

Evaluation of maize hybrids stability using parametric and non-parametric methods

Henryk Bujak^{1*}, Kamila Nowosad¹, Roman Warzecha²

¹Wrocław University of Environmental and Life Sciences, Department of Genetics, Plant Breeding and Seed Production, Plac Grunwaldzki 24A, 53-535 Wrocław, Poland

²Plant Breeding and Acclimatization Institute, Radzików, 05-870 Błonie, Poland

*Corresponding author: E-mail: henryk.bujak@up.wroc.pl

Abstract

The purpose of the study was to compare four parametric and three nonparametric methods for the assessment of agronomic stability of eight maize cultivars chosen from postregistration trials carried out at 16 locations in Poland for a period of three years. Significant correlations were found between mean yield and two parametric measures: b_i and D_i . Of nonparametric statistics only the new proposed measure (R_{ij}) was significantly associated with yield ($r=0.86$), whereas Kang's rank sum just missed significance ($r=0.68$). Correlations between parametric and non-parametric measures were in general not significant. Full correlation was found between Wricke's ecovalence and Shukla's stability variance. Hühn's stability measures S_i^1 and S_i^2 were also highly positively associated ($r=0.92$). As expected high correlation was observed between ecovalence and S_{di}^2 ($r=0.98$). The results showed that high yielding cultivars can also be stable. The new proposed method based on homogeneous groups ranks can be a useful alternative to Kang's rank sum parameter in studies of agronomic stability of maize hybrids.

Keywords: agronomic stability, cultivars, genotype-environment (GxE) interaction, maize

Introduction

In Poland, as many as 147 maize cultivars were on the National Variety List in 2013 (COBORU, 2013). Farmers are interested in those cultivars which will give high and stable yields. And thus, there is a need to investigate the genotype-environment (GxE) interaction which can be useful in microregionalization (targeting cultivars to specific environments). The effects of cultivars and the environments are statistically non-additive, which means that differences in cultivar yields will depend on the environment (Hühn 1996; Yue et al, 1997). It can be concluded from this that the choice of cultivars based on the mean yield in a given environment will be less efficient (Hopkins et al, 1995). To identify stable and superior crop cultivars univariate parametric methods of Finlay and Wilkinson (1963), Eberhart and Russel (1966) have often been used. Eberhart and Russel (1966) proposed regression coefficient to evaluate cultivar responsiveness to environment and deviation mean square (S_{di}^2) to assess its yield stability. Shukla (1972) proposed an unbiased estimate of variance (δ^2) for the assessment of stability. Significance of the variance points out to the cultivar's unstable yielding performance. Similar approach was developed by Caliński (1960). Wricke (1962) developed a method of ecovalence, which measures the contribution of each genotype to the sum of squares for the GxE interaction. A low value of this statistic indicates high stability of the variety.

Hanson (1970) introduced a method for evalua-

tion of the genotype stability for a small number of varieties and environments by estimating parameter D_i . In this procedure, the stability of a variety is defined as deviation of the expected (E_{ij}) from the stable (S_{ij}) yield. If certain assumptions like normality, homogeneity of variance, additivity or linearity of genotype and environmental effects are not satisfied, then parametric models can lead to erroneous conclusions. Therefore, some researches proposed non-parametric models which are distribution free and do not require such assumptions (Hühn 1990a; 1990b; Kang 1988; Fox et al, 1990).

Many non-parametric and statistical methods have been developed for testing of GxE interaction (Azalini and Kox 1984; Brederkamp 1974; De Kroon and von der Laan 1981; Hildebrand 1980; Kubinger 1986). One of the advantages of non-parametric measures is that they are easy to calculate and interpret. Kang's method (1988), also termed rank sum (RS), combines ranked yield and Shukla's stability variance into one measure, whereas in the method of Fox et al (1990) ranked cultivars are assigned to three different fractions: top, medium, and bottom. The genotypes in the top third are considered the most desirable because they are high yielding and stable. The methods of Kang and Fox share a common deficiency as they do not take into account the significant differences in yields among the cultivars, and the calculated measures are often poorly correlated with the yield (Mohammadi et al, 2007a; 2007b; 2008. Bujak et al, 2008a; 2008b; 2013) proposed a non-parametric

Table 1 - Assessment of yield stability for the maize cultivars as measured by parametric methods.

