UDC 575. 633.15
https://doi.org/10.2298/GENSR2202871B
Original scientific article

STUDY OF MAIZE YIELD STABILITY WITH NONPARAMETRIC METHODS

Dragana BRANKOVIĆ-RADOJČIĆ*, Marija MILIVOJEVIĆ, Tanja PETROVIĆ,
Snežana JOVANOVIĆ, Aleksandar POPOVIĆ, Snežana GOŠIĆ DONDO, Jelena SRDIĆ

Maize Research Institute Zemun Polje, Belgrade, Serbia

Branković-Radojčić D., M. Milivojević, T. Petrović,S. Jovanović, A. Popović, S. Gošić Dondo, J. Srdić (2022). *Study of maize yield stability with nonparametric methods*. - Genetika, Vol 54, No.2, 871-885.

High and stabile yield in different production environments is priority in maize breeding. New statistical methods are constantly being sought to accompany analysis of variance, in order to achieve more reliable hybrid assessment. In this study nonparametric stability analysis is applied in order to assess GxE interaction for yield of 36 commercial maize hybrids. The experiment was set up at five locations in Serbia for three years according to the Randomised complete block design in three replications. Yield stability of investigated genotypes was analysed by stability parameters $Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$, $Si^{(6)}$ TOP and RS. Analysis of variance identified highly significant F values for all experimental factors. Bredenkamp method confirmed the existence of non-crossover GxE interaction, for maize yield. Hybrid ZPH15 achieved the most stable yield based on parameters $Si^{(1)}$ and $Si^{(2)}$. According to parameter $Si^{(3)}$ it was ZPH5, while based on parameter $Si^{(6)}$ it was ZPH34. The highest overall yield achieved ZPH36 (11.18 t ha^{-1}), which was quite unstable (rank 24 in parameters $Si^{(1)}$ and $Si^{(2)}$), and very unstable (rank 34 in parameters $Si^{(3)}$ and $Si^{(6)}$). The most stable hybrids had average yields. In total, the hybrid ZPH23 had the best average rank (15.93). Based on TOP parameter, ZPH36 had the best rank (yield), followed by ZPH11, ZPH20, ZPH21 and ZPH9. However, RS parameter revealed that ZPH21 was the most stable hybrid, so taking into account both TOP and RS parameters this is the most productive and the most stable hybrid. Based on this research, TOP and RS are the best parameters for selecting new maize hybrids for production in particular environment. In case of identical TOP value, the genotype with the lowest RS

Corresponding author: Dragana Branković-Radojčić, Maize Research Institute Zemun Polje, Slobodana Bajica 1, Belgrade, Serbia, email: dbrankovic@mrizp.rs

value should be selected. The parameters Si $^{(1)}$, Si $^{(2)}$, Si $^{(3)}$ and Si $^{(6)}$ can be used as alternative methods for the selection of genotypes with moderate yield and high stability.

Key words: G x E interaction, maize, nonparametric methods stability, yield

INTRODUCTION

Maize (*Zea mays*) is the most represented crop in Serbia (STAT. YEARB. SERB., 2020) and also a significant source of income for a large number of people. This culture is grown on most of the areas without irrigation. Due to climate change and global warming, sudden temperature changes occur more and more often as well as alternating extremely dry and rainy periods (ČAMDŽIJA *et al*., 2012; BRANKOVIĆ-RADOJČIĆ, 2019).

Scientists are trying to create genotypes that will express phenotypic stability in as many test environments as possible. This is a challenging task, since the environment in which certain genotype is grown has a great influence on the manifestation of genotype traits. The genotype x environment interaction directly affects the yield of genotypes in diverse environments (MALOSETTI *et al*., 2013; MENG *et al*., 2016; BRANKOVIĆ-RADOJČIĆ *et al*., 2019). This is the main problem when comparing maize hybrid performance in different locations (KANG, 1990; BISHNOI, 2015), and their selection for further testing (MITROVIĆ *et al*., 2018; MANJUBALA *et al*., 2018). Furthermore, GxE interaction is one of the main reasons for the large number of genotypes on the seed market, which are recommended for cultivation in certain regions.

The challenge of creating stable and high-yielding genotypes for certain regions constantly forces researchers to search for a better and more precise statistical methods that will be used in processing field experimental data.

Two main approaches are used for analysis of GxE interactions (ROMAGOSA and FOX, 1993; HUEHN, 1996).

The first is the classic parametric approach, based on absolute data, and it implies several assumptions (normality of distribution, homogeneity of variances, additively of effect). If any of these assumptions are not met, the validity of these methods may be impaired (DELIC *et al*., 2004). Analysis of variance (ANOVA) is the most commonly used method of calculating GEI in multiple environments. The main limitation of this analysis is the assumption of homogeneity of variances between environments required to determine genotypic differences (ZOBEL *et al*., 1998). The usual analysis of variance is an additive model, it identifies the interaction as a source but does not analyse it, does not provide insight into the individual genotypes and locations participating in the interaction (SAMONTE *et al*., 2005). It may happen that due to the large number of degrees of freedom, the interaction appears as an insignificant source of variation, regardless of the fact that it includes a large part of the variability of the total sum of squares (CROSSA, 1990).

The second approach is nonparametric and it defines the environment and phenotypes in relation to biotic and abiotic factors. Analysis of nonparametric stability parameters reduce/avoid bias, caused by values that are significantly lower or higher than most other values in the data set, and it does not require a certain distribution of phenotypic values (FOX *et al*., 1990; HUEHN, 1990; KANG, 1990). These stability parameters are based on ranks, they are easy to compare and interpret. The addition or omission of one or more genotypes does not cause large differences in estimates and the values obtained in this way are applicable in the selection process, in breeding and testing of varieties and hybrids (NASSAR and HUEHN, 1987; MUT *et al*., 2009; FARSHADFAR *et al*., 2014; ZORIĆ *et al*., 2015; MOHAMMADI, 2016; KHALILI and POUR-ABOUGHADAREH, 2016; VERMA *et al*., 2017). With such data, it is only important to know whether interaction is present or not, because it leads to a change in the order of genotypes in different environments (HUEHN, 1996). According to this author, two environments with different yields and similar ranks of tested genotypes are considered more similar than environments with similar values and different ranks. These G×E interaction test methods provide a useful alternative to parametric methods such as ANOVA (TAMESGEN *et al*., 2015; ABDIPOUR *et al*., 2017).

