POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 32(2): 223–235, Y. 2017

GRAIN YIELD VARIABILITY OF WINTER WHEAT CULTIVARS IN POST-REGISTRATION TESTS IN LOWER SILESIA

***Ryszard Weber*[1], *Kamila Nowosad*[2], *Henryk Bujak*[2], *Edward Gacek*[3]**

[1] Department of Weed Science and Tillage Systems in Wrocław
Institute of Soil Science and Plant Cultivation, State Research Institute in Puławy, Poland
[2] Department of Genetics, Plant Breeding and Seed Production
Wroclaw University of Environmental and Life Sciences,
[3] Research Center for Cultivar Testing, Słupia Wielka

Key words: winter wheat, cultivars, genotype x environment interaction.

Abstract

The paper provides an analysis of the variability in grain yield by a number of the winter wheat cultivars in Lower Silesia based on Post-Registration Variety Testing experiments carried out in 2010, 2011 and 2013. The study analyzes the yield values of nine winter wheat cultivars obtained in trials performed within the frames of the Post-Registration Variety Testing Agrotechnical System (PDO) in Lower Silesia. The experiments were established at four localities characterized by diverse soil conditions. Among the cultivars under research, Askalon was found to produce higher yields than the remaining cultivars, both in the standard and intensive tillage mode. A lower grain yield in both tillage modes was characteristic of Figura. The significant interaction of the cultivars tested with the localities indicates their varied performance at particular locations. The considerable differences in the winter wheat yield values in some of the localities as compared with average yields in the Lower Silesian area point out to essential influence of microregionalization in the territory concerned.

Address: Ryszard Weber, Department of Weed Science and Tillage Systems in Wrocław, State Research Institute in Puławy, ul. Orzechowa 61, 50-540 Wrocław, Poland, phone: +48(71) 336 26 58, e-mail: rweber@iung.pulawy.pl

ZMIENNOŚĆ PLONOWANIA ODMIAN PSZENICY OZIMEJ W DOŚWIADCZENIACH POREJESTROWYCH NA DOLNYM ŚLĄSKU

***Ryszard Weber*[1], *Kamila Nowosad*[2], *Henryk Bujak*[2], *Edward Gacek*[3]**

[1] Zakład Herbologii i Technik Uprawy Roli we Wrocławiu
Instytut Uprawy Nawożenia i Gleboznawstwa – Państwowy Instytut Badawczy w Puławach, Polska
[2] Katedra Genetyki, Hodowli Roślin i Nasiennictwa
Uniwersytet Przyrodniczy we Wrocławiu, Polska
[3] Centalny Ośrodek Badania Odmian Roślin Uprawnych w Słupii Wielkiej, Polska

Słowa kluczowe: pszenica ozima, odmiany, interakcja genotypowo-środowiskowa.

Abstrakt

Celem pracy była analiza zmienności plonowania kilku odmian pszenicy ozimej na Dolnym Śląsku na podstawie wyników doświadczeń porejestrowych z lat 2010, 2011 i 2013. W badaniach wykorzystano plony dziewięciu odmian pszenicy ozimej uzyskane z doświadczeń prowadzonych w ramach systemu Porejestrowego Doświadczalnictwa Odmianowego (PDO) na Dolnym Śląsku. Doświadczenia założono w czterech miejscowościach odznaczających się zróżnicowanymi warunkami glebowymi. Spośród analizowanych odmian Askalon charakteryzował się istotnie wyższymi plonami w porównaniu z pozostałymi zarówno w wariancie standardowej, jak i intensywnej agrotechniki. Niższym plonowaniem w obu wariantach uprawy odznaczała się Figura. Istotna interakcja odmian z punktami doświadczalnymi wskazuje na zróżnicowane plonowanie odmian w poszczególnych miejscowościach. Znaczne różnice w plonach odmian pszenicy ozimej w niektórych miejscowościach, w porównaniu ze średnimi plonami na Dolnym Śląsku, wskazują na duże znaczenie mikrorejonizacji na obszarze tego regionu.

