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The response of population and hybrid wheat to selected agro-environmental factors

J. Buczek, W. Jarecki, D. Bobrecka-Jamro

Department of Crop Production, University of Rzeszow, Rzeszow, Poland

ABSTRACT

The field experiment was conducted in the years 2011–2014 at three localities (Przecław, Dukla, Lubliniec) of south-east Poland with changing environmental conditions. Population cultivars (Batuta and Bogatka) and hybrid cultivars (Hybred and Hymack) of winter wheat and cultivation technologies (extensive, low-input, medium-input, high-input) were studied. The aim of this study was to evaluate the effect of cultivation technology levels and environmental conditions on the grain yield and protein composition in the grain of population and hybrid wheat cultivars. Higher grain yield, the contents of protein, gluten and fraction of gliadins and high molecular weight (HMW)-glutenins were observed in the case of wheat growing in gleic fluvisol and at precipitation of 453–776 mm than in haplic luvisol and at precipitation of 599–805 mm. The high-input technology affected an increase in grain parameters (yield, protein, gluten) and the amount of gluten proteins by 6.6 (medium-input) and by 26.5% (extensive). The population cv. Bogatka showed higher crude protein and gluten content, the grain yield amounted to 6.6 t/ha and the amount of gluten proteins was 51.7 mAU·s. The hybrid cv. Hymack was characterized by the highest grain yield (7.2 t/ha) but the lowest amounts of protein, gluten and allergenic subunits α/β, γ, ω-gliadins.

Keywords: *Triticum aestivum*; cereal crop; nitrogen fertilization; rainfall; climatic and soil conditions

From among the cereal crops, wheat is the species whose production for food and feed in Poland is a sign of the intensity level of agricultural production and affects the model of consumption (Podolska and Sułek 2012). The fundamental criterion deciding about the usefulness of wheat grain for food is the quantity and quality of protein (Daniel and Triboi 2000). Properties of protein vary, depending on factors that affect them during wheat plant growth and grain maturing, as well as after harvest, during grain drying, storage and processing (Ducsay and Ložek 2004, Plessis et al. 2013). Nitrogen fertilization and plant protection mostly affect the content of gluten proteins in grain, differentiating the amount of gluten and the content of gliadins, especially of ω and γ types and glutenin subunits high molecular weight (HMW) (Konopka et al. 2007b). Genotype determines the cultivar response to environmental factors, which conditions the particular value of wheat grain qualitative properties (Anderson et al. 2004, Malik et al. 2013). Under conditions of changing environmental factors, hybrid wheat may be an alternative to population wheat. Hybrid cultivars of wheat are characterized by a higher grain yield (from 3.5–15.0%) and tolerance to stress climatic and soil conditions, as compared with the population ones, but the grain protein quality of those cultivars is hardly known (Whitford et al. 2013, Zhao et al. 2013). This study presented the assessment of the characterization of key differences between population and hybrid wheat cultivars in seed yield and protein composition depending on the levels of cultivation technology and environmental conditions.

MATERIAL AND METHODS

Field experiments. The four-factor field experiments were carried out in 2011–2014 at the Experimental Stations of Cultivar Assessment in

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Table 1. Description of the three trial locations

Location	GPS position	Altitude (m a.s.l.)	Basic soil characteristic					
			1	2	3	4	5	6
Przecław	50°11'N, 21°29'E	185	6.33	13.1	186	207	146	CL
Dukla	49°34'N, 21°41'E	324	6.26	11.9	157	235	91	SC
Lubliniec	50°16'N, 23°06'E	217	6.07	10.1	253	228	93	LS