Cultivars	Yield t ha ⁻¹	Eberhart and Russell b _i	S ² _{di}	Hanson D _i	Wricke W _i	Shukla σ ² _i
Aster	10.54	1.09	144.25	90.16	941.53	41.84
ES Paroli	10.48	1.12	288.35	86.99	855.23	37.42
Coxximo	10.44	0.96	143.23	99.68	442.11	16.23
MAS 25A	10.42	1.01	242.70	101.78	1643.38	77.83
Amadeo	10.40	1.01	547.66	95.17	433.98	15.81
Monumental	10.30	1.03	216.09	94.68	656.00	27.20
Silas	10.29	0.91	362.80	107.14	1151.75	52.62
System	9.57	0.86	246.58	110.42	909.93	40.22

method based on distinct homogenous groups ranks (R_D) and coefficient of variation (CV) to assess agronomic stability of cultivars. Commonly used multiple comparison tests do not separate means into non-overlapping groups, therefore in the proposed method [Haufe and Geidel test \(1984\)](#) was applied.

The aim of the study is to compare and evaluate the usefulness of parametric and nonparametric methods for estimating agronomic stability of maize hybrids.

Materials and Methods

Experimental material

A subset of 8 maize hybrids were chosen from postregistration experiments arranged in incomplete block design with four replications at 16 locations for a period of three years. The cultivars Amadeo, Coxximo, ES Paroli, Monumental, System, Asteri, Mas 25A and Silas were chosen because they were common to all years and locations distributed over a wide range of environments in Poland. Harvested plot size was 16m². Stability analyses were made using the following parametric and non-parametric methods.

Statistical analysis

Parametric methods

1. Eberhart and Russell method (1966)

Eberhart and Russell (1966) proposed evaluation of the reaction of cultivars to changeable environmental conditions through the use of the linear regression coefficient b_i and variance of deviations from regression S^2_{di} :

$$b_i = 1 + \frac{\sum_j (x_{ij} - \bar{x}_i - \bar{x}_j + \bar{x}_{..})(\bar{x}_j - \bar{x}_{..})}{\sum_j (\bar{x}_j - \bar{x}_{..})^2}$$

Table 2 - Estimates of non-parametric measures for 8 maize hybrids yield stability assessment.

Cultivars	Yield t ha ⁻¹	Kang	S ¹ _i	Hühn	S ² _i
Aster	10.54	7	2.43		4.51
ES Paroli	10.48	6	2.73		5.72
Coxximo	10.44	5	2.24		3.89
MAS 25A	10.42	12	2.94		6.98
Amadeo	10.40	6	2.00		2.92
Monumental	10.30	9	2.35		4.59
Silas	10.29	14	2.41		4.47
System	9.57	13	1.49		2.42

$$S^2_{di} = \frac{1}{E-2} \left[\sum_i (x_{ij} - \bar{x}_i - \bar{x}_j + \bar{x}_{..}) - (b_i - 1)^2 \sum_i (\bar{x}_j - \bar{x}_{..})^2 \right]$$

where: x_{ij} = yield of the i^{th} cultivar in the j^{th} environment; \bar{x}_i = mean yield of the i^{th} cultivar; \bar{x}_j = mean yield in the j^{th} environment; $\bar{x}_{..}$ = overall mean; E = number of environments.

Varieties having regression coefficient $b_i > 1$ are better adapted to favourable environmental conditions. In the case when $b_i < 1$, they perform better in low yielding environments. If $b_i = 1$, then the varieties are characterized by average adaptability to different environments. Cultivars with variance $S^2_{di} = 0$ are the most stable, whereas a high value of S^2_{di} indicates low stability.

2. Shukla's stability variance (1972)

The stability statistic of Shukla (1972) is a measure of the share of each particular variety in the GxE interaction.

$$\sigma_i^2 = \frac{1}{(s-1)(t-1)(t-2)^x} \left[t(t-1) \sum_i (x_{ij} - x_i - x_j + x_{..})^2 - \sum_i \sum_j (x_{ij} - x_i - x_j + x_{..})^2 \right]$$

where: s = number of environments; t = number of varieties.

A low value of σ_i^2 testifies to high yield stability of a given cultivar.

