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ORIGINAL PAPER

SPRING WHEAT GRAIN QUALITY IN RELATION TO A CROPPING SYSTEM*

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Abstract

In a field experiment, an assessment was made of the quality and chemical composition of grain of spring wheat sown in the following cropping systems: 1) crop rotation A: pea – spring wheat – durum wheat, 2) crop rotation B: pea – spring barley – spring wheat, and 3) cereal monoculture: spring barley – spring wheat – durum wheat. It was found that the content of total protein and wet gluten in spring wheat grain and the value of the sedimentation index were significantly higher in crop rotation A than in crop rotation B and in the cereal monoculture. Wheat grain harvested in crop rotations A and B had significantly higher specific weight and better uniformity than grain from the cereal monoculture. In turn, grain from the cereal monoculture had a higher content of total ash than grain from crop rotations A and B. The same grain also had a higher content of phosphorus than grain from crop rotation B, and a similar content of phytic acid to that of grain from crop rotations A and B. Moreover, the content of polyphenols in grain harvested from the monoculture was higher than in grain from crop rotation A. On the other hand, the content of vitamin C in grain from crop rotations A and B was higher than in grain from the cereal monoculture. The components of variance analysis indicate that the content of protein and gluten in grain and the value of the sedimentation index were more affected by the cropping systems than by the study years, although the grain volume weight, grain uniformity and ash content were determined to a greater extent by the course of weather conditions in the study years than by the cropping systems.

Keywords: total protein, wet gluten, P-phytic, polyphenols, crop rotation, cereal monoculture.

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INTRODUCTION

The quality and chemical composition of cereal grain depends on the habitat conditions and elements of the cultivation technology combined, and especially the succession of plants, soil tillage systems, doses and methods of nitrogen fertilisation (Morris et al. 2010, Rachoń et al. 2016, Woźniak 2016), crop plant species and cultivars, soil conditions and weather conditions (Gomez-Becerra et al. 2010). Commonly applied crop rotations lead to some deterioration of grain quality and even to changes in the chemical composition of grain (Woźniak 2016). Generally, it can be stated that in crop rotations with excessive saturation with cereals there is a decrease in the content of protein and starch, and an increase in the content of fibre and phytates (Woźniak 2016). In addition, grain from monoculture has a lower content of phosphorus, calcium, iron and zinc than grain from a crop rotation (Woźniak, Makarski 2013).

More and more frequent reductions of soil tillage, consisting in the substitution of ploughing with ploughless tillage, have an effect on the quality of the yield (Amarakoon et al. 2012). De Vita et al. (2007), as well as Montemurro and Maiorana (2014), demonstrated that higher yields and grain of better quality are obtained with plough tillage on soils with moderate moisture, and with the use of ploughless tillage in arid regions. This is also supported by the research conducted by Woźniak et al. (2014), who found that in an area with annual precipitation totals of 500 to 700 mm wheat grain from plough tillage had a higher content of total protein, wet gluten and a higher specific weight that grain from ploughless tillage. A tillage method also has an effect on the mineral composition of grain (Woźniak, Makarski 2013), although according to Wang et al. (2010) this trait depends on habitat conditions, cultivars, and years as well. Also, Amarakoon et al. (2012) report that the mineral composition of seeds is subject to notable variation in relation to the genotype and habitat conditions.

Phytates play an important role in human nutrition (Ficco et al. 2009). Until recently, phytates have been attributed mainly with negative properties due to the fact that they form complex bonds with nutrients and reduce the availability of phosphorus, calcium, iron and zinc (Tavajjoh et al. 2011). As reported by Sandberg (2002), phytic acids form complex bonds with iron and zinc, which may cause a deficit of those elements in food. Now it is known that phytates have a positive function as they reduce the risk of myocardial ischaemia, arterial atherosclerosis and development of diabetes, while displaying antioxidant properties (Kumar et al. 2010). These compounds are formed during the ripening of seeds and can account for 60 to 90% of total phosphorus (Loewus 2002). In the grain of cereals, polyphenols are an important group of antioxidants (Gorelik et al. 2013). They are secondary metabolites in plants, with a high positive effect on human health. They are accumulated mainly in the outer layer of the kernel, and their amount depends on cereal species, cultivar, and on the weather conditions. They enter into positive interactions with food components and vitamins, although a loss of nutritive value is also possible as a result on interactions with proteins and enzymes (JAKOBEK 2015).

