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Quality and productivity of hybrid wheat depending on the tillage practices

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Abstract: The aim of this study was to assess the impact of soil tillage systems on technological characteristics, mineral composition and grain yield of selected hybrid wheat cultivars grown in variable climatic conditions. The following factors were studied: tillage systems, namely conventional (CT), reduced (RT) and no tillage (NT) and hybrid cultivars of winter wheat (Hyfi, Hybiza and Hystar). Cvs. Hyfi and Hybiza were characterised by good technological parameters and protein quality, and additionally by a higher Fe and Zn content and a higher grain yield than cv. Hystar. Meteorological conditions (rainfall total 414.9 mm, mean temperature 8.8 °C) during the growing season caused an increase in the yield of grain, protein, gluten and Zeleny test as well as the total gliadins and glutenins. Higher rainfall reduced grain quality and Fe and Zn content, while precipitation deficits reduced grain yield. Quality parameters and grain yield, as well as total gliadins and glutenins in CT and RT were similar, and significantly higher compared with NT. Soil tillage systems did not differentiate mineral composition, except for the higher content of Fe in CT as well as the content of albumins and globulins, α/β, ω gliadins and low molecular weight (LMW) glutenins and protein fraction ratios in grain.

Keywords: *Triticum aestium* L.; agronomic factor; weather condition; macronutrients; micronutrients; fertilisation

The criterion determining the suitability of wheat grain for food purposes is the quantity and quality of protein, while the protein properties change depending on environmental and agronomic factors affect them mainly during the period of wheat growth and development (Triboï et al. 2003, Bouacha et al. 2014). The quality of wheat grain, including the quantity and quality of protein, as well as the content of macronutrients and micronutrients, also depend on soil moisture, thermal and rainfall conditions and the cultivar genotype (Šíp et al. 2013, Marin et al. 2015). Literature data on the effect of soil tillage systems on the quality characteristics and mineral composition of wheat grain are ambiguous. Studies by some authors (Gürsoy et al. 2010, Taner et al. 2015, Jaskulska et al. 2018) show that tillage systems do not significantly differentiate the basic quality characteristics and mineral composition of wheat grain. Other authors report that conventional tillage compared to reduced tillage and direct seeding – no tillage promotes higher protein and gluten contents and Zeleny test in the grain (De Vita et al. 2007, Hausherr Lüder et al. 2019), as well as the content of some macronutrients and micronutrients (Gao and Grant 2011, Woźniak and Stępniowska 2017). Current research shows that hybrid wheat cultivars compared to population cultivars are characterised by higher yields, faster growth and development rates and tolerance to reduced soil quality (Zhao et al. 2013, Gupta et al. 2019). However, the yield level, as well as the technological quality and mineral composition of the grain of hybrid wheat cultivars is not well known in research.

The aim of this study was to determine the effect of soil tillage systems on the technological quality, mineral composition and grain yield of three hybrid wheat cultivars grown in varied meteorological conditions. The research hypothesis assumed a variable reaction of hybrid wheat cultivars depending on environmental and agronomic factors.

MATERIAL AND METHODS

Field experiment. The two-factor field experiment was carried out in three seasons, in the years 2013–2016, at the Podkarpackie Agricultural

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Table 1. Chemical characteristics of soil in the research plots

Year	Content of available nutrients (mg/kg DM of soil)						
	P[1]	K[1]	Mg[2]	Fe[3]	Zn[3]	Mn[3]	Cu[3]
2013/2014	67.5	165.1	84.1	833	15.1	188	5.4
2014/2015	72.3	145.1	75.5	1 165	12.5	131	6.3
2015/2016	109.1	153.4	69.1	1 033	13.1	135	6.5

According to the methods: [1]Egner-Riehm (0.04 mol/L $C_6H_{10}CaO_6$); [2]Schachtschabel (0.0125 mol/L $CaCl_2$); [3]Rinkis (1 mol/L HCl); DM – dry matter

Advisory Center in Boguchwała (49°59'N, 21°56'E), Podkarpackie Voivodeship, Poland. The experiment was carried out in 3 replications in a randomised block design (6 × 75 m), divided into 3 split-plots. The first (I) studied factor were tillage systems: conventional (CT) – shallow plowing (10–12 cm deep), harrowing, pre-sowing plowing (20–22 cm deep); reduced tillage (RT) – disking (13–15 cm deep), combined tillage unit (cultivator and string roller) and direct seeding – no tillage (NT) – seeder with double disc coulters. The second (II) factor were three bread hybrid cultivars (breeder Saaten-Union GmbH, Estrées-Saint-Denis, France) of winter wheat: Hybiza (quality class A), Hyfi and Hystar (quality class B). The experiment was located in soil originated from silty clay, medium-heavy soil, classified as Haplic Cambisol (CMha) according to the FAO (2015). During the study period, the soil was characterised by slightly acidic and neutral pH (in 1 mol/L KCl = 5.9–6.7). The organic carbon content ranged from 14.0 to 15.5 g/kg. The amount of N_{min} as measured before wheat sowing varied from 52.4 to 63.0 kg/ha. The content of the available nutrients (measured each year just after a forecrop harvesting from the soil depth of 0.3 m) are presented in Table 1.

