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STABILITY ASSESSMENT OF MAIZE HYBRIDS BY DIFFERENT METHODS IN RELATION TO THEIR ZONING

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Abstract

A many-sided evaluation of grain yield stability of 22 maize hybrids from the early group (FAO 300-400), tested in 4 locations was done. Different methods and models were applied: variation and regression analysis; AMMI and cluster analysis as well.

A modified method for grouping of hybrids by mean yield and mean values of the regression coefficient b_i was proposed. A good accordance between that method and AMMI-1 analysis was observed. The cluster analysis also confirms this consent.

Calculated theoretical yields by locations create conditions for more precise zoning of hybrids according to environments.

Key words: *maize hybrids, stability parameters, AMMI analysis, zoning*

INTRODUCTION

The multienvironments testing of hybrids is a final stage of the breeding. The main purpose of that testing is their stability assessment as a result of the genotype-environment interaction and determining of the best locations for their growing (zoning) as well. Agronomical (phenotype) stability can be defined by means of parametrical methods – most often the regression or variation analysis, or by nonparametrical ones – the cluster and rang analysis (Abou El Fitouh, 1969; Becker and Leon, 1988). Modern methods like the AMMI analysis – the Additive Main Effects and Multiplicative interaction effects model - Zobel et al. (1988); Gauch (1992), and its modification – the GGE biplot analysis (Yan and Tinker., 2006; Gauch, 2006) are applied also for determining of the genotype stability and suitable cultivation areas.

As hybrid models they use the analysis of variance (ANOVA) and the principle component analysis (PCA) with coordinates placement of genotypes and environment in the biplot for a final data interpretation.

According Mitrovic et al. (2012) there is not a big difference between the AMMI and the GGE biplot analysis and they could be used with equal success for maize hybrids stability evaluation at testing in different environments. Brancovic et al. (2018) make a comparison of linear regression models with the AMMI analysis in relation to maize hybrids stability. A similarity is observed, but regression models evaluate this stability by one axis – the regression line, while the AMMI-analysis makes rates by two ones – PC1 and PC2. At the prediction of genotype performance – their yield stability in different locations some unpredictable factors occur – the so called “noise” (Crossa, 1990; Crossa et al. 1990).

The aim of that study is to determine stability parameters of experimental hybrids by well known methods – the regression and variances analysis, and to compare their effectiveness with AMMI results. A modified method of Francis and Kannenberg (1978) model is proposed and included in comparisons. Another aim is to make a connection between the cluster and other analyzes in relation to the accordance of assessments of hybrids stability and their zoning.

MATERIALS AND METHODS

22 maize hybrids from the early maturity group (FAO 300) are tested in 2018 at 4 locations. These are: Knezha (Maize Research Institute), Ruse (Agricultural and seed science Institute "Obraztsov Chiflik"), Pavlikeni (Experimental stations for soybean and grain crops) and Pazardzhik (Experimental station for irrigation practice, vil. Ivailo). The experiment has been a part from the ecological (multilocational) network of the Maize Research Institute – Knezha which testing includes hybrids from all FAO groups before official government testing. The trial is made by randomized block design (RBD) with 3 replications and 10 m^2 harvesting plots. A two-way ANOVA is performed for the studied trait-grain yield (Perkins and Jinks, 1968; Hallauer, 1988). Phenotype stability parameters are calculated according Eberhart and Russell (1966) and Shukla (1972) models and Francis and Kannenberg (1978) methods with additional modification. AMMI analyses of data (Zobel at al., 1988; Gauch, 2006) includes AMMI-1 and AMMI-2 biplots.

The general adaptation index according Vulchinkov (2007) is applied also. The cluster analysis of the results is performed by the Ward (1963) method. A computer program SPSS25 has been used for all calculations, including the principle component analyses.

The expected theoretically of one hybrid yield by locations is calculated according Zobel et al. (1988) formula (reworked):

$$x = a_1 + a_2 - a_3 + (PC_{1g}.PC_{1e})$$

a_1 – hybrids mean from all locations

a_2 – mean form one particular location

a_3 – general mean of the trial

PC_{1g} – PC_1 of the hybrid (genotype)

PC_{1e} – PC_1 of the location (environment)

RESULTS AND DISCUSSION

Table 1 shows the results (in combined form) of the performed ANOVA. It includes a two - factor analysis of grain yield with a variance of the replications in the conditions (according to Hallauer, 1988), a differentiated variance of the genotype - environment interaction (according to Perkins and Jinks, 1968) of the linear and nonlinear part (heterogeneity and balance) and a differentiated variance of the three main components (PC_1, PC_2 and PC_3) characterizing the genotype - environment interactions.

The results show that there are significant variances for all sources of variation (in the first part of the analysis), with the locations (environmental conditions) having the highest value, which is logical in this type of study (Ilker et al., 2009).

