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NUTRITIONAL FEATURES OF TRITICALE AS AFFECTED BY GENOTYPE, CROP YEAR, AND LOCATION

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Traditionally, triticale is mainly used as animal feed, the use for human utilization is still uncertain. However, in the past few decades, importance of triticale is increasing globally. Therefore, the determination of nutritionally important parameters of triticale and study of their genetic and environmental (G×E) variability have essential importance. In this study, ten hexaploid triticales along with reference wheat and rye varieties were grown at two locations in Hungary in a three-year-long experiment. Crude protein (8.6–16.3%), crude fat (0.86–1.98%), starch (57.6–65.0%), and dietary fibre values (7.5–13.7%) showed notable differences, significant genotype control were detected in all tested parameters except ash content (1.42–2.10%). The analysis of variance confirmed that crop year affected all traits, and also location had significant effect on the formation of protein and – to a lesser extent – the fibre levels. Furthermore, interactions between the effects were observed. Generally, nutritional characteristics of triticales were positioned between wheat and rye in this experiment; however, there were notable differences between the genotypes, and also the magnitudes of environmental effects were significant. Nutritional values of triticale provide a prospect for food production and human consumption.

Keywords: triticale, nutritional composition, genotype effect, environmental effects, dietary fibres

Triticale (× *Triticosecale* Wittmack), a man-made cereal from crossing wheat (*Triticum* sp.) and rye (*Secale* sp.), has an excellent yield potential and a great flexibility to adapt to difficult agronomic conditions (Pena, 2004). Globally, its acreage shows continuous growth, it reached over 4 million ha by 2014. In Hungary, triticale production started in late 1960s on sandy soil areas, in the middle regions of the country, nowadays the harvested area is around 123 000 ha (FAOSTAT, 2016). Triticale is mainly used as animal feed, and it can be also used as a renewable crop for energy and biofuel production. However, its utilization for human food is still uncertain (Wos & Brzeziński, 2015). Cereal foods are on essential part of the daily diet (protein, carbohydrate, and dietary fibre intake), and the people in general became more health conscious. This leads to the current customer trend of trying new products and increased the interest in triticale (McGoverin et al., 2011).

In most scientific studies, nutritional characteristics of triticale are at intermediate positions between wheat and rye, but more similar to wheat (McGoverin et al, 2011; Rakha et al., 2011; Obuchowski et al., 2015). The crude protein content varies between 10.2–15.6%, which is usually higher than of rye and lower than of wheat. The second and third generation cultivars do possess a lower grain-protein concentration than the older ones, possible due to the consequent selection (Pena, 2004; Wos & Brzeziński, 2015). Crude fat level is among 1.0–2.4%, ash content is 1.4–3.0% (Rakha et al., 2011). Starch is the major storage polysaccharide in cereals, contents of 63.3–73.0% have been reported for triticale grain

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(Tohver et al., 2005; Burešová, et al., 2010; Dennett et al., 2013). The dietary fibre (DF) content is between 10.2–15.6%, typically higher than of wheat and lower than of rye (Boros, 1999; Dennett et al., 2013). DF components have been shown to have many health benefits, including prebiotic properties, immunomodulatory activity, lowering cholesterol level, attenuate type II diabetes, and they are also potential antioxidants, due to the presence of ferulic acid (Lafiandra et al., 2014).

In the present study we thoroughly characterized the most important nutritional components of Hungarian triticale cultivars and advanced lines, investigating the effects of genotype, crop year, location, and the magnitude of their possible interactions.

1. Materials and methods

1.1. Plant materials and experimental design

Three hexaploid triticale cultivars, widely used in the Hungarian agriculture (GK Idus, GK Rege, GK Szemes), and seven advanced lines (Tc1, Tc2, Tc3, Tc4, Tc5, Tc6, and Tc7) were tested in this experiment. GK Idus is a spring triticale with high protein content and good adaptability. GK Szemes and GK Rege are winter triticales with high and stable yield potential and high level of disease resistance. Advanced lines are from our breeding material with different genetic sources. These lines have favourable agronomical traits (e.g. yield potential, disease resistance, grain characteristics). These genotypes were grown in trials using randomized complete block design in four replications at two different locations in Hungary; in nursery field of our Experimental Station 1) Kiszombor (Latitude N 46˚11’ 24.7”, Longitude E 20˚ 24’ 4.1”) and 2) Szeged (Latitude N 46˚ 15’ 10.8”, Longitude E 20˚ 8’ 29.1”). The two locations are not too far from each other (cca. 35 km), but there is a remarkable difference in the soil type: Kiszombor is a black, calcareous meadow chernozem soil, while in Szeged, the soil is a calcareous multi-layer humic gley soil. Three-year-long agronomical trial was executed in 2012, 2013, and 2014. Every year, agronomical conditions of the experiments showed average features. Crop years 2012 and 2014 had average weather conditions, but in 2013 the precipitation values were higher than usual. Also, in 2014 there was a yellow rust infection in Hungary. Two wheat cultivars: GK Békés (new, modern, premium breadmaking quality) and Jubilejnaja-50 (stable, good breadmaking quality) and one rye cultivar: Wibro were used as controls.

