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Original scientific paper

EVALUATION OF MAIZE GRAIN YIELD AND YIELD STABILITY BY AMMI ANALYSIS

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Significant genotype x environment interaction for quantitative traits, such is grain yield, reduces the usefulness of genotype means, over all environments, for selecting superior genotypes. AMMI model is a valuable statistical tool in identifying systemic variation contained in the interaction effect. Obtained data could be applied in maximizing yield potential in every environment based on both narrow and wide genotype adaptability, without the necessity of developing breeding programs for smaller targeted environments. Precise assortment of superior genotypes, with the assistance of AMMI model, leads to the better recommendation of newly bred hybrids, and thus increasing maize grain yield in a targeted environment. In this research genotype x environment interaction and yield stability of 36 maize hybrids of FAO 300-700 maturity group was investigating. The trial was set according to Randomized Complete Block Design (RCBD). Data were processed in order to obtain average estimates of grain yield, and yield stability was assessed by the method of AMMI analysis. The highest average grain yield was achieved in 2011 (11.62 t/ha), and the lowest in the most stressful and dry 2012 (6.90 t/ha). In the region Loznica L2 the highest average yield was noticed (13.81 t/ha), while at L7 (Sremska Mitrovica) average grain yield was the lowest (6.97 t/ha). Results of AMMI analysis gave precise

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recommendation for production of maize hybrids in certain environments, by determining winning areas of hybrids H20, H11 and H36. Medium early maturing and high yielding hybrids (H11 and H20) are therefore considered more favorable for production in environments with lower precipitation, while high yielding and more stable hybrids H21 and H35 are suitable for a wider range of environments. Hybrid H36 (FAO 700) showed its full potential at L2, and L3 which did not suffer from a lack of moisture. This hybrid also expressed its best potential in environments with favorable conditions.

Key words: AMMI model, GxE interaction, maize grain yield, yield stability

INTRODUCTION

Global predictions indicate that by 2025, maize will become crop with the largest production in the world, and that needs for this crop in developing countries by 2050 will be doubled (ROSEGRANT *et al*., 2008). Maize of all cereals has the highest yielding potential (BEKRIĆ and RADOSAVLJEVIĆ, 2008). Average maize grain yield in recent years is approaching 5 t/ha on global scales, while the most developed countries reach the average of 8 – 9 t/ha of dry grain. In Serbia in the period 2010 – 2017 average maize grain yield was 5.9 t/ha (STAT. YEARB. SERB, 2018).

Maize breeding strategies have clear tasks to create highly adaptable genotypes, capable to produce high yields over wide range of different production environments. The importance of GxE interaction is significant in plant breeding because it highly affects genetic gain, recommendation and selection of genotypes with wide adaptability (SOUZA *et al*., 2009; BOAKYEWAA, 2012; BANJAC *et al*., 2014). On the other hand different genotypes express different performances in certain regions, which could be used to achieve maximum productivity (SOUZA *et al*., 2008; BABIĆ *et al*., 2011; OYEKUNLE *et al*., 2017a, 2017b).

Analysis of variance (ANOVA) is widely applied in evaluation of field trials and estimation of yield. It provides assessment of variance components based on different factors (genotype, environment and GxE interaction), and the basic requirement for its application is the assumption of variance homogeneity (ZOBEL *et al*., 1998). Nevertheless, ANOVA only identifies interactions as the sources of variance, but it doesn't decompose it furthermore. Significant impact on breeding strategies had early concepts of stability, based on linear regression (LR) which presented first attempts of interaction analysis (YATES and COCHRAN, 1938; FINLAY and WILKINSON, 1963; EBERHART and RUSSELL, 1966; LIN and THOMPSON, 1975; BECKER and LEON, 1988; CROSSA, 1990). Nowadays, highly developed computer technologies enable wide application of multivariate models which use Singular Value Decomposition (SVD) of a matrix such is the principal components analysis (PCA). Multivariate statistical models are more adjusted to a certain set of data and therefore present a better insight on the part of variability which originates from the GxE interaction (BABIĆ *et al*., 2013). GAUCH (2006) and GAUCH *et al*., (2008) stated that AMMI (Additive Main Effect and Multiplicative Interaction), GGE, and other models based on SVD method are in general equally efficient. Moreover, AMMI model stands out because it always decomposes main sources of variance (G, E and GxE), which is essential in most of agronomic researches, and at the same tame it decomposes systemic variation and noise as well as other models. Therefore AMMI model is the most suitable in concept of agronomic trials and the interpretation of results is simpler. AMMI model explains effects of genotype (G) and environment (E) as additive effects, by analysis of variance, while GxE interaction as the multiplicative nonaditive component is analyzed by principal components analysis. From the sum of squares it separates one or more significant principal components (PC axis), which may have biological explanation. When interpreting results biplot graphs are applied. Biplot graphs present simultaneous presentation of additive (G, E) and interaction effects (IPCA1, IPCA2), for genotypes and environments. This allows a visual display of main effects and interaction, extraction of most stabile genotypes in given environments, as well as "ideal" environments for each genotype in which they can express its maximum yielding potential (YAN *et al*., 2000; 2001; 2007; YAN and HUNT, 2001; GAUCH, 2013).

