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STABILITY OF YIELD COMPONENTS IN WHEAT (*Triticum aestivum L.*)

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Variability and stability of yield components for the large number of divergent common wheat genotypes originated in different world breeding institutions were studied. Interaction genotype x environment has been evaluated, in different environmental conditions. The experiment was performed using randomized block design in three replications on the experimental field in different environmental conditions. A total number of 60 plants have been analyzed in the full maturity stage. The analyzed

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cultivars showed very significant differences in the average values of analyzed traits. The significant influence of cultivars, year and their interaction on expression of traits was found. The effects of each of analyzed traits on phenotypic variability were different. The most stable genotypes have been determined for analyzed yield component. On the base of stability and phenotypic variability the genotypes can be used as parents in wheat breeding programs.

Key words: AMMI, plant height, harvest index, grain yield per plant, wheat.

INTRODUCTION

Stability and adaptability represent genotype reaction to environmental variation. Adaptability is a natural reaction of genotype in order to survive and reproduce. Stability means very small genotypic reaction to environmental changes, and in a broad sense, could not be considered as evolutionary favorable in natural conditions. However, in agriculture, stability represents desirable reaction of cultivated genotypes, forced and supported by humans, ensuring the similar yield level in different environmental conditions through small genotype-environmental interaction. The border between adaptability and stability is quite hazy, reflecting in different and sometimes mixed up definitions of these two. FEDERER and SCULY (1993) are in favor of further discussions and more suitable definitions. LIN and BINNS (1991, 1994) expressed the opinion that very little evidence of obtaining stable genotypes in breeding programs, according to contemporary definitions, had been given. In practice, in developed breeding programs the concept of creating varieties suitable for precisely defined target regions is a common approach. These target regions called mega-environments (GAUCHE and ZOBEL, 1997), or sub-regions (ANNICCHIARICO, 1997) are of similar environmental, agricultural and economical conditions. The aim of adaptability-stability research of yield, and the yield components, as well, is to find genotypes with desirably small genotype-environmental interaction in these well-defined target regions. That goes for varieties in respect of wide production, as well as, potential parents in breeding programs. According to above mentioned, the issue of defining genotype reaction to environmental variation is very complex. So is the problem of finding the most appropriate model for partitioning trial variation in stability and genotype-environmental interaction studies (LI *et al.*, 2006; MUT *et al.*, 2009). If one decides to use parametric approach, the problem of additive (genotype main effect, and environmental main effect) and multiplicative (genotype-environmental interaction) nature of variation sources requires the combination of additive and multiplicative models in order to partition the total sum of squares in satisfactory way. That is a general idea in combined models commonly consisting of Analysis of variance (ANOVA) as an additive model and linear regression or principal components analysis (PCA) as multiplicative models (FINLAY and WILKINSON, 1963; EBERHART and RUSSEL, 1966; BRADY and GABRIEL, 1978). Finally, the global climatic changes, as well as, climatic changes in the region are influencing the behavior of agricultural plants. The period that experiment was conducted in, was a begging of vivid temperature increment in Serbia (POPOVIC *et al.*, 2009). Studies of varietal variation are needed to comprehend and adequately respond to environmental changes.

The aim of the study is to follow divergent genotype behavior through genotype-environmental interaction, in different environments on the basis of the yield components variation in common wheat.

