

## STABILITY OF GRAIN YIELD PERFORMANCE OF WINTER WHEAT GENOTYPES

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### Abstract

Bread wheat is one of the most represented field crops whose level and stability of yield is very important for the food security in Republic Serbia. In the paper was investigated stability of yield expression of 15 winter bread wheat genotypes in different agroecological conditions of Serbia, using the Additive main effects and multiplicative interaction (AMMI) model and GGE-biplot method of analysis. Aim of investigation was to determine which of applied analysis is superior in identification of the most desirable genotypes for cultivation in given environments. Analysis of variance showed that genotype and genotype-environment (G×E) interaction represent highly significant sources of variability in expression of grain yield. AMMI and GGE analyses were point out similar results and an indisputable conclusion is that multienvironment trials, besides routine usage of analysis of variance, must be analyzed with one of this two models, which combine analysis of variance and PCA analysis. AMMI analysis is simpler for interpretation and closer to the concept of view of the agronomical trial, while GGE analysis is more complex and gives more precise interpretation of “*which-won-where*“, i.e. for defining of narrowly adapted genotypes in given environments. Thus, G11 as the genotype with highest average yield is narrow adapted to the environment Sombor and can be recommended, as well as in the environment 2 (Kruševac), while genotypes with modest requests (G2) rather can be recommended for cultivation in the environment 1 (Kragujevac), which is characterized by less fertile soil and a smaller amount and uneven distribution of precipitation.

**Keywords:** adaptability, genotype × environment interaction, stability, wheat, yield

### Introduction

Bread wheat (*Triticum aestivum* ssp *vulgare*) represents the highest step on the evolutionary road of the genus *Triticum*. During spontaneous hybridization in natural conditions, from economically less important species (*Aegilops speltoides*, *Triticum urartu* and *Aegilops tauschii*), allo-hexaploid hybrid appeared, with high variability and great potential for genetic improvement. During the natural selection and selection by humans,

well-known plant species were differentiated, characterized by excellent yield and technological quality of the grain, in the first place. Overall average wheat yield in the world increased by more than 250% in the second half of the 20<sup>th</sup> century (Calderini and Slafer, 1998), 1.1% yr<sup>-1</sup> in US Central Plains from 1992 to 2014 (Rife et al., 2019) or 45.5 kg ha<sup>-1</sup> yr<sup>-1</sup> in Southern Pannonian Plain between 1930 and 2015 (Miroslavljević et al., 2020). Very high yield

Originalni naučni rad (Original Scientific Paper)

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variability was observed by years and environments at the beginning of the 21<sup>st</sup> century and possible causes were of genetic, agronomic or climatic nature.

The main factor in this improvement was represented by selection of cultivars with lower stem and greater earliness, higher grain number per area, better harvest index and tolerant to numerous biotic and abiotic stresses (Liu et al., 2017). Calderini et al. (2013) pointed out that the most important genetic advance was achieved by breeding of yield components forming during vegetative period of wheat development in favorable conditions (spikes number per area and grain number per spike), compared with grain weight, component which was formed in unfavorable conditions of temperature and moisture.

High yield potential of wheat genotype represents his ability to capture natural resources efficiently and produce the highest yield in a target environment (Senapati and Semenov, 2020). The true value of genotype depends not only on productivity or expression of individual characteristics, but also on the ability to realize this traits at a high level in different, often unfavorable agroecological conditions (Hristov et al., 2007). According to genotype adaptability, selection of wheat genotypes is carrying out in optimal or less favorable environment conditions, depending on whether the goal of selection were wide or narrow adaptability. An ideal genotype with wide adaptability, generally show low genotype by environment ( $G \times E$ )

interaction variance, above average response to environmental yield potential and lower deviations from the expected response within a target environment (Arain et al., 2011).

Aiming the accurately evaluation of values of every genotype and environment, Studnicki et al. (2016) were highlighted necessity of monitoring the effects of genotype and  $G \times E$  interaction, as the two most important sources of variation in total phenotypic variance. The aim of examination of yield and yield components is to find genotypes with small interaction through performance analysis of different genotypes in different environments (Dimitrijević et al., 2011). Genotypes of wide adaptability in different agro-ecological conditions represent the best parents for future crosses due further genetic improvement (Ljubičić, 2022). The base for these studies were multi-environment yield trials including different numbers of cultivars and conducted during one or few years. Various statistical methods (univariate and multivariate) were used for analysis of yield stability.