1.2. Sample preparation

After harvesting the experimental plots, 3 kg bulk sample from each replication were taken and cleaned. The grains were ground in a Cyclotec 1093 Sample Mill (Tecator, Sweden) to pass through a 1 mm screen. All ground samples were stored in plastic bags at the temperature of 17 ºC until analysis.

1.3. Analytical methods

Dry matter was determined by drying the samples at 135 °C for 1 h to constant weight (MSZ EN ISO, 2010a). Crude protein content was detected by Dumas combustion method (ICC, 2000) and ash content by using dry ashing (MSZ EN ISO, 2010b). The crude fat content was extracted by Soxtec extraction (ICC, 1984). DF was measured according to an enzymatic-gravimetric method (AOAC 985.29). Starch content was estimated by calculating the percent remaining after all the other components have been measured. The samples were analysed at least in triplicates.

1.4. Statistical analysis

The results were analysed for genotype, location and crop year effect with factorial analysis of variance (ANOVA) using a general linear model (GLM) by StatSoft STATISTICA 12 program (StatSoft Inc., USA). Significance level was set to $P<0.05$ and 0.01. Normality of distributions and homogeneity of variances was determined, the results met the criteria of ANOVA. Post-hoc Tukey's HSD test was used to determine differences between means.

2. Results and discussion

2.1. Analysis of location, crop year, and genotype effects and their interactions

Investigation of the genotypic variance and the effect of the environment (crop year, location) and the level of their interactions are essential for targeted breeding efforts. In this experiment, numerous effects were detected. Significant genotype differences were detected in all tested parameters except ash content (Table 1). Among the tested values, DF content was most strongly under genotypic control. The analysis of variance confirmed that the location had significant effect on the formation of crude protein and – to a lesser extent – the DF levels. However, crude fat, ash, and starch concentrations were not affected by the location factor in this experiment. The crop year effect was significant in all cases, it had particularly high effect on the protein content and starch formation. The location by genotype interaction showed strong significance at DF and starch concentrations. The crop year by genotype interaction was more dominant, only the DF content was exception. Also, a strong location by crop year interaction was observed as well as in the case of triple interaction.

Table 1. Results of the ANOVA for samples of two locations and three years

Effect	Crude protein	Crude fat	Ash	Dietary fibre	Starch
Genotype	3.22**	14.61**	1.59^{NS}	15.60**	4.30**
Location	40.50**	3.67^{NS}	0.39^{NS}	5.38*	2.16^{NS}
Year	147.62**	10.62**	4.00**	3.54*	72.10**
Genotype × Location	1.77^{NS}	1.79^{NS}	1.09^{NS}	2.72**	129.50**
Genotype × Year	3.06**	2.73**	2.77**	1.30^{NS}	2.30**
Location × Year	13.03**	50.85**	1398.5**	351.15**	294.00**
Genotype × Location × Year	185.00**	5.46**	51.10**	5.29**	20.00**

NS: not significant; *, **: significant at the 0.05 or 0.01 probability levels, respectively

2.2. Nutritional composition of triticale grain samples

Nutritional characterization of triticale entries and the wheat and rye controls are shown in Table 2. Triticale cultivars and advanced lines showed a notable variation (8.6–16.3%) in crude protein content, similar variation of this trait was reported in earlier studies (Rakha et al., 2011; Dennett et al., 2013). Triticales grown at Szeged displayed significantly higher protein contents than those of Kiszombor. In the background of this difference is the higher availability of N (more favourable soil structure) in location Szeged. Wheat seems to have the same tendency, while there is no significant difference in protein values of ryes at the two locations. At location Szeged, the triticale's protein mean was positioned between the control wheat and rye cultivars, in agreement with earlier findings (Heger & Eggum, 1991; Boros, 1999; Rakha et al., 2011), and Tc3 advanced line had the highest protein content. In Kiszombor, the average protein content of triticale entries were lower if compared to both wheat and the rye cultivars, but Tc2 line over-yielded all controls. Among the released triticale cultivars, GK Idus possessed the highest crude protein values at both locations. The protein content was significantly lower in 2013 compared to the other years at both locations. The values from 2012 and 2014 differed from each other, which is likely associated with the significantly different weather and abiotic stress effects.