1 – pH in KCl; 2 – total organic carbon (g/kg); 3 – phosphorus (mg/kg); 4 – potassium (mg/kg); 5 – magnessium (mg/kg); 6 – soil textural class (CL – clay loam; SC – silty clay; LS – loamy sand). Description of the three trial locations and content of available forms of macronutrients (by Polish Standards)

three localities of south-east Poland with changing climate and soil conditions. The experiments were located in gleic fluvisol (Przecław), haplic cambisol (Dukla) and haplic luvisol (Lubliniec). These soils are commonly used for growing wheat in that area of Poland. The typical physical and chemical properties of the soil assessed before the experiment are given in Table 1. The weather conditions data were obtained from a local observation measurement unit located at the Experimental Station. Precipitation totals were more varied in the years of the study than the average air temperatures. Considerable deviations of the precipitation totals from the long-term values occurred especially at Przecław and Dukla, and in the season 2013/2014, also at Lubliniec. The growing period 2011/2012 was drier and warmer (Table 2). This applies particularly to the period of formation of grain and its quality (3rd decade of June–1st decade of August).

Plant material and experimental methods. The experiment was set up as a split-plot design with 4 replications. The area of an individual plot was 16 m^2. Material for the study comprised four cultivars of winter wheat, including population cvs. Batuta and Bogatka (breeder Danko Hodowla Roślin sp. z o.o., Choryń, Poland) and hybrid cvs. Hybred and Hymack (breeder Saaten-Union GmbH, Estrées-Saint-Denis, France). Cvs. Batuta and Bogatka are bread cultivars with semi-early time of ear formation and maturing. They are characterized by good grain uniformity with good baking quality. Cvs. Hybred and Hymack are high-yielding bread cultivars, with good tolerance to ear and root base diseases. The well-developed root system allows for their cultivation in less fertile soils.

In all study years, wheat was sown in the third decade of September, at sowing density of 400 seeds/m^2 for population cultivars and

Table 2. Weather conditions in 2011–2014 and the multi-annual average of 1956–2010

Year/month	Przecław			Dukla			Lubliniec		
	t	r	d	t	r	d	t	r	d
2011/2012	8.6	453	+0.1	7.9	730	0.0	8.6	599	+0.4
			–160			–143			–44
3/VI–1/VIII	20.6	80	–	19.6	105	–	18.9	110	–
2012/2013	8.4	738	–0.1	8.1	668	+0.2	8.6	713	+0.4
			+125			–204			+70
3/VI–1/VIII	19.9	155	–	18.7	180	–	18.0	115	–
2013/2014	9.0	776	+0.5	9.2	919	+1.3	9.2	805	+1.0
			163			+47			+162
3/VI–1/VIII	18.5	180	–	18.5	283	–	18.8	219	–
1956–2010	8.5	613	–	7.9	872	–	8.2	643	–

Data are from local weather stations located in the experimental fields; t – mean air temperature (°C) from sowing to harvest wheat; r – sum rainfall (mm) from sowing to harvest wheat; d – deviations from multi-annual average temperature (°C)/sum rainfall (mm); 3/VI–1/VIII – the period of grain formation (ten-day period/June–ten-day period/August)

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220 seeds/m^2 for hybrid cultivars. Furthermore, the experimental design included four levels of cultivation technology (A – extensive; B – low-input; C – medium-input; D – high-input). The used technologies differed in the rates of NPK fertilization and chemical plant protection (Table 3). Herbicides were used at the wheat spreading time (21–22 BBCH), fungicides at the stages of stalk shooting (32–33 BBCH) and ear formation (54–56 BBCH), whereas insecticides at the stage of ear formation (54–56 BBCH) and the growth retardant at the stalk shooting stage (32–33 BBCH). Preparations were applied according to the producer's instructions. In B, C, D technologies, N fertilization was applied after the start of growth – 60 kg/ha, at the stages of stalk shooting – 30 kg/ha (32–33 BBCH) and ear formation – 30 kg/ha (54–56 BBCH). Fertilization with P and K was applied under pre-sow ploughing.

Analytical methods. Wheat grain samples were collected at harvest. The grain was then dried to approximately 14% and cleaned from dust and tailings in a laboratory sieve-air separator. The following parameters were determined: grain yield, protein content (ICC 105/2, 1994) and wet gluten content in the grain (ICC 155, 1994). The quantitative and qualitative proteins in the grain characteristics were determined with the RP-HPLC technique according to Wieser et al. (1998) and Konopka et al. (2007a). The content of albumins, globulins, gliadins and glutenins was analysed. The results were analysed with the use of a computer program HPLC 3D ChemStation (Palo Alto, USA) and was presented in mAU·s, which expresses an area of chromatographic peaks.