The objective of our study was to analyze the expression of yield stability of different wheat genotypes based on the Additive main effects and multiplicative interactions (AMMI) model and Genotype plus genotype-by-environment (GGE) biplot method to conclude the most suitable statistical tools for the choice of candidates for the process of cultivar approval and usage for breeding purposes in the future.

## Material and methods

Research material was represented by 14 genotypes of winter bread wheat (*Triticum aestivum* spp *vulgare*), selected in the Center for Small Grains and Rural Development in Kragujevac, Serbia. Cultivar Pobeda was used as a check cultivar, selected at the Institute of Field and Vegetable Crops in Novi Sad. The research was conducted on the trial fields of the Center for Small Grains and Rural Development in Kragujevac, Institute for forage crops in Kruševac and Agrounstitute in Sombor, during the season 2018/2019. Trials were carried

out according to a completely randomized block design, in three replications, with a plot size of 5 m<sup>2</sup>. Machine sowing was conducted, wherein 10 rows were sowed within the plot, with 10-12 cm row spacing.

The most important climate indicators (average temperatures of air and precipitations) during period of investigation and period of 20 years were presented in Figure 1. The main characteristic was extremely large amount of precipitations in May and June in Kragujevac and Sombor, compared with 20-years average.

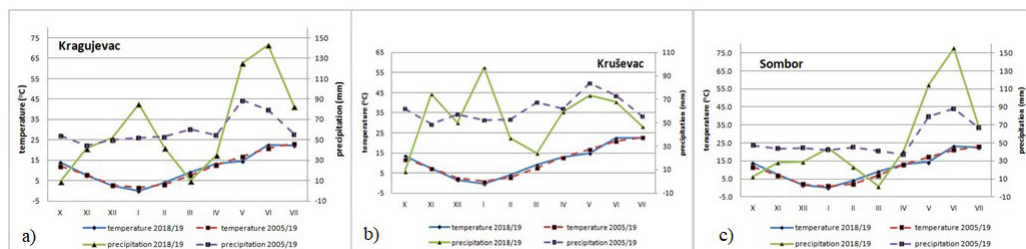


Figure 1. Average temperatures of air and precipitations during 2018/2019 and 15-years (2005-2019) in Kragujevac (a), Kruševac (b) and Sombor (c)

Grafikon 1. Prosečne temperature vazduha i padavine u 2018/2019 i 15-godišnji period (2005-2019) u Kragujevcu (a), Kruševcu (b) i Somboru (c)

Recorded data were used for the calculation of arithmetic mean and coefficient of variation (Zar, 2010). The AMMI model combines analysis of variance and analysis of principal components in the unique model, with additive and multiplicative parameters. The AMMI model is based on equation (Gauch and Zobel, 1996):

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum_n \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger} \quad (1)$$

$Y_{ger}$  – the observed yield of genotype  $g$  in environment  $e$  for replicate  $r$ ,  $\mu$  – the grand mean,  $\alpha_g$  – the deviation of genotype  $g$  from the grand mean,  $\beta_e$  – the deviation of environment  $e$  (additive parameters),  $\lambda_n$  – the singular value for interaction principal component axis (IPCA)  $n$ ,  $\gamma_{gn}$  – the genotype eigenvector for axis  $n$ ,  $\delta_{en}$  – the environment eigenvector (multiplicative parameters),  $\rho_{ge}$  – residuals of variability not covered by model,  $\varepsilon_{ger}$  – experimental error.

Analysis of variance was conducted according to a completely randomized block design (Johnson and Bhattacharyya, 2010). The variance of G×E interaction was divided into the first two principal components, IPCA1 and IPCA2. Also, for every examined wheat genotype principal components of interaction were established, where the stability level was determined by the AMMI1 method. As an additional parameter of stability was used AMMI stability value (ASV) according to Purchase (1997):

$$ASV = \sqrt{\frac{SS_{IPC1} * (IPCA1)^2 + (IPCA2)^2}{SS_{IPC2}}} \quad (2)$$

ASV – AMMI stability value, SS – a sum of squares; IPCA1 – the first interaction principal component axis, IPCA2 – the second interaction principal component axis.

In the analysis of stability and for insight in dispersion of examined genotypes, environments and their mutually interaction AMMI1 biplot was used, where x-axis showing main additive effects of genotypes and environment, while y-axis showing multiplicative effects of G×E interaction, contained in the first PC component (IPCA1) (Hongyu et al., 2014).