AMMI model found its application in testing of interactions genotype x environment (GxE), genotype x year (GxY), or genotype x environment x year (GxExY) in different crops: sugar beet (ĆIRIĆ *et al*., 2017), onion (PAVLOVIĆ *et al*., 2017), spring barley (PRŽULJ *et al*., 2015), barley (MIROSAVLJEVIĆ *et al*., 2014), triticale (KAYA and OZER, 2014), soybean (SOUSA *et al*., 2015), perennial ryegrass (LAKIĆ *et al*., 2015), rice (BOSE KUMAR *et al*., 2014), and of course maize (MITROVIĆ *et al*., 2012; NZUVE *et al*., 2013; SHIRI 2013; KRIŽMANIĆ *et al*., 2014; OYEKUNLE *et al*., 2017a; 2017b; BADU-APRAKU *et al*., 2011).

The aim of this research was to estimate GxE interaction for 36 maize hybrids of different FAO maturity groups at 8 locations in Serbia, during 3 years in order to make recommendation of hybrids identifying: i) genotypes that express highest stability and yielding potential in different environments; ii) genotypes with highest adaptability and yielding potential at target environments. Also the aim was to show usefulness of AMMI model application for more precise recommendation of hybrids for the purposes of achieving highest yields.

MATERIALS AND METHODS

A set of 36 maize hybrids of different FAO maturity groups (300 – 700) were analyzed. From each FAO maturity group one commercial ZP maize hybrid was represented, while the rest were new hybrid combinations developed at Maize Research Institute Zemun Polje, Belgrade – Serbia.

Table 1. List of 36 ZP maize hybrids

FAO 300		FAO 400		FAO 500		FAO 600		FAO 700	
hybrid	label	hybrid	label	hybrid	label	hybrid	label	hybrid	label
ZP341	H1	ZP434	H5	ZP505	H13	ZP666	H23	ZP H71	H33
ZP H31	H2	ZP H41	H6	ZP H51	H14	ZP H61	H24	ZP704	H34
ZP H32	H3	ZP H42	H7	ZP H52	H15	ZP H62	H25	ZP H72	H35
ZP H33	H4	ZP H43	H8	ZP H53	H16	ZP H63	H26	ZP H73	H36
		ZP H44	H9	ZP H54	H17	ZP H64	H27		
		ZP H45	H10	ZP H55	H18	ZP H64	H28		
		ZPH46	H11	ZP H56	H19	ZP H66	H29		
		ZPH47	H12	ZP H57	H20	ZP H67	H30		
				ZP H58	H21	ZP H68	H31		
				ZP H59	H22	ZP H69	H32		

The trial was set at eight locations in Serbia: Kikinda (L1), Loznica (L2), Pančevo (L3), Senta (L4), Šimanovci (L5), Sombor (L6), Sremska Mitrovica (L7), and Svilajnac (L8) for three consecutive years (2011 – 2013). Trial was set according to the Randomized Complete

Block Design (RCBD), with three replications and individual randomization for each location in order to avoid the effect of genotype x genotype. Two border rows were sown at each side of the whole plot area. Each hybrid was sown in four rows, and two inner rows were used for analysis. The plot size was 13.09 m^2 with the sowing density of 62.643 plants per ha.

Data analysis

Obtained data were analyzed using AMMI model (GAUCH and ZOBEL, 1996). Results of AMMI analysis were presented by biplot graphs: AMMI1 biplot – abscissa representing average grain yield data of genotypes and average data of environments and ordinate representing the effects of interaction (IPCA1); and AMMI2 biplot – representing estimates of IPCA1 and IPCA2 on the abscissa and ordinate, respectively..

AMMI analysis was processed by R software, version 2.15.2 (R DEVELOPMENT CORE TEAM, 2005). Following mathematical model was applied (GAUCH, 1988):

$$Yij=\mu+Gi+Ej+\sum_{k-1}^{n}\alpha ik\ \lambda k\ \gamma jk+\ \theta ij$$

where: $i = 1,2...13$, $j = 1,2...7$, Yij – presents grain yield of the i - genotype in the j - environment; μ – the grand mean, Gi – genotypic effect, Ej – environmental effect, λk – *eigen* values of principal component analysis (PCA) axis k, $\alpha iku\ \gamma jk$ – are i – genotype and j - environment of PCA score for PCA axis k, θij – a residue, n – number of PCA axis contained in the model.

Correlations between IPCA1 or IPCA2 scores and grain yield, relative maturity group or the amount of precipitation in June was determined by Pearson's coefficients.

RESULTS AND DISCUSSION

Significant grain yield variation was noticed, due to the fact that three years included in this trail expressed high differences in average monthly temperatures, temperature sums, as well as amounts and distribution of precipitation, during vegetative period. Moreover, this trial encompassed maize hybrids belonging to different FAO maturity groups, and yielding potential, which significantly contributed the grain yield variation both among hybrids of the same FAO maturity group and between groups.

GxE interaction is the source of variation influenced both by genotype and environmental factors. From the statistical point of view GxE interaction appears when two or more genotypes have different responses to the changes of the environmental conditions. Determination of presence and magnitude of interaction is not the only focus of plant breeders, who are even more interested in understanding the impact of GxE interaction on the breeding material (DIMITRIJEVIĆ and PETROVIĆ, 2000). As numerous environmental factors affect genotype, thereafter GxE interaction could be more or less complex phenomenon. The effect of the interaction becomes more complex with the increase of number of factors with the same magnitude that have impact on genotype. Very often one prevalent environmental factor influences the genotype. In such cases linear regression models can comprise a good part of the sum of squares of the interaction and thus explain the stability of the genotype.