MATERIALS AND METHODS

Twelve varieties of hexaploid wheat (*Triticum aestivum L.*) were in study, namely, Partizanka (g1), Jugoslavia (g2), Kragujevačka 56 (g3), Lasta (g4) orignated in Serbia, Skopjanka (g5) (F.Y.R.M.), Dobrudža (g6) (Bulgaria), Fundulea 29 (g7) (Romania), Bezostaja 1 (g8), Kavkaz (g9), Mironovskaja 808 (g10) (Russia), Etoile de Choisy (g11) (France), and Blueboy (g12) (U.S.A.). The trial was designed as a randomized block design in three replications, with 20cm row space, and 1.2m long rows, in two localities (Kragujevac and Novi Sad) for three vegetation periods (1994/95, 1995/96 and 1997/98). Environmental conditions in these two localities appeared to be somewhat different since Novi Sad is in northern part of Serbia (N 45^o 15' of latitude, and E19^o 49' of longitude with about 80m of elevation), while Kragujevac lays in the central part of Serbia (N 44^o 02' of latitude, and E20^o 56' of longitude with 186m of elevation), about 160km SE from Novi Sad. Growth conditions are somewhat different in two localities in study. Novi Sad is in the flat area of Vojvodina, south Bačka (Northern Serbia), while Kragujevac is in the valey in the mountain area of Šumadija (Central Serbia). According to long-term results, climatic conditions differ in average rainfalls about 50mm and average year temperature about 1^{o}C, in favor of Kragujevac. Soil structure is distinct, as well. Novi Sad lays on chernozem on loess and loess-like sediments, calcereous, medium deep, while Kragujevac is on soil-vertisol brownized. Analysis of variance (ANOVA) was used for total sum of squares partitioning. For additional informations about nonadditive sorces of total variation observed, principal components analysis (PCA) was conducted. PCA was calculated from correlation matrix to eliminate the influence of different standard deviations. The variances of all variables are equal to 1. Consequently, the total variance in correlation matrix is equal to the number of variables. Two methods were combined to isolate explainable and agriculturally important variation and to examine the nature of genotype-environmental interaction occurred.

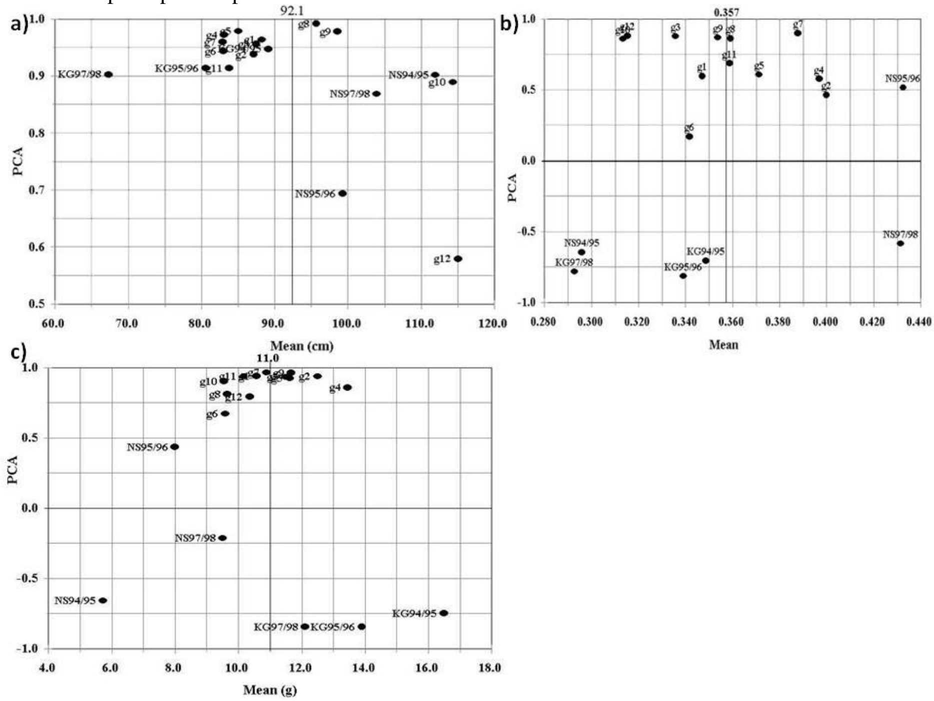
RESULTS AND DISCUSSION

Plant height (PH). This trait was chosen because of its direct effect on genotype-environmental (GE) interaction. The appearance of semi-dwarf wheat genotypes enhanced the interaction between these wheat genotypes and environmental conditions (BRAUN *et al.*, 1992). All the varieties in study belonged to semi-dwarf wheat class expressing the PH from $\overline{x}$= 83cm (Lasta) and $\overline{x}$= 99cm (Kavkaz), except Mironovskaja 808 (Mironovskaya), and Blueboy ($\overline{x}$= 114.4cm, and $\overline{x}$ = 115.0cm, respectively), according to mean values over studied years (tab. 1).

