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GENOTYPE × ENVIRONMENT INTERACTIONS AND PHENOTYPIC STABILITY FOR WHEAT GROWN IN STRESSFUL CONDITIONS

Borislav BANJAC*, Velimir MLADENOV, Miodrag DIMITRIJEVIĆ, Sofija PETROVIĆ, Jan BOĆANSKI

University of Novi Sad, Faculty of Agriculture Novi Sad

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The objective of this study was to present the results of experiment conducted on 11 cultivars of wheat (*Triticum aestivum* L.) and 1 cultivar of triticale (*Triticosecale* W) on stressful conditions of halomorphic solonetz in Kumane, Banat, Serbia. Across three growing seasons genotypic variability, monitoring of phenotypic variation and genotype by environment interaction (GEI) for number of grains per spike and yield was studied. The cultivar were grown in field trails of control treatment and treatments with measures repairs solonetz using phosphogypsum in the amount of 25 t·ha^{-1} and 50 t·ha^{-1}. GEI was tested using AMMI (Additive Main Effects and Multiplicative Interaction) model. The expression of tested traits were statistically significant and showed additive and non-additive sources of variation. The first source of variation, quantified IPCA$_1$ axis explained most of the structure of GEI.

Key words: AMMI, interaction, solonetz, wheat

INTRODUCTION

Wheat (*Triticum* sp.) is one of the oldest and most important plants in the World. It represents a major crop contributing to the nutrient supply of the world's population. Of the total wheat supply, an average of 53% is consumed as food in the developed countries, and close to 85% in the developing countries (PENA, 2007). Main task in wheat breeding is enhancement features of existing varieties and creation of new genotypes which will have higher yield per unit of area. Of a great significance is growing wheat under unfavorable environmental conditions, such as poor soil quality, because it contributes selecting stable genotypes, which can be used in production. For growing plants halomorphic land is one of the major problems in crop production, because of unfavorable environment. Therefore, great attention should be paid to the creation of wheat genotypes that are resistant to soil salinity. The exploitation of genetic variation of

Corresponding author: Borislav Banjac, University of Novi Sad, Faculty of Agriculture Novi Sad, Sq. Dositeja Obradovića 8, 21 000 Novi Sad, phone: +381 (21) 485 32 99; e-mail:borislav.banjac@polj.edu.rs

phenotypic traits through plant breeding could significantly improve growth of cereals in salinity-affected regions, thus leading to improved crop yields (SHELDEN and ROESSNER, 2013).
Solonetz soils cover large areas around the world. In Europe only, they cover more than 20 million ha (BELIĆ *et al.*, 2012). There are about 80.000 ha of solonetz soil in Vojvodina - a region in the south of the Pannonian basin, in the north of the Republic of Serbia. It is characterized by unfavorable physical and chemical features, caused by high contents of clay and sodium in the $B_{t,na}$ horizon. Ion of sodium causes a strong alkaline reaction and peptization of colloids, which are primary causes of extremely unfavorable chemical, physical, water and air properties of solonetz soils. For those reasons, this soil type is typically used as a natural pasture. The objective of applying reclamation measures to solonetz soils is to change their cation content, which is achieved by decreasing the sodium level and increasing the calcium cation level (Ca^{2+}), which leads to the coagulation of soil colloids. Phosphogypsum application leads to the forming of sodium sulphate (Na_2SO_4), which is leached from the soil profile. The application of phosphogypsum increases the content of Ca^{2+} and decreases the alkaline reaction, thus improving the content and stability of structural aggregates, water and air properties, thermal and nutrient status, and the effective fertility of solonetz soils (BELIĆ *et al.*, 2012).

Yield (YLD) is the most important quantitative trait affected by multiple components. It is a complex trait, which is caused by the influence of genetic factors, external environment as well as their interaction (DIMITRIJEVIĆ *et al.*, 2010). Therefore, it is important to accurately determine the source of variation, their effects on yield and its components and select varieties that have been best adapted to stressful conditions of solonetz. Although for the expression of the number of grains per spike (GPS) are responsible minor genes KOBILJSKI (2000) notes that major *Rht* genes, beside effect to the plant height, affect the number of grains per spike and other quantitative traits of wheat. The number of grains per spike is in direct correlation with yield. Highest yields are achieved in years when genotypes have the highest values of the number of grains per spike (BOKAN and MALEŠEVIĆ, 2004).