3. Wricke's ecovalence W_i (1962)

The ecovalence defines the share of each genotype in the sum of squares of the GxE interaction. A low value of W_i points out to high yield stability of the variety.

$$W_i = \sum_j (x_{ij} - x_i - x_j + x_{..})^2$$

4. Hanson's genotype stability measure D_i (1970)

This method is employed when a number of both cultivars and environments is small. The D_i value is a measure of the share of a given genotype in the variance of the GxE interaction and of the genotype's reaction to changeable environmental conditions with the use of the Eberhart and Russell regression coefficient b_i . It is thus a measure of a cultivar's stability expressed as deviation of its expected yield (E_i) from its stable yield (S_{ij}).

Table 3 - Mean yields and assessment of agronomic stability of maize hybrids by the method of homogeneous groups ranks (R_D).

Cultivars	Yield t ha ⁻¹	Rank RD	Coefficient of variability (CV)	Percentage of environments where the cultivar rank			
				1	2	3	remaining
Asteri	10.54	1.67	19.69	48	41	7	4
ES Paroli	10.48	1.89	20.13	44	30	19	7
Coxximo	10.44	1.89	17.23	37	37	26	0
MAS 25A	10.42	1.89	19.18	44	33	11	11
Amadeo	10.40	1.85	18.14	37	41	22	0
Monumental	10.30	2.07	18.85	30	44	15	11
Silas	10.29	2.07	17.36	52	11	19	19
System	9.57	2.89	17.28	7	33	33	26

where:

$$D_i = \left[\sum_j (\hat{E}_{ij} - \hat{S}_{ij})^2 \right]^{\frac{1}{2}}; \hat{E}_{ij} = (x_{ij} + x_{..} - x_{i.} - x_{.j})$$

Non-parametric methods

1. Hühn's stability measures (1990)

Two stability measures have been applied:

$$(1) S_i^1 = \frac{\sum_{j>j'} |r_{ij} - r_{ij'}|}{N(N-1)} = \frac{2 \sum_{j=1}^{N-1} \sum_{j'=j+1}^N |r_{ij} - r_{ij'}|}{N(N-1)}$$

where: r_{ij} = rank of the i^{th} genotype in the j^{th} environment; $r_{ij'}$ = rank based on the corrected values of x_{ij} ; N = number of environments; $x_{ij}' = x_{ij} - x_{i.} - x_{.j} + x_{..}$

$$(2) S_i^2 = \frac{\sum_{j=1}^N (r_{ij} - \bar{r}_i)^2}{N-1}$$

where: $\bar{r}_i = \sum_{j=1}^N r_{ij} / N$; \bar{r}_i = mean rank for the i^{th} genotype.

2. Kang's rank sum (1988)

This method combines cultivar yield and Shukla's stability variance into one statistic. The variety with the highest yield is given a rank of 1, while that of the lowest variance is also assigned a rank of 1. The ranks for yield and variance are summed up. The cultivar having the lowest rank sum is the most desirable.

3. New method based on ranks of homogeneous groups (R_D) and coefficient of variability (CV).

After performing analysis of variance of single experiments for each location and year, the null hypothesis was verified using F test. After rejecting the null hypothesis Haufe and Geidel test was used for multiple comparisons of cultivar means.

Cultivars belonging to the same homogeneous groups were given identical rank. After summing up all ranks for particular cultivars, the mean overall rank (RD) was computed for each cultivar.

Haufe and Geidel test separates means into distinct homogeneous groups which do not overlap. The general formula for the test is as follows:

$$GD = S_x \times T(\alpha, p, k, FG)$$

where: S_x = standard error of a treatment mean; α = level of significance; p = number of means under comparison; k = number of means compared within a group; FG = degrees of freedom for error mean square in analysis of variance; T = tabular value of t .

When we adopt the critical difference as:

$$GD_1 = \sqrt{\frac{S^2}{n}} \times \sqrt{2} \times t_{\alpha, FG}; n = \text{number of replications}$$

with $\alpha = 0.05$ and FG standing for the number degrees of freedom, then the critical value GD_1 is too high and the standard error (S_d) should be reduced according to the following formula:

$$S_d = \sqrt{\frac{S^2}{n} + \frac{S^2}{nk}}$$

Thanks to the correction, we arrive at the modification as follows:

Table 4 - Spearman's rank correlations between parametric and nonparametric stability measures for grain yield.

