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THE APPLICATION OF AMMI MODEL FOR BARLEY CULTIVARS EVALUATION IN MULTI-YEAR TRIALS

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The interpretation of new varieties performance is disturbed under the influence of genotype-by-environment interaction. Among several methods used for understanding this effect, one of the most frequently used methods is Additive Main Effects and Multiplicative Interaction (AMMI) analysis. In this study we used AMMI method with the aim to estimate the genotype - environment interaction of 14 barley genotypes, and to identify barley genotypes that have high and stable performance in different environments. The trials were conducted during 11 growing seasons (1995/96 - 2005/06), arranged in a randomized complete block (RCB) design with four replications in location Rimski Šančevi. The results showed that the influence of environment (seasons), genotypes and their interaction on barley grain yield were significant ($p < 0.01$). Based on AMMI method, two-rowed variety Novosadski 317 and the six-rowed variety Novosadski 331 can be distinguished due their high and stable yields.

Key words: AMMI analysis, *Hordeum vulgare* L., Genotype by environment interaction, Grain yield.

INTRODUCTION

According to the Food and Agriculture Organization of the United Nations (FAO), as one of the most widespread crops in the world, barley (*Hordeum vulgare* L:) was grown on about 49 million hectares in 2012 (FAOSTAT, 2012). For the past five years (2008-2012), European countries such as Russia, Ukraine, Germany and France have been the main global barley producers. Barley is also an important crop in other European countries, and in Serbia it is grown

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on about 100 000 ha across the country. Production conditions in this part of Europe vary considerably among regions and different growing seasons. Climate change has a strong impact on crop growth and temperature and rainfall variations from optimal conditions can considerably impair the crop yields.

The success of genetic improvement of newly created barley cultivars is based on the identification of genotypes adapted to diverse conditions with a stable and high performance. In the process of creating new genotypes, it is necessary to examine their response to different environmental effects. The interpretation of the new varieties performance is a complex process, due to the presence of the interaction between genotype and environment (GEI). GEI involves changes in cultivar or hybrids rank in different agro-ecological environments (KANG, 2004). It reduces the correlation between genotypic and phenotypic parameters and interferes with the progress of selection (COMSTOCK and MOLL, 1963). Therefore, plant breeders must take into account the adaptability and stability of newly produced cultivars. According to LIN and BINNS (1991; 1994) adaptability is the response of the genotypes to the differences between the sites, and the stability is the response of genotypes to differences between years.

Several methods have been proposed to help understand the interaction of genotype by environment such as joint regression (EBERHART and RUSSEL, 1966), type B genetic correlation (BURDON, 1977), additive main effects and multiplicative interaction (AMMI) (GAUCH, 1992) and GGE biplot (YAN *et al.,* 2000). The AMMI analysis is a successful model used to study GEI, and it is a combination of the analysis of variance (ANOVA) and the principal component analysis (PCA). According to ABDI and WILLIAMS (2010) PCA is a multivariate technique that analyzes a data table in which observations are described by several inter-correlated quantitative dependent variables. In AMMI model variability related to the genotype by environment interaction is partitioned by PCA. In addition, AMMI offers a simple graphical interpretation of GEI, where the genotypes and the environment are simultaneously displayed at the biplot (ZOBEL *et al.,* 1988). RODRIGUEZ *et al.* (2007) tested the capacity of the AMMI model to efficiently asses GEI in different barley landraces, recombinant inbred lines and varieties in Mediterranean environment. This model was also used by YÜKSEL and AKÇURA (2012) in order to investigate barley in multi-location trials in Turkey. AMMI efficiency has also been tested in Southeastern Europe, where the GEI effect on yield and yield components was assessed in rapeseeds genotypes (MARJANOVIĆ-JEROMELA *et al.*, 2011), maize hybrids (MITROVIĆ *et al.,* 2012), and bread wheat cultivars (MLADENOV *et al.,* 2012).

The aim of this study is to estimate the genotype - environment interaction, and to identify barley genotypes that have high and stable performance in different environments using AMMI biplot method.

MATERIALS AND METHODS

Eight six-rowed and six two-rowed winter barley varieties were used as plant material. Seven of the eight six-rowed barley cultivars (Novosadski 313, Novosadski 27, Novosadski 317, Novosadski 329, Novosadski 701, Novosadski 703, Novosadski 705) and five of the six two-rowed barley cultivars (Novosadski 293, Novosadski 183, Novosadski 307, Novosadski 331, Novosadski 507) were developed at the Institute of Field and Vegetable Crops, Novi Sad and marked with abbreviation NS. Six-rowed barley variety Partizan and two-rowed barley variety Sladoran were developed at the Center for Small Grains Kragujevac, Serbia and

Agricultural Institute Osijek, Croatia, respectively. These barley cultivars were added to the trials because of their important role in breeding programs in Serbia and neighbouring countries in southeastern Europe.