With aim of additional and precise evaluation of wheat genotypes and environments, GGE-biplot analysis was applied according to Yan and Kang (2003), based on the model:

$$\hat{Y}_{ij} = \mu + \alpha_i + \beta_j + \Phi_{ij} \quad (3)$$

$\hat{Y}_{ij}$  – expected yield of genotype  $i$  in environment  $j$ ,  $\mu$  – grand mean of all observations,  $\alpha_i$  – effect of genotype  $i$ ,  $\beta_j$  – effect of environment  $j$ ,  $\Phi_{ij}$  – interaction of genotype  $i$  and environment  $j$ .

Variability of grain yield expression (due to the effects of genotype and G×E interaction) was represented graphically by the GGE-biplot method. Biometrical analysis of recorded data was based on the application of statistical software GenStat 12<sup>th</sup>, 2009.

## Results and discussion

The most yielding genotypes in Kragujevac, Kruševac and Sombor were G5 (5.250 t ha<sup>-1</sup>), G3 (5.400 t ha<sup>-1</sup>) and G11 (7.200 t ha<sup>-1</sup>), respectively. The greatest average grain yield for all observed environments (Table 1), was expressed by genotype G11 (5.742 t ha<sup>-1</sup>). The lowest value of the coefficient of variation was expressed by genotype G13 (5.47%), while the greatest variability was found for genotype G2 (21.89%).

Sharifi et al. (2017) highlighted that a genotype is more specifically adapted to certain environments in the case of larger IPC score, either negative or positive. Smaller ASV scores indicate a more stable genotype across environments. In our investigation, the most yielding genotype G11 expressed the highest value of AMMI stability value which represents his narrow adaptability to the environments with optimal growing conditions. The most sta-

ble genotype in investigation was G12 which shown the lowest value of ASV accompanied with low average grain yield. G4 and G10 were genotypes with wide adaptability and suitable for cultivating in vast range of environments considering that they possess low ASV values and good average grain yields (Table 1).

The analysis of variance pointed out statistically very significant effects of genotypes, environments and GEI in the expression of grain yield (Table 2). Contributions of genotypes, environments and GE interaction in variations in the total sum of squares were 33.83%, 16.51% and 33.96%, respectively. The investigation of Kaya and Akcura (2014) established that the greatest part of sum of square was attributed to effect of environment (70.20%), while effects of genotype (17.0%) and G×E interaction (12.80%) were smaller.

Table 1. Mean value ( $\bar{x}$ ), coefficient of variation (CV), IPCA1 and AMMI stability value (ASV) for grain yield (t ha<sup>-1</sup>)

Tabela 1. Prosečna vrednost ( $\bar{x}$ ), koeficijent varijacije (CV), IPCA1 i AMMI vrednost stabilnosti (ASV) za prinose zrna (t ha<sup>-1</sup>)

Genotype	Kragujevac (1)	Kruševac (2)	Sombor (3)	$\bar{x}$	CV %	ASV
G1	3.867	4.400	4.633	4.300	8.36	0.298
G2	4.758	3.133	4.967	4.286	21.89	0.914
G3	4.275	5.400	5.167	4.947	11.57	0.633
G4	4.625	5.333	5.433	5.131	9.94	0.397
G5	5.250	4.200	4.333	4.594	11.84	0.990
G6	4.608	4.067	4.700	4.458	7.67	0.395
G7	3.867	4.533	4.100	4.167	9.73	0.587
G8	3.892	4.400	5.700	4.664	20.15	0.692
G9	4.567	4.000	4.200	4.256	10.25	0.636
G10	4.883	4.867	6.033	5.261	11.89	0.327
G11	4.692	5.333	7.200	5.742	21.72	1.125
G12	4.475	4.467	5.133	4.692	9.00	0.012
G13	4.267	4.133	4.333	4.244	5.47	0.378
G14	4.425	3.667	4.600	4.231	13.91	0.449
G15 (check)	4.125	4.800	6.133	5.019	19.16	0.814
Average				4.666	12.84	

Table 2. Analysis of variance of AMMI model for grain yield  
 Tabela 2. Analiza varijanse AMMI modela za prinosa zrna

Source of variation	df	MS	F	F_prob
Genotypes	14	1.956	14.31**	0.00000
Environments	2	6.685	32.63**	0.00000
Blocks	6	0.205	1.50 <sup>ns</sup>	0.18856
GE interaction	28	0.982	7.19**	0.00000
IPCA1	15	1.183	8.65**	0.00000
IPCA2	13	0.750	5.49**	0.00000
Error	84	0.137	*	*
Total	134	0.604	*	*

AMMI analysis of principal components, IPCA1 and IPCA2, was conducted since existence of significant effect of GEI was established. There were recorded highly significant effects of both principal components, wherein IPCA1 covered 64.55% from sum of square of interaction variance, while IPCA2 explained additional 35.45%. Similar conclusions were drawn by Mohamed et al. (2013), Szarecki et al. (2018), and Gupta et al. (2022).