Introduction

The winter wheat occupies the largest area under cultivation in Poland. The acreage where this cereal is sown has recently been incessantly increasing, now reaching 2 mln ha. The species is grown both on the soils reckoned among the black soils but also at locations characterized by less advantageous water-air proportions. Cultivation of the winter wheat on light soils is linked with high danger of declining yields, particularly in years of temporarily insufficient precipitation during the vegetation season. Water accessibility from the soil represents a fundamental factor that influences the plants' performance. The drought-caused stress can result in reduction of all yield components, which – to a varied degree – depend on the plant cultivar (GONZALES et al. 2007). The majority of cultivars registered in Poland are characterized by low resistance to water stress (DRZAZGA et al. 2011), whereas the cultivars distinguishable by high yield stability display significant tolerance to water deficiency during vegetation (AHMAD et al. 2003). Cultivars searched for should be characterized by a high and stable grain yield in defined macro- or microregions of growing (SALOMON et al. 2008, MOHAMMADI et al. 2012). Wide adaptation of a given cultivar to defined environmental conditions is defined as its capability of high productivity in varied environmental conditions of the region, different years or tillage modes (MĄDRY and IWAŃSKA 2011). Consequently, narrow adaptation of a cultivar denotes its ability to produce a substantial yield in subregions of a cultivation area (for instance within areas of certain communes having different environmental conditions). Cultivars which exhibit stable performance in macroregions are distinguishable by remarkable tolerance to the biotic and abiotic types of stress (ALBRIZIO et al. 2010). Pertinent research has revealed that the wheat cultivars grown within the Polish territory are characterized by low grain yield stability (BUJAK and TRATWAL 2011, BUJAK et al. 2013, WEBER et al. 2011). However, the significant genetic diversity of the newly registered cultivars combined with the climatic changes occurring in Europe simply force the necessity to search for genotypes distinguished by good adaptation within the area of a given voivodeship or microregion. The purpose of the present study was to analyze grain yield variability of several winter wheat varieties in Lower Silesia based on results of the post-registration trials from years 2010, 2011 and 2013.

Material and Methods

The study on grain yield variability made use of yield data concerning nine winter wheat cultivars obtained in experiments carried out within the Post-registration Variety Testing Agricultural System (PDO) in Lower Silesia. Of the PDO trials, four localities had been selected which varied with respect to edaphic conditions (Table 1). The analysis covered three-years of the wheat cultivars growing: 2010, 2011 and 2013. The area of a single study plot in each experiment equalled 15 m^2. The significant factor which was responsible for the diversification of the studied cultivars' yields in the years mentioned was the uneven precipitation at the localities under analysis (Table 2). The trials were set up by the method of incomplete block design in two replications, the standard and the intensive tillage mode compared. At the intensive level nitrogen fertilization applied was by 40 kg ha^{-1} higher than in the standard mode. Also, complete chemical protection against fungal diseases, usage of an anti-logging factor, and foliar feeding of the plants with multi-component nutrient distinguished the intensive tillage mode from the standard, where these agronomic measures were not taken. Manuring with the remaining macroelements and other agronomic endeavours were performed at the same extent at all the plots of the analyzed experiments. Calculations were carried out with the average yield obtained from all the plots at the four locations in the three years serving as the basic value. In order to estimate the grain yield variability in the analyzed wheat cultivars at particular localities, statistical analysis as proposed by CALIŃSKI et al. (1987) was employed. The calculations were made with the help of the Sergen 4 software (CALIŃSKI et al. 2003). The calculations have been carried out for the intensive and the standard tillage mode separately.

Table 1

Soil type of the localities and selected tillage measures applied in 2010, 2011 and 2013