The objectives of this research was to determine relative contributions of genotype, environment and their interaction in two most important traits, yield and number of grains per spike, for 12 genotypes tested across 3 years on a stressful conditions of solonetz.

MATERIALS AND METHODS

Plant Material and Field Experiment

Grain samples were obtained from 11 winter wheat cultivars (*Triticum aestivum* ssp. *vulgare* L.) and 1 cultivar of triticale (*Triticosecale* W.), grown in vegetation seasons 2008/09, 2009/10 and 2010/11 on location Kumane (45,539º N, 20,228º E, elevation 72 m). Whole area of field experiment was situated on halomorphic land of solonetz. Since the experiment is set on solonetz, in addition to the results that were analyzed results of the soil in two-level maintenance of 25 $t \cdot ha^{-1}$ and 50 $t \cdot ha^{-1}$ phosphogypsum. Cultivars have diverse pedigrees and represent much of the current elite and historical germplasm grown in Serbia (Table 1).

All cultivars are agronomically suitable for production in this location of Kumane. Triticale was introduced in field experiment as a synthetic species due to of its resistance on stress soil conditions. All cultivars were planted in a randomized complete block design with three replications. Each variety was sawn in eight 12.5 cm spaced rows, 155 m of length. Sowing in all growing seasons was completed by second decade of October, while harvest was ended in first decade of July. Quality tests were performed on the harvested seed of each cultivar for each replication. Each treatment in one growing season is considered a special agro-environment. This produced nine different agro-ecological conditions of cultivation, which were in the same agro-technical terms, but in different treatments of phosphogypsum.

Table 1. Genotype, pedigree of 11 wheat and 1 triticale cultivars and environments description

Genotype	**Pedigree**	**Environment**	
Renesansa	Jugoslavija/NS 55-25	***Code***	***Veg. seasons-Treatments by phosphogypsum***
Pobeda	Sremica/Balkan		
Evropa90	Talent/NSR-2	E1	2008/09-control, non-ameliorated solonetz
NSR-5	NSR1/Tisa//Partizanka/3/Mačvanka 1	E2	2008/09-solonetz ameliorated by 25 $t{\cdot}ha^{-1}$
Dragana	Sremka 2/Francuska	E3	2008/09- solonetz ameliorated by 50 $t{\cdot}ha^{-1}$
Rapsodija	Agri/Nacozari F76//Nizija	E4	2009/10-control, non-ameliorated solonetz
Simonida	NS 63-25/Rodna//NS-3288	E5	2009/10-solonetz ameliorated by 25 $t{\cdot}ha^{-1}$
Cipovka	NS 3288/Rodna	E6	2009/10- solonetz ameliorated by 50 $t{\cdot}ha^{-1}$
Banatka	LV-Banat	E7	2010/11-control, non-ameliorated solonetz
Bankut1205	Bankut 5/Marquis	E8	2010/11 solonetz ameliorated by 25 $t{\cdot}ha^{-1}$
Nevesinjka	Dugoklasa/Jarka	E9	2010/11- solonetz ameliorated by 50 $t{\cdot}ha^{-1}$
Odisej	NSLT 173/87		

Statistical Analyses

Genotype by environment interaction (GEI) was tested using AMMI (Additive Main Effects and Multiplicative Interaction) analysis by ZOBEL *et al.* (1998). Data processing was performed in GenStat 9th Edition (trial ver.) VSN International Ltd (www. vsn-intl.com).

RESULTS AND DISCUSSION

Despite the fact that the main aim of this research was to follow the stability of genotypes, from the perspective of wheat breeding it was very important to consider which varieties reacted favorably to soil amelioration. Regarding this statement the varieties with low and stable reaction on agro-ecological variation were in forefront. In plant breeding programs, analysis of the GEI is based on the examination of the variety across number of years/locations with a goal that interaction will represent the heterogeneity of agro-ecological conditions. Significant differences for genotypes, environments and GE interaction indicated the effect of environments in the GE interaction, genetic variability among the entries and possibility of selection for stable genotypes (FARSHADFAR *et al.* 2011).

