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CHEMICAL COMPOSITION OF SPRING BARLEY *(HORDEUM VULGARE* L.) GRAIN CULTIVATED IN VARIOUS TILLAGE SYSTEMS

Andrzej Woźniak[1], Myroslawa Soroka[2], Anna Stępniowska[3], Bogusław Makarski[3]

[1]Chair of Herbology and Plant Cultivation Techniques
University of Life Sciences in Lublin
[2]Department of Botany
Ukrainian National Forestry University, 79057 Lviv
[3]Chair of Biochemistry and Toxicology
University of Life Sciences in Lublin

Abstract

The study evaluated the chemical composition of spring barley grain sown in 3 tillage systems (main plots): a) conventional tillage (CT) – shallow ploughing and harrowing after harvest of the previous crop, ploughing in the autumn; b) reduced tillage (RT) – only cultivator after harvest of the previous crop, and c) herbicide tillage (HT) – only glyphosate (360 g L^{-1}) after harvest of the previous crop. In the springtime, a cultivation set composed of a cultivator, a string roller and a harrow was used on all the plots. The second experimental factor was barley cultivar (subplots): 1) husked Tocada, and 2) naked-grain Rastik. The depth of tillage varied according to the intended purpose: shallow ploughing to 10-12 cm, autumn ploughing to 25-30 cm, and cultivator tillage to 10-15 cm. The soil under the experiment was Chalk Rendzina with the texture of sandy loam, rich in available phosphorus and potassium and slightly alkaline. The study demonstrated that the content of total protein and crude fiber in the grain depended only on a barley cultivar. In turn, the content of macro- and microelements was affected by both factors: the cultivar and tillage system. Herbicide tillage (HT) was shown to reduce the content of phosphorus (P), potassium (K), calcium (Ca), iron (Fe) and copper (Cu) in barley grain, compared to conventional tillage (CT). Simultaneously, it raised the phytate-P content of grain compared to reduced tillage (RT). The content of phytate-P was significantly higher in cv. Tocada than in cv. Rustik.

Keywords: spring barley, protein, starch, crude fiber, P-phytate, mineral composition, tillage system.

dr hab. Andrzej Woźniak, Chair of Herbology and Plant Cultivation Techniques, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland, e-mail: andrzej.wozniak@up.lublin.pl

SKŁAD CHEMICZNY ZIARNA JĘCZMIENIA JAREGO *(HORDEUM VULGARE* L.) W RÓŻNYCH SYSTEMACH UPRAWY ROLI

Abstrakt

W badaniach oceniano skład chemiczny ziarna jęczmienia jarego wysiewnego w 3 systemach uprawy roli: a) tradycyjnym (CT) – podorywka i bronowanie po zbiorze przedplonu oraz orka wykonana jesienią; b) uproszczonym (RT) – tylko kultywator po zbiorze przedplonu; c) herbicydowym (HT) – tylko glifosat (360 g L^{-1}) po zbiorze przedplonu. Drugim czynnikiem doświadczenia były odmiany jęcznienia: 1) Tocada o ziarnie oplewionym, 2) Rastik o ziarnie nieoplewionym. Zabiegi uprawowe wykonano na określoną głębokość: podorywka 10-12 cm, orka jesienna 25-30 cm, kultywatorowanie 10-15 cm. Wykazano, że zawartość białka ogółem i włókna surowego w ziarnie zależały jedynie od odmiany, natomiast zawartość makro- i mikroelementów – od odmiany i systemu uprawy roli. Herbicydowa uprawa roli (HT) wpływała na zmniejszenie w ziarnie jęczmienia zawartości fosforu (P), potasu (K), wapnia (Ca) oraz żelaza (Fe) i miedzi (Cu), w stosunku do uprawy tradycyjnej (CT). Jednocześnie uprawa HT wpływała na zwiększenie zawartości P-fitynowego w ziarnie, w stosunku do RT. Odmiana Tocada zawierała znacznie więcej P-fitynowego niż odmiana Rastik.

Słowa kluczowe: jęczmień jary, białko, skrobia, włókno surowe, P-fitynowy, skład mineralny, uprawa roli.