Specification – denotations	Zybiszów (ZYB)	Tarnów (TAR)	Naroczyce (NAR)	Tomaszów (TOM)
Soil complex	2	3	5	5
Soil bonitation class	II	IIIa	IVa	Ivb
P [mg kg^{-1}] content in the soil	high	average	average	high
K [mg kg^{-1}] content in the soil	high	high	average	high
Mg [mg kg^{-1}] content in the soil	average	average	high	average
pH of the soil	6.3	6.0	6.1	6.0
Nitrogen rates at a_1 [kg ha^{-1}]	114	110	80	135
Nitrogen rates at a_2 [kg ha^{-1}]	154	150	120	175
Phosphoric rates [kg ha^{-1}]	60	67	60	50
Potasium rates [kg ha^{-1}]	90	101	90	75
Seed dressing	Oxafun T	Funaben Plus	OxafunT	Sarfun T
Herbicide	Legato Plus 1.25 l	Boxer 2l + HelmTribi	Legato Plus 1.5l	Legato Plus 1.5l
Fungicides at a_2	Alert 375 1l	Dobromir 0.6 l	Alert 375 1l	Alert 375 1l
Foliar fertilization at a_2	Basfoliar 8 l	Basfoliar 5 l	Basfoliar 6l	Basfoliar 8l

Table 2

Atmospheric conditions at different localities

Localities	Zybiszów	Tarnów	Naroczyce	Tomaszów
Sum of precipitation [mm] in 2009 (X–XII)/2010 (I–VII)	588	620	559	585
Sum of precipitation [mm] in 2010 (X–XII)/2011 (I–VII)	507	587	663	664
Sum of precipitation [mm] in 2012 (X–XII)/2013 (I–VII)	635	637	740	667
Mean temperature [°C] in 2009 (X–XII)/2010 (I–VII)	9.2	8.6	8.4	8.6
Mean temperature [°C] in 2010 (X–XII)/2011 (I–VII)	9.8	9.2	9.2	8.8
Mean temperature [°C] in 2012 (X–XII)/2013 (I–VII)	8.7	8.3	8.2	7.8

Results and Discussion

A preliminary analysis for each locality has revealed significant diversification of the cultivars' yields both in the intensive and standard tillage mode (Table 3).

Table 3

Mean grain yields of the tested cultivars [t ha^{-1}]

Localities – standard tillage mode					
Cultivar	Zybiszów	Tarnów	Naroczyce	Tomaszów	Average
Figura	7.58	7.09	6.92	5.90	6.87
Muszelka	8.31	7.18	6.87	6.20	7.14
Bogatka	8.26	6.90	6.74	5.98	6.97
Mulan	8.60	7.96	7.67	6.17	7.60
Ostroga	8.26	7.62	7.29	5.61	7.20
Askalon	8.42	8.10	7.57	5.95	7.51
Bamberska	8.62	7.40	7.25	5.83	7.28
Natula	8.62	7.61	7.52	6.02	7.45
Smaragd	9.03	7.62	7.16	6.00	7.45
Mean	8.41	7.50	7.22	5.96	7.27
Intensive tillage mode					
Figura	8.52	7.72	7.74	6.79	7.69
Muszelka	9.29	7.71	8.11	6.94	8.01
Bogatka	9.71	7.85	8.08	6.80	8.11
Mulan	9.67	8.33	8.68	7.05	8.43
Ostroga	9.33	8.05	8.01	6.71	8.02
Askalon	9.72	8.53	8.51	7.05	8.45
Bamberska	10.00	7.96	8.42	7.18	8.39
Natula	9.64	8.37	8.52	6.90	8.36
Smaragd	10.30	8.35	8.45	7.14	8.56
Mean	9.58	8.10	8.28	6.95	8.22

An analysis of variance for the synthesis of many years' period (Table 4) enabled assessment of the variability in respect of years, localities and cultivars, as well as verification of the following hypotheses:
– about lack of interaction of the cultivars with the localities,
– about lack of the cultivars interacting with the years,
– about lack of interaction of the cultivars with the environments.

Table 4

Mean square variation in the overall analysis of variance

Specification	Number of degrees of freedom	Standard tillage mode	Intensive tillage mode
Source of variation		Mean square	Mean square
Years	2	1319.30*	1588.5*
Localities	3	2764.78**	3113.79*
Environments	6	1698.04**	2264.12**
Genotypes	8	75.92*	95.54*
Genotype x year	16	26.59*	30.07*
Genotype x locality	24	20.34*	15.04*
Genotype x environment	48	17.32**	17.46**
Regression on explanatory variable	8	22.26	30.81*
Regression deviation	40	16.33**	14.79**
Experimental error	423	1.97	1.54

