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NUTRITIONAL VALUE AND MINERAL COMPOSITION OF GRAIN OF SELECTED WHEAT SPECIES DEPENDING ON THE INTENSITY OF A PRODUCTION TECHNOLOGY*

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Abstract

The test material originated from a field experiment conducted in 2010-2013, at the Experimental Farm in Felin (51°22' N, 22°64' E), which belongs to the University if Life Sciences in Lublin. A two-factor experiment was conducted in randomised blocks with 4 replicates. The chemical composition of grain of 4 wheat species was analysed: common wheat (*Triticum aestivum* ssp. *aestivum* L.) cv. Tonacja, durum wheat (*Triticum durum* Desf.) cv. Komnata, spelt (*Triticum aestivum* ssp. *spelta* (L.) Thell.) cv. Schwabenkorn, and einkorn wheat (*Triticum monococcum* L.) line PL 5003 (material acquired from the National Centre of the Plant Gene Pool), grown at different production technology intensity (medium and high level of cultivation technology).

The analyses on wheat grain included the content of total protein, crude ash, crude fat, crude fibre, carbohydrates, phosphorus, potassium, magnesium, calcium, copper, iron, manganese and zinc. The results were subjected to an analysis of variance, while the differences were estimated by the Tukey's test at the significance level of $p = 0.05$. In order to identify the correlations and relationships between selected grain quality traits, an analysis of multiple correlation was employed and coefficients of variation were calculated (CV, %).

Einkorn wheat proved to have the highest levels of protein, fat, ash, phosphorus, potassium, magnesium, calcium, copper, zinc, iron and manganese. Among the remaining genotypes, common wheat had the highest levels of carbohydrates and fibre. Irrespective of the genotype, more intensive chemical weed and pest control and nitrogen fertilisation had a favourable effect

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on the content of protein and fat, while reducing the levels of fibre and carbohydrates. Most of the macroelements, except phosphorus, and all the microelements reached higher concentrations under the more intensive production technology. In terms of grain quality, the response of the genotypes to the intensification of production technology was only slightly varied.

Keywords: common wheat, durum wheat, spelt wheat, einkorn wheat, nutrients, microelements, macroelements, production technology.

INTRODUCTION

The global trends in food processing are oriented towards a more extensive use of the plant material with good food and nutritional values which so far has been underestimated. The growing interest in 'old' wheat species is the consequence of the diminishing biological diversity of food. Together with the environmental pollution and stress factors, this is a primary cause of many civilisation diseases. Although their productivity is lower, old species present many advantages, especially those related to the nutritive value of grain and its products (Piergiovanni et al. 1997, Anglani 1998, Serpen et al. 2008, Imtiaz et al. 2010). For this reason, in the contemporary agricultural practice, both in our fields and on our tables, we more often see plant materials and products originating from durum (*Triticum durum*), spelt (*Triticum aestivum* ssp. *spelta*), emmer (*Triticum dicoccum*) or einkorn wheats (*Triticum monococcum*), and not only common wheat (*Triticum aestivum* ssp. *aestivum*) (Rachoń 2001, Cyrkler-Degulis, Bulinska-Radomska 2006, Rachoń et al. 2013). Einkorn wheat is characterised by a high content of protein, minerals, antioxidants and carotenoids, which is why this cereal is highly valued by consumers (Brandolini et al. 2008, Zhao et al. 2009, Suchowolska et al. 2012). Spelt wheat has more digestible protein, high levels of unsaturated fatty acids, fibre, group B vitamins and phosphorus, which makes it highly suitable for the production of health food. In recent years, an interest in husked wheats has been growing, partly because of the revival of extensive production methods (Cyrkler-Degulis, Bulinska-Radomska 2006, Kohajdova, Karovicova 2008).

The objective of the study was to determine changes in the chemical composition of the grain of 4 wheat species under conditions of varied production technology intensity. The hypothesis was that a more intensive cultivation technology will cause varied responses of the genotypes in terms of grain quality.

MATERIAL AND METHODS

The test material originated from a field experiment conducted in 2010-2013, at the Experimental Farm in Felin (51°22′ N, 22°64′ E), which belongs to the University if Life Sciences in Lublin. A two-factor experiment was conducted in randomised blocks with 4 replicates. The experimental field lay on soil developed from silt originating from loess, classified as the good wheat complex. The soil was rich in phosphorus and potassium (P – 79 and K – 180 mg kg^{-1} soil), while its content of magnesium was low – 40 mg kg^{-1} (Rachoń et al. 2013).