The objective of the study was to estimate the effect of various cropping systems on the quality and chemical composition of spring wheat grain.

MATERIAL AND METHODS

Location and scheme of experiment

Experiments with cropping systems were set up in 1988 at the Experimental Farm Uhrusk (51°18′11″ N, 23°36′47″ E) belonging to the University of Life Sciences in Lublin (south-east Poland), while the results presented herein were acquired in the period of 2014-2016. The experiments were set up in a randomised blocks design (6×25 m) with 3 replicates. The experimental factors were plant crop sequences: 1) crop rotation A: pea – spring wheat – durum wheat; 2) crop rotation B: pea – spring barley – spring wheat; 3) cereal monoculture: spring barley – spring wheat – durum wheat. The object of the study is spring wheat (*Triticum aestivum* L.) cv. Sonett. Spring wheat was sown in the plough tillage system, which consisted of skimming after the harvest of the previous crop and pre-winter ploughing in late autumn (to the depth of about 25 cm). In spring, a cultivator and a tillage set were used.

Habitat conditions

The experiment was set up on a soil with the particle size distribution of sandy loam containing 24.3% of clay particles and 13.2% silt particles, with a high content of available forms of phosphorus (120 mg P kg^{-1}) and potassium (220 mg K kg^{-1}), low content of magnesium (70 mg Mg kg^{-1}), and slightly alkaline reaction (pH_{kCL}=7.2). The soil was classified as Rendzic Phaeozem (IUSS Working Group WRB 2015). In a long-term period, the annual sum of atmospheric precipitation in the area under study is over 600 mm, out if which 381 mm fall in the period from the sowing to harvest of spring wheat (from March to August). In the years of the study, the precipitation sums in months from March to August were highly varied – the lowest in 2015 (203 mm) and more than double this sum in 2014 and 2016 (Table 1). The monthly mean air temperatures in the period of wheat growing were fairly constant in all the years (from 14.1 to 14.4°C), but considerably higher than in the multi-year period (13.2°C).

Table 1

Rainfalls and air temperatures according to the Meteorological Observatory at Uhrusk

Year	Months						Sum / Mean
	Mar	Apr	May	Jun	Jul	Aug	
Rainfalls (mm)							
2014	30	44	152	88	36	85	435
2015	39	34	62	16	45	7	203
2016	52	68	55	66	132	53	426
1963-2013	37	45	66	74	86	73	381
Air temperature (°C)							
2014	6.1	9.3	13.9	15.8	20.8	18.8	14.1
2015	4.7	7.7	13.1	17.1	21.7	22.2	14.4
2016	3.8	9.3	14.9	18.1	20.0	18.9	14.2
1963- 2013	2.0	8.5	14.0	17.1	19.3	18.2	13.2

Fertilisation and plant protection

In all the years of the study, spring wheat was sown in the first decade of April, at the sowing density of 450 seeds m^{-2}. Nitrogen fertilisation was 140 kg N ha^{-1}, which was applied as follows: 50 kg N ha^{-1} before sowing, 40 kg N ha^{-1} in the phase of tillering, 30 kg N ha^{-1} in the phase of shoot elongation, and 20 kg N ha^{-1} in the phase of ear formation. Phosphorus and potassium fertilisation was applied prior to the sowing of wheat, at doses of 35 kg P ha^{-1} and 99 kg K ha^{-1}. The fungicides applied for the protection of wheat against fungal diseases, were: Alert 375 SC (flusilazole + carbendazim) in the phase of shoot elongation and Tilt Plus 400 EC (propiconazole + + fenpropidin) in the phase of ear formation. Weed control was performed using the herbicide Chwastox Trio 540 SL (mecoprop + MCPA + dicamba) in the phase of wheat tillering.

Result parameters and statistical analysis

Parameters estimated in the experiment included: 1) total content of protein in grain (g kg^{-1}), 2) content of wet gluten (%), 3) Zeleny's sedimentation index (mL), 4) specific weight of grain (kg hL^{-1}), 5) grain fractions – more than 2.5 mm (%), 6) ash content in grain (g kg^{-1}), 7) content of phosphorus (g kg^{-1} d.m.), 8) content of phytic phosphorus (g kg^{-1} d.m.), 9) content of polyphenols (g kg^{-1} d.m.), and 10) content of vitamin C in grain (mg kg^{-1} d.m.).