In a review paper, HUEHN and LÉON (1995) listed four nonparametric methods for testing genotype x environment interactions according to their authors: BREDENKAMP (1974); HILDEBRAND (1980); KUBINGER (1986), and VAN DER LAAN and DE KROON (1981). These methods are based on the ranking of yield data. Using the first three methods, data are ranked from all locations within one year, and are also defined as quantitative interactions. They are based on the usual linear model of interaction. The methods according to Hildebrand and Kubinger are based on the effects of interaction, on the basis of which the ranking is performed. They are very similar, and reveal both quantitative and qualitative interaction. The Bredenkamp method is the least reliable in the interaction analysis because during processing the total yield data is transformed into ranks, and often does not show the existence of an interaction. In the latter method, ranking is performed for each location separately, and is based on the qualitative concept of interaction, i.e. genotype effects and interaction effects. The sum of these effects is used to rank and define the interaction according to the cross-interaction model. HUEHN (1996) presented the relationship between these methods based on data obtained from German official experiments: Hildebrand ≈ Kubinger> van der Laan and de Kroon> Bredenkamp. The methods of Hildebrand and Kubinger are closely related to ANOVA. If some of the necessary assumptions are not fulfilled, the correctness of the conclusions obtained from standard statistical techniques, for example ANOVA, may be questionable or lost. In such cases, however, rank-based nonparametric assessment and testing results may be more reliable (TRUBERG and HUEHN, 2000).

To assess the stability based on the rank of genotypes in each external environment, NASSAR and HUEHN (1987) proposed 4 nonparametric parameters of stability: $Si^{(1)}$ - average difference of ranks in different environments; $Si^{(2)}$ - variance of ranks; $Si^{(3)}$ - relative deviation from the average rank and $Si^{(6)}$ which is only slightly modified compared to the previous one. The most stable genotype is considered to be the one with the value $Si^{(1)} = 0$ and the smallest possible variance of the rank $Si^{(2)}$ in the observed environments. The same authors used the Zi (m) test to assess the significance of these parameters.

FOX *et al.* (1990), proposed another nonparametric way of ranking genotypes in relation to stability. They used stratified ranking based on TOP, MID and LOW parameters. The TOP parameter singles out genotypes with stable yield in different environments and belongs to dynamic agronomic stability, while the parameters $Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$ and $Si^{(6)}$ indicate static stability (biological). SIMMONDS (1991) emphasizes that static stability would be more useful than dynamic stability to obtain a broader picture of genotype behaviour in different environments. Many researchers (SABAAGHNIA *et al*., 2006; MOHAMMADI and AMRI, 2008; MUT *et al*., 2009; SEGHERLOO *et al*., 2008) referred to this fact and pointed out that TOP parameters are related to the average yield and the dynamic concept of stability.

Rank-Sum (RS) is another nonparametric method (KANG, 1988), where both mean grain yield and stability variance are used (SHUKLA'S, 1972).

When grouping environments with similar ranks, HUEHN and PIEPHO (1994) used different procedures, one of which is Spearman's rank correlation coefficient. This coefficient expresses the distance between two environments and can be used to classify both environments and genotypes.

The parametric approach is based on absolute data, which is not practical if there are deviations in data sets. Field experiments are affected by various factors that researchers cannot predict at the beginning of the research. For this reason, it is very convenient to use nonparametric statistics for data processing in order to obtain realistic data as much as possible, without rejecting the experiment due to incomplete data sets. The objectives of this study were: (1) assessment of GEI at 5 sites over 3 years in 36 experimental ZP maize hybrids of different FAO maturity groups, (2) identification of promising high-yielding and stable maize hybrids in different environments and (3) study of relationships between nonparametric stability parameters.

MATERIAL AND METHODS

Genetic material

This research involved 36 F1 maize hybrids, classified in FAO maturity groups 300-700 (Table 1).

Table 1. List of 36 ZP maize hybrids

FAO 300	FAO 400	FAO 500	FAO 600	FAO 700
ZPH1	ZPH5	ZPH13	ZPH23	ZPH33
ZPH2	ZPH6	ZPH14	ZPH24	ZPH34
ZPH3	ZPH7	ZPH15	ZPH25	ZPH35
ZPH4	ZPH8	ZPH16	ZPH26	ZPH36
	ZPHH9	ZPH17	ZPH27	
	ZPH10	ZPH18	ZPH28	
	ZPH11	ZPH19	ZPH29	
	ZPH12	ZPH20	ZPH30	
		ZPH21	ZPH31	
		ZPH22	ZPH32	

Field trials

The trials were set up as a randomized complete block design (RCBD) at 5 locations in Serbia (Šimanovci, Kikinda, Sombor, Loznica and Svilajnac) in 2011, 2012 and 2013.

Trial was set in three replications and individual randomization for each location in order to avoid the effect of genotype x genotype interaction. Two border rows were sown at each side of the whole plot area. The basic plot size was 13.09 m^2 with the plant density of 62.643 plants per hectare. Each hybrid was sown in four rows with 41 plants, and only the middle rows were used for analysis, while the border rows were the protection for each plot separately. The planting was done mechanically, with the distance of 0.76 m between rows and 0.21 m within the rows. The harvest was also done mechanically.

During the experiment, the most important meteorological indicators were monitored: maximum, minimum and average air temperatures, precipitation and relative humidity.

Mean monthly temperatures (°C) and precipitation (mm), by years, are shown in Figure 1.