INTRODUCTION

The implementation of modern tools and machines for crop cultivation as well as plant protection chemicals has resulted in a variety of innovative solutions in plant cultivation, resulting in the development of new tillage systems. In practice, however, these solutions are not always optimal because their effectiveness depends on the interaction of many natural and economic factors on a farm (Gruber et al. 2012). As reported by Morris et al. (2010), in conventional and no-till systems, the yield of plants is a function of many interacting factors, whose effects are hardly predictable. Nonetheless, in general the no-till system produces slightly lower yields of crops than the conventional system. According to De Vita et al. (2007), zero tillage is more effective than the conventional system on arid soils as it reduces the evaporation of water from soil, thus ensuring better moisture availability to plants. Also López-Bellido et al. (1996) report that crop yielding in the no-till system decreases as the sum of precipitations increases. It is mostly cereals that are sown under various modifications of the zero tillage system, mainly because of the dominant acreage of cereal crops and their good adaptability to agronomic conditions. One of the key cereals is barley, whose grain is widespread in human nutrition (flakes, groats) and in animal feeds. The chemical composition and quality of barley grain change under the combined effects of cultivar-specific traits, weather conditions and agricultural practice (Ruibal-Mendieta et al. 2005, Zeb et al. 2006). Studies by Khan and Zeb (2007) and Chowdhry et al. (1995) demonstrated significant differences in the chemical composition of wheat grains caused by various weather conditions and agronomic treatments. According to Morris et al. (2009), the content of ash in wheat grain is affected more by the weather during its maturation than by its genotype. Also, Kraska (2011) and Woźniak and Makarski (2012) determined a higher ash content in the grain of wheat sown in the ploughless rather than in the conventional (ploughing) system. In turn, according to Araus et al. (1998), the highest content of minerals was assayed in grain exposed to drought at the early stage of maturation. As reported by Paris and Gavazzi (1972) and Eser et al. (1997), the chemical composition of grain depends on the soil type and fertilization. As shown by Morris et al. (2009), habitat conditions and cultivar-specific preferences also affect the content of protein and gluten in wheat grain. In a study by Peltonen and Virtanen (1994), high doses of nitrogen increased the protein content in grain, whilst in the research by Woźniak (2013) the protein content of grain was modified by tillage systems, with more protein determined in the grain harvested from the herbicide than from the conventional (ploughing) system.

The goal was to evaluate the effect of tillage systems on the chemical composition of grain of two spring barley cultivars.

MATERIAL AND METHODS

A field experiment with different tillage systems was carried out in 2010-2012 at the Experimental Farm in Uhrusk (51°18′12″N, 23°36′50″E), Poland. It was established with the method of randomized sub-blocks in three replications, where tillage systems were the main experimental factor (*main plots*) and barley cultivars were the second experimental factor (*subplots)*. The blocks 8 m x 75 m in size were divided into 3 sub-blocks, and each of the sub-blocks was further divided into 2 plots. Three tillage systems: a) conventional (CT), b) reduced (RT), and c) herbicide (HT); and two barley cultivars: 1) husked Tocada and 2) naked-grain Rastik, were evaluated. The analyzed cultivars are classified in the Common Catalogue of Varieties of Agricultural Plant Species (EU 2007) and designed for feedstuff purposes. Conventional tillage (CT) included shallow ploughing and harrowing after previous crop (pea) and pre-winter ploughing. Reduced tillage (RT) included only field cultivation after harvest of the previous crop, and herbicide tillage (HT) consisted of an application of glyphosate (360 g L^{-1}) – 4 L ha^{-1} after harvest of the preceding crop. In the springtime, a cultivation set composed of a cultivator, a string roller and a harrow was used on all the plots. The depth of tillage varied according to intended purpose: shallow ploughing to a depth of 10-12 cm, autumn ploughing to 25-30 cm and cultivator tillage to 10-15 cm.

The soil under the experimental area was Chalk Rendzina with the texture of sandy loam, rich in available phosphorus (214 mg P kg^{-1}) and potassium (237 mg K kg^{-1}) and slightly alkaline $pH_{(KCl)}$ = 7.2. The total N content was 1.03 g kg^{-1} and organic C equalled 7.60 g kg^{-1}. According to the classification by the IUSS Working Group WRB (2006), this soil was identified as Rendzic Phaeozem.