The most stable genotypes, with average grain yield above the average value of trial, have proved to be G12, G4, G3 and G10, indicating their wide adaptability and the possibility of growing in areas with different environmental conditions. Genotype G11, as the most yielding in all tested environments, was char-

acterized by specific, narrow adaptability (Figure 2). A similar can be said for G15, which showed high interaction and an above-average yield. Besides this, genotypes G8 and G5 also belong to the group of genotypes with a positive response to optimal growing conditions and intensive crop management application (in Sombor and Kruševac) (Perišić, 2016). Luković et al. (2020) highlighted the significant adaptability and stability of grain yield of wheat genotypes selected at the Center for Small Grains in Kragujevac (Serbia) in a year with extreme wet conditions in the period of intensive wheat development.

GGE biplot analysis pointed out that nearest to the origin was the genotype G12 and it was the most stable examined genotype with

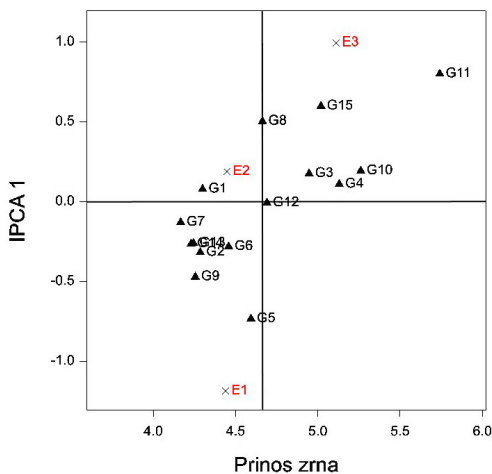


Figure 2. AMMI1 biplot analysis of stability for grain yield  
 Grafikon 2. AMMI1 biplot analiza stabilnosti za prinosa zrna

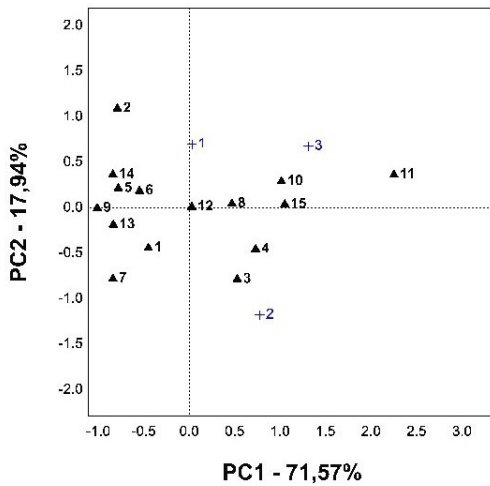


Figure 3. The GGE-biplot genotype-focused scaling for yield performance  
 Grafikon 3. GGE- biplot raspored genotipova prema ostvarenom prinosu

grain yield on the level of trial average (Figure 3). Also, the high stability for grain yield was expressed by genotypes G8, G15 and G10, while the least stable were genotypes G2 and G3. The highest-yielding genotype G11 expressed a satisfactory level of stability which was opposite to the conclusion from the AMMI model. Genotypes of interest in investigation are genotypes with high values of PC1 component and with values of PC2 component close to the zero. Such genotypes are characterized by wide adaptability unlike of genotypes with specific adaptability which are located far away from coordinate origin. Yan et al. (2007) pointed out that the GGE biplot is superior to the AMMI1 graph in mega-environment analysis

and genotype evaluation because it explains more G+GE.

In the total GGE variance for grain yield, first principal component PC1 was covered 71.57%, while the second principal component PC2 explained additional 17.94% (89.51% in total). Similar findings of principal components values in the total GGE variance were obtained by Hagos and Abay (2013), Gupta et al. (2022).