Statistical analyses. Results achieved were elaborated statistically with the analysis of variance (ANOVA), whereas the significance of differences between mean values was evaluated with the Tukey's (*LSD*) test, $P = 0.05$. The computations were done using the Statistica 8.0 programme (StatSoft, Tulsa, USA).

RESULTS AND DISCUSSION

Grain yield. The quantity of wheat grain yield was significantly dependent on the cultivation technology, cultivar, year and location of the experiments and the interaction between the experimental factors (Table 4). Wheat cultivated according to C and D technologies gave significantly higher yields (1.0–2.4 t/ha) as compared with A and B technologies. Also Abedi et al. (2011) as well as Podolska and Sułek (2012) confirm that winter wheat belongs to the group of plants which show a strong response in yield increase to the intensity of cultivation technology, and particularly to nitrogen fertilization. Lloveras et al. (2004) report that the quantity of wheat yield is conditioned by the cultivar genotype and the suitable moisture and quality of soil. Hybrid cvs. Hybred and Hymack gave significantly higher yields than the population of cvs. Batuta and Bogatka. The highest yield 7.2 t/ha was found for the hybrid cv. Hymack. The difference in the yield quantity

Table 3. Characteristics of compared technologies of wheat cultivation

Agronomic factor		A	B	C	D
N fertilization (kg/ha)		–	60	90	120
P + K fertilization (kg/ha)		–	15 + 30	35 + 60	55 + 90
Insecticide (L/ha)	Bi 58 Nowy EC 400	–	–	0.5	–
	Karate Zeon 050 CS	–	–	–	0.1
Herbicide (L/ha)	Chwastox Turbo 340 SL	–	2.0	2.0	–
	Puma Uniwersal 069 EW	–	–	–	1.2
	Sekator 125 OD	–	–	–	0.15
Fungicide (L/ha)	Juwell TT 483 SE	–	–	1.2	1.2
	Swing Top 183 SE	–	–	–	1.2
Growth regulator (L/ha)	Moddus 250 EC	–	–	–	0.4

A – extensive; B – low-input; C – medium-input; D – high-input

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Table 4. Grain yield and composition of proteins in grain wheat

Factor		Grain yield (t/ha)	Protein	Gluten	A + B	Gli	Glu	Gli/Glu
			(%)		(mAU·s)			
Location	Przecław	7.6[a]	14.1[a]	28.8[a]	13.1[a]	29.9[a]	21.9[a]	1.37[a]
	Dukla	6.8[b]	12.5[b]	25.5[b]	12.7[ab]	24.7[bc]	18.9[b]	1.31[a]
	Lubliniec	5.9[c]	12.8[b]	25.8[b]	12.5[b]	27.6[ab]	20.2[b]	1.37[a]
Technology	A	5.6[a]	11.6[a]	23.1[a]	12.2[a]	23.1[a]	17.1[a]	1.36[a]
	B	6.3[b]	12.7[b]	25.5[b]	12.6[ab]	25.9[a]	19.0[a]	1.36[a]
	C	7.3[c]	13.7[c]	27.9[c]	13.0[bc]	29.4[b]	21.6[b]	1.36[a]
	D	8.0[d]	14.6[d]	30.4[d]	13.3[c]	31.1[b]	23.6[c]	1.32[a]
Cultivar	Batuta	6.3[a]	13.5[a]	27.6[a]	13.3[a]	28.1[ab]	20.6[a]	1.37[ab]
	Bogatka	6.6[a]	13.7[a]	28.7[b]	12.8[ab]	29.2[a]	22.5[b]	1.30[a]
	Hybred	7.1[b]	13.0[b]	26.3[c]	12.8[ab]	27.1[b]	19.2[ac]	1.41[b]
	Hymack	7.2[b]	12.4[c]	24.3[d]	12.2[b]	25.0[c]	19.0[c]	1.32[ab]
Year	2012	6.3[a]	13.5[a]	28.5[a]	15.5[c]	34.4[c]	26.8[b]	1.28[a]
	2013	6.6[a]	13.1[b]	26.8[b]	12.5[b]	25.4[b]	17.8[a]	1.42[a]
	2014	7.5[b]	12.9[b]	24.7[c]	10.3[a]	22.4[a]	16.3[a]	1.37[a]
Mean		6.8	13.1	26.7	12.8	27.4	20.3	1.35
$LSD_{0.05}$								
Location (L)		0.5	0.8	2.8	0.4	3.6	1.5	ns
Technology (T)		0.3	0.4	1.2	0.6	3.1	1.9	ns
Cultivar (C)		0.3	0.2	0.9	0.6	1.3	1.3	0.09
Year (Y)		0.5	0.3	1.1	1.2	2.8	2.8	ns
L × T		0.5	0.6	3.1	ns	1.9	0.9	ns
L × C		0.4	0.3	3.3	ns	2.1	1.5	ns
T × C		0.3	0.5	ns	ns	1.6	1.6	ns
Y × C		0.4	ns	1.5	ns	ns	ns	ns