According to ANOVA, partitioning the total sum of squares for the trial revealed that all the main effects (environmental main effect, genotypic main effect) had been statistically highly significant and agronomically important. Environmental sum of squares was additionally partitioned, showing that years, locations, as well as, the interaction between these two main effects, had been highly significant source of variation appeared in the trial. Significant contribution of replication sum of squares to total variation, appeared in consequence of taking replications as a “half factor” depending on year and locality [df = yl (r-1)], instead of treating it as a “full factor” (df = r-1). Nonadditive GE interaction had highly significant share of total sum of squares revealing very rich structure. Though ANOVA, as an additive model, is not suitable for analyzing multiplicative factors, additional partitioning of GE interaction in order to lessen the high degree of freedom value (df = 55), brought up significant F values for the year by genotype (Y x G) interaction, as well as, locality by genotype (L x G) and the year by locality by genotype (Y x L x G) interaction. Second (L x G) of these three, contributed more than a half to GE interaction total sum of squares, giving to locality somewhat more important role as a variation source than to year (tab. 2). These results are in accordance to results obtained for Turkish wheat varieties by AYCICEK and YILIRIM (2006). Their investigation revealed genotype, location and L x G interaction as significant sources of total variation in trial.

In order to analyze the nature of genotype reaction to environmental variation, as well as, to observe some agronomically explainable and important patterns, PCA model was used for further investigation. First PCA axis was retained since it accounted for the most of the variance percentage. According to the biplot, two localities KG, and NS differed more in main effect than in interaction. Wheat varieties in Novi Sad had mean values of PH higher than overall mean, while in Kragujevac the averages through years were lower than grand mean. Locality KG expressed more variability from year to year in main effect, but with quite stable ranking. Consequently, the variation of genotypes in KG locality could be more predictable than in NS. Locality NS differed in main effect, as well as, in interaction (NS 95/96), making that locality somewhat less predictable for the studied trait. Most of the varieties appeared to be similar for the main effect, as well as, interaction. Russian varieties Bezostaja 1 (g8), Kavkaz (g9), and Mironovskaja 808 (g10), as well as U.S.A. variety Blueboy (g12), differed in main effect, from the rest of studied genotypes. Variety Blueboy differed for the interaction, too. Locality NS, generally, went in favor of higher varieties, while environmental conditions in KG locality caused certain stem shortening. Localities favored examined varieties, since the both localities and varieties had positive values of PCA axis). The smallest value of PCA1 revealed variety Blueboy as the most stable, but with somewhat higher PH average (fig. 1a).

Figure 1. Biplot for plant height (a), harvest index (b) and grain yield per plant (c) for 1994/95., 1995/96., and 1997/98 in Kragujevac (KG) and Novi Sad (NS). Genotype codes are listed in Material and Methods values, PCA1 is the first principal component



Harvest index (HI). This “trait” was chosen because it represents plant efficiency in nutritive matter translocation from vegetative to generative plant part. HI is the ratio between grain yield per plant, and the plant weight. Depending on two distinctly quantitative traits, this index carries vast variability. The HI value ranged from $\overline{x} =$ 22.1% for variety Blueboy in NS94/95, to $\overline{x} =$ 55.7%, for the same variety in NS95/96 (tab. 1).

Partitioning the total sum of squares by ANOVA brought forward that all the sorces of variation had statistically highly signifivant F values, except replications. Environmental differences contributed more to total trial sum of squares than genotypic diversity. At a glance, GE interaction made almost 40% of trial variation. Within the interaction, all three sources of variation contributed almost evenly to GE interaction sum of squares (tab. 2).