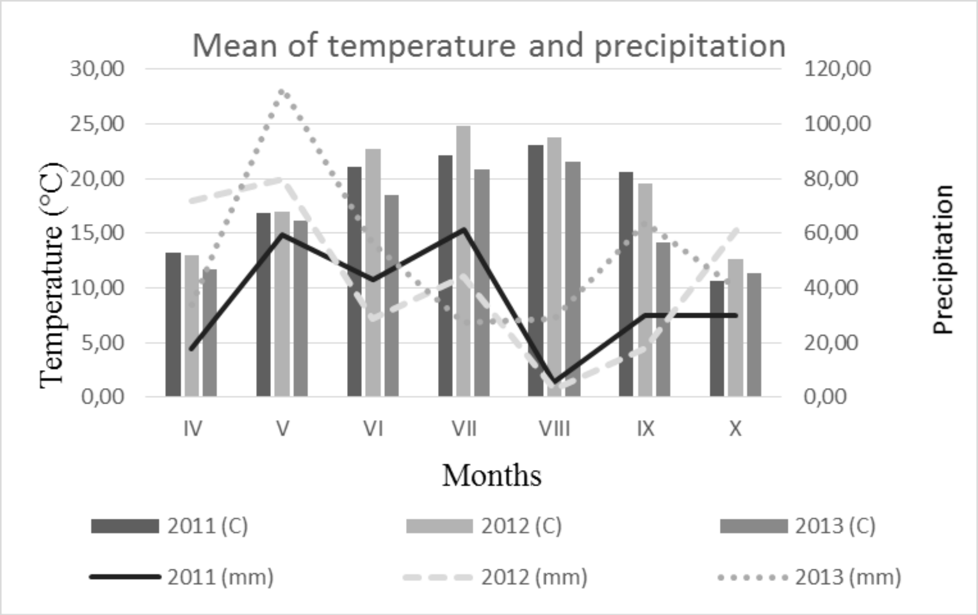

Figure 1. Mean monthly temperatures (°C) and precipitation (mm) in 2011, 2012 and 2013

Statistical analyses

Statistical data processing was performed by analysis of variance (ANOVA) of three-factorial experiment (year / locality / genotype), and significance tested by F test.

Nonparametric methods were used in the analysis of the genotype x environment interaction, and the analysis itself was done in three phases.

First phase was testing the existence of genotype x environment interactions, using four nonparametric methods according to HUEHN AND LÉON (1995) and HUEHN (1996): Bradenkamp, Hilderbrand, Kubinger and Van der Laan and de Kroon method.

Second phase included determination of the stability of genotypes and their ranking. Four nonparametric stability parameters according to NASSAR and HUEHN (1987) were calculated: $Si^{(1)}$ - average differences of ranks in different environments, $Si^{(2)}$ - rank variances, $Si^{(3)}$ - relative deviation from the average rank and $Si^{(6)}$ - relative deviation from the average rank. Two additional parameters were observed: TOP - stratified ranking (FOX *et al*. 1990) and RS - sum of rank stability (SHUKLA, 1972; KANG, 1988).

Third phase encountered the correlation of the results between the examined properties and the stability parameters, as well as the stability parameters themselves. Spearman's correlation coefficient of the rank was determined according to ZAR (1999). The significance of the rank correlation coefficient value was tested using a t-test.

RESULTS AND DISCUSSION

Yield is one of the most important parameters for the selection of maize hybrids in almost all breeding programs. Analysis of variance (ANOVA) revealed significant F values ($P<0.01$) in this experiment, within environments (year-locality), replicates, genotypes and genotype x environment interactions (Table 2). Such a high variation in data for maize yield was expected, considering three very different production years, both in terms of quantity and distribution of precipitation during the vegetation period. There was a particularly significant difference in the amount of precipitation, relative humidity and average daily temperature in some critical phases of maize development, primarily in the phase of pollination, fertilization and grain filling in the period July-August (Figure 1).

The maize hybrids had different yield ranks in different locations over three years, which reflects a significant genotype x environment interaction. These results show that environmental diversity and genetic variability of genotypes are obvious. The average yield ranged from 8.01 t ha^{-1} in Svilajnac to 13.31t ha^{-1} in Loznica. The highest yield of 16.11 t ha^{-1} had ZPH36 in Loznica, while the lowest measured value was 6.02 t ha^{-1} at ZPH14 in Svilajnac (results not presented).

Table 2. Analysis of variance for maize yield

Source of variation	df	SS	MS	F
Environments (E)	14	12793.000	913.785	233.708**
Replications	30	117.298	3.910	2.353**
Genotype (G)	35	461.925	13.198	7.943**
(GxE)	490	1718.934	3.508	2.111**
Error	1050	1744.738	1.662	
Total	1619	16835.800	10.399	
CV= 12.96				

CV –coefficient of variability; ***p< 0.01*

.

The results of the genotype x environment interaction for yield of 36 maize hybrids, obtained by four nonparametric methods, are shown in Table 3. The existence of non-crossover GEI was determined by the Bredenkamp method, which justifies the evaluation of stability parameters of tested maize hybrids. Other methods by Hildebrand, Kubinger and Van der Laan and De Kroon did not confirm the existence of an interaction. ZIVANOVIC *et al*., (2012), comparing the yield stability in F2 maize populations, in different recombination cycles, obtained results that accord with the results found in this paper.

Table 3. The test of genotype × environment interaction for 36 ZP maize hybrids across 15 environments

Method	Breedenkamp	Hildebrand	Kubinger	v.d. Laan-de Kroon
χ^2	152.66**	801.23^{ns}	793.18^{ns}	900.65^{ns}

***p< 0.01; ns* – non significant

χ^2 chi-square test statistic

Obtained results are not consistent with the results of HUEHN and LÉON (1995), who found that the Bredenkamp method is the least reliable and often does not show the existence of an interaction. HUEHN (1996) presented the relationship between these methods based on data obtained from German official experiments: Hildebrand ≈ Kubinger> Van der Laan and De Kroon> Bredenkamp. Similar results as HUEHN (1996) were obtained by MOHAMMADI *et al.* (2007), BALALIĆ and ZORIĆ (2012) and ZORIĆ *et al.* (2015). The results of the study by HAMEED *et al.* (2020) and ABDIPOUR *et al.* (2017), showed the existence of significant interaction in the method according to Bredenkamp and Van der Laan and De Kroon, which indicates that there was both crossover and non-crossover interaction in their experiments.

The stability parameters $Si^{(1)}$ and $Si^{(2)}$ are based on the rank of genotypes in different environments and give equal value to each environment (BECKER and LEON 1988). However, these two parameters usually rank genotypes similarly. The most stable yield (Tables 4 and 5) based on parameters $Si^{(1)}$ and $Si^{(2)}$ achieved ZPH15, while hybrids ZPH32 and ZPH33 were the most unstable, (the highest values for parameters $Si^{(1)}$ and $Si^{(2)}$).