During all of the study years, wheat was sown between the 21st and 30th September, at sowing density of 220 seeds/m^2 with row spacing 14–15 cm, to a depth of 3–4 cm. Winter oilseed rape was the previous crop. Fertilisation with nitrogen (NH_4NO_3) was performed in the spring, after starting growth, at a rate of 60 kg/ha, and additionally during the growing period at rates of 60 and 40 kg/ha, at the stages of shooting (32–33 BBCH) and heading (54–56 BBCH), respectively. Fertilisation with phosphorus ($Ca(H_2PO_4)_2$) at a rate of 80 kg/ha and potassium (KCl) at a rate of 120 kg/ha was applied once in the autumn (CT, RT) or in the spring (NT). Weeds, diseases and pests were controlled throughout the growing season and chemical control was used, as recommended by the IOR-PIB (2013). Wheat was harvested at full grain maturity (89–92 BBCH) using a plot harvester. The grain yield from the plots was calculated per 1 ha taking into account 12% humidity.

Weather conditions. During sowing and autumn growth, the weather conditions were favourable, except for the 2014/2015 season with rainfall deficit (69.8 mm) compared to the multiyear mean (Table 2). The 2013/2014 season from March to August was characterised by higher rainfalls compared to the multiyear mean, with excess rainfall (by 36.7 mm) during grain formation (June–July) and a temperature higher by 1.4 °C compared to the long-term mean. In the 2015/2016 season, individual air temperatures and precipitation totals did not differ significantly from the multiyear data.

Table 2. Weather conditions for three growing seasons (meteorological station in Boguchwała)

Period/months	Air temperature (°C)				Rainfall (mm)			
	I[1]	II[2]	III[3]	M/m[4]	I[1]	II[2]	III[3]	M/y[4]
Autumn/09-11	9.7	10.2	9.5	9.0	144.8	65.4	132.4	135.2
Winter rest/12-03	1.4	1.8	1.6	–1.0	47.9	50.8	81.8	55.8
Spring-summer/04-07	14.2	14.3	14.1	13.8	311.9	216.2	200.7	220.1
Grain formation/06-07	18.8	18.2	17.9	17.4	105.2	61.3	72.7	68.5
Sowing-harvest/09-07	7.5	9.8	8.8	8.9	504.6	332.4	414.9	411.1
Deviations from M/y[4]	–1.4	+0.9	–0.1	–	+93.5	–78.7	+3.8	–

[1]2013/2014; [2]2014/2015; [3]2015/2016; [4]multiyear 1975–2012

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Plant material. Grain samples for chemical analysis were taken at the full maturity stage (89–92 BBCH) of wheat grain. Grain samples harvested from four replications were blended with a shake shifter and cleaned prior to conditioning and milling in order to obtain enough grain for milling and quality analysis.

Analytical methods. To determine macronutrients and micronutrients, grain samples were mineralised in a mixture of concentrated HNO_3:$HClO_4$:HS_2O_4 acids in a 20:5:1 ratio, in an open system, in the Tecator heating block. The content of Fe, Cu, Zn, Mn and Mg was determined in the obtained samples by atomic absorption spectroscopy (AAS) using a Hitachi Z-2000 apparatus (Tokyo, Japan). Crude grain protein content was evaluated by the Kjeldahl method (AACC 200) and wet gluten content by means of a Glutomatic 2200 device (AACC 2000). The Zeleny test followed ICC standard method 116/1 (ICC 2003) and the falling number was determined according to AACC (2000). The test weight of grain was determined using a density meter equipped with a 1 000 mL cylinder.

The content of albumins and globulins, gliadins and glutenins was analysed. Proteins were analysed with the RP-HPLC technique using the solvent system developed by Wieser et al. (1998), with a Hewlett-Packard 1050 apparatus (Palo Alto, USA). Albumins were extracted with the use of distilled water, globulins with a mixture of NaCl and $HKNaPO_4$, gliadins with 60% ethanol, and glutenins in the mixture consisting of 50% propanol-1 + 2 m of urea + tris-HCl and 1 DTE under nitrogen. Detection was carried out with the wavelength of 210 µm. Quantification of proteins was done by UV absorbance at 210 nm. The results were analysed with a computer program HPLC 3D ChemStation (Palo Alto, USA) and were presented in mAU/s (milliabsorbance units/second).