Table 1. Mean values ($\bar{X}$) for plant height (cm) – PH, for harvest index – HI, and grain yield per plant (g) - GYP for 1994/95., 1995/96., and 1997/98 in Kragujevac (KG) and Novi Sad (NS). Gmean is genotypic mean value. Emean is environmental mean value, PCA1 is the first principal component

Varieties	Localities/vegetation periods and traits																		Gmean		
	KG94/95			KG95/96			KG97/98			NS94/95			NS95/96			NS97/98					
	PH	HI	GYP	PH	HI	GYP	PH	HI	GYP	PH	HI	GYP	PH	HI	GYP	PH	HI	GYP	PH	HI	GYP
Partizanka	90.0	0.37	16.5	76.8	0.31	14.0	56.6	0.31	11.4	104.5	0.36	7.3	99.2	0.35	6.2	102.5	0.39	8.1	88.3	0.35	10.6
Jugoslavija	93.5	0.40	18.0	75.5	0.35	13.9	63.3	0.23	13.2	102.4	0.38	9.2	90.5	0.53	10.5	97.6	0.45	10.2	87.2	0.40	12.5
Kragujevačka 56	83.8	0.36	17.1	74.4	0.36	16.8	70.0	0.28	12.5	103.3	0.29	6.4	99.8	0.30	7.0	93.8	0.43	9.3	87.5	0.34	11.5
Lasta	73.0	0.34	18.9	69.6	0.48	21.1	57.2	0.33	13.8	103.7	0.36	9.5	97.0	0.41	7.2	98.3	0.47	10.3	83.1	0.40	13.5
Skopljanka	80.5	0.40	18.5	75.7	0.35	14.2	61.8	0.38	15.2	100.0	0.33	4.9	97.4	0.30	6.0	95.0	0.46	11.1	85.1	0.37	11.6
Dobrudža	71.5	0.27	10.4	73.4	0.31	11.7	62.1	0.22	10.2	99.9	0.32	5.1	95.5	0.45	9.2	95.6	0.48	11.0	83.0	0.34	9.6
Fundulea 29	73.7	0.41	17.3	75.6	0.42	14.6	61.8	0.30	11.2	104.6	0.27	5.3	90.1	0.48	8.1	91.8	0.44	8.9	82.9	0.39	10.9
Bezostaja 1	93.8	0.35	16.7	76.9	0.27	8.3	63.0	0.26	9.9	121.1	0.30	4.7	110.0	0.55	8.9	109.5	0.43	9.4	95.7	0.34	9.7
Kavkaz	97.8	0.39	18.6	78.3	0.39	16.3	64.6	0.29	12.9	124.3	0.24	3.9	115.9	0.46	8.8	110.7	0.40	9.6	98.6	0.35	11.7
Mironovskaja 808	117.3	0.32	15.6	102.0	0.31	11.0	93.9	0.31	13.3	134.5	0.21	3.7	108.7	0.33	5.3	129.8	0.41	8.4	114.4	0.31	9.6
Etoile de Choisy	69.1	0.33	15.0	72.5	0.34	13.8	54.9	0.32	11.3	116.7	0.27	5.8	80.8	0.48	6.5	108.9	0.42	8.5	83.8	0.36	10.2
Blueboy	125.7	0.26	15.5	116.6	0.23	11.3	98.6	0.23	10.6	128.7	0.22	3.1	106.7	0.56	12.4	114.0	0.40	9.4	115.0	0.32	10.4
Emean	89.1	0.35	16.5	80.6	0.34	13.9	67.3	0.29	12.1	112.0	0.30	5.7	99.3	0.43	8.0	104.0	0.43	9.5	*92.1*	*0.36*	*11.0*
																		$LSD_{0.05}$	4.26	0.04	2.16
																		$LSD_{0.01}$	5.58	0.05	2.83

Table 2. ANOVA for plant height (cm), harvest index , and grain yield per plant (g) for 1994/95., 1995/96., and 1997/98) in, Kragujevac (KG) and Novi Sad (NS)