Two other nonparametric statistics ($Si^{(3)}$ and $Si^{(6)}$) pool genotypes yield and stability, which is in the basis of their yield grades in every environment (NASSAR and HUEHN, 1987). Hybrids that had the lowest values for these two parameters showed the greatest stability. The most stable hybrid according to the parameter $Si^{(3)}$ was ZPH5, while based on the parameter $Si^{(6)}$ it was ZPH34 (Tables 4 and 5). The most unstable hybrid was ZPH32 according to both parameters. In this experiment ZPH36 had the highest average yield of 11,18 t ha^{-1}, and thus achieved the highest rank. It was quite unstable according to the parameters $Si^{(1)}$ and $Si^{(2)}$, and very unstable according to the parameters $Si^{(3)}$ and $Si^{(6)}$, while the most stable hybrids had a yield around the average. In total, ZPH7 had the lowest average rank, while ZPH23 had the best overall rank. Evaluation of the most stable hybrid overall and within the FAO group revealed two pairs of stability parameters that were in agreement in most cases $Si^{(1)}$ with $Si^{(2)}$, and $Si^{(3)}$ with $Si^{(6)}$. Complementary results were obtained by other authors, who assessed the parameters of yield stability and other agronomic traits for different plant species (RAHADI *et al.*, 2013; ABDIPOUR *et al.*, 2017; REA *et al.*, 2017; MAJUBALA *et al.*, 2018; SUBAȘI and BAȘALMA, 2021; ABERKANE *et al.*, 2021).

NASSAR and HUEHN (1987) used the $Zi_{(m)}$ test to assess the significance of the $Si^{(1)}$ and $Si^{(2)}$ parameters. $Zi^{(1)}$ is applied for the average difference of ranks in different environments $Si^{(1)}$, while the significance test $Zi^{(2)}$ explains the variance of ranks $Si^{(2)}$. Both tests were not significant.

In this paper, $Zi_{(m)}$ values were calculated for each genotype (Table 4). Both sum $Zi^{(1)}$ (38,669) and $Zi^{(2)}$ (41,284) were less than the critical value (50.99), so no significant differences were observed in rank variation between the 36 hybrids in 15 environments.

Table 4. Mean yields (t ha^{-1}), rank, stability parameter estimates for yield, and tests of nonparametric stability measures for 36 ZP maize hybrids across 15 environments

Hybrid	FAO	Yield	Rank	$Si^{(1)}$	$Zi^{(1)}$	$Si^{(2)}$	$Zi^{(2)}$	$Si^{(3)}$	$Si^{(6)}$	TOP	RS
ZPH1	300	9.03	18.87	14.02	1.670	143.6	1.738	51.4	5.056	20	65
ZPH2	300	9.69	19.33	10.42	1.003	77.8	1.241	40.5	4.794	20	28
ZPH3	300	10.29	19.53	13.28	0.671	126.0	0.447	99.7	8.908	53	25
ZPH4	300	10.17	18.93	11.33	0.175	92.1	0.344	81.1	7.507	53	23
ZPH5	400	9.06	19.87	10.27	1.206	77.7	1.250	27.4	3.302	7	50
ZPH6	400	9.54	18.13	11.26	0.218	90.0	0.440	48.6	5.240	13	37
ZPH7	400	9.12	21.20	14.40	2.356	152.2	2.681	41.1	4.247	13	65
ZPH8	400	9.21	19.20	10.69	0.691	83.3	0.829	28.4	3.592	0	35
ZPH9	400	10.36	19.80	13.52	0.954	130.9	0.722	119.7	9.574	60	27
ZPH10	400	9.92	19.80	11.52	0.089	102.5	0.041	68.0	6.581	33	43
ZPH11	400	10.68	18.40	12.74	0.230	115.0	0.068	118.8	10.056	67	37
ZPH12	400	9.81	17.80	13.03	0.437	127.5	0.523	67.2	5.829	27	37
ZPH13	500	10.04	17.20	11.28	0.207	93.5	0.286	57.0	5.252	20	24
ZPH14	500	9.10	18.20	12.86	0.305	117.9	0.136	59.0	5.173	13	58
ZPH15	500	9.60	18.20	8.80	4.132	60.7	3.046	42.5	4.339	13	38
ZPH16	500	9.99	19.53	11.96	0.000	105.4	0.009	81.6	7.453	40	29
ZPH17	500	9.15	20.33	12.55	0.128	113.4	0.041	37.8	4.000	7	38
ZPH18	500	10.00	17.40	9.81	1.931	71.7	1.797	45.5	5.589	33	19
ZPH19	500	10.23	17.80	13.41	0.817	128.5	0.578	93.0	7.835	40	40
ZPH20	500	10.42	20.00	13.75	1.259	137.4	1.192	132.8	10.635	67	33
ZPH21	500	10.67	18.87	10.95	0.438	86.6	0.625	84.7	8.743	60	9
ZPH22	500	10.25	19.73	12.74	0.230	118.5	0.153	86.5	7.973	53	32
ZPH23	600	9.89	15.93	12.59	0.146	124.9	0.396	75.4	6.169	20	52
ZPH24	600	10.19	17.67	11.75	0.023	100.5	0.075	75.2	6.677	40	34
ZPH25	600	9.69	18.87	9.35	2.825	64.6	2.574	47.6	4.581	13	28
ZPH26	600	10.25	17.87	14.32	2.209	154.6	2.977	100.6	8.826	47	41
ZPH27	600	10.57	17.33	13.01	0.421	123.0	0.309	95.8	8.161	40	30
ZPH28	600	9.41	17.13	11.49	0.104	98.0	0.135	54.3	4.798	13	41
ZPH29	600	10.22	19.20	12.93	0.361	125.9	0.442	111.4	8.457	40	31
ZPH30	600	9.87	17.93	13.62	1.076	137.1	1.163	78.0	6.369	27	43
ZPH31	600	9.72	16.47	13.94	1.547	141.3	1.522	82.3	6.713	20	51
ZPH32	600	10.78	17.07	15.07	3.840	165.4	4.515	138.4	10.803	53	38
ZPH33	700	10.08	18.27	15.09	3.887	169.1	5.118	127.1	9.501	47	51
ZPH34	700	9.34	19.40	10.11	1.429	78.7	1.170	35.1	3.253	7	43
ZPH35	700	10.47	17.27	13.64	1.101	147.9	2.191	84.8	8.327	40	23
ZPH36	700	11.18	17.47	13.16	0.557	127.3	0.513	128.0	10.553	73	34
TOTAL					38.669		41.284				

$Si^{(1)}$ - average differences of ranks in different environments, $Si^{(2)}$ - rank variances, $Si^{(3)}$ - relative deviation from the average rank and $Si^{(6)}$ - relative deviation from the average rank, $Zi^{(1)}$ and $Zi^{(2)}$ are chi-square χ^2 test statistic for $Si^{(1)}$ and

$Si^{(2)}$ (NASSAR and HUEHN 1987); TOP - stratified ranking (FOX *et al.* 1990); RS - sum of rank stability (SHUKLA, 1972 and KANG, 1988).