During the trial period of three years, significant differences were noticed concerning sums and amounts of precipitation, as well as average temperatures in critical phases of maize development such as pollination, fertilization, and grain filling (June – August).

Meteorological conditions in dry and very stressful 2012, were the main reasons for the lowest average yield of all hybrids (6.90 t/ha), while the most productive year was 2011 (11.62 t/ha). Average grain yield of maize hybrids in 2011 ranged from 10.38 t/ha (H1) up to 13.23 t/ha (H36). In 2012 the most productive hybrid was H3 (7.86 t/ha), while the lowest yield was produced by H14 (5.75 t/ha). Grain yield of maize hybrids in 2013 varied from 8.76 t/ha (H4) to 12.01 t/ha (H36).

Table 2. Mean temperatures (°C) at 8 locations in the period April – October (2011-2013)

Location	Year	IV	V	VI	VII	VIII	IX	X
Kikinda	2011	13.0	16.9	21.1	21.4	22.3	20.2	10.3
	2012	12.9	17.2	22.7	24.7	23.3	19.5	12.1
	2013	12.9	17.2	22.7	24.7	23.3	19.5	12.1
Loznica	2011	13.2	16.5	20.9	22.6	23.3	20.3	10.8
	2012	13.0	16.4	23.2	25.1	24.4	19.6	13.0
	2013	13.4	17.2	20.2	22.9	23.4	16.4	13.6
Pančevo	2011	13.2	17.0	21.0	21.8	22.4	20.5	10.4
	2012	13.2	17.6	23.0	24.5	23.1	19.8	12.8
	2013	13.5	18.3	20.4	22.5	23.1	15.9	13.5
Senta	2011	13.3	16.9	21.4	21.8	22.8	19.9	10.2
	2012	12.8	17.3	22.5	25.0	23.8	19.5	12.0
	2013	12.8	17.3	20.3	22.4	22.8	15.0	12.8
Šimanovci	2011	13.4	17.4	21.1	22.6	23.6	21.4	11.0
	2012	12.9	16.7	23.1	25.5	25.1	20.0	13.2
	2013	13.7	17.3	20.1	22.9	23.8	16.1	14.1
Sombor	2011	12.7	16.3	20.4	21.4	22.6	19.9	10.4
	2012	12.3	16.8	22.1	24.7	24.1	19.3	12.1
	2013	12.5	16.7	19.8	22.3	22.9	15.2	13.0
S.Mitrovica	2011	13.6	17.3	21.6	22.4	23.8	21.4	11.2
	2012	12.6	16.8	22.0	24.1	22.9	18.9	12.3
	2013	12.7	16.9	19.6	22.9	22.5	15.5	12.9
Svilajnac	2011	13.1	16.6	21.3	22.8	23.4	20.8	10.4
	2012	14.0	17.0	23.4	25.4	23.5	20.1	13.8
	2013	14.4	18.9	20.9	23.1	24.1	16.5	14.2

Late maturing hybrids in general expressed higher productivity in more favorable 2011 and 2013. On the other hand, in less favorable 2012 medium early maturing hybrids (FAO 300) had higher yields, such as H3 - the most productive hybrid in this year. Medium early maturing hybrids were less stressed by the occurrence of the July's temperature peaks, because they progressed through silking and pollination stages at faster rate. Therefore such hybrids had much better seed set and less barren plants.

The highest three years average grain yield was noticed at the location Loznica (L2 – 13.83 t/ha), while the lowest production was at L7 – 6.97 t/ha (Sremska Mitrovica), (data not shown). Test field at L2 is located near the river Drina, at loam alluvial soil, with relatively high level of ground water, which all contributed to high grain yields even in very dry 2012. On the other hand at L7 (Sremska Mitrovica), as well as on the almost whole area of Srem, prolonged drought of higher or smaller intensity was noticed during whole three year period of these trials. Moreover, this area constantly had unfavorable precipitation distribution during vegetation. Comparing amounts of precipitation during vegetation on those two locations in 2011 and 2012 on L2 over 100 mm, more precipitation was noticed, then on L7, while almost the same amount of precipitation was noticed in 2013. The location Loznica (L2), out of all locations had the highest amounts and the best distribution of precipitation (Table 2 and 3). The driest location was Pančevo (L3), but thanks to the higher winter soil moisture reserves, and better soil quality, on this location, average grain yield was 9.66 t/ha.

Table 3. Precipitation (mm) at 8 locations in the period April – October (2011-2013)