Source of variation		Plant height (cm)				Harvest index				Grain yield per plant (g)			
	df	SS	MS	F Value	Prob.	SS	MS	F Value	Prob	SS	MS	F Value	Prob
Trial	83	84394.783	12292.653	1736.74	0.0000	1.4190	0.1660	337.11	0.0000	3854.557	614.364	336.82	0.0000
Replication [R (YL)]	12	184.284	15.357	2.17	0.0166	0.0070	0.0010	1.18	0.3011	91.383	7.615	4.17	0.0000
Environment (E)	5	48285.180	9657.036	1364.43	0.0000	0.7020	0.1400	284.50	0.0000	2841.698	568.340	311.51	0.0000
Year (Y)	2	8475.065	4237.533	598.72	0.0000	0.1480	0.0740	150.32	0.0000	3.294	1.647	0.90	-
Location (L)	1	36636.721	36636.721	5176.36	0.0000	0.1930	0.1930	390.67	0.0000	2230.825	2230.825	1222.72	0.0000
Y x L	2	3173.394	1586.697	224.18	0.0000	0.3610	0.1810	365.61	0.0000	607.579	303.789	166.51	0.0000
Genotype (G)	11	27047.241	2458.840	347.41	0.0000	0.1620	0.0150	29.89	0.0000	297.744	27.068	14.84	0.0000
Interaction GE	55	8878.078	161.420	22.81	0.0000	0.5480	0.0100	20.17	0.0000	623.732	11.341	6.22	0.0000
Y x G	22	1947.054	88.502	12.50	0.0000	0.1780	0.0080	16.38	0.0000	173.430	7.883	4.32	0.0000
L x G	11	4536.733	412.430	58.27	0.0000	0.1750	0.0160	32.25	0.0000	218.785	19.890	10.90	0.0000
Y x L x G	22	2394.291	108.831	15.38	0.0000	0.1950	0.0090	17.91	0.0000	231.517	10.524	5.77	0.0000
Error	132	934.256	7.078			0.0650	0.0005			240.830	1.824		
Total	215	85329.039				1.4850				4095.387			

Biplot showed that environmental conditions differed in main effect, rather than in interaction, except NS95/96. Locality KG appeared to be more predictable holding no interaction differences, and expressing differences partly in main effects. Locality NS varied in main effects, as well as, in interaction. Genotypes scattered in the positive part of PCA axis, showing differences in main effect, and interaction, as well. The sensitivity of HI under environmental variation noticed BEDAK *et al.* (1999), and TAYYAR (2008), as well. Environmental conditions were particularly suitable for the examined genotypes (both season and the genotypes had the same PCA sign). This could be connected with weather conditions, causing certain stem shortening, which was favorable for nutritive matter translocation, particularly on a good chernozem soil. Varieties expressed different reaction in PH reducing, consequently that had the impact on HI, as well. In that environmental conditions the best interaction reaction exhibited varieties Jugoslavia (g2), and Lasta (g4), and in some extent Fundulea 29 (g7), being less stable variety, and Skopljanka (g5) being closer to overall average. The most stable genotype appeared to be variety Dobrudža (g6), having a position on PCA axis nearly zero, but with HI value lower than grand mean (fig. 1b).

Grain yield per plant (GYP). All the plant efforts reflect in this trait. Being particularly quantitative,GYP always expresses broad variation due to environmental changes. Therefore, the sensitivity of this trait could be very well used in studying plant reaction to environmental variation. The average values of GYP varied between $\overline{x} = 3.1$g (Blueboy, NS94/95), and $\overline{x} = 21.1$g (Lasta,KG95/96), tab. 1.

Screening the ANOVA results, all the sources of variation were statistically highly significant, except the year influence. It seems that for the variation of the trait in study, locality variation played a crucial role. For that reason, GE interaction sum of square contributed significantly (16%), but in smaller extent to total trial sum of square. Splitting the GE interaction sum of square revealed somewhat greater variation in locality x genotype (L x G), and locality x year x genotype (L x Y x G), than in year x genotype (Y x G) interaction, tab. 2.