The trials were conducted during 11 growing seasons (1995/96 - 2005/06), arranged in a randomized complete block (RCB) design with four replications. All field trials were conducted in location Rimski Šančevi near Novi Sad, Serbia. The experimental unit's area was 5 m^2, and plant density varied between 300 to 400 plants per m^2 according to the recommended density in large scale production. The planting and the harvest were performed by machine. Barley grain yield was adjusted to the 14% moisture and expressed in t ha^{-1}. Standard agricultural practices were conducted in all investigated seasons. The application of mineral fertilizers was conducted separately for each season, based on a soil agrochemical analyses.

During the spring months, when the intense barley development occurs, average temperature (°C) and precipitation (mm) were measured (Table 1). The sum of precipitation and the average temperature of the winter months (December-February) were also measured since the accumulated precipitation in the soil and average temperatures in the winter have a significant impact on barley growth.

The AMMI model was used to distinguish the genotype main effect, environment main effect and GEI, and it can be represented with the following formula (ZOBEL *et al.,* 1988):

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger}$$

where Y_{ger} is the yield for the genotype *g* in the environment e the replication r, μ is the grand mean estimated with $\bar{Y}$, α_g is a/the genotypic mean deviation from the total mean estimated from the difference Y_g-$\bar{Y}$, β_e is the environmental mean deviation estimated from the difference Y_e-$\bar{Y}$, N is the number of interaction principal component axis (IPCA), λ_n is a singular value for n interaction principal component axis, γ_{gn} is the genotypic eigenvector for IPCA axis n, δ_{en} is the eigenvector of the environment for IPCA axis n, ρ_{ge} is a residue when not all PCA axis are included and ε_{ger} is the error.

Software STATISTICA 11 was used for two-way ANOVA and means were compared using Duncan's multiple-range test (STEEL and TORRIE, 1980). AMMI analyses were performed in Excel Biplot Macros (LIPKOVICH and SMITH, 2002).

RESULTS AND DISCUSSION

Weather conditions

During the 11 seasons in which our studied genotypes were tested climate conditions were highly diverse. The sum of winter precipitation was exceeding 100 mm, reaching up to 162 mm, except in season 2001/02 when the winter was extremely dry. The distribution and the amount of precipitation during the spring were considerably different across various seasons. During the experiment, an extremely dry spring (March-June) occurred in 2002/03 when the amount of rainfall was only 80 mm. On the other hand, during the spring of 2000/01 the sum of rainfall was over 400 mm. Average temperatures similarly varied during different seasons. Average temperature in April ranged from 7.5°C (1996/97) to 14°C (1999/2009), and in May from 15°C (2003/04) to 20.6°C (2002/03).

Table 1. Average temperature (T) and precipitation (P) in winter (December-Februar), March, April, May and June during 11 tested seasons.

Month	Winter		March		April		May		June	
	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)	T (°C)	P (mm)
1995/96	-0.6	145.0	2.2	29.8	11.6	25.2	18.1	90.0	20.6	79.0
1996/97	0.8	156.6	5.5	32.2	7.5	75.2	17.4	17.4	20.7	62.0
1997/98	3.8	150.1	4.0	22.6	13.2	39.8	16.1	64.1	21.5	103.7
1998/99	-0.4	117.9	8.0	11.0	12.7	61.2	16.9	76.2	20.1	91.0
1999/00	1.1	162.3	6.8	31.7	14.7	24.6	18.5	40.4	22.0	31.5
2000/01	3.5	120.9	10.2	75.9	10.9	15.6	17.8	78.6	18.0	237.4
2001/02	1.1	63.5	8.6	10.1	11.1	30.4	19.1	84.7	22.0	27.5
2002/03	-2.0	112.3	5.6	8.9	11.3	9.2	20.6	21.9	24.2	30.7
2003/04	1.1	118.0	6.4	17.8	12.0	118.6	15.0	87.6	19.5	97.4
2004/05	-0.3	105.6	4.3	40.1	11.8	33.0	17.2	38.1	19.4	135.8
2005/06	0.6	140.5	5.7	72.5	12.7	66.0	16.5	70.1	19.7	104.3