Followed by the variances of hybrids (genotypes) and their interaction (GXE). As a percentage of the total variation in the locations it is 66.91%, in the hybrids - 16.72% and in their interaction - 12.28% respectively. The significant genotype - environment interaction means a different reaction of the hybrids when the environmental conditions change and is the reason for continuing the analyzes to determine their stability parameters.

There have been cases in this type of study where there is no reliable interaction (GXE) due to the large number of degrees of freedom (Zobel at. al., 1988), but the analyzes are continued.

The differentiated variance of genotype - environment interaction (the second part of the table) shows a reliable variance of the balance (nonlinear interactions), which shows the complex nature of this phenomenon. Of the sum of the squares of this interaction, the balance has a dominant part (87.71%). In our previous study (Vulchinkov, 2000) the same fact was established not only for the yield, but also for a number of other traits related to it, both in hybrids and in maize lines. From the variances of the three main components located at the bottom of table 1, it can be seen that only in the first case (PC_1) it has a reliable value with the correspondingly largest share of variation (61.03%). This component is of the greatest importance in the discussion of genotype - environment interactions, respectively the AMMI -1 model.

Table 1. ANOVA results of grain yield (kg/da) maize hybrids - 22 hybrids tested of 4 locations (2018), including partitioning of interactions (LxH) – Heterogeneity, Balance and AMMI (PC scores)

Source of Variation	SS	df	MS	F	% of SS
Total	12388654,4	263			100
Locations	6838998,57	3	2279666,2	176,66++	66,91
Hybrids	1709334,6	21	81396,9	6,30++	16,72
Reps, In locations	418113,7	8	52264,2	4,05+	4,00
LxH	1254392,5	63	19910,9	1,54+	12,28 (100%)
Heterogenity	153540,4	(21)	7311,4	0,56	12,24
Balance	1100852,1	(42)	26210,8	2,03+	87,76
PC1	765527,7	(23)	33283,8	2,58++	61,03
PC2	371342,8	(21)	17682,9	1,37	29,60
PC3	117521,9	(19)	6185,4	0,48	9,37
Eror	2167815,1	168	12903,7		

+,++, Significance at P=5% and P=1%

Table 2 shows the grain yield database of the studied 22 hybrids tested at the four locations together with their main components.

The highest yield of the experiment is observed for hybrid E 13 - 1133.84 kg / da, and the lowest for E 6 - 782.84 kg / da. The hybrids E 13 and E 11, which are the first two in the ranking, exceed the better standard (P 9578) by 113.7% and 110.1%, respectively, and differ significantly from it.

The Knezha 307 standard gave a lower yield than P 9578, but there is no significant difference between them, as evidenced by the LSD values. The highest yield for the experiment is the location Ruse, followed by Knezha, Pazardzhik (despite the irrigated conditions) and Pavlikeni. The highest yield was recorded for hybrid E 7 in Ruse (1501.67 kg / da), and the lowest for E 6. The first principle component (PC_1) has the highest value in Ruse, the other places have negative values. In the case of the E 11 hybrid, the lowest values are observed (closest to zero) for all three components, which we will comment on later.

On table 3 in an expanded form are presented the yields of hybrids, their stability parameters – b_i, s^2d_i, R^2 (by the model of Eberhart, and Russell, 1966); σ_i^2 and S_i^2 (the model of Shukla, 1972), their variation ($CV_{\%}$), relating to the method of Francis and Kannenberg (1978) and the general adaptation index (Vulchinkov, 2007) with the corresponding ranking. Estimates of the first two models show that their stability parameters do not differ significantly from their theoretical values, i.e. b_i=1.0 and s^2d_i=0 for the regression model (Eberhart and Russell, 1966) and σ_i^2=0.0 и S_i^2=1.0 for the variation model (Shukla, 1972).

The observed values at which the parameters s^2d_i, σ_i^2 and S_i^2 have as variances negative values are accepted as zero. At the parameter s^2d_i 12 hybrids have negative values, and at the parameter σ_i^2 only one hybrid (E 11) has such a value. This hybrid, having stability parameters in both models closest to the theoretical ones, can be considered as a standard for stability, although the lack of proven differences in the parameters of the other hybrids makes their estimates relative.