Location	Year	IV	V	VI	VII	VIII	IX	X	∑ (mm)
Kikinda	2011	10.6	61.8	54.0	65.2	1.8	21.8	61.8	277.0
	2012	62.6	45.2	19.6	47.2	6.0	13.8	65.4	259.8
	2013	25.0	74.2	61.8	21.2	36.8	63.6	27.2	309.8
Loznica	2011	33.6	85.8	55.8	79.2	1.1	32.6	30.6	318.7
	2012	116.9	155.8	28.5	31.1	1.6	17.5	72.8	424.2
	2013	38.5	156.7	60.0	27.6	43.4	29.0	66.4	421.6
Pančevo	2011	10.8	9.6	29.0	37.2	6.4	25.0	21.0	139.0
	2012	42.4	30.6	7.4	24.2	3.2	10.6	35.8	154.2
	2013	12.2	64.8	49.6	4.2	12.4	43.2	18.0	204.4
Senta	2011	3.8	63.2	34.0	41.8	2.0	35.8	36.6	217.2
	2012	43.6	66.2	23.0	53.0	6.6	33.2	84.4	310.0
	2013	36.8	138.2	63.8	59.4	34.2	70.4	29.8	432.6
Šimanovci	2011	22.4	57.6	41.2	67.0	5.8	36.6	23.0	253.6
	2012	80.8	47.0	29.2	35.2	0.0	8.6	56.6	257.4
	2013	25.2	144.8	53.8	25.0	12.2	67.6	13.4	342.0
Sombor	2011	11.6	50.4	67.2	49.6	9.6	31.2	24.0	243.6
	2012	47.2	75.4	41.6	35.0	3.8	24.2	83.6	310.8
	2013	37.0	102.0	48.6	24.4	47.2	81.4	62.6	403.2
S.Mitrovica	2011	16.6	52.2	36.6	60.8	1.6	18.2	6.0	192.0
	2012	91.6	90.2	35.2	36.8	1.6	17.8	32.6	305.8
	2013	59.0	144.6	71.2	43.0	16.2	92.2	42.6	468.8
Svilajnac	2011	31.0	93.7	26.7	88.9	16.6	37.5	36.0	330.4
	2012	88.0	126.3	44.3	90.7	0.2	18.0	56.2	423.7
	2013	38.0	78.5	41.8	14.3	26.1	62.1	61.0	321.8

Presented results indicate that meteorological conditions in different years had higher influence on the hybrid ranking than the locations. This is visualized on Fig. 1, where average estimates of three hybrids of similar yields but different IPC scores are presented. Hybrid H36 with the highest average yield, comparing to the other two hybrids was not the best ranking especially in environments in the extremely dry 2012. With the exception of the environment L3/3 in such stressful environments the best ranking was H20 (FAO 500). These results highlight the necessity of multi-year and multi-location testing, before hybrid could be recommended for a certain region. This is in accordance with OYEKUNLE *et al*. (2017b).

In this trial a set of 36 hybrids was tested on 8 locations over three consecutive years, making it all 24 environments. Analysis of variance of the AMMI model (Table 4) showed that mean squares of hybrids, environments and their interactions were significant for maize grain yield. In the total sum of squares environments participated with 80.66%, genotypes with 2.34%, while interactions had 8.09%. Such results are in agreement with YAN *et al*. (2000), and PRŽULJ *et al*., 2015, who also stated that in multi-location trials often environment explains about 80% of the variation, while genotype (G) and interactions share about 10%. Thereafter the application of only ANOVA model and disregarding the effect of interactions leads to losing or neglecting a part of valuable trial information. The F test indicated significance of the first 8 IPC axis. Due to the large number of degrees of freedom, the interaction encompassed the highest proportion of the "noise". In this trial almost half of interactions sum of squares (49%) was „noise". First IPCA axis contained larger amount of systematic variation, and the lower percentage of „noise", and in this case for the first three axiss it amounted 14.9, 20.3, and 30.0%, of „noise" respectively. Therefore, special attention should be paid to the determination of correct number of PCA axis that should be retained in the model, considering the amount of "noise", and systemic variation that are in such way included in the model. It is often noticed that F test shows the significance for a larger number of IPCAs than it is. In practice usually the first three axis are useful and significant. In this trial the first two IPCAs encompassed 79% of useful interaction information, while including the third axis, a part of the "noise" would be entered in the model so for the further analysis only two of them were considered.

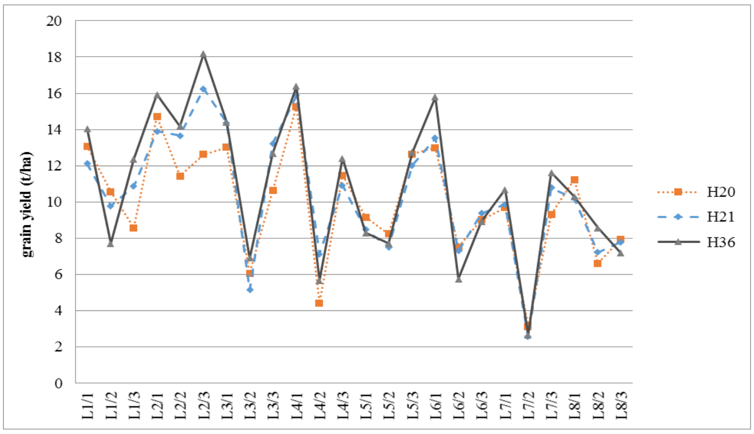

Figure 1. Average grain yields of ZP H20, ZP H21, and ZP H36 maize hybrids over locations

Average grain yield of hybrids were in general plotted close to the grand mean as shown on AMMI1 biplot (Fig. 2). This is expected due to the fact that hybrids chosen for this trials are either commercial or in the process of commercialization characterized by high yielding potential. According to the ordinate (IPCA1) of AMMI1, hybrids were clearly distinguished by the relative maturity. Medium early and medium maturing hybrids had positive estimates of IPCA1, while hybrids belonging to FAO 600 and 700, i.e. late maturing hybrids had negative estimates. Negative significant correlation was established between IPCA1 scores and relative maturity group (r= -0.71**). IPCA axis often separate variability that has some biological explanation. BANJAC *et al*., (2014), found that estimates of interaction axis from the AMMI analysis reflect on the influence of the meteorological conditions during vegetative season on the tested yield components of bread wheat. BABIĆ *et al*. (2011b) found that dominant factors in the hybrid by environment interaction was difference in sums of precipitation for the environments and the relative maturity for hybrids,that were in correlation with the IPCA1 score.