Grain yield

The analysis of variance indicated that the influence of environment (seasons), genotypes and their interaction were significant ($p < 0.01$) (Table 2). Environment had the most important effect on barley yield, and this factor explained 68.72% of total treatment variation. The fact that a large percent of the total treatment variation was explained by the environment effect indicates that climatic conditions varied considerably during different seasons. According to YAN and RAJCAN (2002) environment explains the highest percent of total yield variation. KAYA *et a.l* (2006) showed that genotype explained about 7% of the total variation, while environment explained 81% and GE explained about 13% in bread wheat. STANISAVLJEVIĆ *et al.* (2013) reported that the effects of the environment varied between years, and during the five-year trial, environment captured between 50-84% of the total treatment variation. In our results, the effect of GEI explained 24.97% while the difference between genotypes explained 6.31% of total treatment variation. The values of the first four principal components were highly significant and they accouneted for 40.7%, 21.07, 15.56% and 7.85% of GEI sum of squaeres, respectively. The first four IPCs accounted for a total of 85.18% of GEI, and with 58% for corresponding degrees of freedom.

Genotypes` grain yield varied from to 4.99 to 11.54 t ha^{-1} between seasons. Novosadski 507 had the highest average yield performance followed by Novosadski 317 and Novosadski 331 (Table 3). Partizan was the lowest yielding genotype, with an average yield of 7.59 t ha^{-1}. Average yield per season varied from 6.23 t ha^{-1} in 2002/03 to 10.4 t ha^{-1} in 1999/00. Tested cultivars had the highest average yield in 1999/00 and 1996/97, which can be explained by high levels of winter precipitation. MLADENOV and PRŽULJ (1999) showed a statistically significant positive correlation between winter precipitation and the yield of winter wheat, while the effect of spring precipitation was more dependent on the distribution than on the amount of precipitation. Low levels of winter precipitation, and deficiency of rainfall during the spring in

2002/2003, resulted in a significant reduction in barley grain yields. According to AUSTIN *et al.* (1998), barley yields are strongly dependent on seasonal rainfall, particularly during November–January and March–May of the cropping season.

Table 2. The analysis of variance of main effects and interactions for barley grain yield

Source	df	SS	MS	F	%SS
Total	615	1672459647	2719447	-	-
Treatments	153	1366867501	8933775	14.2	-
Genotypes	13	86190664	6630051	10.5	6.31**
Environments	10	939364326	93936433	88.4	68.72**
Block	33	35087268	1063251	1.69	2.57*
Interactions	130	341312511	2625481	4.16	24.97**
IPCA1	22	138866571	6312117	10	40.70**
IPCA2	20	71932824	3596641	5.7	21.07**
IPCA3	18	53111450	2950636	4.68	15.56**
IPCA4	16	26792003	1674500	2.66	7.85**
IPCA5	14	17295190	1235371	1.96	5.07*
IPCA6	12	15529764	1294147	2.05	4.55*
Residuals	28	17784709	635168	1.01	-
Error	429	270504878	630548	-	-

** significance at 0.01 probability level.

* significance at 0.05 probability level.

AMMI model is a useful method for the analysis of GEI, and it has been used in the evaluation of GEI in different varieties of barley (NURMINIEMI *et a.l*, 2002), wheat (CASTILLO *et a.l*, 2012) and maize (BABIĆ *et al*., 2010). GEI can be explained by the use of different models of AMMI, among which the most frequently used models are AMMI1 and AMMI2. In AMMI1, the x-coordinate represents the main effects (means) and y-coordinate represents the effects of the interaction (IPCA1). The values which are placed closer to the x-axis (IPCA1) contribute less to the interaction compared to those which are placed further away (SILVEIRA *et al*., 2013). Therefore, genotypes that have small IPCA1 values are more stable. The majority of genotypes, in our study were placed around average yield, which was 8.51 t ha^{-1} (Figure 1.). However, among them there was a large difference in their IPCA1 values, in fact, they differ in their reaction to diverse climatic conditions. On the AMMI1 biplot six-rowed and two-rowed barley genotypes were clearly separated. The evident separation to six and two-rowed barley cultivars was expected, given the clear genetic distance between these two groups of barley varieties. Six-rowed barley cultivars had a positive IPCA1 score, while two-rowed barley cultivars had a negative IPCA1 score. Positive IPCA1 scores of six-rowed varieties or negative IPCA1 scores of two-rowed varieties indicating that each group had similar reaction to same agro ecological conditions. Genotypes Novosadski 293 and Novosadski 307 showed the greatest stability compared to other genotypes. On the other hand, cultivars Sladoran and Novosadski 705 were the most unstable. Among winter six-rowed barley varieties, genotypes Novosadski 317 and Novosadski 313 had the highest average yield, however Novosadski 317 can be recommended for further breeding programs due to its greater stability. Similarly, among the two-rowed cultivars, we can draw attention to the Novosadski 331, because of its stability and high yield.