* – significant at the significance level of $\alpha = 0.05$; ** – significant at the significance level of $\alpha = 0.01$

In the considered standard and intensive tillage modes, significant influence of atmospheric conditions on the performance by the studied cultivars in the period 2010–2013 was found. The mean yields of the analyzed cultivars at particular localities also displayed wide variability. However, on the good wheat complex the cultivars' yield values were higher than at the localities having soils of class III or IV. The performed variance analysis has shown that the mean yields of the cultivars at particular localities were substantially diverse. The high value of the cultivar x environment interaction also points out to widely varying reaction of particular cultivars to the diverse edaphic and atmospheric conditions prevailing at the localities under research in each year of study. Diverse environmental conditions, and particularly the varying amount of total precipitation at each locality during the plants' vegetation season, significantly affected the cultivars' performance. The varied response of the varieties to changes in the environmental conditions cannot be explained by their linear regression relative to the environmental effects. The significant deviations from regression in both tillage modes under consideration indicate that the interaction of cultivars with the environments studied cannot be described by simple regression relationship.

Table 5 provides the outcome of a detailed analysis of the studied cultivars in respect of their yield performance and interaction with the environment. In the standard tillage mode, significantly lower yields at the four localities under analysis were characteristic of cultivars Bogatka and Figura. Mulan and Askalon were distinguishable by positive main effects. In the analyzed environments, the latter cultivars mentioned produced significantly higher yields as compared with the overall mean for all the objects studied. The remaining cultivars did not display any significant deviations in their yields from the general mean. Remarkable stability in performance at the analyzed sites was typical of cultivar Askalon, whereas the rest of the cultivars were characterized by significant interaction with the environments. In particular, these were cultivars Muszelka and Ostroga that responded with significant variability in grain yield to the environmental changes bound with soil and atmospheric conditions.

Table 5

Testing of particular cultivars and their interactions

Denotations	Standard tillage mode			Intensive tillage mode		
Cultivar	estimate for the main effect	F statistics for the main effect	F statistics for the interaction with environments	estimate for the main effect	F statistics for the main effect	F statistics for the interaction with environments
Figura	-4.03	18.41	6.06*	-5.32	55.66*	4.46*
Muszelka	-1.35	0.76	16.49*	-2.16	2.24	18.24*
Bogatka	-3.05	13.94	4.58*	-1.15	0.71	16.54*
Mulan	3.25	6.29	11.54*	2.07	3.05	12.34*
Ostroga	-0.78	0.31	13.60*	-2.02	3.08	11.69*
Askalon	2.38	18.40	2.12	2.27	4.20*	10.76*
Bamberska	0.01	0.00	8.45*	1.65	2.17	11.03*
Natula	1.76	2.12	10.09*	1.31	2.06	7.39*
Smaragd	1.80	3.54	6.30*	3.35	10.42*	9.47*
Critical values $\alpha = 0.05$	–	3.78	2.12	–	3.78	2.12

Also at the intensive tillage mode, Figura performed significantly poorer than the other cultivars, whereas Askalon and Smaragd, when under conditions of diverse complexes of agricultural usefulness of soils, were distinguishable by a higher grain yield than the remaining objects. Significant grain yield instability at the intensive tillage mode was characteristic of Muszelka and Bogatka. Assessment of the analyzed localities with regard to the genotype x environment (G x E) interaction was carried out through division of statistics F of this interaction into components corresponding with particular contrasts (comparisons) between cultivars. A corresponding F statistics, expressed as a proportion of statistics F for the G x E interaction from the overall variance analysis, shows what part of this interaction accounts for a given contrast. In order to graphically illustrate the environments on a plane, the first two principal components, which represent estimates of contrasts between cultivars calculated for particular localities, were used. Figure 1 and Figure 2 depicts distribution of localities on a plane in the system of principal components. A locality with a large share in the G x E interaction is distinguishable by a long distance from the origin of the co-ordinate system. The yields of cultivars in this environment-locality differ significantly from the mean yields obtained during the study years under analysis.