Table 4. Analysis of variance of AMMI model for maize grain yield

Source of variation	df	SS	SS%	MS	F
Genotype (G)	35	738.80	2.34	21.11	13.48**
Replications	48	190.40	0.60	3.97	2.53**
Environments (E)	23	25,525.70	80.66	1,109.81	279.77**
GxE	805	2,561.40	8.09	3.18	2.03**
PC1 (23.4%)	57	599.12	23.39	10.51	6.71**
PC2 (16.6%)	55	426.20	16.64	7.75	4.95**
Residuals	416	1536.12	19.2	15.69	2.54**
Error	1,680	2,631.30	8.31	1.57	
Total	2,591	31,647.60	100.00		

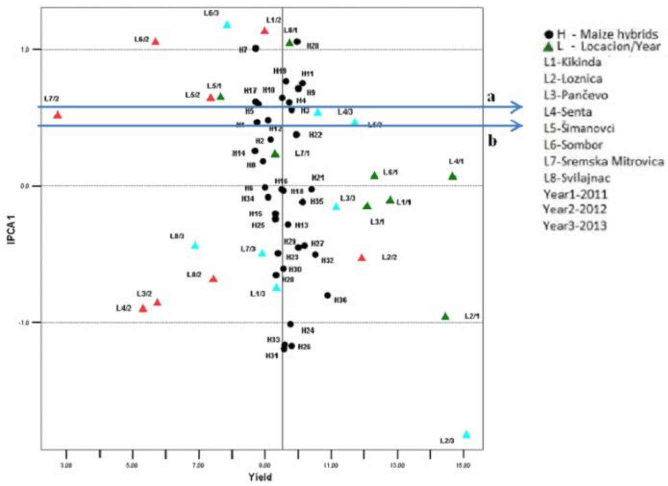

Figure 2. AMMI1 biplot of grain yield of 36 maize hybrids at 24 environments in Serbia (2011-2013)

From the agronomic and commercial point of view desirable genotype is a stable and high yielding. On the AMMI1 biplot (Fig 2) hybrids H21 and H35 stand out according to the grain yield which was above the grand mean and with low IPCA1 score. Those hybrids could be recommended for production in all observed environments, especially to small farmers who demand stable yield throughout seasons. According to obtained IPCA1 scores, winning areas of certain hybrids could be determined. After the calculation it was concluded that there are actually three winners H20, H11 and H36. On the Figure 2. determination line "a" is dividing winning areas of H20 and H11, while the line "b" is determining wining areas of H11 and H36. Thereafter, in all environments above the determination line "a", the highest yielding hybrid according to the AMMI model is H20. In environments L7/2, L4/3 and L5/3, the highest yielding is H11, while in all environments below line "b" the best is H36. As the hybrid H36 had the highest yields in all three years on the location 2 – Loznica and 3 – Pančevo, it could be recommended for production with a great certainty on these locations both under favorable and unfavorable conditions. On the other hand on the location Kikinda (1) under favorable meteorological conditions H36 had best performances, while in the dry year, shorter season hybrid H20 (FAO 500) yielded better. These results also revealed that on the location 6 – Sombor the production of H20 presents less risk in unfavorable 2012 and more favorable 2013, while in the most favorable 2011 the best yielding hybrid was the long season hybrid H36 (Figure 2).

In all three years of this trial, location Loznica (L2/1, L2/2, L2/3), stood out among environments as the highest yielding one, but its markers were plotted far from the stability line. The least variation in maize grain yield was noticed in 2011 in Sombor (L6/1) and Kikinda (L1/1), and in 2013 Pančevo (L3/3), as they were positioned close to the stability line and their means were above the grand mean. In dry and stressful 2012 in all regions with the exception of Loznica, average grain yield was below the grand mean, and the markers for these environments were far from the stability line.

For the presented set of data no connection between IPCA1 scores for environments and some environmental factor was established. Nevertheless, it was noticed that the arrangement of markers of environments according to IPCA2 at AMMI2 biplot (Figure 3) reflects on the amounts and distribution of precipitation during vegetative period. The highest positive scores of IPCA2 axis had environments belonging to the dry 2012 (/2), and negative scores were from the most favorable 2011 (/1). Significant correlations between the amount of precipitation in June and IPCA2 scores (r= -0.46*), as well as between grain yield and IPCA2 (r= -0.71**), were found. Considering the first two interaction components, the lowest scores manifested at genotypes and environments with the smallest vectors (H35, H18, H16, H15, H13; L3/3, L7/1, and L1/1). The highest scores were in environments L2/3, L3/2, L8/2, L5/2, L6/2, L1/2, L6/3 L3/1, L6/1, and L2/1, with the highest number of environments from the extremely dry 2012. The most stable environments were L1/1, L7/1, and L3/3.

As AMMI analysis revealed, interaction of genotypes was influenced by relative maturity, while environment interaction was mostly influenced by quantity and distribution of precipitation during growing season. This is also clarified by the correlation coefficient between grain yield and relative maturity group (r= 0.37*), and grain yield and the amount of precipitation in June (r= 0.41*). Such results are in accordance with BABIĆ et al. (2011a), who stated that the pattern in AMMI biplot often reflects on casual factors like rainfall and hybrids relative maturity, even though the data literally concern something else, such as yield. GAUCH

(2013), emphasized that the exploitation of GxE interaction could be useful in increasing yields, only in predictable ecological factors at certain regions.