Table 2. Data base of grain yield (kg/da) maize hybrids – 22 FAO 300-400 hybrids, tested in 4 locations – Kneja, Ruse, Pavlikeni and Pazardzik, mean values by hybrids, locations and PC scores

Hybrids	Mean	Kneja	Russe	Pavlikeni	Pazardzik	PC1	PC2	PC3
E1	900,40	1053,05	1110,67	617,87	820,03	-0,07	-0,33	0,42
E2	913,81	888,54	1144,67	711,19	910,86	0,08	0,36	-0,18
E3	956,10	1057,39	1150,33	746,51	870,17	-0,10	-0,22	-0,04
E4	945,74	1075,60	1166,20	702,04	839,12	-0,02	-0,36	0,15
E5	1075,35	1034,16	1418,93	851,40	996,92	0,51	0,16	-0,21
E6	782,84	831,74	955,40	564,67	779,53	-0,17	0,18	0,03
E7	1020,89	1004,45	1501,67	684,29	893,17	1,00	-0,07	0,32
E8	924,29	961,08	1090,27	760,29	885,53	-0,18	0,10	-0,31
E9	882,41	1017,73	1032,47	657,02	822,45	-0,29	-0,22	0,14
E10	954,25	1143,14	1034,73	733,99	905,13	-0,57	-0,32	0,22
E11	1106,86	1167,54	1335,07	865,99	1058,84	0,03	0,00	0,10
E12	830,06	781,64	1063,07	621,22	854,33	0,09	0,51	-0,15
E13	1133,81	1115,70	1443,87	922,51	1053,18	0,38	0,10	-0,23
E14	963,95	1070,70	1076,67	812,38	896,07	-0,40	-0,17	-0,29
E15 –Kn307 St	923,86	928,14	1236,47	629,40	901,46	0,36	0,22	0,30
E16	916,60	915,03	1211,53	661,21	878,62	0,30	0,19	0,08
E17	897,35	1037,83	1199,07	719,83	632,68	0,30	-0,88	-0,38
E18	982,09	1023,24	1165,07	766,25	973,80	-0,13	0,18	0,00
E19 – P 9578 St	997,08	1066,53	1056,27	780,00	1085,50	-0,61	0,42	0,19
E20	947,60	986,00	1127,67	783,77	892,96	-0,13	0,05	-0,33
E21	925,54	999,98	1127,67	681,78	892,72	-0,07	0,02	0,16
E22	892,29	970,92	1033,60	687,95	876,69	-0,30	0,07	0,00
$\bar{x}$	948,7	1006,00	1167,00	726,00	896,00			
	LSD 5% = 91,81 LSD 1% = 121,02 LSD 0,1 = 155,34							
Kneja						-0,43	-0,65	0,30
Pavlikeni						-0,25	-0,02	-0,61
Pazardzik						-0,33	0,72	0,25
Ruse						1,00	-0,05	0,06

Table 3. Ranking of hybrids by means of the grain yield (kg/da), stability parameters Eberhart and Russel (1966) and Shukla (1972) and CV% - Francis and Kanneberg (1978) and general adaptation index xi-bi, Vulchinkov S., (2007)

GEN	Rank	Mean	Eberhart and Russel (1966)			Shukla (1972)		CV(%) Francis and Kanneberg (1978)	xi-bi Vulchinkov S., (2007)	Rank
			bi	S^2di	R^2	σi^2	Si^2			
E13	1	1133.81	1.14	2169.41	0.91	5158.14	6470.63	19.56	10.20	1
E11	2	1106.86	1.06	-4258.04	1.00	-172.24	43.18	17.77	10.01	2
E5	3	1075.35	1.22	6083.60	0.88	9192.77	10384.82	22.53	9.53	3
E7	4	1020.89	1.79	9314.98	0.92	33654.55	13616.20	33.98	8.42	11
E19	5	997.08	0.59	9536.00	0.56	16324.61	13837.22	14.56	9.38	4
E18	6	982.09	0.88	-3312.25	0.98	960.43	988.97	16.82	8.94	6
E14	7	963.95	0.66	-858.25	0.87	6649.64	3442.97	13.62	8.98	5
E3	8	956.10	0.96	-2456.92	0.96	1079.74	1844.30	19.03	8.60	9
E10	9	954.25	0.77	11258.14	0.67	13030.80	15559.36	18.46	8.77	7
E20	10	947.60	0.78	-4088.68	0.99	1636.46	212.54	15.38	8.70	8
E4	11	945.74	1.12	-669.89	0.95	2838.82	3631.33	22.53	8.34	12
E21	12	925.54	1.01	-3618.46	0.99	172.02	682.76	20.39	8.25	13
E8	13	924.29	0.74	-4276.95	1.00	2189.49	24.27	14.95	8.50	10
E15	14	923.86	1.31	-392.90	0.96	6125.74	3908.32	26.88	7.93	17
E16	15	916.60	1.19	-923.63	0.96	3526.24	3377.59	24.69	7.98	16
E2	16	913.81	0.91	196.27	0.91	3267.05	4497.49	19.47	8.23	14
E1	17	900.40	1.18	818.02	0.93	4613.13	5119.24	25.15	7.82	19
E17	18	897.35	1.23	23453.52	0.74	22035.04	27754.75	29.65	7.74	20
E22	19	892.29	0.79	-2524.84	0.95	2653.72	1776.38	16.89	8.13	15
E9	20	882.42	0.91	683.94	0.90	3652.19	4985.17	20.19	7.91	18
E12	21	830.06	0.90	3925.71	0.84	6062.93	8226.93	22.09	7.40	21
E6	22	782.84	0.86	-2968.04	0.97	1362.67	1333.18	20.83	6.97	22