Statistical analysis. The results were subjected to an analysis of variance, and significant differences were analysed with the Tukey's (*LSD* – least significant difference) test (P = 0.05) using Statistica 13.3 programme (StatSoft, Tulsa, USA). Results of interaction are not included due to the lack of dependence between the factors studied.

RESULTS AND DISCUSSION

Protein composition. There was a significant increase in the γ gliadin and high molecular weight (HMW) glutenin subunits, as well as the total gliadins and glutenins in grain from CT compared to NT. The increase in the amount of gliadins from CT in relation to NT was 8.6% and in the amount of glutenins 9.7% (Table 3). According to Hofmeijer et al. (2019), in CT there is lower soil compaction compared to RT, and the competition of weeds and plants for mineral components is lower as well. This affects a higher uptake of nutrients by wheat, espe-

Table 3. Composition of proteins

Factor	A + B	Gliadins (Gli)				Glutenins (Glu)		
		α/β	γ	ω	Σ Gli	HMW	LMW	Σ Glu
	(mAU/s)							
Tillage								
CT	12.2^{a}	14.9^{a}	8.9^{a}	4.2^{a}	28.0^{a}	4.5^{a}	15.3^{a}	19.6^{a}
RT	11.6^{a}	14.6^{a}	8.2^{ab}	3.9^{a}	26.7^{ab}	4.3^{a}	14.7^{a}	19.2^{a}
NT	11.1^{a}	13.9^{a}	7.9^{b}	3.8^{a}	25.6^{b}	3.5^{b}	14.2^{a}	17.7^{b}
Cultivar								
Hyfi	11.7^{a}	16.7^{a}	9.5^{a}	4.2^{a}	30.4^{a}	5.5^{a}	16.5^{a}	22.0^{a}
Hybiza	11.0^{a}	13.6^{b}	8.2^{ab}	4.0^{a}	25.8^{b}	3.3^{b}	14.2^{b}	17.5^{b}
Hystar	12.1^{a}	13.2^{b}	7.1^{b}	3.8^{a}	24.1^{b}	3.6^{b}	13.4^{b}	17.0^{b}
Year								
2013/2014	11.8^{a}	14.1^{ab}	7.6^{b}	4.2^{a}	25.9^{b}	4.0^{ab}	14.3^{b}	18.3^{b}
2014/2015	11.2^{a}	13.6^{b}	7.1^{b}	3.6^{a}	24.3^{b}	3.3^{b}	14.0^{b}	17.3^{b}
2015/2016	12.0^{a}	15.8^{a}	10.2^{a}	4.1^{a}	30.1^{a}	4.9^{a}	15.9^{a}	20.8^{a}

Values with different letters (a, b, c) are significantly different (P = 0.05). A + B – sum albumins + globulins; Σ – sum; HMW – high molecular weight; LMW – low molecular weight; CT – conventional tillage; RT – reduced tillage; NT – no tillage

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cially when the weather conditions are unfavourable for mineralisation of crop residues in RT. Soil tillage systems did not differentiate the content of α/β and ω subunits of gliadins and low molecular weight (LMW) glutenins. In the study by Peigné et al. (2014) in the organic farming system, no significant correlations between protein composition in wheat grain from CT compared to RT were shown, but there was a tendency for higher content of gliadins in grain from RT than from CT. Experimental factors did not cause differences in the albumin and globulin content.

The grain of cv. Hyfi contained significantly more gliadins and glutenins as compared to cvs. Hybiza and Hystar, from 15.1% to 22.7%, respectively, and the Gli/Glu ratio was 1.38. Cv. Hystar accumulated lower contents of α/β, γ gliadins as well as HMW and LMW glutenin subunits in grain than cv. Hybiza, and significantly lower than cv. Hyfi (Table 4). No experimental factors, including the cultivars and the years of the study, affecting the content of ω gliadins in the grain was demonstrated (Table 3). Also, De Santis et al. (2017) showed genotypic variability of gliadins and glutenins and their subunits in durum wheat grain, with the exception of the ω gliadin fraction. The contents of γ gliadins and LMW glutenins in wheat grain were significantly higher in the 2015/2016 season, with thermal and rainfall conditions most similar to those of the multiyear period. The influence of weather differentiating protein composition in wheat grain is indicated by Triboï et al. (2003) and Bouacha et al. (2014).