$E(S_i^{(1)})$ = 11.99; $E(S_i^{(2)})$ = 107.92; $var(S_i^{(1)})$ = 11.52; $var(S_i^{(2)})$ = 3023.65; $\chi^2 Z_1, Z_2$ = 10.22; $\sum \chi^2$ = 50.99; *grand mean* 9,945t ha^{-1}.

The analysis of individual Z values showed that none of the hybrids were significantly unstable in relation to the others, since they had small values of Zi in relation to the critical value 10.22. ABDIPOUR *et al.* (2017) and MITROVIC *et al.* (2018), also obtained such small Z values in their research. In the study by HAMEED *et al.* (2020), there was no significant variation between genotypes and environments, but some genotypes showed significant instability, as their values were above the critical value.Based on the TOP parameter of superiority for general adaptability, ZPH36 had the best rank, followed by ZPH11, ZPH20, ZPH21 and ZPH9 (Table 5).

Based on RS parameters, ZPH21 proved to be the most stable hybrid, followed by ZPH18, ZPH4, ZPH35 and ZPH13 (Table 5).

Spearman's rank correlation coefficients

When grouping environments with similar ranks, HUEHN and PIEPHO (1994) proposed different procedures. One of them is Spearman's rank correlation coefficient, which expresses the distance between two environments, and when both environments and genotypes can be grouped. Significant correlation was found between the yield and Si $^{(1)}$ (average difference of ranks) as well as between the yield and Si $^{(2)}$ (variance of ranks). Highly significant rank correlation was found between yield and relative deviation from average rank (Si $^{(3)}$ and Si $^{(6)}$) (Table 6).

The stability parameters Si $^{(1)}$ and Si $^{(2)}$ showed a complete interrelationship in this study, and the same was observed between the parameters Si $^{(3)}$ and Si $^{(6)}$. There is a moderately strong, but also significant correlation ($p<0.01$) between the stability parameters Si $^{(1)}$ and Si $^{(2)}$ on the one hand and Si $^{(3)}$ and Si $^{(6)}$ on the other hand. A significant correlation ($p<0.01$) between Si $^{(1)}$ and Si $^{(2)}$ was obtained by SABAAGHNIA *et al.* (2006), MOHAMMADI and AMRI, (2008), MUT *et al.* (2009), SOLOMON *et al.* (2007).

Opposite to results presented here, ČVARKOVIĆ *et al.* (2009) and DELIĆ *et al.* (2009), obtained a highly negative correlation between the yield of maize hybrids and Si $^{(1)}$ and Si $^{(2)}$. However, their correlation between Si $^{(1)}$ and Si $^{(2)}$ on one hand, and Si $^{(3)}$ and Si $^{(6)}$, on the other hand were in complete relation, like in this paper. The interconnection of Si $^{(1)}$ and Si $^{(2)}$ with Si $^{(3)}$ reported by above mentioned authors was weaker than in this experiment.

Based on the obtained results of all four stability parameters, two groups of parameters are clearly distinguished. The first group of stability parameters consisted of Si $^{(1)}$ and Si $^{(2)}$, whileSi $^{(3)}$ and Si $^{(6)}$ formed the second group. This grouping of parameters has been observed by many other researchers who have used these parameters (NASSAR and HUEHN, 1987); SEGHERIOO (2008); TEMESGENA *et al.*, (2015); MANJUBALA *et al.*, (2018); MITROVIĆ *et al.*, (2018); HAMEED *et al.*, (2020).

Table 5. Ranks of 36 ZP maize hybrids after yield data from 15 environments using 6 nonparametric methods

Hybrid	FAO	RANK	RANK	RANK	RANK	RANK	TOP	RS
	group	yield	$Si^{(1)}$	$Si^{(2)}$	$Si^{(3)}$	$Si^{(6)}$		
ZPH1	300	36	32	31	11	10	22	35
ZPH2	300	26	6	5	5	8	22	8
ZPH3	300	9	25	23	28	30	6	6
ZPH4	300	15	11	10	20	22	6	3
ZPH5	400	35	5	4	1	2	33	30
ZPH6	400	28	9	9	10	12	27	18
ZPH7	400	33	34	33	6	5	27	35
ZPH8	400	31	7	7	2	3	36	17
ZPH9	400	8	27	27	32	32	4	7
ZPH10	400	20	13	14	16	18	18	27
ZPH11	400	3	18	17	31	33	2	18
ZPH12	400	23	23	25	15	15	20	18
ZPH13	500	17	10	11	13	13	22	5
ZPH14	500	34	20	18	14	11	27	34
ZPH15	500	27	1	1	7	6	27	21
ZPH16	500	19	15	15	21	21	12	10
ZPH17	500	32	16	16	4	4	33	21
ZPH18	500	18	3	3	8	14	18	2
ZPH19	500	12	26	26	26	23	12	24
ZPH20	500	7	30	29	35	35	2	14
ZPH21	500	4	8	8	23	28	4	1
ZPH22	500	10	18	19	25	24	6	13
ZPH23	600	21	17	21	18	16	22	33
ZPH24	600	14	14	13	17	19	12	15
ZPH25	600	25	2	2	9	7	27	8
ZPH26	600	10	33	34	29	29	10	25
ZPH27	600	5	22	20	27	25	12	11
ZPH28	600	29	12	12	12	9	27	25
ZPH29	600	13	21	22	30	27	12	12
ZPH30	600	22	28	28	19	17	20	27
ZPH31	600	24	31	30	22	20	22	31
ZPH32	600	2	35	35	36	36	6	21
ZPH33	700	16	36	36	33	31	10	31
ZPH34	700	30	4	6	3	1	33	27
ZPH35	700	6	29	32	24	26	12	3
ZPH36	700	1	24	24	34	34	1	15

$Si^{(1)}$ - average differences of ranks in different environments, $Si^{(2)}$ - rank variances, $Si^{(3)}$ - relative deviation from the average rank and $Si^{(6)}$ - relative deviation from the average rank, TOP - stratified ranking; RS - sum of rank stability

Table 6. Spearman's coefficients of rank correlation for the mean yield and 6 nonparametric stability measures of 36 ZP maize hybrids

Parameter	Yield	Si $^{(1)}$	Si $^{(2)}$	Si $^{(3)}$	Si $^{(6)}$	TOP
Si $^{(1)}$	0.339 *					
Si $^{(2)}$	0.343*	0.992**				
Si $^{(3)}$	0.863**	0.656**	0.651**			
Si $^{(6)}$	0.913**	0.585**	0.578**	0.978**		
TOP	0.912**	0.449**	0.435**	0.895**	0.948**	
RS	-0.542**	0.330*	0.333*	-0.200	-0.318	-0.437**

**p<0.05, **p<0.01*

The TOP parameter showed a significant ($p<0.01$) positive correlation with yield. Such a positive correlation in their data was also observed by MUT *et al.* (2009); KHALILI and POUR-ABOUGHADAREH (2016); RAHADI *et al.* (2013); ABDIPOUR *et al.* (2017); REA *et al.*, (2017); SABAAGHNIA *et al.* (2013); KAYA and SAHIN (2015). This parameter provides researchers an information which hybrids are the most productive in all selected environments.