The content of total protein, wet gluten and Zeleny's sedimentation index were estimated with the NIRS method, using an Inframatic 9200 apparatus. The content of ash in wheat grain was determined after dry mineralisation of samples at the temp. of 620°C. The ash was dissolved in 5 mL of 6M HCL, and then redistilled water was added to the volume of 50 mL.

The measurements were made with the method of atomic absorption spectrometry with air-acetylene flame atomisation. Phytic phosphorus was assayed in accordance with the methods given by Latta and Skin (1980) and Dragičević et al. (2011). The content of polyphenols and vitamin C was determined using the method of Folin-Ciocalteau (Singleton, Rossi 1965). The assays were made in 3 replicates for each plot. The results were processed statistically using the analysis of variance (ANOVA), while the significance of differences between means was verified using the Tukey's HSD test, $P < 0.05$.

RESULTS

Grain quality characteristics

The content of total protein in spring wheat grain was significantly higher in crop rotation A than in crop rotation B and in the cereal monoculture (Table 2). A higher content of protein was also noted in grain harvested in 2016 compared to 2014 and 2015. The content of wet gluten in wheat grain was also higher in crop rotation A than in crop rotation B and in the cereal

Table 2

Quality parameters of spring wheat grain

Crop sequence (CS)	Years (Y)			Mean
	2014	2015	2016	
Total protein (g kg^{-1})				
Crop rotation A	141.0	144.0	146.0	143.7
Crop rotation B	130.0	128.0	137.0	131.7
Cereal monoculture	126.0	122.0	134.0	127.3
Mean	132.3	131.3	139.0	-
$HSD_{0.05}$ for CS = 6.9 Y = 6.9; CS x Y = ns				
Wet gluten (%)				
Crop rotation A	36.4	31.9	36.6	34.9
Crop rotation B	29.2	30.7	33.4	31.1
Cereal monoculture	30.5	30.3	30.6	30.4
Mean	32.0	30.9	33.5	-
$HSD_{0.05}$ for CS = 2.3; Y = 2.3; CS x Y = ns				
Sedimentation value (mL)				
Crop rotation A	47.0	50.9	53.5	50.4
Crop rotation B	48.9	42.9	48.3	46.7
Cereal monoculture	42.8	45.1	46.8	44.9
Mean	46.2	46.3	49.5	-
$HSD_{0.05}$ for CS = 2.4; Y = 2.4; CS x Y = ns				

monoculture, and also in 2016 relative to 2015. The values of the sedimentation index followed a similar pattern to the above characteristics. The highest value of the index was noted for crop rotation A, lower values being observed for crop rotation B and the cereal monoculture. In addition, the value of the sedimentation index was higher in 2016 than in 2014 and 2015. Based on the components of the analysis of variance, it was found that the content of protein and gluten in grain and the value of the sedimentation index depended on the crop sequence to a higher extent than on the years of the study (Table 3).

Table 3

Analysis of variance for grain quality parameters

Specification	Value	[a]CS	[b]Y	CS x Y
Total protein	*F*	197.0	46.31	5.70
	P	**	*	ns
Wet gluten	*F*	13.60	3.80	2.49
	P	**	*	ns
Sedimentation value	*F*	17.32	7.61	2.36
	P	**	**	ns

[a]CS – crop sequence, [b]Y – years, *$P < 0.05$, **$P < 0.01$, ns – not significant

Wheat grain harvested in crop rotations A and B had significantly higher specific weight than grain from the cereal monoculture (Table 4). In addition, for all crop sequences, grain harvested in 2015 was characterised by a higher specific weight than in the other years. Also, grain uniformity depended

Table 4

Milling parameters of spring wheat grain

Crop sequence (CS)	Years (Y)			Mean
	2014	2015	2016	
Grain volume weight (kg hL^{-1})				
Crop rotation A	78.2	81.3	73.5	77.6
Crop rotation B	77.3	78.4	74.1	76.6
Cereal monoculture	73.9	77.2	65.1	72.0
Mean	76.4	78.9	70.9	-
$HSD_{0.05}$ for CS = 1.2; Y = 1.2; CS x Y = 3.0				
Grain fractions (%)				
Crop rotation A	93.1	93.1	81.4	89.2
Crop rotation B	91.7	93.6	73.9	86.4
Cereal monoculture	81.9	91.4	70.3	81.2
Mean	88.9	92.7	75.2	-
$HSD_{0.05}$ for CS = 1.0; Y = 1.0; CS x Y = 2.5				

on the crop sequence and on the years of the study. Better uniformity was characteristic of grain from crop rotation A than B, the lowest being that of grain from the cereal monoculture. Furthermore, better uniformity was characteristic of grain harvested in 2015 than in 2014, and the least uniform was grain from 2016. Based on the components of the analysis of variance, it can be concluded that the specific weight of grain and grain uniformity depended on the year of the study to a greater degree than on the crop sequence (Table 5).