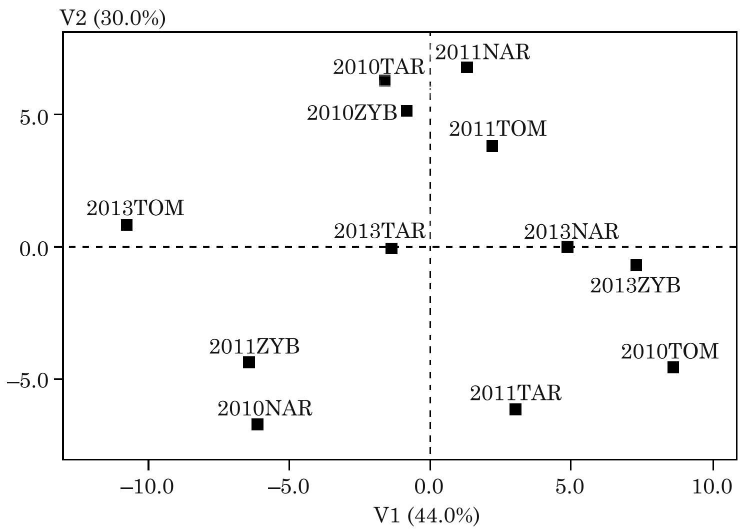

Fig. 1. Distribution of localities in the system of principal components – standard tillage mode; for denotations see Table 1

An analysis of the standard tillage mode (Figure 1) allows a statement that the most distant from the origin of the system are localities 2010NAR and 2011NAR, and also 2010TOM and 2013TOM, all representing Naroczyce and Tomaszów. These localities are characterized by the mean grain yield values significantly deviating from the averages for the cultivars tested in Lower Silesia. The substantial differences in the cultivars' performance at the localities under research – as compared with the average grain yields of the studied objects in the analyzed macroregion – result from changeable atmospheric conditions during the three years of investigations. This is evidenced by long distances between the analyzed localities in particular years (2010NAR, 2011NAR and 2013NAR, or 2010TOM, 2011TOM and 2013TOM).

Figure 2 presents the localities in the system of the first two principal components for the intensive tillage mode. Also in this variant, points

2010TOM and 2013TOM as well as 2011ZYB and 2013ZYB, denoting Tomaszów and Zybiszów, display a considerable distance from the origin of the co-ordinate system, which indicates substantial differences in the cultivars' grain yields at these localities in comparison with their performance at the other sites. The localities mentioned exhibit also considerable differences between the wheat yield values in particular study years, which is testified by long distances between the points of 2010TOM, 2011TOM, 2013TOM, 2010ZYB, 2011ZYB and 2013ZYB.

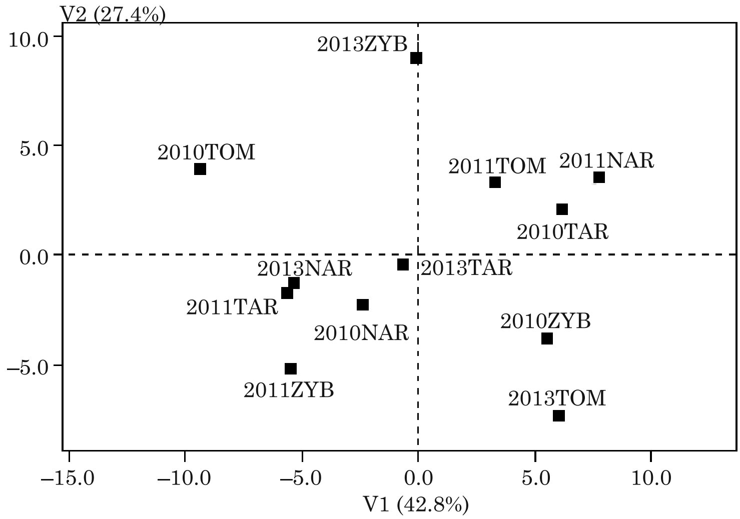

Fig. 2. Distribution of localities in the system of principal components – intensive tillage mode; for denotations see Table 1

Applying an analysis of dual components, the structure of the G x E interaction in respect of cultivars can be analyzed. Figure 3 shows the cultivars in the system of principal components for the standard tillage mode. The magnitude (share) of the interaction of particular cultivars with the environments is depicted by the section (vector) of the *F* statistics value drawn from each point to the origin of the system. The largest shares in the sum of deviation squares for the G x E interaction are those of cultivars Mulan, Ostroga and Muszelka. These particular cultivars are distinguishable by more variable performance in the studied localities than the remaining objects. On the other hand, higher grain yield stability is characteristic of Smaragd, Askalon and Bogatka.