Barley was sown in the first decade of April, at a seed density of 320 seeds m^{-2}. Mineral fertilization was as follows: 70 kg N ha^{-1}, 26 kg P ha^{-1} and 83 kg K ha^{-1}. The herbicide (a.s. mecoprop + MCPA + dicamba) was applied in a dose of 1.5 L ha^{-1} at the tillering stage (22-23 on the Zadoks scale (Zadoks et al. 1974)).

Determinations of the content of mineral components in wheat grain were conducted after dry mineralization of the samples at 600°C. The resultant ash was dissolved in 5 cm^3 of 6M HCl, then replenished to the volume of 50 cm^3 with redistilled water. Measurements were carried out by Absorption Spectrometry with excitation in acetylene-air flame on a UNICAM 939 apparatus. Phytate-phosphorus was extracted from the ground sample with 5% TCA for 60 min. Next, the extract was centrifuged for 10 min at 3000 rpm. Phytate-P in the supernatant was determined with the spectrophotometric method (λ = 500 nm) using Wade reagent (0.3 g $FeCl_3$ $6H_2O$ + 3.0 g sulfosalicylic acid in 1.0 L) (Latta, Skin 1980, Dragičević et al. 2011). Nitrogen in barley grain was determined with the Kjeldahl's method and converted into total protein (N · 6.25). The starch content was assayed by shaking the grain samples with TRIS buffer (pH=9.2) until complete solubilization of protein. The remaining precipitate was hot-dissolved in water. Starch was determined spectrophotometrically (λ = 660 nm) in the form of a complex with iodine. Crude fiber was determined using a Fibertec TM 2010 system for dietary fiber assay in food according to AOAC, AACC and AOCS standards. The method was based on the producer's application called FOSS TECATOR.

The results were processed statistically using analysis of variance (Anova), while the significance of differences between mean values was evaluated with the Tukey's HSD test, $P < 0.05$.

RESULTS AND DISCUSSION

The tillage system appeared to have no effect on the protein content in grain, which depended only on a barley cultivar (Table 1). Grain of the hull-less cultivar Rastik contained significantly more protein than grain of the husked cultivar Tocada. Similar observations were made for crude fiber content in grain, which was influenced only by a barley cultivar, being twice as high in husked Tocada as in naked-grain Rastik. Also the variance components (*F*-Value) indicate that values of the above parameters are cultivar-specific rather than influenced by tillage system (Table 2). In contrast, the content of starch in grain was the same in both barley cultivars but differentiated by the tillage systems. The grain originating from HT was characterized by a higher starch content than the CT grain. The quality and

Table 1

Content of total protein, starch and crude fiber in spring barley grain

Cultivars (C)	Tillage systems (TS)			Mean
	CT*	RT	HT	
Total protein (%)				
Tocada	8.5	8.4	8.3	8.4
Rastik	12.7	12.6	12.7	12.7
Mean	10.6	10.5	10.5	-
** $HSD_{0.05}$ for TS – ns; C – 0.23; TS · C – ns				
Starch (%)				
Tocada	59.6	60.3	61.0	60.3
Rastik	60.0	60.1	60.9	60.3
Mean	59.8	60.2	61.0	-
** $HSD_{0.05}$ for TS – 0.87; C – ns; TS · C – ns				
Crude fiber (%)				
Tocada	4.4	4.4	4.5	4.4
Rastik	2.1	2.2	2.2	2.2
Mean	3.3	3.3	3.3	-
$HSD_{0.05}$ for TS – ns; C – 0.19; TS · C – ns				

* CT – conventional tillage, RT – reduced tillage, HT – herbicide tillage,
** $HSD_{0.05}$ – honestly significant difference, ns – not significant, $P < 0.05$;

Table 2

F-Value for total protein, starch and crude fiber in spring barley grain, $P < 0.05$

Effects	Total protein	Starch	Crude fiber
	F-Value		
TS*	0.19	6.38	0.20
C**	2343.9	0.62	1083.7
TS · C	0.46	0.90	0.11

* TS – tillage systems, ** C – cultivars;

chemical composition of grain are determined by the interaction of cultivar-specific, habitat and agrotechnical factors (RUIBAL-MENDIETA et al. 2005, ZEB et al. 2006). This implies that grain of the same cultivar grown under various agronomic, climatic, soil and technical conditions may differ in levels of mineral and organic compounds (protein, starch or dietary fiber). Of similar opinion are KHAN and ZEB (2007), MORRIS et al. (2009), KRASKA (2011) as well as WOŹNIAK and MAKARSKI (2013). In our experiment, the content of protein and crude fiber depended largely on a barley cultivar, whereas the starch content was determined by a tillage system. Woźniak (2013) showed no effect of tillage system on one wheat cultivar and its significant impact on another one. Nonetheless, both wheat cultivars contained highly diverse protein content in grain in particular years.

