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В сборнике представлены тезисы докладов конференции по следующим направлениям: селекция и семеноводство картофеля, инновации в технологиях возделывания картофеля, технологии хранения и переработки картофеля, механизация картофелеводства, экологическое состояние природной среды при использовании удобрений и средств химизации в технологиях возделывания клубнеплодов, повышение экономической эффективности АПК на основе инновационной модернизации производства. Материалы предназначены для научных сотрудников, преподавателей, студентов и аспирантов высших учебных заведений, работников информационно-консультационных служб, торговли и общественного питания, слушателей курсов повышения квалификации, специалистов и руководителей сельскохозяйственных и перерабатывающих предприятий АПК разной организационно-правовой формы. Материалы изданы в авторской редакции.

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GxE INTERACTION BY AMMI MODEL IN MELON BREEDING

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Key words: GxE ineraction, AMMI analysis, melon, yield

Summary: Melon is plant that is used for human consumption as a vegetable and for the production of seed oils. In this paper was investigated genotype x environment (GxE) stability of yield per plant in melons that have different length of growing season. Early, medium and late melon genotypes were grown in greenhouses and in the open field. Experiments were conducted at the Institute for Vegetable Crops in Smederevska Palanka, Serbia, during years 2010 and 2011. The aim of study was to determine melon genotype with stable yield per plant in both modes of production. Additional, we have set the goal to identified melon genotypes suitable for greenhouse production and melon genotypes suitable for the production in the open field. For analyses of GxE stability we used the additive main effect and multiplicative interaction (AMMI) model. We have calculated values of principal components (PC) of genotypes and environments, and values of genotype x environment interaction (GEI). It was found that earlier melon genotypes have a higher yield per plant when grown in an open field, while late melon genotypes had higher yield per plant when grown in a greenhouse. The most stable melon genotypes were "A2-3lb" and „Honeydew", while the least stable were melon genotypes „ED-3" and „Chinese muskmelon".

Introduction. The interaction of genotype x environment (GxE) is significant both in plant breeding programs and for the introduction of new varieties and hybrids in the agricultural production of a country (Freeman, 1985). Knowledge of the GxE interaction is important as a measure to mitigate climate change. Also, knowledge about varieties, their yield and stability help entrepreneurs to increase and diverse their production.

During the long period of time, the interaction of genotype x environment (GxE) was estimated principally by analysis of variance (ANOVA) for different plant characteristics. ANOVA as an additive statistical model was effective in distribution of the total sum of squares on a) the effect of genotype; b) the effect of the environment, and c) the effect of GxE interaction. However, ANOVA does not provide a detailed description of GxE interaction (Gauch and Zobel, 1988). Gauch (1988, 1992) proposed the use of AMMI model in field trials for analysis of the GEI. Nowadays, AMMI model - Additive Main Effects and Multiplicative Interaction Model, is increasingly used in the analysis of main effects and GxE interaction in experiments involving different genotypes growing on various sites (Mahalingam et al., 2006). AMMI model is a complex statistical analysis that consists of two models: ANOVA and Principal Component Analysis (PCA). AMMI model recalculates values of principal components of genotypes and environments and shows GxE interaction more precise than ANOVA (Naveed et al., 2007).

There are a number of AMMI models, depending on the number of axes of the main components. Most used are AMMI 1 and AMMI 2 models. AMMI 1 biplot presents the main effects (G and E) that are shown on the abscissa and the value of the first principal component which is shown on the ordinate (Zobel et al., 1988). AMMI 2 biplot presents the ratio of the first and second principal components.

If the value of the first principal component of genotype or environment is close to zero, it can be concluded that the genotype or environment had low effect of interaction. If the genotype and the environment are with the same sign, either positive (+) or negative (-), their interaction is positive, while if they are with different sign, their interaction is negative (Mahalingam et al., 2006).

To use AMMI analysis, it is not necessary to set up field experiments in a special way. The important thing is that the different genotypes are grown in variable conditions (location, years, systems of agriculture, fertilization, treatments). Efficiency AMMI analysis is shown by various authors. In Serbia were carried out research in maize genotypes (Babic et al., 2010), wheat (Hristov and Mladenov, 2005; Petrovic et al., 2005; Petrovic et al., 2010), beans (Vasic et al., 2010), eggplant (Zdravkovic et al., 2011), sunflower (Tančić et al., 2011), rapeseed (Marjanovic-Jeromela et al., 2011). In addition to mentioned species, AMMI analysis was used in different international studies such as those in rice (Mahalingam et al., 2006), potatoes (Hassanpanah, 2010), tobacco (Sadeghi et al., 2011), cotton (Naveed et al., 2007), beans (Flores et al., 1996) and other crops.