The mean marked by the same letter do not differ significantly; A – extensive; B – low-input; C – medium-input; D – high-input; ns – non-significant; A + B – total albumins + globulins; Gli – total gliadins; Glu – total glutenins; Gli/Glu – ratio gliadins/glutenins; ns – non-significant; *LSD* – least significant difference

between the hybrid cultivars was statistically insignificant and amounted to 0.1 t/ha. The grain yield of the hybrid cv. Hybred and cv. Hymack was higher in comparison with the population cv. Batuta (by 12.7% and 14.3%) and cv. Bogatka (by 7.6% and 9.1%). Higher grain yield was found for growing wheat in gleic fluvisol and at precipitation of 453–776 mm (Przecław) than in haplic luvisol and at precipitation of 599–805 mm (Lubliniec).

Protein and gluten content. The obtained results confirm the thesis presented by Konvalina et al. (2009) and Malik et al. (2013) that the amount of gluten increases proportionally to the protein content in grain, and the correlation coefficient of both traits is high. Significantly higher content of grain protein (14.6%) and gluten (30.4%) was found in grain from technology D than in technologies A, B and C (Table 4). Smaller content of protein and gluten from two technologies (90 kg N/ha and 120 kg N/ha), not differing statistically, was obtained by Faměra et al. (2015). Rharrabti et al. (2003) report that qualitative parameters of wheat grain are determined by the environmental conditions. This is confirmed by the interaction of the location of experiments with the technologies and cultivars, and for protein content, also with the years of experiments. Significantly higher content of protein and gluten was obtained in the growing period 2011/2012 characterizing by the temperature similar to that from the long-term period and by moderate precipitation. In the third year of the study with a higher total precipitation, the values

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of those traits were significantly the lowest. Daniel and Triboi (2000) report that the excess of rainfall may cause an increased synthesis of gliadins in protein, weakening the mechanical strength of gluten, which is also dependent on the wheat genotype. The hybrid cultivars stored significantly less protein and gluten in grain than the population cultivars. Cv. Bogatka was distinguished by a tendency to higher values of protein (13.7%) and particularly gluten (28.7%). Cv. Hymack showed significantly the lowest value of those parameters (protein 12.4%, gluten 24.3%). Smaller amount of protein and gluten of the hybrid cultivars, including especially cv. Hymack, could be caused by its lodging before harvest (Ingver et al. 2010). Moreover, the grain quality of hybrid cultivars may be lowered, which is a result of breeding of these cultivars, when sterility of the female parent is not fully preserved (Whitford et al. 2013, Zhao et al. 2013). Fowler (2003) reports that when grain yield of wheat cultivars increases as a result of the intensity of cultivation technology, the protein content may decrease by diluting of biomass.