The content of phosphorus (P) was significantly higher in grain from RT and CT plots than in the grain from the HT system (Table 3), as well as in grain of cv. Rastik compared to cv. Tocada. The analysis of variance components (*F*-Value) demonstrates that the phosphorus (P) content in grain

Table 3

Content of macroelements and phytate-P in spring barley grain

Cultivars (C)	Tillage systems (TS)			Mean
	CT*	RT	HT	
P (g kg^{-1} d.m.)				
Tocada	3.19	3.20	3.23	3.21
Rastik	3.94	3.97	3.50	3.80
Mean	3.57	3.59	3.37	-
** $HSD_{0.05}$ for TS – 0.19; C – 0.16; TS · C – 0.28				
Phytate-P (g kg^{-1} d.m.)				
Tocada	1.82	1.69	1.93	1.81
Rastik	1.49	1.56	1.52	1.52
Mean	1.66	1.62	1.72	-
$HSD_{0.05}$ for TS – 0.08; C – 0.06; TS · C – 0.11				
K (g kg^{-1} d.m.)				
Tocada	3.21	3.63	3.12	3.32
Rastik	3.41	3.30	2.91	3.21
Mean	3.31	3.47	3.02	-
$HSD_{0.05}$ for TS – 0.14; C – ns; TS · C – 0.20				
Mg (g kg^{-1} d.m.)				
Tocada	0.96	1.01	0.94	0.97
Rastik	0.95	0.90	0.89	0.91
Mean	0.95	0.96	0.92	-
$HSD_{0.05}$ for TS – ns; C – 0.04; TS · C – ns				
Ca (g kg^{-1} d.m.)				
Tocada	0.56	0.38	0.30	0.41
Rastik	0.32	0.30	0.37	0.33
Mean	0.44	0.34	0.33	-
$HSD_{0.05}$ for TS – 0.07; C – 0.05; TS · C – 0.09				

* CT – conventional tillage, RT – reduced tillage, HT – herbicide tillage,
** $HSD_{0.05}$ – honestly significant difference, ns – not significant, $P < 0.05$;

Table 4

F-Value for mineral composition of spring barley grain, $P < 0.05$

Effects	P	Phytate-P	K	Mg	Ca	Fe	Zn	Cu	Mn
	F-Value								
TS*	5.36	6.24	36.05	1.19	11.48	476.21	137.80	22.97	0.10
C**	94.01	150.71	6.58	6.64	16.01	79.15	711.40	37.84	0.29
TS x Y	7.37	12.98	13.32	1.98	18.18	323.61	157.27	20.10	0.34

* TS – tillage systems, ** C – cultivars;

depended more on cultivar-specific traits than on a tillage system (Table 4). In turn, the content of phytate-P was significantly higher in the HT than in the RT system. The grain of cv. Tocada contained significantly more phytate-P than the grain of cv. Rastik. The tillage system was found to affect potassium (K) in grain, with the highest concentrations of this element noted in grain from RT plots, followed by CT plots, and the lowest ones in grain from HT plots. The content of magnesium (Mg) depended only on a barley cultivar and was higher in the grain of cv. Tocada than in the grain of cv. Rastik. Finally, the content of calcium (Ca) was higher in grain from the CT system than from the RT and HT systems, and in the grain of cv. Tocada than cv. Rastik. The evaluation of variance components indicates that the Ca content of grain depended to a similar extent on the cultivar-specific traits and tillage systems.