For example, the standard P 9578 (E 19) is relatively stable under less favorable (stress) conditions with bi = 0.59, and the other standard - Knezha 307 (E 15) is relatively responsive under more favorable conditions (bi = 1.31). The values of the coefficient of determination (R^2), which is accepted as an indicator of genetic stability, are high everywhere

The second parameter (S_i^2) according to Shukla (1972) generally has higher absolute values, as established in our previous study (Vulchinkov, 2000), i.e. it determines the stability of genotypes more precisely, but in this case the lack of reliable differences again leads to relativity of estimates. In other words, there is a good coherence between the two models. The range of variation in $CV_{\%}$ values is from 13.62% for hybrid E 14 to 33.98% for E 7. Only in this hybrid can the variation be considered strong because it is over 30%. In the method of Francis and Kannenberg (1978), the authors did not discuss what the maximum size of the average coefficient of variation should be. At a $CV_{\%}$> 30% value, genotype estimates of their stability can become quite inaccurate. In our experiment the average value of $CV_{\%}$ is 20.57%, i.e. the results of the evaluations are acceptable.

The right part of table 3 shows the general adaptation index of the tested hybrids. As a difference from the average size of the yield and the first parameter of stability b_i from the Eberhart and Russell model (1966), it gives priority to the genotypes with relatively high and stable yields. The table shows that the first three hybrids ranked by yield retain their ranking by x_i-b_i index. These are E 13, E 11 and E 5. The fourth in yield (E 7) goes to 11th place in terms of general adaptation due to the high value of b_i = 1.78 - responsive to favorable conditions, its relatively high parameters s^2d_i, σ_i^2 and S_i^2 as variances, as well as its high value of CV $_{\%}$ we talked about. The E 19 (P 9578) standard with its low value for b_i=0.59 from 5th place in yield goes to 4th place in general adaptation. The next hybrid E 18 retains its position, and E 14 from 7th goes to 5th place and so on. The other standard E 15 (Knezha 307) goes down from 14th to 17th place. The last two hybrids in the ranking - E 12 and E 6, are without displacement.

Figure 1 shows the distribution of hybrids according to the average yield and the average $CV_{\%}$ value from the experiment – *Francis* and Kannenberg model (1978). This distribution includes 4 groups (quadrants). The first quadrant is with the genotypes above the average yield from the experiment and $CV_{\%}$ below the average value – this is the most desirable group for the breeders. The second quadrant is for the forms with a high yield, but also with a higher than average variation – these are the genotypes responsive to more favorable conditions, which are also interesting for the selection.