In this experiment, crude fat content varied from 0.86% to 1.98%. Similarly to crude protein, crude fat contents of triticale and the average were higher at location Szeged. In accordance with the results of Rakha and co-workers (2011), the location effect was not significant in case of triticale, wheat, or rye. In Szeged, triticale cultivars GK Rege and GK Idus were superior compared to the other triticale entries. In both locations, GK Idus even produced significantly higher values than control wheat and rye checks. Comparing the years, 2013 showed the highest fat contents, and the variance was significantly different from 2012 and 2014.

Ash content of the triticale entries ranged between the minimum value of 1.42% and the maximum of 2.10%. This is a wider range compared to findings of Obuchowski and co-workers (2015). Overall ash content values of the triticales were either equal or closer to the rye cultivar Wibro and higher than the wheat cultivars. For ash content, significant difference between the two experimental places was not observed for triticale. The control species showed higher means in location Kiszombor. In Kiszombor, crop year 2012 showed maximum values and 2014 minimum ones, this two years significantly differed from each other, while in Szeged, crop year 2013 and 2014 had the highest ash contents.

Levels of DF among triticale entries (7.5–13.7%) had significant variability similarly to wheat and rye, in contrast with study of Silva and Ciocca (2003). Each year and at each location, rye control had the highest total DF contents, this is in accordance with other findings (Andersson et al., 2009; Bona et al., 2014). As it was expected from a previous report, triticales have higher DF contents compared to wheat cultivars, which emphasizes its health benefits (Cyran & Lapiňski, 2006). In our study, Tc3 (8.5–10.9%) had the lowest – and cultivar GK Idus (11.7–13.7%) performed the highest total DF content. Thus, beside the fact that the genotype plays fundamental role in the magnitude of DF content in triticale, environmental factors also have slight effect on the final score of this valuable parameter. Samples from Kiszombor had a significantly higher mean than from Szeged. It seems that soil conditions have opposite effect on the DF quantities than on protein concentrations. DF also showed changes through the years, but significant difference could not be calculated. We measured 0.52–0.98% soluble DF in triticale genotypes (data not shown). Both in triticale and in wheat genotypes less than 10% of the total DF was soluble, and this percentage was lower than that of the rye (15%). Some triticale entries (Tc1, Tc4 and Tc5) possessed higher values for soluble DF than wheat cultivars, but no significant differences were calculated between triticale genotypes in this study. We noticed no environmental (neither location nor crop year) effects on soluble DF.

Table 2. Crude protein (%), crude fat (%), ash (%), total dietary fibre (%), and starch (%) concentrations of triticale genotypes and control wheat and rye cultivars from two locations and three years (Contents are on dry matter basis.)