Table 3. Average grain yields (t ha^{-1}) of barley varieties over 11 growing seasons

Genotype	Grain yield (t ha-1) Growing seasons											
	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	Mean
NS 183	7.79	9.90	8.85	8.39	10.16	6.81	9.90	5.19	7.22	8.38	7.93	8.23e
NS 27	6.02	10.77	9.58	9.17	10.39	7.08	7.69	5.80	5.67	8.92	8.89	8.18e
NS 293	7.98	9.89	9.09	9.23	10.62	8.34	7.35	6.19	9.35	9.00	8.82	8.71abc
NS 307	7.47	9.67	9.20	8.35	10.78	7.25	8.47	6.81	8.80	8.40	8.70	8.53bcde
NS 313	8.06	11.54	9.21	7.74	10.43	7.62	7.14	7.34	6.99	9.30	9.69	8.64abcd
NS 317	7.48	10.56	10.01	9.19	11.35	8.16	7.69	7.60	7.88	9.08	9.64	8.97a
NS 329	6.37	11.28	10.15	8.27	8.94	7.89	8.11	6.58	8.72	8.83	9.68	8.62abcd
NS 331	7.67	10.87	9.45	8.00	10.92	8.20	9.73	6.84	8.38	9.38	8.30	8.88ab
NS 507	8.36	9.86	10.66	9.07	11.07	9.15	10.15	5.57	6.79	9.41	8.84	8.99a
NS 701	5.10	10.05	10.11	7.26	9.70	8.50	8.35	5.85	8.22	8.12	8.94	8.20e
NS 703	6.51	11.05	8.98	7.23	10.55	7.85	8.22	6.01	7.03	9.14	8.42	8.27de
NS 705	6.46	10.60	9.08	8.21	11.24	6.16	7.05	7.14	6.38	10.46	9.88	8.42cde
Partizan	5.56	9.99	8.91	6.86	8.89	7.69	7.14	4.99	6.50	8.26	8.71	7.59f
Sladoran	9.30	9.06	8.85	10.18	10.55	7.99	10.17	5.28	8.25	9.65	7.99	8.84ab
Mean	7.15f	10.36a	9.44b	8.37d	10.40a	7.76e	8.37d	6.23g	7.58e	9.02c	8.89c	8.51

Different letters indicate significant difference at $P < 0.05$ level.

During 1996/97 and 2001/02 growing seasons, environment was responsible for the greatest GEI for the yield, and that mainly explains the high difference in genotype ranking. For example, in 96/97 genotype Novosadski 313 had the highest yield, while in 01/02 it was the second worst genotype. On the other hand, in 01/02 season cultivar Sladoran was the most productive genotype, but in season 96/97 had the lowest yield.

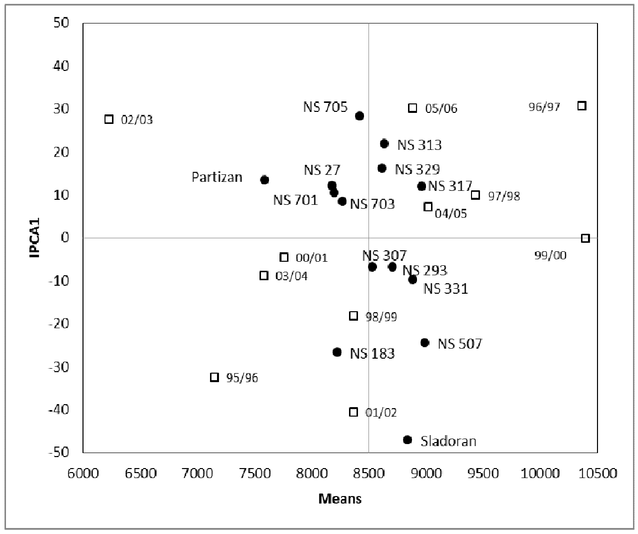

Figure 1. AMMI1 biplot of 14 barley varieties across 11 environments

Figure 2. shows the AMMI2 biplot generated using genotypic and enivronmental scores of the first two interaction axis. AMMI2 biplot clearly reveals the "which-won-where" pattern, and also indicates the sensitivity degree of cultivars to the environment (LI *et al*, 2006). Genotypes that are positioned closer to the biplot origin have higher stability. Based on their positions on the biplot, Novosadski 307 and Novosadski 703 can be singled out as the most stable genotypes. Genotypes Novosadski 705, Novosadski 701 and Sladoran were the most unstable, since they were farther from the bilplot origin, indicating that these genotypes have specific adaptations.