The content of iron (Fe) was higher in grain from the CT system compared to the RT and HT systems (Table 5). A higher Fe content was determined in the grain of cv. Tocada than cv. Rastik. Based on the *F*-Value, it may be concluded that the Fe content was more dependent on a cultivar than on a tillage system. The content of zinc (Zn) was also higher in grain from CT plots, lower in grain from HT plots and the lowest in grain from RT system. The grain of cv. Tocada contained 3-fold more Zn than cv. Rastik. In turn, the *F*-Value indicates that the Zn content of grain was affected more by a cultivar than by a tillage system. Also, the content of copper (Cu) was significantly higher in grain from CT plots than in grain from the RT and HT systems. The grain of cv. Tocada contained more Cu compared to the grain of cv. Rastik. In turn, the content of manganese (Mn) in grain remained unaffected by the experimental factors.

The grain of the two barley cultivars differed in the content of minerals. This trait was also differentiated by the tillage systems. This confirms the results reported by Kraska (2011) or Woźniak and Makarski (2012), where the mineral composition of grain depended on a tillage system. In our experiment, the HT system resulted in a lower content of phosphorus (P), potassium (K), calcium (Ca), iron (Fe) and copper (Cu) and in an increased content of phytate-P in grain compared to the CT or RT system. Similar observations were made by Jackowska and Borkowska (2002) or by Paris and Gavazzi (1972). In the research by Woźniak and Makarski (2012), grain

Table 5

Content of microelements in spring barley grain

Cultivars (C)	Tillage systems (TS)			Mean
	CT*	RT	HT	
Fe (mg kg^{-1} d.m.)				
Tocada	115.00	45.22	28.32	62.85
Rastik	55.45	52.16	45.31	50.97
Mean	85.22	48.69	36.82	-
** $HSD_{0.05}$ for TS – 4.36; C – 3.56; TS · C – 6.16				
Zn (mg kg^{-1} d.m.)				
Tocada	55.41	15.42	42.10	37.64
Rastik	13.20	13.41	7.98	11.53
Mean	34.31	14.41	25.04	-
$HSD_{0.05}$ for TS – 3.20; C – 2.61; TS · C – 4.52				
Cu (mg kg^{-1} d.m.)				
Tocada	10.61	6.49	5.48	7.53
Rastik	5.54	5.42	5.36	5.44
Mean	8.08	5.96	5.42	-
$HSD_{0.05}$ for TS – 1.11; C – 0.90; TS · C – 1.56				
Mn (mg kg^{-1} d.m.)				
Tocada	14.29	15.26	14.56	14.70
Rastik	14.39	14.49	15.00	14.63
Mean	14.34	14.88	14.78	-
$HSD_{0.05}$ for TS – ns; C – ns; TS · C – ns				

* CT – conventional tillage, RT – reduced tillage, HT – herbicide tillage,
** $HSD_{0.05}$ – honestly significant difference, ns – not significant, $P < 0.05$;

originating from the no-till system was characterized by more total ash, zinc (Zn) and copper (Cu) but less potassium (K), magnesium (Mg) and manganese (Mn). Higher concentrations of macroelements in grain can be explained by the fact that these elements are better accessible to plants by being able to penetrate more easily into deeper soil strata, especially in intensively scarified (aerated) soil in the ploughing system. The diversified content of elements in grain may also be due to various conditions of soil hydration in the tested tillage systems. The mineral uptake by plants from very dry soil is considerably reduced than from well-hydrated soil (WOŹNIAK, MAKARSKI 2012). Especially interesting seems to be the iron (Fe) content in the grain from the CT system compared to the RT and HT systems. Also KRASKA (2011) demonstrated changes in the mineral composition of wheat grain harvested from different plots. The grain harvested after red clover had a higher content of iron (Fe) than the grain harvested after other preceding crops. In our experiment, this may be explained by the easy and rapid mineralization of organic matter in the ploughing system, which means good release to soil nitrogen compounds, which are available to plants. In turn Jackowska and Borkowska (2002) report that a high nitrogen content in soil reduces the availability of some microelements to plants, thereby decreasing their content in grain.

CONCLUSIONS

1. The tillage systems had no significant effect on the content of total protein and crude fiber in barley grain, which were observed to depend only on a barley cultivar.

2. The herbicide tillage system (HT) compared to the conventional tillage system (CT) decreased the content of phosphorus (P), potassium (K), calcium (Ca), iron (Fe) and copper (Cu) while raising the phytate-P content in barley grain.

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