The aim of this study was to show the efficiency of AMMI analysis in melon.

Melon is plant that is used for human consumption as a vegetable and for the production of seed oils. Melon fruits are present on the market of Serbia during the whole year. Serbia is located in the moderate temperate climate zone and the cultivation of melons in the open field is recommended only when soil temperature is above 10^{o}C. Suitable period for the melon growth in open field is from the end of spring (May) to late summer, ie. when there is no danger of frosts. Mention period is long around five months in total. In aim to obtain melon fruits during the remaining seven months of the year it is necessary to cultivate the melon in a protected area.

Both modes of melon production are important, they reduce the dependence of the market from imports of melon and encourage entrepreneurship.

In this experiment, we examined nine melon genotypes from the collection of the Institute for Vegetable Crops in Smederevska Palanka, Serbia, and we tried to answer on the following questions: 1) Which genotype has the most stable yield in a protected area and in the open field; 2) Which genotype is suitable for growing in greenhouses and in the open field.

Material and methods

Aim of this research was to determinate the stability of yield per plant of melon genotypes grown in greenhouse and in the open field. In the experiment were used 9 melon genotypes in total: 2 melon genotypes of earlier growing season (Sesame and Fiata), 3 melon genotypes of medium growing season (Pobeditel, Chinese muskmelon and A2-3lb), and 4 melon genotypes of late growing season (ED-3, ED-4, Anannas and Honeydew).

Seeding of the melon seeds in the clay pots (10 cm in diameter) was performed in the first week of April in the greenhouse of the Institute for Vegetable Crops. A total of 540 plants were sown. After a stage of 3-5 true leaves the plants were planted at the experimental fields. Only the half of the plants was transferred to the open field. The second half of plants was planted in the greenhouse at the Institute for Vegetable Crops. The experiments in the greenhouse and in the open field were done in three replications. Each replication consisted of nine rows (distance between rows 100 cm) and 10 plants within the row (the distance between plants was 50 cm in protected area and 150 cm in open field). In the greenhouse experiment next to each plant were placed Manila rope i.e. strings in aim to facilitate plant climbing and fruit formation. When the climbing melon fruits reach a length of 10 cm they were protected by knitted bags and thus they remain protected until harvest.

In both experiments, in the open field and in greenhouses, we have recorded the values of the following characteristics: 1) fruit weight and 2) the number of fruits per plant, and then by multiplying the obtained values we have calculated the yield per plant.

Obtained values were statistically analyzed using AMMI method. The AMMI stability values (ASV) were calculated in order to rank the genotypes in terms of stability. For calculating ASV we used the formula (Purchase, 2000):

$$ASV = \sqrt{\left[\frac{SSPC1}{SSPC2}\quad (PC1\ value)\right]^2 + [PC2\ value]^2}$$

where:

SSPC1 = Sum of squares of PC1

SSPC2 = Sum of squares of PC2

PC1 value = first principal component value for each genotype;

PC2 value = second principal component value for each genotype.

AMMI analysis was performed with the R software, version 2.15.2 (A Language and Environment, Copyright 2012).

Results and discussion

Analysis of variance of AMMI model (Tab. 1) shows significant differences between locations (open field and greenhouse), years (2010 and 2011) and genotypes (1-9) and their interactions for yield per plant in melons. Even 42.38% of the total sum of squares referred to the interaction effect of genotype x environment which is about 2.5 times more than the value of the sum of squares of environment. This means that there was a significant difference between the responses of genotypes under different environment. Results also show that the sum of the squares of the first and second principal component (PC1 and PC2) makes 99.09% of the sums of squares of interaction. Based on these facts it can be concluded that the AMMI model with only two main components (Zobel et al., 1988) the best model for our investigations.