The Gli/Glu and HMW/LMW glutenins ratios were not significantly differentiated by tillage systems and the years of the study and were on average 1.42 and 0.28. According to Mayer et al. (2015), the Gli/Glu and HMW/LMW ratios in wheat grain amounted to 0.94 and 0.37, showing no significant variation for years of the study and wheat tillage systems. A higher Gli/Glu ratio may suggest a reduced technological quality of wheat cultivar protein (Peigné et al. 2014). According to De Vita et al. (2007), the ratio of gliadins to glutenins increases with a rainfall deficit during the grain filling period.

Quality parameters. A significantly higher content of protein, gluten and Zeleny test was obtained in grain in CT compared to NT. These qualitative parameters did not differ statistically between CT and RT (Table 4). Also, from the studies by Gürsoy et al. (2010) and Taner et al. (2015), it follows that tillage systems do not significantly differentiate the basic quality characteristics of wheat grain. According to Šíp et al. (2013), in turn, CT compared to RT results in better use of nitrogen, which improves the quality parameters of wheat grain (especially protein); similar conclusions were reported also by Hausherr Lüder et al. (2019). In the present study, the lower wheat grain quality with NT could be caused by the higher degree of infection by fungal wheat diseases as compared with RT and CT. As shown by De Vita et al. (2007), wheat infection by powdery mildew and leaf rust resulted in grain senescence and lowering

Table 4. Quality parameters and the ratio of protein fractions

Factor	Protein (g/kg)	Gluten (%)	Zeleny test (mL)	Falling number (s)	Test weight (kg/hL)	Ratio	
						Gli/Glu	H/L
Tillage							
CT	133^{a}	29.8^{a}	43.7^{a}	329^{a}	77.9^{a}	1.43^{a}	0.29^{a}
RT	130^{a}	28.9^{a}	41.2^{a}	320^{a}	78.2^{a}	1.39^{a}	0.29^{a}
NT	128^{b}	27.2^{b}	32.2^{b}	325^{a}	77.2^{a}	1.44^{a}	0.25^{a}
Cultivar							
Hyfi	131^{a}	28.6^{b}	45.2^{a}	338^{a}	79.2^{a}	1.38^{a}	0.33^{a}
Hybiza	135^{a}	30.1^{a}	38.2^{b}	322^{b}	77.6^{b}	1.47^{b}	0.23^{b}
Hystar	125^{b}	27.2^{b}	33.6^{c}	314^{b}	76.5^{b}	1.42^{ab}	0.27^{ab}
Year							
2013/2014	126^{c}	27.8^{c}	38.5^{b}	326^{a}	76.8^{b}	1.42^{a}	0.28^{a}
2014/2015	129^{b}	28.6^{b}	35.0^{b}	328^{a}	78.0^{a}	1.40^{a}	0.28^{a}
2015/2016	136^{a}	29.5^{a}	43.5^{a}	320^{a}	78.5^{a}	1.45^{a}	0.27^{a}

Values with different letters (a, b, c) are significantly different ($P = 0.05$). Gli – gliadins; Glu – glutenins; H/L – ratio HMW (high molecular weight)/LMW (low molecular weight); CT – conventional tillage; RT – reduced tillage; NT – no tillage

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Table 5. Mineral composition

Factor	Fe	Cu	Zn	Mn	Mg
	(mg/kg DM)				(g/kg DM)
Tillage					
CT	45.30[a]	2.35[a]	36.25[a]	36.75[a]	0.94[a]
RT	43.60[b]	2.40[a]	36.15[a]	37.61[a]	0.99[a]
NT	41.30[c]	2.20[a]	35.97[a]	36.40[a]	1.11[a]
Cultivar					
Hyfi	44.11[a]	2.36[a]	36.54[a]	37.65[a]	1.06[a]
Hybiza	43.85[a]	2.35[a]	36.37[a]	36.66[a]	1.02[a]
Hystar	42.25[b]	2.25[a]	35.45[b]	36.45[a]	0.94[a]
Year					
2013/2014	42.55[a]	2.25[a]	35.89[a]	37.60[a]	0.92[a]
2014/2015	43.75[b]	2.36[a]	36.35[b]	36.45[a]	1.06[a]
2015/2016	43.89[b]	2.35[a]	36.13[b]	36.70[a]	1.04[a]

Values with different letters (a, b, c) are significantly different (P = 0.05). DM – dry matter; CT – conventional tillage; RT – reduced tillage; NT – no tillage

of the grain test weight and protein content in NT as compared to CT in years with higher precipitation.