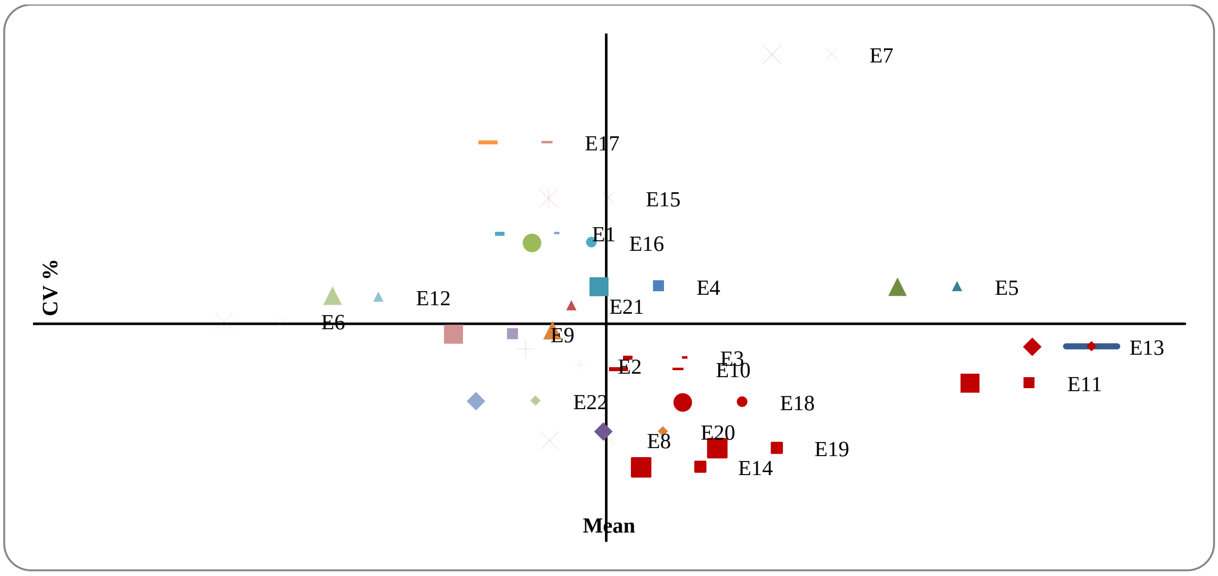

Fig. 1. Distribution of hybrids according to the general means of the grain yield (kg/da) and CV (%) – Franscis and Kanneberg (1978)

The third quadrant is for the genotypes with a lower than average yield, but with a lower variation. The last, forth quadrant is for the genotypes with a lower yield, but with a higher than the average variation, which is the most unfavorable group for the selection.

This figure shows that the first quadrant includes 7 hybrids: E 3, E 10, E 18, E 14, E 19, E 11 and E 13, the last two having the higher yield in the experiment. The second quadrant includes only two hybrids – E 5 and E 7, as 9 hybrids in total falling into the highly productive area. In the other area there are 13 hybrids, in third quadrant there are 6 and in forth quadrant – 7, which we will not discuss in detail.

This method is accepted as a quick and easy way to determine the agronomic type of stability (Francis and Kannenberg *(1978)*, because it can be performed with less than three environmental conditions, while the models of Eberhart and Russell *(1966)* and Shukla *(1972)* require this minimum of conditions. As noted above, with strong variation ($CV_{\%}$> 30.0%), estimates of genotype stability become unrealistic, especially those with $CV_{\%}$ values close to the average when it is high. On the other hand, if we make a parallel assessment of the stability of genotypes by several methods simultaneously, as in our case, it is seen that some of them, although in the productive area, are unrealistically in its stable part. This applies to the E 11 and E 13 hybrids, which have stability parameters from the last two models rather than an intensive (responsive) type of cultivation (table 3). The same applies to some hybrids of III and IV quadrant, respectively E 6, E 12 and E 21.

In the study we make some modification in the distribution of hybrids and instead of the average value of $CV_{\%}$, we use the average (theoretical) value of b_i, which is 1. A similar approach is applied by Ilchovska (2019) in determining the stability of maize hybrids, without, however, making a comparison with the method of Francis and Kannenberg *(1978)*.

Figure 2 shows this modified distribution. In this figure as in figure 1 the highly productive, respectively the low productive, areas are the same. The change in the distribution is seen vertically on $CV_{\%}$, respectively $b_{i.}$ In the figure the distribution of hybrids is as follows: two hybrids pass from the first to the second quadrant – E 11 and E 13, with 5 hybrids remaining in the first quadrant and 4 remaining in the second – E 7, E 5, E 11 and E 13. In the low productive areas, there is a "jump" of E 21 from third to fourth quadrant, although in both figures it's $CV_{\%}$ and b_i values are close to average.