In this study, TOP was in a very significant positive correlation with Si $^{(1)}$, Si $^{(2)}$, Si $^{(3)}$ and Si $^{(6)}$ stability parameters. In the most productive hybrids, the yield varied the most. REA *et al.* (2017) found no significant difference between TOP and Si parameters. ABDIPOUR *et al.* (2017); KAYA and SAHIN (2015), RAHADI *et al.* (2013), found a negative correlation between TOP and Si $^{(1)}$ and Si $^{(2)}$ parameters, and significant negative correlation between TOP and Si $^{(3)}$ and Si $^{(6)}$ parameters.

The RS parameter was negatively correlated with yield and TOP parameter, indicating that the sum of rank stability varied, and that the most productive hybrids were not the most stable. Similar results were obtained by KHALILI and POUR-ABOUGHADAREH (2016). SABAAGHNIA *et al.* (2013), RAHADI *et al.* (2013), ABDIPOUR *et al.* (2017), MUT *et al.* (2009).

HAMEED *et al.* (2020) determined the existence of a positive correlation between RS and average yield, which is a combination of high yield and high stability. RAHADI *et al.* (2013), REA *et al.* (2017), ABDIPOUR *et al.* (2017), reported no correlation between the RS and TOP parameters, while MUT et al. (2009) found positive correlation.

RS was in a positive correlation with parameters Si $^{(1)}$ and Si $^{(2)}$, which confirms the existence of a large variation between genotypes, while the correlation with Si $^{(3)}$ and Si $^{(6)}$ was not significant.

CONCLUSIONS

Highly significant F values were determined by analysis of variance within environments (year-locality), replicates, genotypes and genotype x environment interactions. Bredenkamp method revealed the existence of non-cross-interaction of genotype x environments for maize yield. The most stable yield achieved hybrid ZPH15 based on parameters Si $^{(1)}$ and Si $^{(2)}$. According to parameter Si $^{(3)}$ it was ZPH5, while based on parameter Si $^{(6)}$ it was ZPH34. ZPH36 was the most productive hybrid in the experiment which was quite unstable based on the range of parameters Si $^{(1)}$ and Si $^{(2)}$, and very unstable based on the range of parameters Si $^{(2)}$ and Si $^{(6)}$. The most stable hybrids had a yield around the average. In total, the hybrid ZPH23 had the best average rank. Based on TOP parameter, ZPH36 had the best rank (yield), followed by

ZPH11, ZPH20, ZPH21 and ZPH9. According to RS parameter, hybrid ZPH21 proved to be the most stable, followed by ZPH18, ZPH4, ZPH35 and ZPH13. Assessment based on both parameters leads to the conclusion that ZPH21 was the most productive and at the same time the most stable hybrid. Final conclusion of this study was that TOP and RS are the best parameters for selecting new maize hybrids. TOP parameter is easy to calculate and has a significant positive correlation with yield. In case of identical TOP value, the genotype with the lowest RS value should be selected. This parameter was negatively correlated with yield and TOP parameter. The parameters Si $^{(1)}$, Si $^{(2)}$, Si $^{(3)}$ and Si $^{(6)}$ can be used as alternative methods for the selection of genotypes with moderate yield and high stability.

Received, October 14th, 2021
Accepted May 28th, 2022

REFERENCES

ABDIPOUR, M., B. VAEZI, M. YOUNESSI-HAMZEKHANLU, S. HAMID, R. RAMAZANI (2017): NONPARAMETRIC PHENOTYPIC STABILITY ANALYSIS IN ADVANCED BARLEY (HORDEUM VULGARE L.) GENOTYPE. J. CROP SCI. BIOTECH. 20 (4): 305 – 314.

ABERKANE, H., A., AMRI, B., BELKADI, A., FILALI-MALTOUF, J., VALKOUN, Z., KEHEL (2021); Contribution of Wild Relatives to Durum Wheat (*Triticum turgidum* subsp. *durum*) Yield Stability across Contrasted Environments. Agronomy, *11*: 1992.

BALALIĆ, I., M., ZORIĆ (2012): Non-Parametric Stability Analysis of Sunflower Multilocation Trials. The Forth Joint UNS-PSU International Conference on BioScience: Biotechnology and Biodiversity, Novi Sad, Serbia, Book of the proceedings, 314-330.

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

BISHNOI, S. (2015): Statistical models for evaluating genotype × environment interaction in wheat (*Triticum aestivum* L.). CCSHAU.

BRANKOVIĆ-RADOJČIĆ, D., V., BABIĆ, Z., GIREK, T., ŽIVANOVIĆ, A., RADOJČIĆ, M., FILIPOVIĆ, J., SRDIC (2018): Evaluation of maize grain yield and yield stability by AMMI analysis. Genetika, *50* (3): 1067-1080.

BREDENKAMP, J. (1974): Nonparametrische Prüfung von Wechselwirkungen. Psychologische Beiträge, 16: 398–416.

ČAMDŽIJA, Z., M., FILIPOVIĆ, M., STEVANOVIĆ, S., MLADENOVIĆ DRINIĆ, J., VANČETOVIĆ, M., BABIĆ (2012): Prinos i komponente prinosa komercijalnih ZP hibrida kukuruza različitih grupa zrenja. Selekcija i semenarstvo, *18* (1): 41-48.

CROSSA, J. (1990): Statistical analyses of multi-location trials. Adv. Agron., *44*: 55-85.