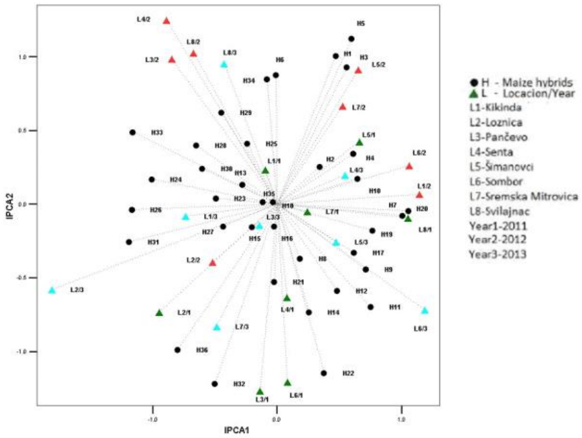

Figure 3. AMMI2 biplot of grain yield of 36 maize hybrids at 24 environments in Serbia (2011-2013)

Drought stress presents prevalent stress factor for maize production in Serbia, so there is great importance of breeding maize hybrids tolerant to it. Nevertheless, global climatic changes further complicate this task (FILIPOVIĆ *et al.*, 2015). In testing yielding potential and comparison of genotypes by their yields, rarely parameters that could be associated to some biotic or abiotic stress are considered. Therefore, when analyzing the stability of certain genotype, it must be beard in mind that it could be a consequence of different factors, such as drought tolerance, resistance to important diseases or pests. Consequently, genotype stability set in one experiment, should not be generalized. It primarily represents certain genotype stability towards prevalent stress factor at the given moment in the experiment. For the presented data set, AMMI analysis revealed that the amount and distribution of precipitation and genotypes relative maturity group had the most significant influence on the hybrid ranking. That is the reason why those are the parameters at which the highest attention should be paid when recommending hybrids for production in a certain region.

CONCLUSION

Multi-location field trials are the most important, but at the same time the most expensive part of hybrid evaluation in the process of their commercialization. Selection of hybrids is based on their yields, but also on some other important agronomic traits. Nevertheless, GxE interaction diminishes reliability of obtained results, and complicates the selection of hybrids for a targeted environment. A yield trial with many genotypes and environments generates multivariate data with high dimensionality, but ordinarily the main causal factors affecting yield are rather few. Hence, the application of multivariate models provides valuable information which is contained in the interaction effect. More precise recommendation for production of maize hybrids in certain regions is obtained by AMMI analysis. Based on the expected yields, according to AMMI model, AMMI1 biplot is divided to the winning areas of three hybrids H20, H11 and H36. More stable hybrids H21 and H35 that are characterized by high yielding potential are suitable for a wide range of environments, especially for small producers who are concerned about the yield stability, making the risk of their maize production much lower. Hybrid H36 (FAO 700) is convenient for production in environments such as Loznica and Pančevo, which were not hit by drought stress. At such environments this hybrid could fully express its yielding potential.

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REFERENCES

BABIĆ, V., M. BABIĆ, M. IVANOVIĆ, M. FILIPOVIĆ (2011a): Pattern in interaction in maize yield trial. J. Agric. Sci., *56* (2): 101-110.

BABIĆ, M., V. BABIĆ, N. DELIĆ, V. ANĐELKOVIĆ, S. PRODANOVIĆ (2011b): The comparison of stability parameters according to the Finlay-Wilkinson, Eberhart-Russell and AMMI model. Selekcija i semenarstvo, *17* (2): 35-40.

BABIĆ, V., S. PRODANOVIĆ, M. BABIĆ, N. DELIĆ, V. ANĐELKOVIĆ (2013): The identification of bands related to yields and stability in maize hybrids and their parental components. Genetika, *45* (2): 589-599.

BADU-APRAKU,B., R. O. AKINWALE, S. O. AJALA, A. MENKIR, M. A. B. FAKOREDE, M. OYEKUNLE (2011): Relationships among Traits of Tropical Early Maize Cultivars in Contrasting Environments. Agronomy J., *103* (3): 717-729.

BANJAC, B., V. MLADENOV, M. DIMITRIJEVIĆ, S. PETROVIĆ, J. BOĆANSKI (2014): Genotype x environment interactions and phenotypic stability for wheat grown in stressful conditions. Genetika, *46* (3): 799-806.

BECKER, H.C., J. LEON (1988): Stability analysis in plant breeding. Plant Breeding, *101*: 1-23.

BEKRIĆ, V., M. RADOSAVLJEVIĆ (2008): Savremeni pristupi upotrebe kukuruza. J.Processing and Energy in Agriculture, *12*: 93-96.

BOAKYEWAA, A.G. (2012): Genotype by enviroment interaction and grain yield stability of extra early maize (Zea mays L.) hybrids evaluated at three locations in Ghana. Ph.D Thesis., Faculty Of Agriculture, Kwame Nkrumah University Of Science And Technology, Kumasi, Sunyani, Ghana. HTTPS://WWW.RESEARCHGATE.NET/PROFILE/GLORIA_ADU/PUBLICATION/270510898_GENOTYPE_BY_ENVIRONMENT_INTERACTION_AND_GRAIN_YIELD_STABILITY_OF_EXTRA-EARLY_MAIZE_ZEA_MAYS_L_HYBRIDS_EVALUATED_AT_THREE_LOCATIONS_IN_GHANA_BY/LINKS/54AC6BF

A0CF21C477139F773/GENOTYPE-BY-ENVIRONMENT-INTERACTION-AND-GRAIN-YIELD-STABILITY-OF-EXTRA-EARLY-MAIZE-ZEA-MAYS-L-HYBRIDS-EVALUATED-AT-THREE-LOCATIONS-IN-GHANA-BY.PDF

BOSE KUMAR, L., N. NAMDEORAO JAMBHULKAR, K. PANDE (2014): Genotype by Environment interaction and stability analysis for rice genotypes under Boro condition. Genetika, *46* (2), 521-528.