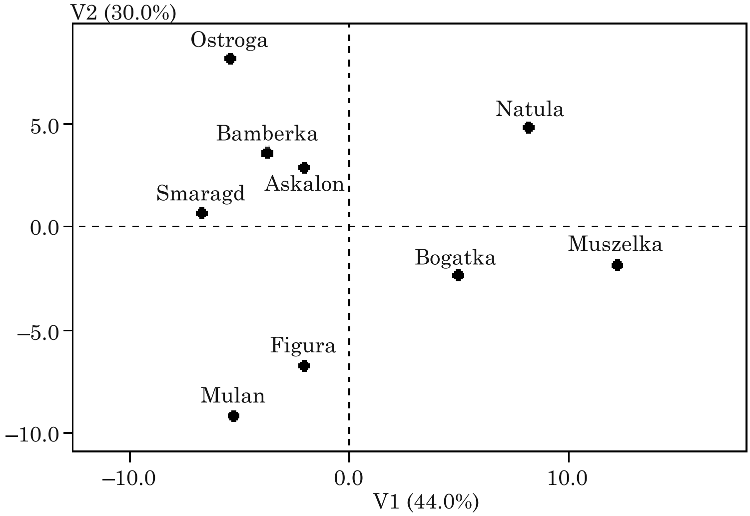

Fig. 3. Representation of cultivars in the system of principal components – standard tillage mode

At the intensive tillage mode (Figure 4), Muszelka and Bogatka were characterized by significant grain yield variability within the studied localities, whereas more stable performance was characteristic of Smaragd and Figura. A comparison of distances between particular cultivars when under intensive and standard tillage mode reveals significant differences. This points out to the cultivars variedly responding to the doses of nitrogen fertilizer and plant protection preparations applied and to atmospheric conditions. The investigations by PODOLSKA (2009) show that the Polish cultivars can be divided into two groups. The first one comprises ones that need an average dose of nitrogen, whereas the other group is composed of cultivars distinguishable by the grain yield growing at high-dose nitrogen fertilization.

Cultivar Askalon was characterized by substantially higher grain yields as compared with the remaining cultivars both at the standard and intensive tillage mode, and therefore this particular cultivar deserves to be recommended for Lower Silesia. Poorer performance at both tillage modes was typical of Figura. It should be emphasized, however, that at the intensive agronomy level this cultivar exhibited significant grain yield variability in particular study years. Good performance by cultivars Smaragd and Askalon at the intensive tillage mode depends to a great extent on favourable distribution of precipitation in the vegetation season, which guarantees optimum soil moisture in critical phases of the plants' development. The main factor responsible for lower grain yields of the studied cultivars on light soils was water deficit during the period of the wheat vegetation, which finds confirmation in the research

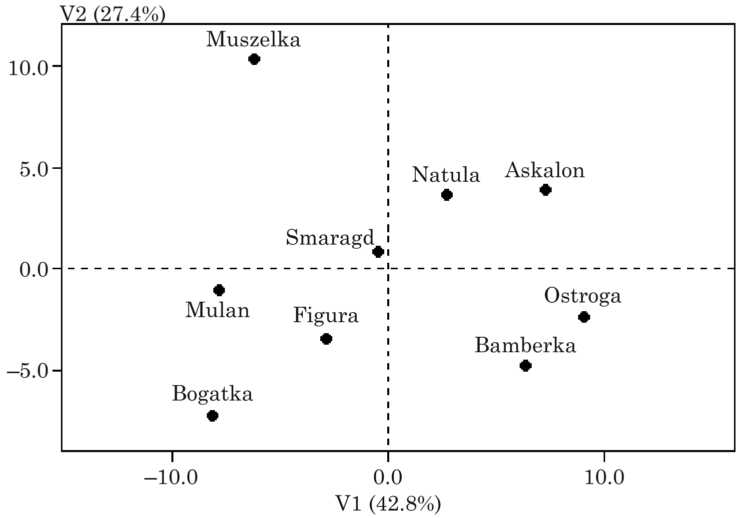

Fig. 4. Representation of cultivars in the system of principal components – intensive tillage mode