ČVARKOVIĆ, R., G., BRANKOVIĆ, I., ĆALIĆ, N., DELIĆ, T., ŽIVANOVIĆ, G., ŠURLAN MOMIROVIĆ (2009): Stability of yield and yield components in maize hybrids. Genetika, *41*(2): 215 -224.

DE KROON, J.P.M., P., VAN DER LAAN (1981): Distribution - free test procedures in two-way layouts; a concept of rank-interaction. Statistica Nederlandica, *35*: 189-213.

DELIĆ, N., M., BABIĆ, V., ANĐELKOVIĆ, G., STANKOVIĆ, G., SARATLIĆ (2004): Primena neparametarske statistike u oceni interakcije genotip x spoljna sredina. Zbornik apstrakata III kongresa genetičara Srabije, 175.

DELIĆ, N., G., STANKOVIĆ, K., KONSTATINOV (2009): Use of non-parametric statistics in estimation of genotypes stability. Maydica, *54*: 155-160.

FARSHADFAR, E., N., MAHMUDI, A., SHEIBANIRAD (2014): Nonparametric methods for interpreting genotype × environment interaction in bread wheat genotypes. J. Bio. Env. Sci., *4*: 55-62.

FOX, P.N., B., SKOVMAND, B.K., THOMPSON, H.J., BRAUN, R., CORMIER (1990): Yield and adaptation of hexaploid spring triticale. Euphytica, *47*: 57-64.

HAMEED, M., S.H., SHAH, H.H., KHAN (2020): A Nonparametric Analysis for Stability of Wheat Genotypes Tested in Southern Punjab, Pakistan. European Online Journal of Natural and Social Sciences, *9* (1): 153-163.

HILDEBRAND, H. (1980): Asymptotisch verteilungsfreie Rangtests in linearen Modellen. Med. Inform. Stat., *17*: 344-349.

HUEHN, M. (1990): Nonparametric measures of phenotypic stability. Part 1: Theory. Euphytica, *47*: 189-194.

HUEHN, M. (1996): Nonparametric analysis of genotype x environment interactions by ranks. In: Genotype by environment interaction. (Eds.): M.S. Kang and H.G. Gauch. CRC Press, Boca Raton, FL, USA, 213-228.

HUEHN, M., H.P., PIEPHO (1994): Relationships Between Kendall's Coefficient of Concordance and a Nonparametric Measure of Phenotypic Stability with Implications for the Consistency in Rankings as Affected by Variance Components. Biometrical Journal, *36* (6): 719–727.

HUEHN, M., J., LÉON (1995): Nonparametric analysis of cultivar performance trials: Experimental results and comparison of different procedures based on ranks. Agron. J., *87*: 627-632.

KANG, M. (1988): A rank-sum method for selecting high-yielding, stable corn genotypes. Cer. Res. Comm., *16*: 113-115.

KANG, M.S. (1990): Genotype-by-environment interaction and plant breeding. Louisiana State University, Baton Rouge, 69-93.

KAYA, Y., M., SAHIN (2015): Non-parametric stability analyses of protein content in multi-environment trials of wheat (*T. aestivum* L.). Genetika, *47* (3): 795 - 810.

KHALILI, M., A., POUR-ABOUGHADAREH (2016): Parametric and non-parametric measures for evaluating yield stability and adaptability in barley doubled haploid lines. J. Agric. Sci. and Technol., *18*: 789-803.

KUBINGER, K.D. (1986): A note on nonparametric test for the interaction in two-way-layouts. Biometrical J., *28*: 67-72.

MALOSETTI, M., J.M., RIBAUT, F.A., VAN EEUWIJK (2013): The statistical analysis of multi environment data: modelling genotype-by-environment interaction and its genetic basis. Frontiers in Physiology, *4*: 1-17.

MANJUBALA, M., R., VASANTHI, P.S., GANAPATI, R., PUSHPAM (2018): Comparative study on different nonparametric stability measures in soybean. M. Electronic J. Plant Breeding, *9* (2): 551-557.

MENG, Y., P., REN, X., MA, B., LI, Q., BAO, H., ZHANG, J., WANG, J., BAI, H., WANG (2016): GGE Biplot-based evaluation of yield performance of barley genotypes across different environments in China. J. Agr. Sci. Tech., *18*: 533-543.

MITROVIĆ, B., D., STANISAVLJEVIĆ, F., FRANETA, S., MIKIĆ, P., ČANAK, B., VUJOŠEVIĆ, E., NIKOLIĆ-ĐORIĆ (2018): Non-parametric approach to the analysis of phenotypic stability of two half-sib maize populations. Genetika, *50* (3): 1081-1094.

MOHAMMADI, R. (2016): Efficiency of yield-based drought tolerance indices to identify tolerant genotypes in durum wheat. Euphytica, *211*: 71-89.

MOHAMMADI, R., A., ABDULAHI, R., HAGHPARAST, M., AGHAEE, M., ROSTAEE (2007): Nonparametric methods for evaluating of winter wheat genotypes in multi environment trials. World J. Agric. Sci., *3*: 137-142.

MOHAMMADI, R., A., AMRI (2008): Comparison of parametric and nonparametric methods for selecting stable and adapted durum wheat genotypes in variable environments. Eupthyca, *159*: 419-255.

MUT, Z., N., AYDIN, H.O., BAYRAMOĞLU, H., ÖZCAN (2009): Interpreting Genotype × Environment Interaction in Bread Wheat (*Triticum aestivum* L.) Genotypes Using Nonparametric Measures. TÜBİTAK, Turk. J. Agric, *33*: 127-137.

NASSAR, R., M., HUEHN (1987): Studies on estimation of phenotypic stability: Test of significance for nonparametric measures of phenotypic stability. Biometrics, *43*: 45- 53.

RAHADI, V.P., M., SYUKUR, S., SUJIPRIHATI, R., YUNIANTI (2013): Nonparametric stability analysis of yield for nine chili pepper (*Capsicum annuum* L.) genotypes in eight environments, Agrivita, *35* (2):193-200.

REA, R., O., SOUSA-VIEIRA DE, A., DÍAZ, M., RAMÓN, R., BRICEÑO (2017): Genotype by environment interaction and yield stability in sugarcane Rev. Fac. Nac. Agron., *70* (2): 8129-8138.

ROMAGOSA, I., P.N.FOX (1993): Genotype x environment interaction and adaptation. In: Hayward, M.D., Bosemark, N.O., Romagosa, I. (Eds.), Plant Breeding: Principles and Prospects. Chapman & Hall, Cambridge, UK, 373–390.