Tab. 1. Analysis of variance of AMMI model

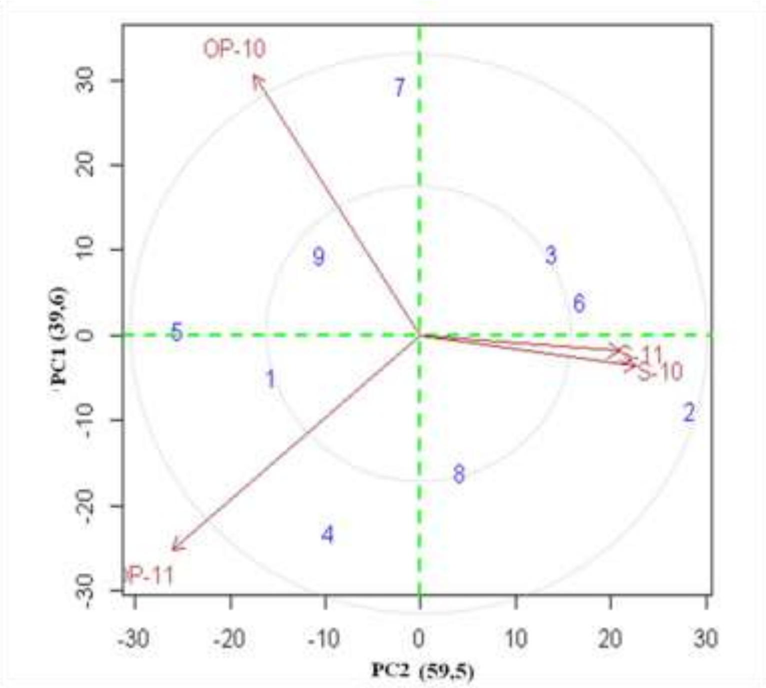
Source	Degree of freedom	Sum of squares (SS)	SS (%)	Mean squares	F- ratio
Genotypes (G)	8	26466324	38.69	3308290	394.99^{**}
Environments (E)	3	12281262	17.95	4093754	239.38^{**}
Replication (Environments)	8	136810	0.20	17101	2.04^{ns}
GxE	24	28993549	42.38	1208065	144.24^{**}
PC1	10	17250551	59.50	1725055	205.96^{**}
PC2	8	11478119	39.59	143477	171.30^{**}
PC3	6	264879	0.91	44147	5.27^{**}
Error	64	536044	0.78	8376	
Total	100	68413989			

*Legend: PC1 - first principal component; PC2 - second principal component; PC3 - third principal component

The figure 1 shows AMMI 2 model biplot (PC1 and PC2), i.e. graphically displays GxE interaction (GEI). It is known that the smaller the angle between the vectors of interaction represents a greater similarity in their interaction (Babić et al., 2010).

On the base of the biplot in the Figure 1 one can see that there was a greater interaction between genotypes and environmental in open field than in protected area. The effect of years is highly expressed in the open field while in the greenhouse is almost negligible.

Melon genotypes with later maturation have stronger interaction with the environment during cultivation in a protected area while the genotypes with early and middle maturation have stronger interaction with the environment during cultivation in the open field.



**Legend: 1 - Sesame; 2 - ED-3; 3 - ED-4; 4 - Pobeditel; 5. Chinese muskmelon; 6. Anannas; 7. Fiata; 8. Honeydew; 9. A2-3lb; S-10 – greenhouse in 2010; S-11 – greenhouse in 2011; OP-10 - open field in 2010; OP-11 - open field in 2011*

Fig. 1. AMMI 2 biplot of 9 genotypes evaluated in 2 locations

According to Figure 1 and the ASV value from table 2 it can be concluded that the smallest interaction was recorded in genotypes labeled with 9 (A2-3lb) and 8 (Honeydew), while the strongest interactions was visible in genotypes labeled with 2 (ED-3) and 5 (Chanise muskmelon). Lower GxE interaction indicates to more stable (adaptable) genotypes, while higher values of ASV have less stable genotypes (Sadeghi et al., 2011).