The first experimental factor included 4 species of winter wheat: common wheat (*Triticum aestivum* ssp. *aestivum* L.) cv. Tonacja, durum wheat (*Triticum durum* Desf.) cv. Komnata, spelt wheat (*Triticum aestivum* ssp. *spelta* (L.) Thell.) cv. Schwabenkorn, and einkorn wheat (*Triticum monococcum* L.) line PL 5003 (material acquired from the National Centre of the Plant Gene Pool). The second factor comprised 2 levels of cultivation technology: 1) medium level: mineral fertilisation (N – 70, P – 30.5 and K – 99.6 kg ha^{-1}), grain dressing and weed control; 2) high level: increased nitrogen fertilisation (N – 140, P – 30.5 and K – 99.6 kg ha^{-1}), grain dressing, weed control, 2 treatments against diseases, insecticide and growth regulator.

Prior to sowing, the wheat grain was treated with the preparation Baytan Universal 094 FS in a dose of 400 ml of the agent mixed with 200 ml of water per 100 kg of grain. Soil tillage was typical of the plough system. After harvesting the preceding crop, a set of post-harvest tillage operations was performed, while mineral fertilisation followed by ploughing and harrowing were carried out 10-14 days before sowing. The sown area of the experimental plots was 22 m^2, and the harvest area was limited to 10 m^2. Sowing at the density of 450 kernels per 1 m^2 was performed at the optimum time, on a stand after winter rapeseed. Every year after harvest, the grain was dried and cleaned in a laboratory thresher, after which grain samples were taken for chemical analyses.

The analyses on grain samples included the content of total protein (total nitrogen content with the Kjeldahl's method × 5.75), crude ash (the gravimetric method), crude fat (the gravimetric method according to Soxhlet), crude fibre (the gravimetric method), carbohydrates (by detracting other dry matter components), phosphorus (the CFA method), potassium (atomic emission spectrometry), magnesium, calcium, copper, iron, manganese and zinc (the FAAS method).

The results underwent an analysis of variance and the differences were assessed with the Tukey's test at the significance level of p = 0.05. The coefficients of variation were calculated (CV in %).

With respect to the weather conditions during the study, the considerable variation occurring in air temperatures and precipitation sums in the 3-year period is noteworthy, as well as their substantial diversion from the mean values for the long-term period of 1951-2010 (Table 1). More significant differences were noted in the amounts of precipitation. The good moisture conditions in the autumn of 2010 were favourable for the germination and emergence of winter wheat. The long plant growing period extending in the

Table 1

Rainfalls and air temperatures according to the Meteorological Observatory at Felin

Year	Months											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
	rainfalls (mm)											
2010/2011	119.0	11.2	46.8	32.4	24.8	25.2	8.1	29.9	42.2	67.8	189.0	65.3
2011/2012	5.4	28.5	1.0	34.5	33.6	22.1	28.6	34.0	56.3	62.8	52.3	37.6
2012/2013	35.5	88.8	29.8	28.8	57.7	28.5	60.8	51.1	101.6	105.9	126.1	17.8
Mean for 1951-2010	53.7	40.1	38.2	31.4	23.4	25.8	28.0	39.0	60.7	65.9	82.0	70.7
Year	air temperature (°C)											
2010/2011	12.5	5.6	6.4	-4.7	-0.8	-4.8	2.3	10.3	14.2	18.6	18.4	18.8
2011/2012	15.2	8.0	2.4	2.0	-1.8	-7.1	4.3	9.5	15.0	17.3	21.5	19.2
2012/2013	15.0	8.0	5.5	-3.8	-3.8	-1.0	-2.4	8.1	15.3	18.5	19.2	19.2
Mean for 1951-2010	12.6	7.6	2.6	-1.6	-3.7	-2.8	1.0	7.4	13.0	16.3	18.0	17.2

autumn and the mean air temperature in November being 3.8^{o} C higher than in the multi-year period made the winter wheat forms enter the winter period well-tillered. The growing season of 2012/2013 was the wettest and despite good precipitation distribution it had a negative effect on grain quality (the lowest protein content). In contrast, less precipitation, high air temperatures and good insolation in the 2011-2012 season resulted in the highest content of protein.

RESULTS AND DISCUSSION

The study revealed significant variation in the content of nutrients in winter wheat grain with relation to the factors analysed (Table 2). Irrespective of the cultivation level, the highest content of protein was determined in einkorn wheat (mean for the 3-year period was 17.40%); lower values were obtained for the other wheat species: 15.59% – spelt wheat, 14.20% – durum wheat, and 13.08% – common wheat. The higher protein content in einkorn wheat compared to common and durum wheat is supported by Abdel-Aal et al. (1995) and Brandolini et al. (2008). According to those authors, there were forms of spelt wheat with a lower content of this nutrient, but there were also forms for which no significant differences were demonstrated. Other authors (Krawczyk et al. 2008, Rachoń, Szumiło 2009) also showed that the protein content in common wheat grain was usually lower than in durum and spelt wheats.