Since the yield represents a complex of traits and knowing the fact that its expression is determined with large number of components, the contribution of each individual component may vary in the different environmental conditions. If cultivars were considered, number of grains per spike, grain weight per spike and especially grain yield were more drought sensitive than plant height and number of spikelets per spike. Consequently, the effect of drought stress was manifested in lower number and weight of grain per spike as well as in grain yield, and a slight increase in the number of sterile spikelets per spike (DENČIĆ *et al.* 2000).

Analysis of variance for GPS showed approximately equal influence of genotype and environmental factors on the development for number of grains per spike. In addition, genotype contributed with 30.63%, and environment with 27.84% of the total variation of the experiment. AMMI analyses revealed complex nature of GEI and 6 statistically significant principal components were allocated. The first source of variation, quantified $IPCA_1$ axis was also the largest 39.11% share in the sum of squares (Table 2). In accordance with PETROVIĆ *et al.* (2009) analysis of variance showed significant genotype by environment interaction, where all agronomical explainable variance was brought out by the first PCA including number of grain per spike.

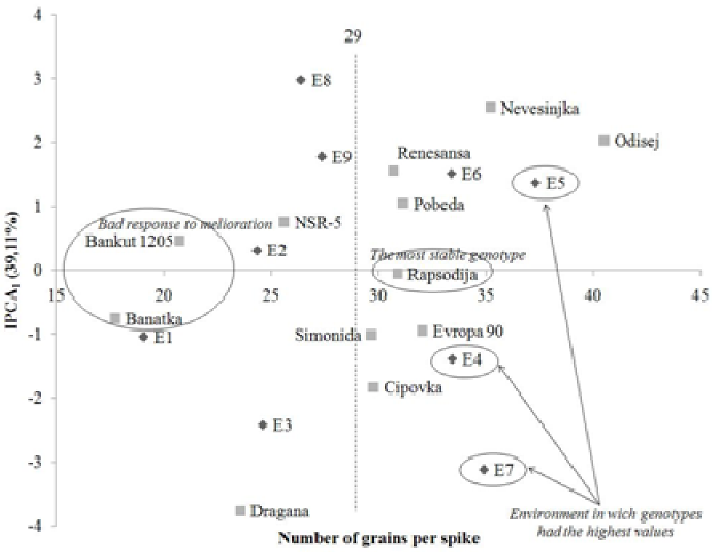
Table 2. AMMI analysis of variance for the number of grains per spike of 11 wheat and 1 triticale cultivars examined across 9 environments

Source[1]	***df***	***SS***	***MS***	***F-value***	***Prob.***	***The share of total variation %***
Total	323	37780	117,0	-	-	100
Treatments	107	31439	293,8	10,49	0,000**	83,22
Genotypes	11	11572	1052,0	37,56	0,000**	30,63
Environments	8	10516	1314,5	29,74	0,000**	27,84
Blocks	18	796	44,2	1,58	0,069 ns	2,11
Interactions	88	9352	106,3	3,79	0,000**	24,75
$IPCA_1$	18	3658	203,2	7,26	0,000**	39,11
$IPCA_2$	16	2086	130,4	4,65	0,000**	22,31
$IPCA_3$	14	1230	87,9	3,14	0,000**	13,52
$IPCA_4$	12	962	80,2	2,86	0,002**	10,29
$IPCA_5$	10	721	72,1	2,57	0,006**	7,71
$IPCA_6$	8	492	61,5	2,20	0,029*	5,26
$IPCA_7$	6	135	22,5	0,80	0,568 ns	1,44
Residuals	4	68	16,9	0,60	0,660	-
Error	198	5545	28,0	-	-	-

[1] All sources were tested in relation to the error

ns non-significant ; * p<0,05; ** p<0,01

Schedule of points representing agro-ecological environments and genotypes indicates high variability in the number of grains per spike. Genotypes Banatka and Bankut 1205 had the lowest values for number of grains per spike and did not react positively to the repairation of soil. If we consider differently negative reaction to repairation of soil represents stable reaction in the most unfavorable conditions in first year of experiment from a local population Banatka and old cultivar Bankut 1205. Observing clustering growing seasons its quite obvious that the highest averages were achieved in the second, and the least in the first season. The second growing season (2010/11) made the largest contribution to the GEI considering the distance of points E7 and E8 from the axis of stability. Treatment with 25 t·ha^{-1} phosphogypsum in the first growing season of the study was the most appropriate for achieving a stable response, but not satisfying the average in terms for number of grains per spike. Across the three years of field experiment genotype Rapsodija was the most stable (Graph 1).