Genotypes and environments that are positioned close to each other on the biplot have a positive association. For instance, genotypes Partizan and Novosadski 329 reacted positively with the 97/98 season, but negatively with seasons 1998/99 and 1995/96. Novosadski 27 had specific adaptation to environment 04/05. On the other hand, Sladoran was adapted to season 95/96, but reacted negatively with seasons 2005/06 and 1996/97. Novosadski 293, Novosadski 307 and Novosadski 331 were highly correleted on AMMI2 biplot graph. Association between these three genotypes was expected since they originated from similar genetic pool.

The main objective of the barley breeding process is to create new genotypes with high and stable yields, regardless of the interfering effect of genotype and environment interaction (PRŽULJ *et al.*, 2010). The evaluation of the response of new varieties to different environmental influences requires a considerable use of time and resources. Additionally, the results obtained from these trials are often difficult to interpret. The most commonly used statistical analysis for the interpretation of the data is the ANOVA. ANOVA is an additive model and it identifies GE interaction, but it does not analyze the way how the genotypes interact with different environments. On the other hand, AMMI analysis reveals a highly significant interaction component that has clear agronomic meaning (ZOBEL *et al.,* 1988).

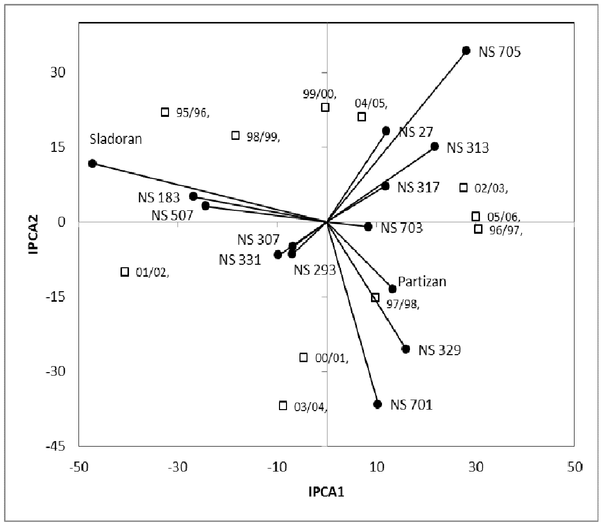

Figure 2. AMMI2 biplot of 14 barley varieties across 11 environments

CONCLUSION

In this study we proved that the AMMI method can be successfully applied to the performance analysis of large number genotypes over several years. AMMI analysis enabled improved understanding of GEI in 14 genotypes in 11 environments, by using the first two principal components axis. Two genotypes, the two-rowed variety Novosadski 317 and the six-rowed variety Novosadski 331 can be distinguished because of their high and stable yields. These varieties represent an important material for the further barley breeding, and they can potentially be used as donors of adaptability in changing agro-ecological conditions on the territory of South-Eastern Europe.

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PRIMENA AMMI MODELA ZA ANALIZU VIŠEGODIŠNJIH OGLEDA JEČMA

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Izvod

Procena performansi novih sorti/hibrida je često otežana usled uticaja interakcije genotipa i sredine. Aditivni glavni efekti i višestruka interakcija (AMMI) metod predstavlja jedan od najčešće upotrebljavanih medoda za analizu ove interakcije. U ovom radu AMMI metod se koristio sa ciljem procene interakcije genotipa i sredine, kao i identifikacije genotipova ječma koji poseduju visok prinos i stabilnost u različitim seozonama gajenja. Rezultati ovog istraživanja pokazuju značajan uticaj ($p < 0.01$) sezone, genotipa i njihove interakcije na prinos ječma. Dvoredi ječam Novosadski 317 i šestoredi ječam Novosadski 331 se mogu izdvojiti u odnosu na druge sorte na osnovu visokog i stabilnog prinosa.

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