Dispersion of points on GGE-biplot (Figure 4) indicate large differences in average values for grain yield between examined genotypes, but also between examined environments. Genotypes located on the angles of created polygon represent the best or the worst genotypes in one or few sectors. In this investigation five

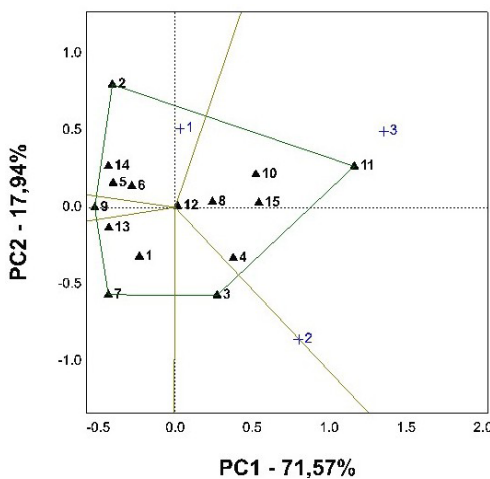


Figure 4. The "which-won-where" polygon of the GGE biplot for grain yield  
 Grafikon 4. „Gde-ko –pobeduje“ poligon na GGE biplotu za prinosa zrna

sectors were occurred. The environments E1 and E3 were located in two different sectors while environment E2 was located between two sectors. Genotype G11 was belonging to the same sector as environment E3 and represent vertex genotype which means it the was specifically adapted to this environment. This genotype will be the high yielding genotype in this and other similar mega-environments. Within this sector, better grain stability and grain yield performance above the average value of trial were established by genotypes G12, G8, G15 and G10. Genotypes G3 as vertex genotype, and G4 were the best-adapted genotypes for Kruševac (E2) and represented the highest yielding genotypes for this environment. Fur-

thermore, since E2 was located between two sectors, genotype G11 also possesses good adaptability to grow in this environment conditions. According to the yield performance of examined wheat genotypes in Kragujevac (E1), a conclusion can be drawn that this environment was characterised as favourable for genotypes with stable performance and grain yield below the average grain yield of the trial (G2, G14, G5, and G6). Reasons for such performance of genotypes were low soil fertility (Perišić, 2016) and according to this, detrimental effect on main yield components and grain yield itself, where low-yielding genotypes were expressed better adaptability.

## Conclusions

The results of the investigation e indicated that the grain yield of examined wheat genotypes was highly influenced by G×E interaction effects. According to AMMI analysis of grain yield expression, the most stable genotypes have proved to be G12, G4, G3 and G10, indicating their wide adaptability and the possibility of growing in areas with different environmental conditions. Genotype G11 with

the highest average yield was characterized by specific, narrow adaptability. GGE biplot analysis pointed out that the most stable were genotypes G12, G8, G15 and G10 with grain yield above the trial average. Opposite to the conclusion from the AMMI model, the highest yielding genotype G11 expressed satisfactory level of stability according to GGE biplot analysis.

## Acknowledgements

This research was supported by the Ministry of Education, Science and Technology Development of the Republic of Serbia, according

to the Contract on realization and financing scientific research organizations in 2022, No 451-03-9/2021-14/200216.

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# STABILNOST PRINOSA ZRNA GENOTIPOVA OZIME PŠENICE

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## Sažetak

Hlebna pšenica je jedna od najzastupljenijih ratarskih vrsta, čiji je nivo i stabilnost prinosa veoma važan za prehrambenu sigurnost Republike Srbije. U radu je ispitivana stabilnost ekspresije prinosa zrna 15 genotipova ozime hlebne pšenice u različitim agroekološkim uslovima Srbije, korišćenjem AMMI modela i GGE-biplot analize. Cilj je bio da se utvrdi koja od primenjenih analiza je superiornija u identifikaciji najpoželjnijih genotipova za gajenje u datim sredinama. Analiza varijanse je pokazala da genotip i interakcija genotip-sredina ( $G \times E$ ) predstavljaju veoma značajan izvor varijabilnosti pri ekspresiji prinosa zrna. AMMI i GGE analize su dale slične rezultate, pa je nesporan zaključak da je neophodno višelokacijske ogleda, pored analizom varijanse koja se najčešće rutinski koristi, analizirati i jednim od ova dva modela, koji kombinuju analizu varijanse i PCA analizu. AMMI analiza je jednostavnija za interpretaciju i bliža je agronomskom konceptu poimanja ogleda, dok je GGE analiza kompleksnija i jasnija za interpretaciju gde ko pobeđuje, odnosno za definisanje usko prilagođenih genotipova datim sredinama. Tako G11, kao genotip sa najvećim prosečnim prinosom je usko prilagođen lokaciji Sombor, pa se prevashodno može preporučiti toj lokaciji ali i lokaciji 2 (Kruševac), dok se genotipovi skromnijih zahteva (G2) pre mogu preporučiti za gajenje u lokaciji 1 (Kragujevac), koja se odlikuje lošijim zemljištem i manjom količinom i lošijim rasporedom padavina.

**Ključne reči:** adaptabilnost, interakcija genotip-sredina, pšenica, prinos, stabilnost

Primljen: 23.11.2022.  
Prihvaćen: 05.12.2022.