Protein characteristics. Bread quality of wheat depends mostly on the amount and composition of storage proteins, especially glutenins, and is dependent, among others, on the environmental conditions or N fertilization, being also a varietal characteristic (Konopka et al. 2007b). The experimental factors differentiated the content of protein fractions in wheat grain to a different extent (Table 4). A higher level of wheat cultivation technology created favourable conditions for accumulating gluten proteins in grain as the basic ones, which conditions the predominant position of wheat among cereals (Shewry 2007). Accumulation of those fractions in grain from technology D in comparison with technology A was higher by 26.5%. Significantly the highest content of gliadins and glutenins was found in cv. Bogatka, and the lowest in cv. Hymack. A similar range of gliadins (26.3–29.5 mAU·s) and glutenins (16.7–21.69 mAU·s) in winter wheat grain fertilized with meat-bone meal is reported by Stępień and Wojtkowiak (2013). No explicit effect of the cultivar, year of the study and the location of experiments and interaction of factors on the content of fractions of albumins and globulins was indicated. Nevertheless, interactions between the experimental factors were observed (no interaction of years × cultivar) for the content of gliadins and glutenins. Location of the experiments (Przecław) determined a higher accumulation in grain of gliadins and HMW-glutenins, as well as albumins and globulins in the grain.

The amount and mutual proportions of gluten proteins determines the usefulness of wheat cultivars for baking purposes (Konopka et al. 2007a). The highest percentage in grain protein was found in the fraction of gliadins (45.3%), lower of glutenins (33.5%) and the lowest of albumins and globulins (21.2%). A similar distribution of protein fractions in wheat grain was observed by Kindred et al. (2008). Fuertes-Mendizábal et al. (2010) reports a higher content of the fraction of glutenins than gliadins in wheat grain, at a gliadins to glutenins ratio of 0.58–0.75. The ratio of the fraction of gliadins to glutenins in the grain of population and hybrid cultivars was similar (1.35) and it was not differentiated with experimental factors.

Cultivation technologies differentiated the content of protein subunits, monomeric gliadins and polymer glutenins (Table 5). Higher NPK fertilization and applied pesticides in C and D technologies resulted in a significant increase in subunits α/β, γ and ω-gliadins and HMW and LMW glutenins as compared with A and B technologies. Correlation between the intensity of technology and the content of subunits ω and α/β-gliadins was similar and, depending on location, amounted to: $r = 0.66–0.67^{**}$ (Przecław) and $r = 0.81–0.82^{**}$ (Lubliniec). Weaker correlation ($r = 0.45–0.47^{*}$ Dukla) and $r = 0.67–0.60^{**}$ Lubliniec) was observed for HMW and LMW of glutenins, and the weakest for subunits γ-gliadins ($r = 0.40–0.47^{*}$).

Interactions location × technology and location × cultivar indicate a significant effect of the environmental conditions on the content of these gluten subunits, which is also reported by Plesiss et al. (2013). Significant differences were indicated in the content of α/β, γ and ω-gliadins between hybrid and population cultivars. The baking value of flour is affected by an increase in HMW fraction and the HMW to LMW particle ratio. Besides the composition of subunits of glutenins, the HMW fraction is regarded as the most active in creating dough rheological properties and bread quality (Daniel and Triboi 2000). Cv. Batuta and cv. Hymack were characterized by the lowest content of HMW and cv. Bogatka and cv. Hybred by the highest. The grain of cv. Bogatka and cv. Batuta accumulated more LMW subunits as compared with cv. Hybred and cv. Hymack. The HMW/LMW ratio

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Table 5. Gluten and content of subunits of storage proteins in grain wheat