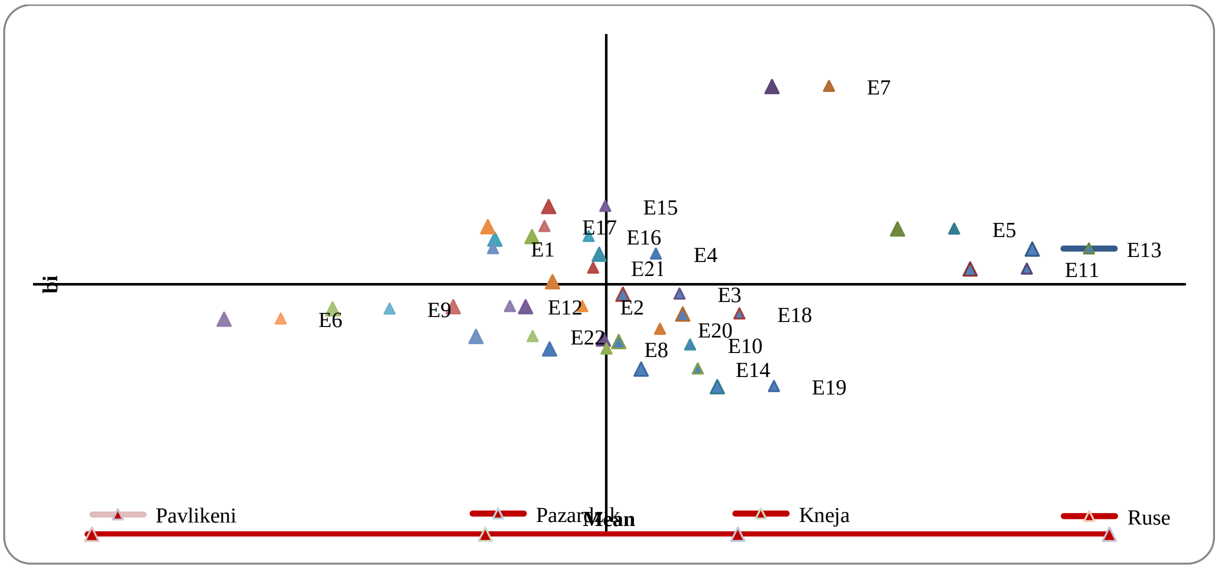

Fig. 2. Distribution of hybrids according to the general means of the grain yield (kg/da) and first stability parameter (bi) – Eberhart and Russel (1966)

The updated estimates relate mainly to hybrids E 13 and E 11. The stable and high - yielding hybrids are E 10, E 3, E 14, E 18 and E 19 (st. P 9578), and the high - yielding intensive ones are E 13, E 11, E 5 and E 7. The Knezha 307 standard is in the most unfavorable IV quadrant in both figures.

Figure 3 presents the biplot of the AMMI-1 analysis, which presents in a complex way the hybrids, the environments and their interaction. It uses the first main components (PC_1) of the two groups - hybrids and conditions, and on the abscissa are data on the average yields of hybrids from the four locations and the averages of all hybrids from one location as a projection. On the ordinate axis in this order are the main (PC_1) components of hybrids and locations. The biplot also has a high and low productive area, as in figure 1 and 2. On the ordinate axis, the zero value of the main components divides the space into two fields or groups with positive and negative interactions, which can be considered as a responsive and stable area, analogous to the distribution of figure 2. The most stable are considered to be the hybrids that are located closest to this axis with zero value of PC_1 - for example hybrid E 11. Its stability parameters listed in table 2, have relative values, closest to the theoretical ones, with a low value of $CV_{\%}$ and very good general adaptation (its index is over 10).

As for the locations, they are indicated as vectors, as Ruse and Knezha are in the highly productive area, and Pazardzhik and Pavlikeni in the low productive area. On the other hand, only Ruse is in the area with positive interactions (the responsive area), and the other three locations are in the negative one. The vector of location Ruse shows coordinates of average yield for all 22 hybrids 1167.0 kg / da and value of PC_1 over 1.00, which can be seen in table 2.

There is a great similarity between the AMMI-1 biplot and the modified distribution of hybrids in terms of yield and stability (figure 2). As figure 2 has four quadrants, so can figure 3 the AMMI – 1 biplot be divided into 4 analogical areas. First of all, there is no change in the number of hybrids in the high yield area - a total of 9, against 13 for the other area, as the hybrids are distributed in figures 1 and 2. The four hybrids, which fall into the second quadrant of figure 2 - E 11, E 13, E 5 and E 7, are seen clearly - they are the same ones in the place analogous to this quadrant - the highly productive area with the subarea with positive interactions.

In the same way in the place of the first quadrant - highly productive and stable under stress conditions hybrids, in the subarea of figure 3 the same 5 hybrids are found - E 3, E 18, E 14, E 10 and E 19. Of these, the closest to the theoretical center is E 3 with the lowest value of PC_1 and the closest yield to the general average. Its stability parameters are comparable to those of E 11, but its yield is lower (table 2).

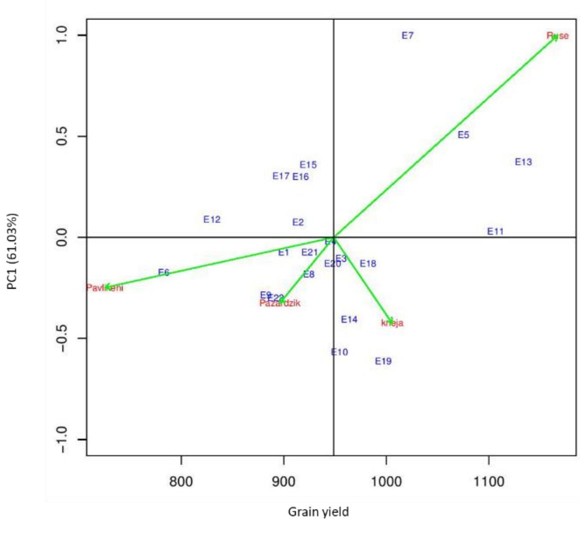

Fig. 3. AMMI 1 biplot of grain yield (kg/da) of 22 maize hybrids, tested in 4 locations

In the case of hybrids from the low productive areas, a certain shift is observed if we compare the II and IV quadrants (figure 2) with their analogous areas of the biplot from figure 3. Of the seven hybrids in quadrant III, 5 remain in the analogous area of the biplot, and E 2 and E 12 pass into the area corresponding to quadrant IV. E 4 with the lowest value of PC_1 and yield closest to the average is directed from this area to the theoretical center.