Table 2

Content of total protein. crude fat and crude ash in grain of wheat (% d.m.)

Genotypes		Total protein			Crude fat			Crude ash		
		ML	HL	mean	ML	HL	mean	ML	HL	mean
Tonacja *T. aestivum* ssp. *aestivum*	M	12.51	13.65	13.08	1.70	1.49	1.60	1.84	1.79	1.82
	SD	0.90	1.27	1.22	0.40	0.35	0.38	0.12	0.14	0.13
PL 5003 *T. monococcum*	M	16.57	18.22	17.40	2.75	2.87	2.81	2.17	2.22	2.20
	SD	1.48	0.76	1.42	0.73	0.92	0.81	0.21	0.13	0.17
Komnata *T. durum*	M	13.76	14.65	14.20	1.84	2.06	1.95	1.95	1.91	1.93
	SD	1.24	0.69	1.07	0.43	0.45	0.44	0.20	0.26	0.22
Schwabenkorn *T. aestivum* ssp. *spelta*	M	14.78	16.41	15.59	2.23	2.36	2.29	1.95	2.01	1.98
	SD	2.25	1.49	2.03	0.49	0.58	0.52	0.07	0.13	0.11
Mean		14.41	15.73	–	2.13	2.19	–	1.98	1.98	–
LSD		a – 0.33; b – 0.17; $a \times b$ – 0.46			a – 0.08; b – 0.04; $a \times b$ – 0.12			a – 0.07; b – ns; $a \times b$ – ns		
CV (%)		14.7	13.1	–	30.6	35.4	–	9.9	11.6	–

ML – medium level of cultivation technology, HL – high level of cultivation technology, M – mean for the years 2011-2013, SD – standard deviation, CV – coefficient of variation, LSD (p = 0.05), a – for genotypes, b – for cultivation technology, $a \times b$ – for interaction genotypes × cultivation technology, ns – not significant

Irrespective of the wheat species, a higher level of cultivation intensity led to an increase in the value of the above parameter in all of the genotypes studied, which finds support in the research by RACHOŃ et al. (2013). On the other hand, KWIECIŃSKA-POPPE et al. (2011) demonstrated an increase in the protein content in grain of spelt wheat, while SAMEEN et al. (2002) and BRZOZOWSKA (2008) reported more protein in grain of common wheat.

Similar relationships were noted for the fat and ash content (Table 2). The highest levels of these ingredients were found in einkorn wheat grain: 2.81% and 2.20%, respectively, and the lowest amounts were determined in common wheat grain: 1.60% and 1.82%, which corresponds with the results obtained by ABDEL-AAL et al. (1995), KRAWCZYK et al. (2008) and HIDALGO and BRANDOLINI (2008). The highest ash content in einkorn wheat grain was also reported by BRANDOLINI et al. (2008) and HIDALGO et al. (2008). The more intensive cultivation technology caused a significant increase in the fat content but had no effect on the ash content. In the case of fat, the response of the species was varied. The higher level of cultivation technology increased the fat concentration in grain of einkorn, durum and spelt wheats, while decreasing it in grain of common wheat.

A different kind of relationship was demonstrated for fibre and carbohydrates (Table 3). The highest levels of those components were detected in common wheat: 2.70% and 80.82%, respectively. The lowest values were noted for einkorn wheat and spelt wheat: 2.29% and 75.30%, and 2.28% and 77.85%, respectively, which finds support in the study by ABDEL-AAL et al. (1995). Irrespective of the species, the higher level of cultivation technology reduced the content of fibre and carbohydrates.

Table 3

Content of crude fibre and N-free extract in grain of wheat (% d.m.)