Factor		Gliadins			Glutenins		H/L
		α/β	γ	ω	HMW	LMW	
		(mAU·s)					
Location	Przecław	16.1[a]	10.8[a]	3.0[a]	5.6[a]	16.3[a]	0.34[a]
	Dukla	13.3[b]	9.3[b]	2.2[b]	4.6[b]	14.3[a]	0.32[b]
	Lubliniec	15.2[a]	9.6[ab]	2.7[ab]	5.2[b]	15.0[a]	0.35[a]
Technology	A	12.4[a]	8.6[a]	2.1[a]	4.2[a]	12.9[a]	0.32[a]
	B	14.1[b]	9.4[b]	2.4[a]	4.8[b]	14.2[b]	0.34[b]
	C	15.9[c]	10.6[c]	2.9[b]	5.5[c]	16.2[c]	0.34[b]
	D	17.0[d]	11.0[c]	3.1[b]	6.1[d]	17.5[d]	0.35[b]
Cultivar	Batuta	14.9[a]	10.6[a]	2.7[ab]	4.6[a]	16.0[a]	0.29[a]
	Bogatka	15.3[b]	10.9[a]	2.9[a]	5.4[b]	17.1[b]	0.32[b]
	Hybred	15.1[b]	9.4[b]	2.6[b]	5.5[b]	13.7[c]	0.40[c]
	Hymack	14.1[c]	8.6[c]	2.3[c]	4.9[a]	14.1[c]	0.35[d]
Year	2012	17.8[c]	13.4[b]	3.2[b]	7.0[b]	19.8[b]	0.35[a]
	2013	14.0[b]	8.6[a]	2.8[b]	4.1[a]	13.7[a]	0.30[b]
	2014	12.8[a]	7.6[a]	1.9[a]	4.2[a]	12.1[a]	0.35[a]
Mean		14.9	9.9	2.6	5.1	15.2	0.34
$LSD_{0.05}$							
Location (L)		1.9	1.2	0.6	0.3	ns	0.02
Technology (T)		1.7	1.1	0.4	0.5	1.4	0.01
Cultivar (C)		0.7	0.6	0.2	0.4	1.0	0.02
Year (Y)		1.1	1.4	0.6	1.1	2.0	0.04
L × T		0.5	1.0	0.7	0.7	ns	ns
L × C		ns	0.5	0.4	0.5	ns	ns
T × C		ns	ns	0.5	0.8	ns	ns
Y × C		ns	0.9	ns	ns	1.1	ns

The mean marked by the same letter do not differ significantly; A – extensive; B – low-input; C – medium-input; D – high-input; H/L – ratio HMW (high molecular weight)/LMW (low molecular weight); ns – non-significant; *LSD* – least significant difference

was on average 0.34, ranging from 0.29–0.40. These results are consistent with the results obtained by Konopka et al. (2007a), where wheat cultivars contained 8.0–13.0% of HMW fraction, and the HMW/LMW ratio ranged between 0.27–0.40. A higher content of protein fractions and their subunits in grain was indicated in the season 2011/2012 with a lower total rainfall. According to Rharrabti et al. (2003) and Lloveras et al. (2004), the qualitative traits of wheat grain are improved under conditions of moderate water deficit, which was observed particularly in Przecław.

In conclusion, the factors that had the decisive effect on the grain yield and quality of population and hybrid wheat cultivars were cultivation technologies, location of the experiments and the weather conditions (years). Increased NPK fertilization and the use of pesticides in wheat cultivation technologies caused an increase in the yield of grain, protein and gluten and the content of gliadins in relation to glutenins. More favourable environmental conditions resulted in accumulation in grain of larger amounts of α/β, γ, ω-gliadins and HMW-glutenins, not differentiating albumins and globulins. The climatic conditions with lower total precipitation caused an increase in the amounts of protein and gluten and gluten subunits in the grain, but they reduced the grain yield. The hybrid cv. Hybred and cv. Hymack had a higher grain yield, but worse quality traits than

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the population cv. Bogatka and cv. Batuta. The hybrid cv. Hymack was characterized by the lowest amount of protein, gluten, fraction of albumins and globulins and allergenic subunits of α/β, γ, ω-gliadins.

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Corresponding author:
Dr. inż. Jan Buczek, University of Rzeszow, Department of Crop Production, Zelwerowicza 4, 35 601 Rzeszow, Poland; e-mail: janbuczek7@gmail.com