Tab. 2. Genotype mean, AMMI stability value and rank

No	Genotype	Yield per plant (kg)		PC1	PC2	ASV	
		Mean	Rank			Value	Rank
1	Sesame	2556.74	2	-15.67	-4.85	578.15	4
2	ED-3	1697.29	7	28.36	-8.86	1895.17	9
3	ED-4	2039.14	4	13.86	9.62	526.45	3
4	Pobeditel	1987.58	5	-9.51	-23.19	742.06	6
5	Ch. muskmelon	2342.74	3	-25.50	0.56	1469.05	8
6	Anannas	1453.96	8	16.80	3.90	652.71	5
7	Fiata	2907.07	1	-2.10	29.33	870.21	7
8	Honeydew	1308.83	9	4.25	-16.04	298.08	1
9	A2-3lb	1706.53	6	-10.51	9.54	340.51	2

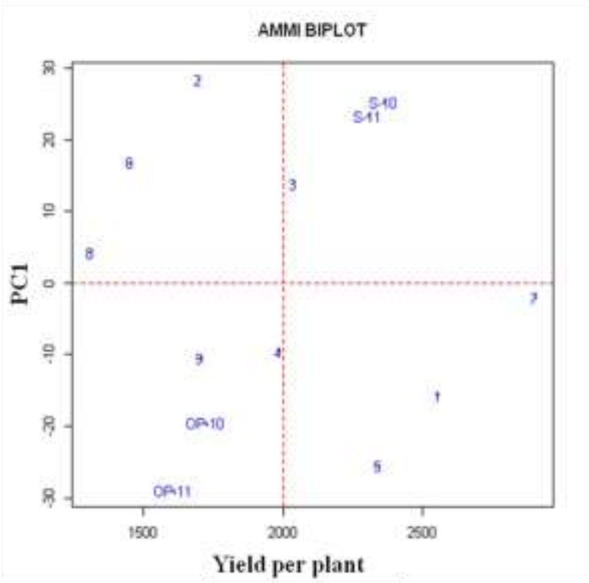
*Legend: PC1 - first principal component; PC2 - second principal component

AMMI biplot model 1 (PC1 and yield) is shown in Fig. 2. Positive value of the first principal component and a high average yield was recorded in a protected area in both years of study, while a negative value of the first principal component and low average yields was recorded in the open field in both years of study. On the base of this result we can conclude that different environmental factors have stronger affect on the yield of melons in open field than in protected area. In greenhouses we can control and regulate many environmental factors as temperature, air humidity and soil moisture.

The most stable genotype in terms of yield per plant was ED-4. This genotype has a medium-sized fruit. The melon variety Fiata has proved to be the highest yield genotype.

Genotypes ED-3, Anannas and Honeydew generally had a low average yield, but showed a stronger interaction with the environment in a protected area where the yield per plant was above average. On the other hand, the early maturing genotypes Sesame and Fiata, as well as medium term maturing genotypes Chinese muskmelon showed a stronger interaction with the environment in the production in the open field. It is known that the genotype who achieves the highest average yield with the positive interaction is desirable genotype for a specific environment (Babić et al., 2010).

On the Fig. 2 one can see the positive interaction between the early maturing genotypes Sesame, Fiata and Chinese muskmelon, as well as medium-late genotypes Pobeditel and A2-3lb with the environment in open field (OP). Based on this, it can be concluded that these genotypes are suitable for growing in the open field. On the other hand, genotypes that are later matured: Anannas, Honeydew, ED-3 and ED-4 had a positive interaction with the environment in protected area (S). Therefore, these genotypes are recommended for growing in glasshouse production. Previous facts mean that positive interaction between certain genotypes and environment in specific mode of production lead to higher their higher yield per plant in such conditions.



** Legend: 1 - Sesame; 2 - ED-3; 3 - ED-4; 4 - Pobeditel; 5. Chinese muskmelon; 6. Anannas; 7. Fiata; 8. Honeydew; 9. A2-3lb; S-10 – greenhouse in 2010; S-11 – greenhouse in 2011; OP-10 - open field in 2010; OP-11 - open field in 2011*

Fig. 2. AMMI 1 biplot of 9 genotypes evaluated in 2 locations

Conclusion

The aim of this paper was to determine the most stable melon genotypes and the best mode of production for each genotype with the use of AMMI model. AMMI analysis showed that among genotypes, environments and GxE interactions there were very significant difference.

Genotypes A2-3lb and Honeydew proved to be the most stable genotypes, while the ED-3 and Chinese muskmelon were least stable. Genotype ED-4 was pointed out as the ideal genotype for cultivation in both modes of production, in greenhouses and in the open field. This genotype has equal value of the average yield per plant in both modes of production. Early and medium early genotypes were more suitable for growing in the open field, because in these conditions, they reach higher yields per plant. Late melon genotypes may be recommended for growing in the greenhouse.

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