Genotypes		Crude fibre			Carbohydrates		
		ML	HL	mean	ML	HL	mean
Tonacja	M	2.86	2.54	2.70	81.11	80.53	80.82
T. aestivum ssp. *aestivum*	SD	0.11	0.21	0.23	1.56	2.02	1.78
PL 5003	M	2.28	2.30	2.29	76.22	74.38	75.30
T. monococcum	SD	0.34	0.39	0.35	1.71	1.05	1.67
Komnata	M	2.67	2.49	2.58	79.78	78.90	79.34
T. durum	SD	0.21	0.26	0.25	1.79	1.24	1.56
Schwabenkorn	M	2.25	2.30	2.28	78.77	76.92	77.85
T. aestivum ssp. *spelta*	SD	0.23	0.24	0.23	2.80	1.88	2.50
Mean		2.51	2.41	–	78.97	77.68	–
LSD		*a* – 0.09; *b* – 0.05; *a*×*b* – 0.13			*a* – 0.58; *b* – 0.31; *a*×*b* – 0.82		
CV (%)		13.7	12.1	–	3.4	3.6	–

* key under Table 2

Significant differences were noted in the content of macroelements with relation to the experimental factors (Tables 4, 5). Einkorn wheat grain proved to be the richest in macroelements among the four wheat species. The content of phosphorus, potassium, calcium and magnesium was the highest:

Table 4

Content of phosphorus and potassium in grain of wheat (% d.m.)

Genotypes		Phosphorus			Potassium		
		ML	HL	mean	ML	HL	mean
Tonacja *T. aestivum* ssp. *aestivum*	M	0.434	0.378	0.406	0.434	0.423	0.429
	SD	0.054	0.057	0.061	0.091	0.083	0.085
PL 5003 *T. monococcum*	M	0.529	0.477	0.503	0.482	0.495	0.489
	SD	0.057	0.087	0.076	0.118	0.131	0.121
Komnata *T. durum*	M	0.450	0.476	0.463	0.435	0.443	0.439
	SD	0.038	0.026	0.034	0.116	0.127	0.118
Schwabenkorn *T. aestivum* ssp. *spelta*	M	0.453	0.474	0.464	0.429	0.464	0.447
	SD	0.038	0.049	0.044	0.082	0.125	0.104
Mean		0.466	0.451	–	0.445	0.456	–
LSD		*a* – 0.019; *b* – 0.010; *a*×*b* – 0.027			*a* – 0.019; *b* – 0.010; *a*×*b* – 0.027		
CV (%)		12.6	15.7	–	22.6	25.4	–

* key under Table 2

Table 5

Content of calcium and magnesium in grain of wheat (% d.m.)

Genotypes		Calcium			Magnesium		
		ML	HL	mean	ML	HL	mean
Tonacja *T. aestivum* ssp. *aestivum*	M	0.049	0.046	0.048	0.131	0.134	0.133
	SD	0.011	0.007	0.009	0.022	0.012	0.017
PL 5003 *T. monococcum*	M	0.060	0.066	0.063	0.144	0.155	0.149
	SD	0.008	0.009	0.009	0.013	0.013	0.014
Komnata *T. durum*	M	0.057	0.064	0.060	0.117	0.117	0.117
	SD	0.014	0.019	0.017	0.024	0.024	0.023
Schwabenkorn *T. aestivum* ssp. *spelta*	M	0.047	0.053	0.050	0.131	0.158	0.144
	SD	0.012	0.014	0.013	0.014	0.028	0.026
Mean		0.053	0.057	–	0.131	0.141	–
LSD		*a* – 0.002; *b* – 0.001; *a*×*b* – 0.003			*a* – 0.006; *b* – 0.003; *a*×*b* – 0.008		
CV (%)		22.7	26.2	–	15.7	18.6	–

* key under Table 2

0.503%, 0.489%, 0.063% and 0.149%, respectively. Significantly lower values were noted in grain from the other species, among which the lowest were assayed for common wheat: 0.406%, 0.429%, 0.048% and 0.133%, respectively. In the case of magnesium, its content in durum wheat was even lower: 0.117%. Higher levels of phosphorus and potassium in einkorn wheat compared to common wheat grain were also demonstrated by ABDEL-AAL et al. (1995). SUCHOWILSKA et al. (2012) showed similar relationships in the case of phosphorus and magnesium, while the levels of potassium and calcium were not significantly varied. In turn, GRELA (1996) found a higher content of potassium in spelt wheat compared to common wheat, whereas RACHOŃ, SZUMIŁO (2009) reported higher concentrations of those macroelements in grain of spelt and durum wheat compared to common wheat.

Under the more intensive cultivation technology, the content of phosphorus decreased while the levels of potassium, calcium and magnesium increased. The response of the particular species was varied. The intensification of cultivation caused an increase in the content of phosphorus, potassium and calcium in grain of durum wheat and a decrease in the content of those elements in common wheat, as well as an increase of the levels of potassium, calcium and magnesium and a decrease of phosphorus in grain of einkorn wheat. In turn, spelt wheat responded with higher levels of phosphorus, calcium and magnesium, but a lower content of potassium. BRZOZOWSKA (2008) reported an increase of the content of magnesium and phosphorus in grain of common wheat in response to a more intensive plant protection technology.