SABAGHNIA, N., H., DEHGHANI, S.H., SABAGHPOUR (2006): Nonparametric methods for interpreting genotype x environment interaction in lentil genotypes. Crop Sci., *46*: 1100-1106.

SABAGHNIA, N., M., MOHAMMADI, R., KARIMZADEH (2013): Interpreting genotype x environment interaction of beard wheat genotypes using different nonparametric stability statistics. Agriculture & Forestry, *59* (2): 21-35.

SAMONTE, S.C.P.B., L.T., WILSON, A.M., MCCLUNG, J.C., MEDLEY (2005): Targeting cultivars onto rize growing environments using AMMI and SREG GGE biplot analysis. Crop Sci., *45*: 2414-2424.

SEGHERLOO, A.E., S.H., SABAGHPOUR, H., DEHGHANI, M., KAMRANI (2008): Non-parametric measures of phenotypic stability in chickpea genotypes (*Cicer arietinum* L.). Euphytica, *162*: 221-229.

SHUKLA, G. (1972): Some statistical aspects of partitioning genotype environmental components of variability. Heredity, *29*: 237-245.

SIMMONDS, N. (1991): Selection for local adaptation in a plant breeding programme. TAG, *82*: 363-367.

SOLOMON, K.F., H.A., SMIT, E., MALAN, W.J., DU TOIT (2007): Comparison Study Using Rank Based Nonparametric Stability Statistics of Durum Wheat. World J. Agric. Sci., *3*(4): 444-450.

STATISTICAL OFFICE OF THE REPUBLIC OF SERBIA (2020): Statistical year book of the Republic of Serbia. Statistical office of the Republic of Serbia, Belgrade, http://data.stat.gov.rs

SUBAŞI, I., D., BAŞALMA (2021): Assessment of Genotype × Environment Interaction of Safflower (*Carthamus tinctorius* L.) Genotypes by Parametric and Non-Parametric Methods. European Journal of Agriculture and Food Sciences, *3* (1): 112-118.

TEMESGENA, T., G., KENENIB, T., SEFERA, M., JARSOB (2015): Yield stability and relationships among stability parameters in faba bean (*Vicia faba* L.) genotypes. The Crop Journal, *3* (3): 258-268.

TRUBERG, B., M., HUEHN (2000): Contributions to the analysis of Genotype× Environment interactions: Comparison of different parametric and non-parametric tests for interactions with emphasis on crossover interactions. J. Agron. Crop Sci., *185*: 267-274.

VERMA, A., J., SINGH, V., KUMAR, A., KHARAB, G., SINGH (2017): Non parametric analysis in multi environmental trials of feed barley genotypes. Int. J. Curr. Microbiol. App. Sci., *6*(6): 1201-1210.

ZAR, J. H. (1999): Biostatistical Analysis, 4th edition. Prenice-Hall, Inc., New Jersey, USA, *28*: 556–58.

ŽIVANOVIĆ, T., G., BRANKOVIĆ, M., ZORIĆ, G., ŠURLAN-MOMIROVIC, S., JANKOVIĆ, S., VASILJEVIĆ, J., PAVLOV (2012): Effect of recombination in the maize breeding population with exotic germplasm on the yield stability. Euphytica, *185*: 407–417.

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

ZORIĆ, M., J., GUNJAČA, D., ŠIMIĆ (2015): Stabilnost prinosa ozime pšenice u sortnim pokusima. 50 Hrvatski i 10 Međunarodni Simpozij Agronoma / Pospišil, Milan - Zagreb: Sveučilište u Zagrebu, Agronomski fakultet, Zbornik radova, 207-210.

PROUČAVANJE STABILNOSTI PRINOSA KURUZA NEPARAMETRIJSKIM METODAMA

Dragana BRANKOVIĆ-RADOJČIĆ*, Marija MILIVOJEVIĆ, Tanja PETROVIĆ, Snežana JOVANOVIĆ, Aleksandar POPOVIĆ, Snežana GOŠIĆ DONDO**,** Jelena SRDIĆ

Institute za kukuruz “Zemun Polje”, Beograd, Srbija

Izvod

U ovom radu primenjena je neparametarska analiza stabilnosti kako bi se procenila GxE interakcija za prinos 36 hibrida kukuruza. Eksperiment je postavljen na pet lokacija u Srbiji u trajanju od tri godine po potpuno slučajnom blok dizajnu (RCBD) u tri ponavljanja. Stabilnost prinosa ispitivanih genotipova analizirana je parametrima stabilnosti Si $^{(1)}$, Si $^{(2)}$, Si $^{(3)}$, Si $^{(6)}$, TOP i RS. Hibrid ZPH15 je postigao najstabilniji prinos na osnovu parametara Si $^{(1)}$ i Si $^{(2)}$, prema parametru Si $^{(3)}$ ZPH5, dok je na osnovu parametra Si $^{(6)}$ to bio ZPH34. Najrodniji hibrid ukupno u ogledu bio je ZPH36 sa prosečnim prinosom od 11,180 t/ha, koji je na osnovu ranga parametara Si $^{(1)}$ i Si $^{(2)}$ bio dosta nestabilan (rang 24), a na osnovu ranga parametara Si $^{(3)}$ i Si$^{(6)}$ veoma nestabilan (rang 34). Najstabilniji hibridi imali su prinos oko proseka. Ukupno, najbolji prosečan rang imao je hibrid ZPH 23 (15,93). Na osnovu TOP parametra najbolji rang (prinos) imao je ZPH36, a zatim ZPH11, ZPH20, ZPH21 i ZPH9. Međutim, RS parametar je pokazao da je ZPH21 najstabilniji hibrid, tako da je uzimajući u obzir i TOP i RS parametre ovo najproduktivniji i najstabilniji hibrid. Na osnovu ovog istraživanja, od svih posmatranih neparametarskih parametara, parametri TOP i RS pokazali su se kao najbolji za odabir novih hibrida kukuruza za gajenje u određenom regionu. U slučaju identične TOP vrednosti, treba izabrati genotip sa najnižom RS vrednošću, dok se parametri Si $^{(1)}$, Si $^{(2)}$, Si $^{(3)}$ i Si $^{(6)}$ mogu koristiti kao alternativne metode za selekciju genotipova sa umerenim prinosom i visokom stabilnošću.

Primljeno 14.X.2021.
Odobreno 28. V. 2022.