Graph 1. AMMI 1 biplot of 11 wheat and 1 triticale cultivars across 9 environments for theestimation of GE interaction for number of grains per spike

AMMI analyses for YLD revealed that the agro-ecological environment were an important source of variation. This results are in accordance with MLADENOV *et al.* (2001) and DIMITRIJEVIĆ *et al.* (2011). They stated that factors of environment had larger effect than genotype. Results of AMMI analyses showed that the share of the main effects in the total sum of squares was 45.28% (Table 3). Out of that the share of agro-ecological environment was 30.57%, genotype effects was 14.71%, while the GEI represented 35.94%. Differences in growing seasons and diversity of treatments, caused a considerable sum of squares for environmental factors in the total variation and and indicates that these factors were the most responsible for the variation of YLD. Sum of squares of GEI is 2.4 times higher than the sum of the squares for genotype, meaning that between genotypes were significant differences in behavior in different agro-ecological environments. In further analysis from the sum of squares for GEI has been allocated six major components, and the first ($IPCA_1$) explains about 63.4% of the structures of interaction. The second principal component ($IPCA_2$) contained about 14.2% of the sum of squares of the interaction.

Table 3. AMMI analysis of variance for yield of 11 wheat and 1 triticale cultivars examined across 9 environments

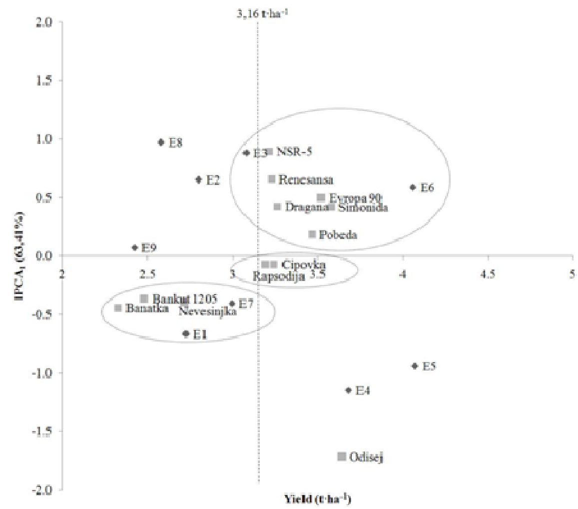
Source[1]	***df***	***SS***	***MS***	***F***	***p***	***The share of total variation%***
Total	323	369,80	1,145	-	-	100
Treatments	107	300,35	2,807	8,80	0,000**	81,22
Genotypes	11	54,40	4,945	15,51	0,000**	14,71
Environments	8	113,04	14,130	40,34	0,000**	30,57
Blocks	18	6,30	0,350	1,10	0,356 ns	1,70
Interactions	88	132,91	1,510	4,74	0,000**	35,94
$IPCA_1$	18	84,28	4,682	14,68	0,000**	63,41
$IPCA_2$	16	18,95	1,184	3,71	0,000**	14,26
$IPCA_3$	14	12,70	0,907	2,85	0,001**	9,56
$IPCA_4$	12	7,49	0,624	1,96	0,030*	5,64
$IPCA_5$	10	6,12	0,612	1,92	0,045*	4,60
$IPCA_6$	8	1,97	0,246	0,77	0,628ns	1,48
Residuals	10	1,41	0,141	0,44	0,924ns	-
Error	198	63,14	0,319	-	-	-

[1] All sources were tested in relation to the error
ns non-significant ; * p<0,05; ** p<0,01

High share of GEI was determined by SINGH *et al.* (2009) also using AMMI analyses in wheat. Results were in accordance with MLADENOV *et al.* (2012) and high share of the first principal component in the overall GEI was confirmed by AMMI analysis of yield in wheat and share of IPCA1 was around 57%. Average values for YLD were ranged from 2.4 $t \cdot ha^{-1}$ in treatment with 50 $t \cdot ha^{-1}$ phosphogypsum, across 2010/2011 to 4.1 $t \cdot ha^{-1}$ in the ameliorated soil during the growing season 2009/2010.