by MITTLER (2000). And thus, the wheat cultivars more resistant to water stress during the critical developmental phases are distinguishable by significantly better performance in comparison with other cultivars (GUPTA et al. 2001, FOULKES et al. 2001). Certain breeding programmes are aimed at acquisition of such genotypes that would be characterized by high tolerance to soil salinity and water deficiencies during vegetation (FAROOQ and AZAM 2007). If the genotype variance exceeds the variance of the effects of the interaction (genotype x experimental station), then a breeder can attain good efficacy of selection and obtain breeding lines characterized by high stability in a given region. In a reverse situation, selection of cultivars of narrow adaptation can prove to be a better strategy (GRÜNBERG et al. 2005). The remarkable diversity of environmental conditions in Lower Silesia contributed to occurrence of high interaction of the studied cultivars with the localities both at the intensive and standard tillage mode. A desirable wheat cultivar should be distinguishable by stable performance in all types of environments within the target region and to display high grain yield stability through years (NAVABI et al. 2006). A cultivar which is dynamically stable in each environment produces a grain yield that differs by a constant quantity from the average yield value for all cultivars in a given environment. On the other hand, a statically stable cultivar maintains a constant grain yield level at any location. Frequently, also those cultivars are acknowledged as desirable which are narrowly adapted to a defined environment and exhibit high repeatability of production through years (ANNICCHIARICO et al. 2006).

The advancement in breeding during the last twenty-year span is the main factor behind growing yields. At present, such wheat cultivars are recommended which are characterized by capability of wide adaptation to changeable environmental conditions (the so-called universal) or ones distinguishable by high and stable grain yields within a small acreage. Yet, the significant diversification of climatic conditions within particular regions makes microregionalization (often pertaining to a poviat or even commune territory) gaining in importance. A good choice of localities for wheat cultivars PDO testing in particular voivodeships contributes to more precise delineation of regionalized cultivation. Based on PDO results, it is possible to distinguish cultivars that are recommendable not only at a given tillage mode but also to define their macro- or microregionalization.

Conclusions

1. The significant interaction of the cultivars with the localities indicates their diverse performance.
2. The changeable atmospheric conditions in the three years of study, and particularly water deficit on lighter soils during the plants' vegetation season, brought about lower stability in grain yield by the wheat cultivars in the localities under analysis.
3. Due to the varied number of cultivars studied in the post-registration experiments in each year, the genotype x environment interaction underwent significant changes. Therefore, the number of experimental localities, characterized by changeable soil and atmospheric conditions, should not be reduced substantially.
4. The considerable differences in performance by the cultivars at some locations in comparison with the mean values for Lower Silesia point out to great significance of microregionalization in the acreage of this voivodeship.

Accepted for print 25.01.2017

References

AHMAD R., QADIR S., AHMAD N., SHAH K.H. 2003. *Yield potential and stability of nine wheat varieties under water stress conditions*. Int. J. Agri. Biol., 5(1): 7–9.

ANNICCHIARICO P., RUSSI L., PIANO E., VERONESI F. 2006. *Cultivar adaptation across Italian locations in four turf grass species*. Crop Sci. 46, 264–272.

ALBRIZIO R., TODOROVIC M., MATRYC T., STELLACH A.M. 2010. *Comparing the interactive effects of water and nitrogen on durum wheat and barley grown in Mediterranean environment*. Field Crops Res., 115: 179–190.

BUJAK H., TRATWAL G. 2011. *Ocena stabilności plonowania odmian pszenicy ozimej na podstawie doświadczeń porejestrowych w Polsce.* Biuletyn IHAR 260/261: 69–79.