This study also shows that the grain collected in the 2015/2016 growing season, with temperatures close to the multiyear mean and rainfall of 414.9 mm, was characterised by a higher content of protein, gluten and Zeleny test. Excess rainfall in the 2013/2014 season, during the grain formation period, caused a significant decrease in test weight (Gürsoy et al. 2010) and the values of other grain quality parameters (De Vita et al. 2007). No statistical variation was found between the years of the study for the falling number.

Cvs. Hybiza and Hyfi had significantly higher contents of protein than the cv. Hystar, in case of cv. Hybiza, also gluten was higher. Moreover, cv. Hyfi was characterised by significantly higher other quality parameters of the grain, i.e. the Zeleny test, falling number and grain test weight. The range of contents of the mentioned quality parameters in the hybrid wheat cultivars tested did not differ significantly from those reported by Taner et al. (2015) and Jaskulska et al. (2018).

Mineral composition and grain yield. Grain from CT contained significantly more Fe compared to ploughless tillage systems (RT, NT), and the difference between these systems was also significant and amounted to 2.30 mg Fe/kg (Table 5). RT promoted the accumulation of Cu and Mn in grain, whereas NT of Mg content, which was also confirmed in the study by Woźniak and Stępniowska (2017). Higher Zn content in grain from CT and RT than from NT were not statistically proven. Gao and Grant (2011) showed a higher Zn content in grain from CT than from RT when wheat was grown on sandy loam, and the inverse relationship was found for growing on loamy sand. Jaskulska et al. (2018) showed no effect of soil cultivation systems on the mineral composition of wheat grain. Only CT and strip-till, after applying a nitrogen rate of 200 kg/ha, increased the Ca content in grain. The grain of the cv. Hyfi contained the most Cu, Mn and Mg and significantly more Fe and Zn than the grain of cvs. Hybiza and Hystar. No significant effect of the cultivar on Cu, Mn and Mg content was demonstrated. Significantly less Fe and Zn was found in the 2013/2014 season, characterised by a higher temperature and higher rainfall during the grain formation period, as noted by Gao et al. (2012).

A grain yield higher by 11.1% was obtained in CT, and was significantly the lowest in the NT treatment (Figure 1). Also, the difference in yield between RT and NT was significant and amounted to 0.64 t/ha. Jug et al. (2011) showed a significant increase in wheat yield in simplified RT compared with NT. In the study by Šíp et al. (2013), wheat grain yield was more dependent on soil moisture and the cultivar genotype, and the difference in yield between CT and simplified RT was only 3.0%, which was also confirmed in the present author's research.

Cvs. Hyfi and Hybiza gave significantly higher yields than cv. Hystar, and the difference in yield amounted to 6.9% and 8.9%. The highest wheat grain yield was found in the 2015/2016 season with moderate rainfall of 414.9 mm and the mean temperature during the

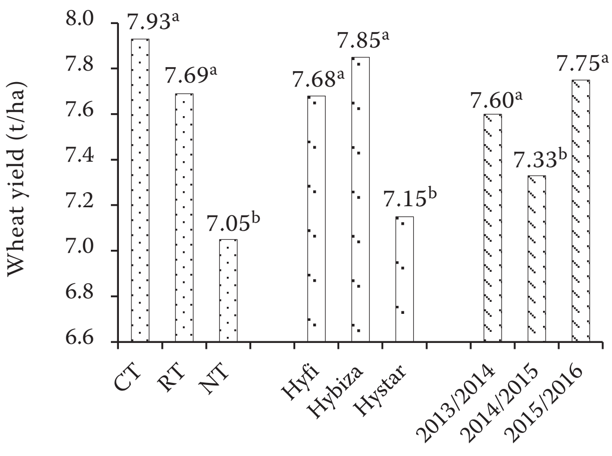

Figure 1. Cultivar wheat yield, the average for all factors. Values with different letters (a, b, c) are significantly different (P = 0.05). CT – conventional tillage; RT – reduced tillage; NT – no tillage

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growing period amounting to 8.8 °C. According to Marin et al. (2015), a total rainfall over 350 mm during the spring-summer growth allows for comparable wheat grain yields in CT and RT.

Our results demonstrated that cvs. Hyfi and Hybiza had favourable technological parameters and protein quality, higher Fe and Zn content (cv. Hyfi) and grain yield (cv. Hybiza). Furthermore, the yield and quality characteristics of the grain in CT and RT were similar and significantly higher than for NT, without differentiation of grain mineral composition.

Good quality characteristics, including favourable gluten protein composition and grain yield of hybrid cultivars with higher Fe and Zn content were obtained in moderate thermal and precipitation conditions during the wheat vegetation period. Under conditions of changing agro-environmental factors, hybrid wheat may be an alternative to "population wheat".

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