Measures	b_i	S_{di}^2	Hanson	Wricke	Shukla	Kang	Hühn S_i^1	Hühn S_i^2	R_D
Grain yield	0.82*	0.10	0.76*	0.04	0.04	0.68	-0.57	-0.48	0.86*
b_i		0.02	0.86*	0.10	0.10	0.52	-0.63	-0.61	0.80*
S_{di}^2			0.31	0.98*	0.98*	0.76*	0.59	0.42	0.05
Hanson				0.33	0.33	0.63	-0.40	-0.47	0.64
Wricke					1.00	0.73*	0.62	0.45	0.24
Shukla						0.73*	0.61	0.45	0.24
Kang							0.07	0.10	0.66
Hühn S_i^1								0.92*	-0.52
Hühn S_i^2									-0.45

$$GD_k = \sqrt{\frac{S^2}{2}} \times \sqrt{\frac{k+1}{2k}} \times t_{\alpha, FG}$$

After calculation – with the use of the correction coefficient $\sqrt{\frac{k+1}{2k}}$ – of GD_1 as a value of the least significant difference (NIR_{α}), the following formula for the critical value is obtained:

$$GD_k = GD_1 \times \sqrt{\frac{k+1}{2k}}$$

Compute the observed difference $D_1 = \bar{x}_1 - \bar{x}_2$ and compare it with GD_1 value. If $D_1 > GD_1$ the cultivars are assigned to separate groups. If $D_1 < GD_1$ the cultivars are in the same group. Next, calculate the difference:

$$D_2 = \bar{x}_3 - \frac{(\bar{x}_1 + \bar{x}_2)}{2}$$

and compare with the corrected GD_2 value. The procedure is continued until all comparisons are made. In the end we obtain non overlapping groups of treatment means.

Results

Analyses of variance have revealed significant variability between the cultivars, locations, years and significant GxE interactions.

Table 1 shows the estimation of yield stability by four parametric methods. According to Eberhart and Russell method the most stable cultivars were Coximo and Amadeo and they also had average adaptability to environmental conditions. Hybrid ES Paroli was less stable and tended to be better adapted to more favourable environments whereas hybrid System showed adaptedness to lower yielding environments.

D_i values of Hanson pointed to the highest yielding cultivars Es Paroli and Asteri as the most stable. The lowest yielding hybrid System was the least stable.

Because Shukla's stability variance is a linear combination of the ecovalence so for ranking purposes

these methods are equivalent. It can be seen from **Table 1** that cultivars Amadeo and Coximo were the most stable. The least stable cultivar was Mass 25A.

Table 2 shows non-parametric measures of stability estimated according to Hühn and Kang. Two Hühn's parameters S_1^1 and S_1^2 gave similar ranking of cultivars. The lowest yielding hybrid System was the most stable followed by high yielding Amadeo and Coximo.

According to Kang's rank sum method Coximo, Amadeo and ES Paroli were the most stable and desirable cultivars while lower yielding Silas and System were the least stable.

R_D values computed according to the new method are presented in **Table 3**. The lowest R_D values indicate the cultivars which perform best and are characterized by high stability. Top ranking cultivar Asteri was the highest yielder. Cultivars ES Paroli, Coximo, Mas 25A and Amadeo obtained the same rank although they differed in regard to percentage of environments in which they occurred in particular homogenous groups. In order to get more information about stability and desirability of a cultivar, R_D values should be combined with coefficient of variability. **Figure 1** shows R_D values plotted against coefficient of variability. Cultivar Coximo in the upper left quadrant is the most desirable due to its performance and stability. Cultivar Silas is also stable but its performance is below over all treatment mean. Cultivars Asteri, Mas 25A and ES Paroli are high yielding but below average stability as measured by coefficient of variability.