BUJAK H., TRATWAL G., WEBER R., KACZMAREK J., GACEK E. 2013. *An analysis of spatial similarity in the variability of yields of winter wheat cultivars in Western Poland.* Zemdirbyste Agriculture, 100(3): 311–316.

CALIŃSKI T., CZAJKA S., KACZMAREK Z. 1987. *A model for the analysis of series of experiments repeated at several places over a period of years.* I. *Theory*. Biul. Oceny Odm., 10: 7–33.

CALIŃSKI T., CZAJKA S., KACZMAREK Z. 1987. *A model for the analysis of series of experiments repeated at several places over a period of years.* II. *Example*. Biul. Oceny Odm., 10: 35–71.

CALIŃSKI T., CZAJKA S., KACZMAREK Z. KRAJEWSKI P. 2003. *Podręcznik użytkownika programu SERGEN 4.* Instytut Genetyki PAN w Poznaniu, Katedra Metod Matematycznych i Statystycznych Akademii Rolniczej w Poznaniu, pp. 5–65.

DRZAZGA T., KRAJEWSKI P., ŚMIALOWSKI T., ŚMIAŁEK E. 2011. *Ocena odmian pszenicy ozimej pod względem tolerancji na suszę.* Biuletyn IHAR, 260/261: 135–142.

FAROOQ S., AZAM F. 2007. A *new allopolyploid wheat for stressed lands and poverty alleviation.* Field Crops Res., 100(2–3): 369–373.

FOULKES M.J., SCOTT R.K., SYLVESTER BRADLEY R. 2001. T*he ability of wheat cultivars to with stand drought in UK conditions*. J. Agricul. Science, Cambridge, 137: 1–16.

GONZALEZ A., MARTIN I., AYERBE L. 2007. *Response of barley genotypes to terminal soil moisture stress: phenology, growth, and yield.* Aust. J. Agric. Res., 58: 29–37.

GRÜNBERG W.J., MANRIQUE K., HANG D., HERMANN M. 2005. *Genotype x environment interactions for a diverse set of sweet potato clones evaluated across varying ecogeographic conditions in Peru.* Crop Sci., 45: 2160–2171.

GUPTA N.K., GUPTA S., KUMAR A. 2001. *Effect of water stress on physiological attributes and their relationship with growth and yield of wheat cultivars at different stages*. J. Agronomy & Crop Science, 186: 55–62.

MĄDRY W., IWAŃSKA M. 2011. *Przydatność metod oraz miar statystycznych do oceny stabilności i adaptacji odmian.* Biuletyn IHAR, 260/261: 193–218.

MITTLER S. 2000. *Okovariabilitat von Winterweizen unter Standortbedingungen Nordostdeutschlands.* Dissertation Landwirtschaftlich-Gartnerischen Fakultat der Humbolt-Universitat zu Berlin, pp. 4–155.

MOHAMMADI M., KARIMIZADEH R., SABAGHNIA N., SHEFAZADEH M.K. 2012. *Genotype\environment interaction and yield stability analysis of new improved bread wheat genotypes*. Tur. J. Field Crops., 17(1): 67–73.

NAVABI A., YANG R.C., HELM J., SPANER D.M. 2006. *Can spring wheat-growing megaenvironments in the Northern Great Plants be dissected for representative locations or niche-adapted genotypes?* Crop Sci., 46: 1107–1116.

PODOLSKA G. 2009. *Reakcja odmian pszenicy ozimej na nawożenie azotem w doświadczeniach wazonowych.* Biuletyn IHAR, 253: 83–91.

SALOMON K.F., SMIT H.A., MALAN E., DU TOIT W.J. 2008. *Parametric model based assessment of genotype x environment interactions for grain yield in durum wheat under irrigation*. Inter. J. Plant Prod., 2(1): 23–36.

WEBER R., ZALEWSKI D., BUJAK H., KACZMAREK J., ŚMIAŁEK E. 2011. *Interakcja odmian pszenicy ozimej z warunkami środowiska w kształtowaniu plonowania na podstawie wyników PDO na Dolnym Śląsku*. Annales Universitas Mariae Curie-Skłodowska Lublin, Sectio E: 1–10.