If we compare Francis and Kannenberg method (1978) (figure 1) with the biplot from figure 3, we will find that the coincidences or similarities in the distribution of the hybrids are less, which proves that the modification of this method proposed by us in figure 2, is a more convenient way to easily characterize genotypes.

Figure 4 graphically presents the results of the AMMI - 2 analysis, which uses the two main components (PC_1 and PC_2) of the hybrids and the locations, which occupy over 90% of the total variation. It provides a more in - depth assessment of the nature of the interactions and the stability of the genotypes. Projections of the coordinates of the two components of the hybrids and the locations are also used here - along the abscissa for PC_1 and along the ordinate axis for PC_2, respectively. There is a rotation of the data compared to the results of figure 3. The areas with positive or negative interactions are located diagonally. The figure also shows an outlined pentagon, on the vertices of which the hybrids with the highest size of interactions are coordinated, evident from the values of their components (PC_1 and PC_2) - table 2. These are the hybrids E 10 – in the area with negative interactions, clockwise – E 19 (in the positive area), E 12 (in the negative) and the hybrids E 7 and E 17 in the second positive area. The last two hybrids have values of the first stability parameter b_i higher than one from the model of Eberhart and Russell (1966), the other 3 are with values under 1.0 (table 3), but the relatively high values of their other parameters – s^2d_i; σ_i^2 and S_i^2 (according to Shukla, 1972) as variances actually characterize them as hybrids with unstable behavior in both groups of conditions - stress and intense. For example, we have indicated above that hybrid E 7 has given the highest yield from the whole experiment in location Ruse, but in Pavlikeni its yield is lower than the average for the location. There is consistency between the AMMI - 2 analysis and the two models, especially if their stability parameters - s^2d_i, σ_i^2 and S_i^2 as variances have reliable values. Hybrids that are closer to the theoretical center of the biplot (figure 4) have a stability better consistent with the theoretical models. In this ideal center - the intersection of the zero values of PC_1 and PC_2, is a hybrid E 11, which we have already commented. Hybrid E 4 after rotation is again on the zero axis of PC_1 (figure 3 and 4).

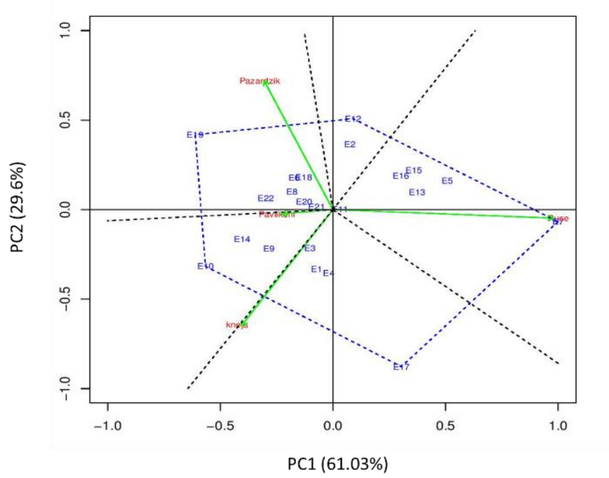

Fig. 4. AMMI 2 biplot of grain yield (kg/da) of maize 22 hybrids, tested in 4 locations, 2018

The AMMI - 2 analysis also indicates that the locations Ruse and Pazardzhik, located in the areas with positive interactions, are suitable for growing hybrids of responsive type (the second location is under irrigated conditions), such as E 7 and E 17 for the first location. Respectively, the locations Knezha and Pavlikeni are outlined as places for growing a stable type of hybrids - the area with negative interactions. The hybrid with the highest yield from the experiment – E 13, is actually located in this area (figure 4).

The analysis made so far shows that there is a relatively good consistency between the different methods we use to assess the stability of hybrids. Provided that the variation of PC_1 has the largest share of the total variation, the AMMI - 1 analysis, which also works with the average yield, appears to be more suitable for assessing the agronomic type of stability of hybrids, especially since it shows good consistency with the modified distribution of hybrids in terms of average yield and stability (b_i).

Tsenov and Gubatov *(2018)*, comparing different methods and models for assessing the stability of genotypes (wheat varieties), come to the conclusion that some simple assessment models – with the variation or regression analysis give almost the exact data as other models, which require special computer programs, such as the AMMI – 1 analysis. We agree with their opinion. Of course, this modern analysis should not be underestimated, because it can give us a very good orientation regarding the zoning of hybrids.

