull-less oat genotypes had the highest content of tryptophan (on average 0.206% d.m.). Among the tested oat genotypes, the highest content of tryptophan (0.239% d.m.) was detected in Novosadski ovas, the lowest (0.190% d.m.) in NSO 049/2010. However, the highest content of tryptophan (0.245% d.m.) was detected in hull-less barley cultivar Apolon (Table 3). There was no significant difference ($P < 0.05$) in the mean tryptophan content between hull-less oat and hull-less barley. However, a relatively high variation for tryptophan content was found within hull-less barley genotypes (CV = 19.93%), while coefficients of variation was low within hull-less oat genotypes (CV = 10.19%). Obtained ranges for tryptophan in tested hull-less oat genotypes were rather lower to those reported by NYACHOTI *et*

al. (2010) for Canadian hull-less oat (0.483 to 0.569% d.m.). The average value of rye, bread and durum wheat samples for tryptophan content was 0.105, 0.144 and 0.157 d.m., which was 1.96, 1.43 and 1.37-fold lower than that of oat, respectively. Hull-less oat genotypes had the highest content of total protein and this could be the reason for QI (on average 1.31% of total protein) similar of 1.48, 1.35 and 1.34% for hull-less barley, bread and durum wheat, respectively (Table 3a). According to results reported by (SHEWRY, 2007) tryptophan was absent from the major prolamin fraction of wheat, rye and barley, but QI of grain proteins was 1.1, 1.1 and 1.9%, respectively. ZHU and KHAN (2001) suggest that conditions of nitrogen nutrition of plants have a substantial effect on the amino-acid composition of protein substances in wheat. With a nitrate source of nitrogen, the content of the aromatic amino acids tryptophan and tyrosine are substantially increased in wheat while given ammonia nutrition the cystine content is higher. Also, normal phosphorus nutrition is vitally important for tryptophan synthesis in wheat.

CONCLUSION

The results indicated that tested small grain cereals could meet improved diet requirements with their content of dietary fibres and for their proteins quality. It should be noted that most widely used species, such as bread and durum wheat and rye, showed the highest dietary fibre contents among small grain cereals. However, hull-less barley and hull-less oat had higher total protein and tryptophan contents than other cereals. Although more research is required to understand the effect of growing location and conditions, the observed differences between genotypes with the highest and lowest concentration of fibres and proteins suggest that it may be possible to develop small grain varieties which are enriched in with benefits to the health of consumers.

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POREĐNJE SITNOZRNIH ŽITARICA PREMA SADRŽAJU DIJETALNIH VLAKANA I PROTEINA

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I z v o d

U zrnu genotipova hlebne i durum pšenice, raži, golozrnog ječma i golozrnog ovsa određen je sadžaj dijetalnih vlakana (celuloze, hemiceluloze, lignina, NDF-a, ADF-a), triptofana i proteina, kao i njihov indeks kvaliteta. Pored toga određen je i sadržaj β-glukana u zrnu četiri reprezentativna genotipa golozrnog ječma. U proseku, golozrni ječam i ovas imali su najniži sadržaj hemiceluloze (22.54 i 13.11% s.m.), celuloze (1.36 i 1.41% s.m.), lignina (0.98 i 0.49% s.m.), kao i NDF (24.84 i 15.16% s.m.) i ADF (2.30 i 2.04% s.m.). Najviši sadržaj hemiceluloze bio je u zrnu durum šenice (u proseku 33.47% s.m.), sledi raž (u proseku 29.63% s.m.) i hlebna pšenica (u proseku 23.24% s.m.). U zrnu ispitivanih genotipovima golozrnog ječma sadržaj β-glukana se kretao od 4.1% d.m. (IWHBON 97-18) do 5.6% d.m. (Apolon). Najviši sadržaj proteina (u proseku 15.65% d.m.) i triptofana (u proseku 0.206% d.m.) bio je u zrnu golozrnog ovsa. Najviši indeks kvaliteta proteina bio je u zrnu golozrnog ječma (u proseku 1.48%), sledi hlebna i durum pšenica i golozrni ovas (1.35, 1.34 i 1.31%), a zatim raž (0.93%). Rezultati ukazuju na genetičku divergentnost u sadržaju dijetalnih vlakana i proteina između ispitivanih genotipova i mogućnost odabira genotipova za selekcione linija visokog nutritivnog kapaciteta, kao za i poboljšane zahteva ishrane.

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