ĆIRIĆ M., Ž. ĆURČIĆ, M. MIROSAVLJEVIĆ, A. MARJANOVIĆ JEROMELA, G. JAĆIMOVIĆ, S. PRODANOVIĆ, T. ŽIVANOVIĆ (2017): Assessment of sugar beet root yield by AMMI analysis. Genetika *49*, (2): 663 – 675 .

CROSSA, J. (1990): Statistical analyses of multilocation trials. Adv. Agron., *44*: 55–85.

DIMITRIJEVIĆ, M., S. PETROVIĆ (2000): Genotype adaptability and stability. Selekcija i semenarstvo, *7* (1-2): 21-28.

EBERHART, S.A., W.A. RUSSELL (1966): Stability parameters for comparing varieties. Crop Sci., *6*: 36-40.

FILIPOVIĆ, M., Ž. JOVANOVIĆ, M. TOLIMIR (2015): Pravci selekcije novih ZP hibrida. Zbornik radova, "XX Savetovanje o biotehnologiji", 13-14.3.2015., Čačak, *20* (22): 7-13.

FINLAY, K.W., G.N. WILKINSON (1963): The analysis of adaptation in a plant-breeding programme. Aust. J. Agric. Res., *14*: 742–754.

GAUCH, H.G.JR. (2006): Statistical Analysis of Yield Trials by AMMI and GGE. Crop. Sci., *46*: 1488-1500.

GAUCH, H.G. (1988): Model selection and validation for yield tri- als with interaction. Biometrics, *44*: 705–715

GAUCH, H.G., R.W. ZOBEL (1996): AMMI analysis of yield trials. In: Kang MS, Gauch HG (eds.), Genotype by environment interaction. CRC Press, Boca Raton, FL, 85- 122.

GAUCH, H.G., JR., H.-P. PIEPHO, P. ANNICCHIARICO (2008): Statistical analysis of yield trials by AMMI and GGE: Further considerations. Crop Sci., *48*: 866–889.

GAUCH, H.G. (2013): A simple protocol for AMMI analysis of yield trials. Crop Sci., *53* (5): 1860–1869.

KAYA Y., E. OZER (2014): Parametric stability analyses of multi-environment yield trials in triticale (xTriticosecale Wittmack). Genetika, *46*, (3): 705- 718.

KRIŽMANIĆ, G., T. ČUPIĆ, B. ŠIMIĆ, J. BRKIĆ, V. JURKOVIĆ, G. JUKIĆ, M. MARKOVIĆ (2014): Utjecaj klimatskih uvjeta na stabilnost prinosa kukuruza. 49. hrvatski 9. međunarodni simpozij agronoma - Dubrovnik, Hrvatska. Genetika, oplemenjivanje bilja i sjemenarstvo, 249-253.

LAKIĆ, Ž., I. BALALIĆ, S. VOJIN (2015): Interpretation of genotype x environment interaction in perennial ryegrass (Lolium perenne L.). Genetika, *47* (2): 509-522.

LIN, C.S., B. THOMPSON (1975): An empirical method of grouping genotypes based on a linear function of the genotype-environment interaction. Heredity, *34*: 255-263.

MIROSAVLJEVIĆ, M., N. PRŽULJ, J. BOĆANSKI, D. STANISAVLJEVIĆ, B. MITROVIĆ (2014): The application of AMMI model for barley cultivars evaluation in multi-year trials. Genetika, *46* (2): 445-454.

MITROVIĆ, B., D. STANISAVLJEVIĆ, S. TRESKIĆ, M. STOJAKOVIĆ, M. IVANOVIĆ , G. BEKAVAC, M. RAJKOVIĆ (2012): Evaluation of experimental Maize hybrids tested in Multi- location trials using AMMI and GGE biplot analysis. Turkish J. of Field Crops, *17* (1): 35-40.

NZUVE, F., S. GITHIRI, D.M. MUKUNYA, J. GETHI (2013): Analysis of Genotype x Environment Interaction for Grain Yield in Maize Hybrids. J.Agric. Sci., *5* (11): 75-85.

OYEKUNLE, M., A. HARUNA, B. BADU-APRAKU, I.S. USMAN, H. MANI, S.G. ADO, G. OLAOYE, K. OBENG-ANTWI, R.O. ABDULMALIK, H.O. AHMED (2017a): Assessment of Early-Maturing Maize Hybrids and Testing Sites Using GGE Biplot Analysis. Crop Sci., *57*:2942–2950.

OYEKUNLE, M., A. MENKIR, H. MANI, G. OLAOYE, I.S. USMAN, S.G. ADO, U.S. ABDULLAHI , H.O. AHMED, L.B. HASSAN, R.O. ABDULMALIK, H. ABUBAKAR (2017b): Stability Analysis of Maize Cultivars Adapted to Tropical Environments Using AMMI Analysis. Cereal Res. Comm., *45* (2): 336–345

PAVLOVIĆ, N., Z. GIREK, M. ZDRAVKOVIĆ, J. GVOZDANOVIĆ VARGA, Đ. MORAVČEVIĆ, J. ZDRAVKOVIĆ (2017): Mode of inheritance and AMMI analysis of onion (Allium cepa L.) bulb traits. Genetika, *49* (2): 729 – 742.