Rank correlation between pairs of parametric and non-parametric measures are presented in **Table 4**. Significant correlations were found between mean yield and two parametric measures b_i and D_i . Of non-parametric statistics only R_D was significantly associated with yield ($r = 0.86$) whereas Kang's rank sum just missed significance ($r = 0.68$). Wricke's ecovalence

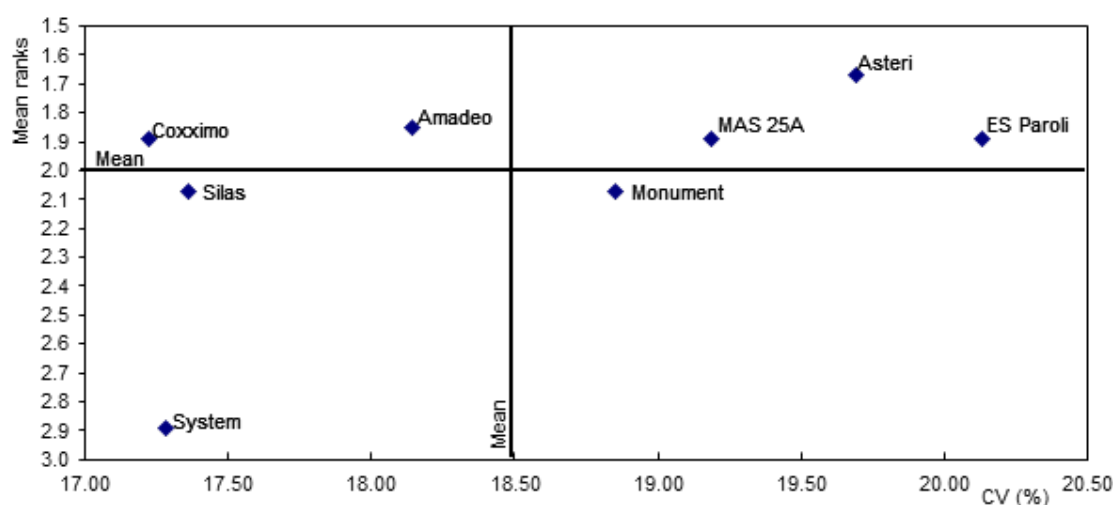


Figure 1 - Mean ranks (R_D), plotted against coefficients of variability (CV)

(W_i) and deviation from regression (S^2_{di}) were very highly correlated ($r = 0.98$). Full correlation was found between Wricke's and Shukla's statistics. Hühn's stability measures S^1_i and S^2_i were highly positively associated ($r = 0.92$).

Discussion

Both parametric and non-parametric measures of stability, with the exception of Hanson method, indicated either Amadeo or Coxximo as the most stable hybrids. This unusual consistency not found in other studies (Mohammadi et al, 2007; 2008) may be due to relatively small number of hybrids which were high yielding and their regression coefficients were close to 1.

Overall however, only b_i , D_i , and R_D were significantly correlated with yield. Significant negative association between b_i and yield was also found by Mohammadi et al (2008). There was no significant correlation between Hühn's stability measures S^1_i , S^2_i , and yield. Similar results were also reported in durum wheat (Mohammadi et al, 2007; 2008), winter wheat (Mohammadi et al, 2007), and lentil (Sabaghnia et al, 2006). Strong correlation ($r=0.98$) between S^2_{di} and Wricke's ecovalence was observed, but these parameters were not significantly associated with yield. Similar findings were reported by Mohammadi et al (2008). In stability studies either S^2_{di} or Shukla's stability variance or Wricke's ecovalence can be used.

Numerous methods have been developed to analyse phenotypic stability which implies they all have their limitations and there is no superior method to be recommended in all circumstances. The new proposed method based on homogenous groups is strongly correlated with yield and can be a useful alternative to Kang's rank sum or Fox's stratified ranking technique in studies of agronomic stability of maize hybrids.