Einkorn wheat also proved to be the richest in microelements (Tables 6, 7). The levels of all the microelements, i.e. iron (53.65 mg kg^{-1}), copper

Table 6

Content of copper and iron in grain of wheat (mg kg^{-1} d.m.)

Genotypes		Copper			Iron		
		ML	HL	mean	ML	HL	mean
Tonacja *T. aestivum* ssp. *aestivum*	M	3.37	3.59	3.48	43.60	45.66	44.63
	SD	0.44	0.80	0.64	6.25	4.55	5.41
PL 5003 *T. monococcum*	M	3.97	4.11	4.04	51.99	55.32	53.65
	SD	0.61	1.14	0.89	11.17	9.05	10.01
Komnata *T. durum*	M	3.22	3.39	3.31	39.19	41.88	40.54
	SD	0.33	0.93	0.68	1.56	2.47	2.44
Schwabenkorn *T. aestivum* ssp. *spelta*	M	3.36	3.90	3.63	51.14	53.16	52.15
	SD	0.56	0.89	0.78	11.10	10.43	10.50
Mean		3.48	3.75	–	46.48	49.01	–
LSD		*a* – 0.13; *b* – 0.07; *a*×*b* – 0.19			*a* – 1.72; *b* – 0.92; *a*×*b* – ns		
CV (%)		16.1	25.4	–	21.0	18.3	–

* key under Table 2

Table 7

Content of manganese and zinc in grain of wheat (mg kg^{-1} d.m.)

Genotypes		Manganese			Zinc		
		ML	HL	mean	ML	HL	mean
Tonacja *T. aestivum* ssp. *aestivum*	M	42.92	43.44	43.18	46.99	51.77	49.38
	SD	4.94	3.82	4.30	8.85	8.86	8.93
PL 5003 *T. monococcum*	M	55.16	54.36	54.76	61.44	70.13	65.78
	SD	6.93	5.85	6.24	16.58	18.48	17.61
Komnata *T. durum*	M	44.26	36.81	40.53	52.01	53.88	52.94
	SD	15.99	7.49	12.70	11.56	9.37	10.25
Schwabenkorn *T. aestivum* ssp. *spelta*	M	43.07	40.00	41.53	46.04	48.00	47.02
	SD	7.53	2.94	5.77	8.94	9.05	8.79
Mean		46.35	43.65	–	51.62	55.94	–
LSD		*a* – 1.74; *b* – 0.93; *a*×*b* – 2.46			*a* – 1.98; *b* – 1.06; *a*×*b* – 2.80		
CV (%)		23.1	19.3	–	25.1	25.8	–

* key under Table 2

(4.04 mg kg^{-1}), zinc (65.78 mg kg^{-1}) and manganese (54.76 mg kg^{-1}), were the highest among the four wheat species. Significantly lower values were obtained for the other species, among which the lowest were noted for common wheat (iron, copper and manganese) and spelt wheat (zinc). Common wheat was characterised by intermediate values. The results obtained by SUCHOWILSKA et al. (2012) confirm a high concentration of microelements in einkorn wheat grain. Copper was an exception in that it reached the highest concentration in grain of spelt wheat. Common wheat had the lowest concentrations of the microelements. A low concentration of microelements in grain of common wheat compared to spelt and durum wheat was also demonstrated by RACHOŃ, SZUMIŁO (2009).

The higher level of cultivation technology caused a significant increase in the levels of all the analysed microelements. The response of the species was similar with respect to iron, copper and zinc, while in the case of manganese more intensive cultivation resulted in a decrease in the content of this microelement in grain of durum and spelt wheat. The remaining two species did not display significant correlations.

A coefficient of variation determines the distribution of values of a trait. Lower values of a coefficient indicate that a given trait is more stable. Low values of the coefficient of variation were obtained for the content of protein, ash and carbohydrates, but high ones were calculated for the content of fat, potassium, calcium and zinc.

CONCLUSIONS

1. Einkorn wheat proved to be the richest in protein, fat, ash, phosphorus, potassium, magnesium, calcium, copper, zinc, iron and manganese.

2. Among the remaining genotypes, common wheat had the highest content of carbohydrates and fibre.

3. Irrespective of the genotype, the intensification of cultivation or chemical protection and fertilisation had a favourable effect on the levels of protein and fat, but decreased the content of fibre and carbohydrates.

4. Most of the macroelements, except phosphorus, and all the microelements occurred in higher concentrations under the more intensive production technology.

5. In terms of grain quality, the response of the wheat genotypes to a more intensive production technology was only slightly varied.

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