AMMI1 biplot showed that the maximum distance from the average (3.16 $t \cdot ha^{-1}$) had cultivar Banatka and at the same time this cultivar had highest distance from the $IPCA_1$ (Graph 2). This can be explained by the fact that the yield of this variety is very variable and that this cultivar can be considered as a very unstable in terms of amelioration repair solonetz with low yield. Similar behavior to Banatka was manifested by cultivars Bankut 1205 and Nevesinjka. Highest YLD was achieved by cultivar Odisej. This cultivar is triticale so it was expected knowing the fact that this species was more resistant to harmful environmental conditions than the others from experiment. However, this does not favor this variety compared to the others, concerning great variation to the environment.

Small GEI values and YLD on the average level, was achieved by cultivars Cipovka and Rapsodija. Exatcly for these reasons reffered cultivars stand out as a most stable and most suitable for growing on solonetz. Highest yield and a solid stability was achieved by cultivar Pobeda. Observing schedule of genotypes compared to different levels of repair solonetz, it can be concluded that across growing seasons 2008/2009 and 2009/2010 on the treatment of phosphogypsum 50 $t \cdot ha^{-1}$ highest yields for the most genotypes were achieved. (Pobeda, Simonida, Dragana, Evropa 90, Renesansa and NSR-5). Some genotypes better utilized reduced conditions of solonetz to achieve the highest YLD. These statements were in accordance with the results of DIMITRIJEVIĆ *et al.* (2010).



Graph 2. AMMI 1 biplot of 11 wheat and 1 triticale cultivars across 9 environments for the estimation of GE interaction for yield

CONCLUSION

Through experiment and examination of genetic variation and GEI on solonetz without repairs and soil with different amounts of phosphogypsum, it was shown that there was a distinct reaction of wheat genotypes at the level of repairs. For grain yield across all three growing seasons multivariate testing component was more pronounced than additive. The most stable genotypes were Cipovka and Rapsodija recording IPCA1 values close to zero and with average values for YLD. Consequences of soil reparation indicated that the cultivars responded well to melioration solonetz and that was confirmed through the fact that all environments were on the positive side of absciss axes. For both examinated traits, YLD and GPS, better stability was recorded among local population Banatka and old cultivar Bankut 1205. This fact indicates that these genotypes were better adapted to stressful conditions of abiotic stress solenetz, in comparison to new cultivars. The results could help in the process of breeding new wheat genotypes, with aim to grow them on a soil with higher concentrations of sodium and unfavorable physical properties. For growing wheat on solonetz cultivars Banatka and Bankut 1205 will be a good sources of genes for future breedings.

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INTERAKCIJA GENOTIP × SPOLJNA SREDINA I FENOTIPSKA STABILNOST PŠENICE GAJENE U STRESNIM USLOVIMA

Borislav BANJAC*, Velimir MLADENOV, Miodrag DIMITRIJEVIĆ, Sofija PETROVIĆ, Jan BOĆANSKI

Univerzitet u Novom Sadu, Poljoprivredni fakultet, Srbija

Izvod

U radu su prikazani rezultati ogleda sa jedanaest sorti pšenice (*Triticum aestivum* L.) i jednom sortom tritikalea (*Triticosecale* W.) u stresnim uslovima na lokalitetu Kumane u Banatu, u Srbiji, na halomorfnom zemljištu tipa solonjec. Tokom tri vegetacione sezone ispitana je genotipska varijabilnost, praćenjem fenotipske varijacije i interakcije genotip×spoljna sredina za broj zrna po klasu i prinos ispitivanih genotipova. Ogled je postavljen na kontrolnoj varijanti i tretmanima sa merama popravke solonjeca uz primenu fosfogipsa u količini od 25 $t \cdot ha^{-1}$ i 50 $t \cdot ha^{-1}$. Za analizu interakcije genotipa i spoljne sredine je primenjen Model glavnih efekata i višestruke interakcije- model AMMI (Additive Main Effects and Multiplicative Interaction). U ekspresiji oba ispitivana svojstva, statističku značajnost su pokazali i aditivni i neaditivni izvori varijacije. Prvi izvor varijacije, kvantifikovan na $IPCA_1$ osi objasnio je najveći deo strukture interakcije genotip×spoljna sredina.

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