	Crude protein				Crude fat				Ash				Total dietary fibre				Starch			
	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean
Triticales Kiszombor																				
Tc1	13.4	8.6	12.4	**11.7**^{a}	1.12	1.45	1.11	**1.12**^{ab}	1.65	1.58	1.51	**1.58**^{a}	12.8	12.8	11.5	**12.4**^{d}	59.7	64.2	59.7	**61.4**^{ab}
Tc2	14.4	12.6	16.2	**14.4**^{b}	1.21	1.64	1.34	**1.40**^{bc}	1.61	1.64	1.58	**1.61**^{ab}	12.5	11.3	10.2	**11.2**^{bcd}	58.9	60.6	57.6	**59.0**^{bc}
Tc3	14.1	10.1	11.8	**12.0**^{ab}	1.14	1.44	1.19	**1.25**^{abc}	1.61	1.56	1.42	**1.53**^{a}	10.9	10.4	8.5	**9.8**^{ab}	60.9	64.2	63.8	**62.9**^{a}
Tc4	12.2	9.6	12.1	**11.3**^{a}	1.05	1.22	0.97	**1.08**^{ab}	1.63	1.58	1.59	**1.60**^{ab}	11.7	11.2	9.8	**10.9**^{abcd}	62.4	64.9	62.1	**62.9**^{a}
Tc5	11.7	8.8	12.1	**10.9**^{a}	0.89	1.24	0.99	**1.04**^{a}	1.65	1.76	1.65	**1.68**^{b}	12.1	12.6	10.4	**11.7**^{cd}	62.5	63.6	61.5	**62.5**^{a}
Tc6	11.3	8.8	12.0	**10.7**^{a}	0.98	1.24	1.12	**1.13**^{ab}	1.61	1.72	1.53	**1.62**^{ab}	12.5	11.3	10.5	**11.2**^{cd}	62.5	64.8	61.3	**62.9**^{a}
Tc7	12.6	8.9	12.3	**11.3**^{a}	0.86	1.10	1.12	**1.03**^{a}	1.67	1.77	1.61	**1.68**^{b}	11.9	11.3	10.5	**11.2**^{bcd}	61.9	65.0	60.7	**62.6**^{a}
GK Szemes	12.0	8.7	12.9	**11.2**^{a}	1.09	1.22	1.12	**1.14**^{ab}	1.63	1.48	1.45	**1.52**^{a}	10.5	10.8	10.1	**10.4**^{abc}	63.3	65.8	60.8	**63.3**^{a}
GK Rege	12.9	8.8	13.1	**11.4**^{a}	1.45	1.53	0.93	**1.30**^{abc}	1.71	1.54	1.64	**1.63**^{ab}	10.2	9.5	9.5	**9.7**^{a}	61.8	67.6	61.6	**63.7**^{a}
GK Idus	11.8	9.8	15.4	**12.3**^{ab}	1.59	1.85	1.29	**1.58**^{c}	1.62	1.55	1.78	**1.65**^{b}	13.7	12.4	12.5	**13.1**^{f}	60.0	62.4	56.6	**59.3**^{bc}
Mean	**12.6**^{f}	**9.4**^{e}	**13.0**^{g}	**11.7**^{A}	**1.14**^{e}	**1.39**^{f}	**1.12**^{e}	**1.20**^{A}	**1.64**^{e}	**1.62**^{ef}	**1.58**^{f}	**1.66**^{A}	**11.9**^{e}	**11.4**^{e}	**10.4**^{e}	**11.2**^{B}	**61.4**^{f}	**64.3**^{g}	**60.6**^{e}	**62.1**^{A}
Controls Kiszombor																				
GK Békés wheat	12.9	10.4	16.0		1.43	1.64	1.35		1.69	1.71	1.90		10.2	10.9	9.7		61.8	63.1	58.4	
J-50 wheat	12.8	10.2	14.9		1.45	1.56	1.32		1.38	1.49	1.34		8.9	10.4	9.6		63.4	63.4	59.3	
Wibro rye	13.1	9.4	14.5		1.26	1.47	1.16		1.66	1.77	1.54		15.1	15.0	14.8		58.3	59.7	54.1	
Triticales Szeged																				
Tc1	14.0	12.8	13.8	**13.6**^{ab}	1.10	1.45	1.25	**1.27**^{a}	1.43	1.74	1.60	**1.58**^{abc}	10.4	11.2	12.5	**11.4**^{b}	62.2	61.7	57.6	**60.5**^{a}
Tc2	12.9	12.7	13.8	**13.1**^{ab}	1.12	1.39	1.30	**1.27**^{a}	1.40	1.62	1.52	**1.51**^{ab}	10.9	12.8	11.5	**11.9**^{ab}	62.9	59.5	58.5	**60.3**^{a}
Tc3	14.3	12.6	16.3	**14.4**^{b}	1.07	1.27	1.15	**1.17**^{a}	1.59	1.50	1.62	**1.57**^{abc}	7.5	9.0	10.3	**8.9**^{a}	66.7	63.3	58.1	**62.7**^{a}
Tc4	13.5	12.5	13.1	**13.0**^{ab}	1.13	1.20	1.18	**1.17**^{a}	1.46	2.10	1.95	**1.83**^{abc}	9.7	10.5	11.4	**10.7**^{ab}	62.4	62.1	59.4	**61.3**^{a}