Table 5

Analysis of variance for the milling parameters of spring wheat grain

Specification	Value	[a]CS	[b]Y	CS x Y
Grain volume weight	*F*	70.75	135.9	11.05
	P	**	**	**
Grain fractions	*F*	192.7	995.3	41.3
	P	**	**	**

[a]CS – crop sequence, [b]Y – years, *P < 0.05, **P < 0.01, ns – not significant

Chemical composition of grain

Spring wheat grain harvested in the cereal monoculture had a considerably higher ash content than grain from crop rotations A and B (Table 6). A higher ash content was also noted in grain harvested in 2016 than in the other years, in particular grain harvested in 2016 from the cereal monoculture (by 3.25% on average). Estimation of the components of the analysis of variance indicates that ash content in grain depended to a higher extent on the years of the study than on the crop sequence (Table 7). Also, the phosphorus content was higher in wheat grain from the cereal monoculture than from crop rotation B, while the content of P-phytic was higher in crop rotation A than in crop rotation B. The share of P-phytic in the total content of phosphorus in grain varied from 63.5 to 69.4%, depending on the crop sequence (Table 8).

The content of polyphenols and vitamin C in wheat grain depended only on the crop succession (Table 9). Grain harvested in crop rotation B and in the cereal monoculture had a higher content of polyphenols than grain from crop rotation A, and grain harvested in crop rotations A and B contained more vitamin C than in the cereal monoculture (Table 10).

DISCUSSION

The quality and chemical composition of cereal grain affect the quality of the product obtained. Under unfavourable agroclimatic and agrotechnical conditions, the quality of grain is poor and the grain cannot be used for food

Table 6

Content of ash, phosphorus and phytic phosphorus in spring wheat grain

Crop sequence (CS)	Years (Y)			Mean
	2014	2015	2016	
Total ash (g kg^{-1} d.m.)				
Crop rotation A	16.4	16.3	22.5	18.4
Crop rotation B	16.8	16.9	27.4	20.3
Cereal monoculture	17.9	18.1	32.5	22.8
Mean	17.0	17.1	27.4	-
$HSD_{0.05}$ for CS = 1.1; Y = 1.1; CS x Y = 2.6				
Phosphorus (g kg^{-1} d.m.)				
Crop rotation A	1.30	1.31	1.32	1.31
Crop rotation B	1.22	1.29	1.27	1.26
Cereal monoculture	1.34	1.42	1.37	1.37
Mean	1.28	1.34	1.32	-
$HSD_{0.05}$ for CS = 0.09; Y = ns; CS x Y = ns				
Phytic phosphorus (g kg^{-1} d.m.)				
Crop rotation A	0.92	0.92	0.89	0.91
Crop rotation B	0.83	0.91	0.81	0.85
Cereal monoculture	0.90	0.85	0.87	0.87
Mean	0.88	0.89	0.85	-
$HSD_{0.05}$ for CS = 0.05; Y = ns; CS x Y = ns				

Table 7

Analysis of variance for the content of ash, phosphorus and phytic phosphorus in spring wheat grain

Specification	Value	^{a}CS	^{b}Y	CS x Y
Total ash	*F*	554.9	3980.0	217.1
	P	**	**	**
Phosphorus	*F*	87.58	1.40	1.58
	P	**	ns	ns
Phytic phosphorus	*F*	5.61	1.33	0.23
	P	**	ns	ns

^{a}CS – crop sequence, ^{b}Y – years, *$P < 0.05$, **$P < 0.01$, ns – not significant

but only for feed or other uses (Montemurro, Maiorana 2014). Woźniak and Makarski (2013) demonstrated that wheat grain obtained from monoculture was characterised by considerably inferior baking and milling parameters than grain from crop rotation. Also, in our study it was found that wheat grain from the cereal monoculture contained less protein and wet gluten and