According to the biplot, clear differences were noticed between KG and NS site. Generally, KG site showed higher mean values for GYP. That could be in consequence of better vegetative-generative parts ratio in KG, since plants at this locality appeared to be shorter through examined vegetation seasons than in NS. Locality KG differed in main effect, but not in interaction. Holding the similar relative ranking examined varieties made this locality more predictable for GYP. Locality NS expressed diversity in main effect, as well as, in interaction, meaning that seasons affected GYP greatly at the NS site, and the genotypes in study differently reacted to environmental variation, changing rank through seasons. Following the PH and HI results, environmental conditions for GYP were in favor of that trait formation in Novi Sad, 1995/96 (NS95/96), since it had the same sign of PCA axis, as all the genotypes. Varieties varied more in main effect than in interaction, appearing to be of very similar stability for the trait. Somewhat better stability result was obtained for variety Dobrudža (g6), which was in accordance to HI stability a result (fig. 1c).

As a general discussion, it could be stated, that used additive and multiplicative model combination gave satisfactory results in following genotype reaction to environmental changes. Problem is how to fit complex genotype reaction holding more PCA axes in two-way presentation. VAN EEUWIJK and KROONENBERG (1998) noticed that, and it stays for the results in this article, as well. PH, being under major (Rht) and minor gene complex control could fit better in a more simple model, but quantitative trait as GYP, and in particular HI appeared to have more complex reaction to environmental variation, where even three-way model would not be the best model which could be used. More complex models are more precise, but require a presentation not always too clear to follow. In the other hand more simple models are commonly more clear in presentation, but on account of preciseness. The other question is whether stability studies of yield components give usable results. The yield *per se* is the result of all the plant efforts, individually and on a population level. The stability results of this trait could be used in wide production, as well as, in breeding programs in some extent. But stability of the yield components is only a part of overall genotype stability directly and indirectly influenced by vast variation sources. In that respect stability studies of the yield components could be accepted only in a sense of understanding complex genotype reaction to environmental variation, or as an effort seeking for suitable and stable trait markers in early generations for the yield improvement in a breeding process.

CONCLUSION

In a conclusion could be stated that two localities in study were greater source of variation for PH, HI and GYP, than years. This is understandable since weather conditions are only one part of a whole locality variation. Varieties in study were fairly stable, particularly at the Kragujevac site opening a chance of better prediction at that locality. Locality Novi Sad provoked different genotype reaction to environmental changes, but in favorable year conditions, varieties performed better at this site for studied traits. Generally speaking, genotypes reacted similarly to environmental variation for PH, and GYP, differing in main effect, but not in interaction. On the contrary, genotype reaction for HI differed in main effect, as well as, in interaction making phenotypic expression for this trait more unpredictable. Finally, though the vegetation periods covers second half of 90's, the results of the nature of GEI variation are generally applicable in similar agro ecological conditions.

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STABILNOST KOMPONENTI PRINOSA PŠENICE
(*Triticum aestivum L.*)

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I z v o d

U radu je ispitivana varijabilnost i stabilnost većeg broja divergentnih genotipova hlebne pšenice poreklom iz programa oplemenjivanja različitih institucija. Procenjena je varijabilnost interakcije genotipa i spoljne sredine u rezličitim agroekološkim uslovima gajenja. Eksperiment je postavljen po slučajnom blok sistemu u tri ponavljanja u različitim uslovima lokaliteta i godina. Ispitivana kvantitativna svojstva 12 sorti pšenice su značajno varirala pod uticajem genetičke osnove i uslova sredine i iskazale različitu interakciju genotip x spoljna sredina. Utvrđeni su genotipovi stabilne reakcije za ispitivane komponente prinosa. Na bazi iskazane stabilnosti ove sorte mogu da se uzmu u obzir kao roditelji u programima ukrštanja pšenice.

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