Table 2. continued

	Crude protein				Crude fat				Ash				Total dietary fibre				Starch			
	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean	2012	2013	2014	Mean
Tc5	13.3	12.2	14.0	**13.1**^{ab}	1.15	1.19	1.17	**1.16**^{a}	1.40	1.89	1.85	**1.70**^{abc}	10.0	10.8	13.2	**11.4**^{b}	63.5	61.9	57.0	**60.8**^{a}
Tc6	12.6	12.3	13.2	**12.7**^{ab}	1.17	1.17	1.18	**1.17**^{a}	1.50	1.76	1.69	**1.65**^{abc}	10.0	11.5	12.7	**11.3**^{ab}	63.7	60.9	58.8	**61.1**^{a}
Tc7	12.1	11.8	13.2	**12.4**^{a}	1.08	1.37	1.20	**1.22**^{a}	1.57	1.68	1.60	**1.62**^{abc}	10.4	12.0	13.3	**12.1**^{b}	63.4	61.5	57.7	**60.8**^{a}
GK Szemes	12.7	12.1	13.8	**13.0**^{ab}	1.06	1.21	1.34	**1.20**^{a}	1.59	1.68	1.62	**1.62**^{abc}	9.0	10.0	10.8	**9.9**^{ab}	64.4	62.9	59.5	**62.3**^{a}
GK Rege	13.2	12.0	12.5	**12.6**^{ab}	1.57	1.55	1.51	**1.54**^{b}	1.78	2.01	2.10	**2.02**^{ac}	10.5	10.0	9.7	**10.1**^{ab}	62.0	62.4	61.5	**61.9**^{a}
GK Idus	13.5	12.8	14.5	**13.6**^{ab}	1.98	1.64	1.80	**1.81**^{c}	1.36	1.79	1.60	**1.58**^{abc}	11.7	11.5	12.9	**12.0**^{b}	61.9	59.9	56.9	**59.6**^{a}
Mean	**13.0**^{f}	**12.4**^{e}	**13.9**^{g}	**13.1**^{B}	**1.24**^{e}	**1.35**^{f}	**1.31**^{f}	**1.30**^{A}	**1.49**^{e}	**1.78**^{f}	**1.71**^{f}	**1.66**^{A}	**10.0**^{e}	**11.0**^{e}	**11.8**^{e}	**10.9**^{A}	**63.3**^{f}	**61.6**^{f}	**58.5**^{e}	**61.1**^{A}
Controls Szeged																				
GK Békés wheat	15.3	13.5	16.1		1.33	1.35	1.60		1.32	1.70	1.60		7.6	10.1	10.6		63.6	61.3	57.8	
J-50 wheat	14.5	13.2	15.8		1.41	1.00	1.51		1.19	1.55	1.43		8.2	10.2	10.9		63.8	62.0	58.2	
Wibro rye	13.3	12.1	10.4		1.20	1.29	1.32		1.62	1.89	1.62		9.4	13.1	13.7		63.6	59.6	60.4	
SD	0.85	1.69	1.32		0.27	0.22	0.23		0.11	0.16	0.20		1.35	1.05	1.46		1.48	1.80	2.10	

Means with unequal letters significantly differ at $P<0.05$ (lowercase for genotype (a–d) and crop year (e–g), uppercase for location)

The starch contents of triticales (57.6–65.0%) were more similar to wheat cultivars than to rye control, which latter species are generally low in starch (Rakha et al., 2011., Dennett et al., 2013). The overall starch contents under Hungarian conditions were somewhat lower than in other studies (Burešová et al., 2010; McGoverin et al., 2011). Location affected the starch contents in none of the species. Advanced line Tc2 and cultivar GK Idus had lower starch contents than the other triticales, and this difference was significant at location Kiszombor. The smallest amounts of starch were observed in 2014. Crop years differed from each other, significantly affected starch quantity, likely associated with abiotic influences (rainy weather) and also biotic influences (epidemic yellow rust disease).

3. Conclusions

Generally, nutritional characteristics of triticales were positioned between wheat and rye in this study; however, there were notable differences between the genotypes. Cultivar GK Idus had outstanding crude protein, fat, and fibre contents, and crude fat and soluble DF values of GK Rege were advantageous as well as compared to other triticale genotypes. GK Szemes showed average features of all nutritional components. Experimental lines Tc2, Tc4, and Tc5 may have importance in such efforts. This opens up the opportunity to pick valuable existing cultivars for human consumption and select value added populations for breeding programs to create nutrient rich genotypes. Although, the magnitude of observed environment effects draws attention to the need of careful selection.

Formerly, triticale was considered as feed grain cereal, but the nutritional values of these genotypes provide a prospect for human utilization. Health conscious consumer trends to increasingly use novel, valuable grain sources and products in the daily based diets could give a chance to triticale. Flour of triticale grain could possibly be suitable for food industry as per se. However, because of their complementary values, blending wheat with triticale may provide better results and effective solution for large-scale utilization of triticale for human consumption, to compensate the weaker technological qualities (e.g. low gluten content) of triticale.

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