PRŽULJ, N., M. MIROSAVLJEVIĆ, P. ČANAK, M. ZORIĆ, J. BOĆANSKI (2015): Evaluation of Spring Barley Performance by Biplot Analysis. Cereal Res. Comm., *43* (4): 692–703.

R DEVELOPMENT CORE TEAM (2005): R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, www.R-project.org.

ROSEGRANT, M.W., S. MSANGI, C. RINGLER, T.B. SULSER, T. ZHU, S.A. CLINE (2008): International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description. International Food Policy Research Institute: Washington, D.C. www.ifpri.org/themes/impact/impactwater.

SHIRI, M. (2013): Grain yield stability analysis of maize (Zea mays L.) hybrids in different drought stress conditions using GGE biplot analysis. Crop Breeding J., *3* (2): 107-112.

SOUSA, L.B., O.T. HAMAWAKI, A.P. NOGUERIA, R.O. BATISTA, V.M OLIVEIRA, R.L. HAMAWAKI (2015): Evaluation of soybean lines and environmental stratification using the AMMI, GGE biplot, and factor analysis methods. Genet. Mol. Res., *14* (4): 12660- 74

SOUZA, A.R.R., G.V. MIRANDA, M.G. PEREIRA, L.V. SOUZA (2009): Predicting the genetic gain in the Brazilian white maize landrace. Ciência Rural, *39*: 19-24.

SOUZA, L.V., G.V. MIRANDA, J.C.C. GALVÃO, F.R. ECKERT, E.E. MANTOVANI., R.O. LIMA, L.J.M. GUIMARÃES (2008): Genetic control of grain yield and nitrogen use efficiency in tropical maize. Pesquisa Agropecuária Brasileira, *43*: 1517-1523.

STATISTICAL OFFICE OF THE REPUBLIC OF SERBIA (2018): Statistical yearbook of the Republic of Serbia. Statistical office of the Republic of Serbia, Belgrade, http://data.stat.gov.rs

YAN, W., L.A. HUNT, Q. SHENG, Z. SZLAVNICS (2000): Cultivar evaluation and mega- environment investigation based on the GGE biplot. Crop Sci., *40*: 597-605.

YAN, W., L.A. HUNT (2001): Interpretation of genotype by environment interaction forwinter wheat yield in Ontario. Crop Sci., *41*: 19-25.

YAN, W., P.L. CORNELUIS, J. CROSSA, L.A. HUNT (2001): Two types of GGE biplots for analyzing multi-environment trial data. Crop Sci., *41*: 656-663.

YAN, W., M.S. KANG, S. MA, S. WOODS, P.L. CORNELIUS (2007): GGE biplot vs. AMMI analysis of genotype-by-environment data. Crop Sci., *47*: 596–605

YATES, F., W.G. COCHRAN (1938): The analysis of group experiments. J. Agric. Sci., *28*: 556–580

ZOBEL, R.W., M.J. WRIGHT, H.G. GAUCH (1998): Statistical analysis of a yield trial. Agron. J., *80*: 388-393.

PROCENA VISINE I STABILNOSTI PRINOSA ZRNA KUKURUZA AMMI ANALIZOM

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Izvod

U radu je ispitivana interakcija genotip x sredina i stabilnost prinosa zrna 36 hibrida kukuruza FAO grupe zrenja 300-700. Ogled je postavljen na 8 lokalteta u Srbiji tokom tri godine (2011-2013), po potpuno slučajnom blok sistemu (RCBD). Na osnovu dobijenih podataka, izračunate su prosečne vrednosti, a za procenu stabilnosti prinosa korišćen je metod AMMI analize. Posmatrano po godinama, najveći prosečan prinos zrna u ogledu ostvaren je u 2011. godini (11,62 t/ha), a najmanji u veoma sušnoj i stresnoj 2012. godini (6,90 t/ha). Najveći prinos zrna kukuruza u proseku za sve tri ispitivane godine bio je na lokalitetu L2 (13,81 t/ha), a najmanji na lokalitetu L7 (6,97 t/ha). Primenom AMMI analize dobijene su preciznije preporuke za gajenje hibrida u određenim sredinama. Pa se hibridi kraće vegetacije i visokog potencijala rodnosti kao što su H3, H4, H9, H11, mogu najpre preporučiti sredinama sa manjom količinom padavina, dok se stabilni hibridi H21 i H35, ujedno visokog potencijala rodnosti mogu preporučiti širokom spektru sredina. Hibridi H32 i H36, najduže vegetacije mogu se preporučiti lokaciji L2, koja nije patila od nedostatka vlage, gde će ovi hibridi moći da ispolje svoj pun kapacitet. Takođe, u povoljnim godinama potencijal rodnosti ovakvih hibrida dolazi do izražaja. U uslovima suše variranja prinosa su mnogo manja i manji je rizik ako se gaje hibridi kraće vegetacije. Ovakvi rezultati još jednom naglašavaju značaj oplemenjivanja na povećanja tolerantnosti hibrida kukuruza na stres suše, koja očito predstavlja prevalentni stresni factor za gajenje kukuruza na ispitivanom području Srbije

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