Table 8

Share of phytic phosphorus in total phosphorus content in spring wheat grain (%)

Crop sequence	Years			Mean
	2014	2015	2016	
Crop rotation A	70.7	70.2	67.4	69.4
Crop rotation B	68.0	70.5	63.8	67.4
Cereal monoculture	67.2	59.8	63.5	63.5
Mean	68.6	66.8	64.9	-

Table 9

Analysis of variance for the content of polyphenols and vitamin C in spring wheat grain

Specification	Value	[a]CS	[b]Y	CS x Y
Polyphenols	*F*	10.52	1.10	1.74
	P	**	ns	ns
Vitamin C	*F*	6.27	0.77	1.05
	P	*	ns	ns

[a]CS – crop sequence, [b]Y – years, *$P < 0.05$, **$P < 0.01$, ns – not significant

Table 10

Content of polyphenols and vitamin C in spring wheat grain

Crop sequence (CS)	Years (Y)			Mean
	2014	2015	2016	
Polyphenols (g kg^{-1}d.m.)				
Crop rotation A	0.45	0.47	0.42	0.44
Crop rotation B	0.61	0.59	0.53	0.57
Cereal monoculture	0.57	0.46	0.56	0.53
Mean	0.54	0.50	0.50	-
$HSD_{0.05}$ for CS = 0.07; Y = ns; CS x Y = ns				
Vitamin C (mg kg^{-1} d.m.)				
Crop rotation A	155.3	157.8	153.1	155.4
Crop rotation B	149.7	130.3	137.9	139.3
Cereal monoculture	111.3	112.9	120.1	114.8
Mean	138.8	133.7	137.0	-
$HSD_{0.05}$ for CS = 7.8; Y = ns; CS x Y = ns				

had lower values of the sedimentation index that grain from crop rotations. One could attribute this finding to the high share of small grains in the yield, with poorly filled parenchyma, i.e. worse uniformity than in crop rotations. In consequence, grain with poorly filled parenchyma contained less ash than grain from crop rotations. Gomez-Becerra et al. (2010) emphasise the high variation of technological traits of wheat between years of study. Generally, in moderately wet years with high insolation grain is characterised by a high content of protein and gluten, and in dry years grain has poor uniformity and low specific weight, but a high content of ash. The opinions have been largely confirmed by our results. In 2015, a year with considerably lower precipitations than in 2014 and 2016, a lower content of protein and gluten in grain was observed. Agrotechnical factors also affect the chemical composition of grain (Ficco et al. 2009, Gomez-Becerra et al. 2010). In general, increased fertilisation with nitrogen causes an increase in the content of calcium, magnesium and iron in grain, but a decrease in that of phosphorus and potassium (Woźniak et al. 2104). However, in a study by Woźniak and Makarski (2013), wheat grain from monoculture had a lower content of phosphorus, calcium, iron and zinc than grain from crop rotation. Moreover, Woźniak (2016) observed a lower content of phytic P in triticale grain from a cereal monoculture than in grain from crop rotation. In our study, the content of P-phytic in wheat grain from the cereal monoculture was at a similar level to that in grain from the crop rotations. Liu et al. (2005) observed that the content of phytates in grain depends on the cultivar, on environmental conditions, and their mutual interaction.

Polyphenols are an important group of antioxidants in cereal grain (Gorelik et al. 2013). In our study, their content in grain from the monoculture was similar to that in grain from crop rotation B, in which wheat was sown after barley, but higher than in grain from crop rotation A, where wheat was sown after pea. Jakobek (2015) claims that, the content of polyphenols depends on the cereal species, cultivar, and on weather conditions. In our study, the weather conditions did not differentiate the content of polyphenols in spring wheat grain.

CONCLUSIONS

Summing up, spring wheat grain from crop rotations A and B had a higher content of total protein and wet gluten than grain from the cereal monoculture. In addition, it was characterised by a higher value of the sedimentation index, higher specific weight, and better uniformity relative to grain from the cereal monoculture. That grain also had a lower content of total ash and a higher content of vitamin C. On the other hand, the content of phytic phosphorus in grain from crop rotations A and B was at a similar level to that in grain from the cereal monoculture, while the content of polyphenols was similar in crop rotation B and in the cereal monoculture.

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