References

- Azalini A, Kox DR, 1984. Two new tests associated with analysis of variance. *J Roy Stat Soc B* 46: 335-343
- Brederkamp J, 1974. Nonparametric Prüfung von Wechselwirkung. *Psychol Beitr*, 16: 398-416
- Bujak H, Jedyński S, Kaczmarek J, 2008. Application of the method of homogeneous group ranks and coefficients of variability to evaluation of yield stability of rye cultivars. *Biul IHAR* 250: 217-224 (in Polish)
- Bujak H, Jedyński S, Kaczmarek J, 2008. Evaluation of yield stability of rye cultivars on the basis of parametric and nonparametric methods. *Biul IHAR* 250: 189-201 (in Polish)
- Bujak H, Tratwal G, Weber R, Kaczmarek J, Gacek E, 2013. An analysis of spatial similarity in the variability of yields of winter wheat (*Triticum aestivum* L) cultivars in Western Poland. *Zemdirbyste-Agric culture*, 100(3): 311-316
- Calinski T, 1960. On a certain statistical method of investigating interaction in serial experiments with plant varieties. *Bull Acad Polon Sci* 12: 565-568
- De Kroon J, van der Laan P, 1981. Distribution-free test procedures in two-way layout: a concept of rank-interaction. *Stat Neerl* 35: 189-213
- Eberhart SA, Russell WA, 1966. Stability parameters for comparing varieties. *Crop Sci* 6: 36-40
- Finlay KW, Wilkinson GN, 1963. The analysis of adaptation in a plant breeding programme. *Crop Pasture Sci* 14: 742-754
- Fox P N, Skovmand B, Thompson B, Braun HJ, Cormier R, 1990. Yield and adaptation of hexaploid spring triticale. *Euphytica* 47: 57-64
- Hanson WD, 1970. Genotypic stability. *Theoretical and Applied Genetics* 40: 226-231
- Hildebrand H, 1980. Asymptotische verteilungsfreie Rangtests in linearen Modellen. *Med Inform Stack* 17: 344-349 (in German)
- Haufe W, Geidel H, 1984. Vorschlag eines Schätzverfahrens zur Klassifizierung von Versuchsergebnissen. *Arbeitsgemeinschaft der Saatzüchtleiter*. A-8952 Irdning, 257-290 (in German)
- Hopkins AA, Vogel KP, Moore KJ, Johnson KD, Carlson LT, 1995. Genotype effects and genotype by environment interactions for trait of elite switchgrass populations. *Crop Sci* 35: 125-132
- Hühn M, 1990a. Non parametric measures of phenotypic stability. Part 1. Theory. *Euphytica* 47: 189-194
- Hühn M, 1990b. Non parametric measures of phenotypic stability. Part 2. Application. *Euphytica* 47: 195-201
- Hühn M, 1996. Non parametric analysis of genotype-environment interaction by ranks, pp. 235-271. In: *Genotype by environment interaction: Kang MS, Gauch HS Eds. CRC Press, Boca Raton*
- Kang MS, 1988. A rank sum method for selecting high yielding and stable crop genotypes. *Cereal Res Commun* 16: 113-115
- Kubinger KD, 1986. A note on non-parametric tests for the interaction on two-way layouts. *Biometrical J* 28: 67-72
- Mohammadi R, Abdulahi A, Haghparast R, Armion M, 2007. Interpreting genotype x environment interactions for durum wheat grain yields using non-parametric methods. *Euphytica* 157: 239-251
- Mohammadi R, Abdulahi A, Haghparast R, Aghaee M, Rostae M, 2007. Nonparametric methods for evaluating of winter wheat genotypes in multi-environment trials. *World J Agric Sci* 3: 237-342
- Mohammadi R, Amri A, 2008. Comparison of parametric and non-parametric methods for selecting stable and adapted durum wheat genotypes in variable environments. *Euphytica* 159: 419-432
- National Variety List 2013. Edition of the Research Centre for Cultivar Testing (COBORU) Stupia Wielka, Poland (in Polish)

- Sabaghnia N, Dehghani H, Sabaghpour SH, 2006. Nonparametric methods for interpreting genotype x environment interaction of lentil genotypes. *Crop Sci* 46: 1100-1106
- Shukla GK, 1972. Some aspects of partitioning genotype-environmental components of variability. *Heredity* 29: 237-245
- Wricke G, 1962. Über eine Methode zur Erfassung der ökologischen Streubreite in Feldversuchen. *Z Pflanzenzucht* 47: 92-96 (in German)
- Yang CR, Crossa J, Cornelius LP, Burgueno, J, 2009. Biplot analysis of genotype x environment interaction, Proceed with caution. *Crop Sci* 49: 1564-1576
- Yue GL, Roozemboom KL, Schapaugh WT Jr, Liang GH, 1997. Evaluation of soybean using parametric and nonparametric stability estimates. *Plant Breeding* 116: 271-275