Table 4 shows the results from the actual yields of hybrid E 13, which has the highest yield from the experiment (table 2 and 3), as well as the theoretically expected calculated by the formula of Zobel at al. (1988). The average yield from both rows is the same (1133.81 kg/da), which confirms the theory, but differences are observed by locations. For example, in the locations Knezha and Pazardzhik the expected yields are higher than the actually obtained, and in Ruse (where the highest yield of this hybrid was obtained) and Pavlikeni they are lower than the actually obtained. This can guide us that higher yields can be expected from the hybrid E 13 at the locations Knezha and Pazardzhik and it can be grown (zoned) with priority in these two places. If more locations are included in the experiment, the zoning picture of each hybrid, if the applied formula is used, will be even clearer, although it works with the main effects - the genotype and the environment and their interaction only from their first components (PC_{1g} and PC_{1e}), i.e. the AMMI - 1 analysis.

The calculated theoretically expected yields of the hybrid (E 11) next in the ranking have very close values (without publishing them) to the actual yields obtained from the four locations. This hybrid can easily be zoned for all four locations. This is confirmed by its position in the center of the AMMI - 2 graphics (figure 4).

Table 4. Received and expected grain yields (kg/da) (theoretical) of E13 hybrid from 4 locations of testing

Locations	Kneja	Russe	Pavlikeni	Pazardjik
Grain yield (kg/da)	1115,7	1443,9	922,5	1053,2
Expected yield (kg/da)	1190,9	1352,4	910,9	1080,9

The observed differences are due to the so-called "noise" from interactions, which increases with the use of more main components that have a smaller share of the total variation (Zobel et al., 1988; Crossa, 1990; Babic et al., 2010).

The last figure 5 represents results of hierarchical cluster analysis by the method of Ward (1963), which is shown instead of a dendrogram as a nesting design. Only two components participate in the analysis – yield of grain and stability parameter b_i, grouping the hybrids around their average values. This way of presentation more clearly designs clustered hybrids. Three separate clusters are observed. The first one – upper right of figure 5 includes 4 hybrids: E 7, E 5, E 11 and E 13 – the same ones that are in II quadrant on figure 2 and in the subarea of the high productive hybrids with positive interactions on the AMMI – 1 biplot (figure 3).

The second cluster contains 6 hybrids, which are at a close (Euclidean) distance from each other. Of them only E 8 is in the III quadrant on figure 2, the rest are in I, and E 3 goes in the third cluster. This cluster consist of the rest 12 hybrids, which are located in III and IV quadrant, respectively in the low productive area of the AMMI – 1 biplot, with main components from +0.30 to -0.36 respectively for E 22 and E 15.

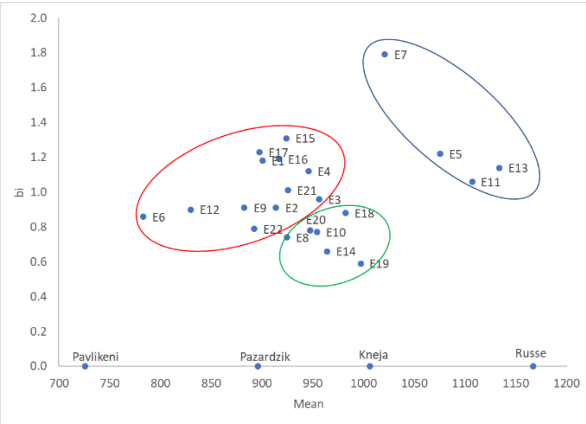

Fig. 5. Clustering of 22 maize hybrids tested in 4 locations by average grain yield (kg/da) and bi

The observed correspondences are mostly in the high productive area of figure 2 and 4 and the first two clusters of figure 5. Babic et al. (2010) report good consistency between the results of AMMI and cluster analysis when testing maize hybrids and grouping them for different conditions. Similar conclusion make Oztuck and Korkut (2020) at wheat genotypes assessments by GGE biplot and cluster analysis.

CONCLUSIONS

The made multilateral analysis of the stability of the studied maize hybrids gives us grounds for the following conclusions.:

1. The combined dispersion analysis (ANOVA) shows significant variances for hybrids, locations, their interaction, dominated by its nonlinear part, as well as the variance of the first principal component (PC_1) of the AMMI analysis.

2. The offered modification of the method of Francis and Kannenberg *(1978)* for the distribution of hybrids by average yield and the average value of the parameter b_i gives more objective assessment of their stability.

3. Coherence in the assessments of the hybrids, especially in the high productive area, is observed between this modification and the AMMI – 1 analysis.

4. The AMMI analysis as an integrated method gives a comprehensive assessment of the behavior of hybrids in places, respectively for their more correct zoning.

5. The cluster analysis for yield and stability of hybrids shows good consistency with the AMMI - 1 analysis and with the modified methodology for their distribution.

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