International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 8, No. 5, p. 32-38, 2016

RESEARCH PAPER OPEN ACCESS

Evaluation of Balkan wheat cultivars for grain yield stability based on the GGE biplot analysis

Boshev Dane*[1], Jankulovska Mirjana[1], Ivanovska Sonja[1], Azemov Irfan[2], Kamberi Mensur[2]

[1]SS Cyril and Methodius University, Faculty of Agricultural Sciences and Food, Skopje, Republic of Macedonia

[2]Ministry of Agriculture Forestry and Water Economy, Directorate for Seed and Seedlings, Skopje, Republic of Macedonia

Article published on May 12, 2016

Key words: Wheat, GGE biplot, Yield, Genotype, Environment.

Abstract

The objective of this study was to evaluate and quantify the magnitude of the genotype x environment interaction effects on wheat grain yield and to determine the winning genotype for the test environment. During ten years (2003-2013), 44 wheat cultivars from six Balkan countries were tested at three locations (Skopje, Strumica and Prilep) in Republic of Macedonia. The average grain yield data were subjected to the GGE biplot analysis. These analysis depicted the adaptation pattern of genotypes at different locations and discrimination ability of testing locations. Genotypes 27, 28 and 21 had the highest average yield and were the most stable genotypes. Out of the three locations, Strumica was identified as the most discriminative and representative location.

* **Corresponding Author:** Boshev Dane ✉ dbosev@yahoo.com

Introduction

Wheat is the most important cereal crop in Republic of Macedonia. In the last five years (2009-2013), it is grown on approximately 84,000 ha. Average grain yield of cultivated genotypes is insignificantly higher (3,056 kg ha^{-1}) than the global average yield (3,010 kg ha^{-1}), but compared with the highest yield (7,772 kg ha^{-1}) it is far below this value (FAO, 2012). In order to mitigate this, different improved cultivars are continually created or introduced. Those cultivars are being evaluated at different locations to test their performance and to identify the best genotypes in specific environments. The genotype x environment (GE) interaction usually complicates the selection for improved yield (Sabaghnia *et al.*, 2013). According to Rodriguez *et al.* (2002) in the cases when the magnitude of GE is large, it impedes the selection of stable genotypes and the selection advancement is slow.

Ceccarelli (1989) claimed that adaptation in crop plants corresponds to yield stability over time and environments. Considering this, when unpredictable GE interaction is present, cultivar evaluation must be carried out in multiple locations in order to fully test the target environment (Cooper *et al.*, 2007). Consequently, for assessing genotypic value and cultivar's stability for yield performance, multi environmental trial (MET) data are required. The main purpose of MET is to identify superior cultivars which could be recommended to farmers and to determine sites that best represent the target environment (Yan and Hunt, 2001).

The genotype performance across different environments could be difficult to determine without the help of graphical display of the data (Yan *et al.*, 2001). Yan and Hunt (2001) proposed a GGE biplot that allows visual examination of the GE interaction pattern of the data. GGE biplot refers to the genotype main effect (G) and the genotype x environment interaction (GE), the main two sources of variation that are important to cultivar evaluation. It can be used to identify superior cultivars and test environments that facilitate identification of such cultivars. The detection of genotypes that have the highest yield across a number of environments could be useful to breeders and producers (Kaya *et al.*, 2006). Thus, information on wheat cultivar stability in different environments, along with high yield may be helpful in selection of genotype(s) that have the best performance in favorable environments.

Many researchers have been using GGE biplot technique to identify the association between genotypes and environments, in order to determine the adaptation and/or magnitude of the G×E interaction, or to identify mega-environments and suitable wheat genotypes for specific regions (Mohhamadi *et al.*, 2012; Castillo *et al.*, 2012; Benin *et al.*, 2014; Mehari *et al.*, 2015). In the Republic of Macedonia, the information about stability and adaptability of newly released domestic and introduced wheat varieties, as well as the identification of most suitable varieties for specific growing regions is lacking. Considering this, the analyses performed within this study aim to interpret the main effects of genotype and environment, as well as G × E interaction effects on grain yield of 44 bread wheat varieties in 3 different environments using the GGE biplot technique and to identify varieties which express their maximum yield potential in a wide variety or in specific environments.

Materials and methods

Plant material and experimental design

The trials were conducted during ten years (2003-2013) under supervision of the Directorate for Seed and Seedlings, Ministry of Agriculture Forestry and Water Economy in Skopje, Republic of Macedonia. 44 wheat cultivars from 6 Balkan countries: Republic of Macedonia (MKD), Bulgaria (BUL), Serbia (SRB), Croatia (CRO), Hungary (HUN) and Austria (AUS), were grown and tested in 3 experimental field stations (Strumica, Skopje and Prilep). Field station Strumica is located in the south-east (41°26'32" N, 22°39'56" E, Altitude 221 m), Skopje in the north (42°02'02" N, 21°27'10" E, Altitude 303 m) and Prilep (41°22'06" N, 21°30'49" E, Altitude 665 m) in the south-west part of the country. The name of the cultivars, their code, their origins and their average grain yield from three environments are given in Table 1.

Table 1. Wheat cultivars included in the study.

Code	Name of cultivar	Origin	Code	Name of cultivar	Origin
1	Radika	MKD	23	Zdenka	CRO
2	IJZK-13/95	MKD	24	Tina	CRO
3	Sk-17/98-1/4	MKD	25	Liberta	CRO
4	Mak. Rana	MKD	26	Golubica	CRO
5	Balkanija	MKD	27	Klara	CRO
6	Mak. Rodna	MKD	28	Osk-314/00	CRO
7	Bt 04-069	MKD	29	Osk 266/3	CRO
8	Aglika	BUL	30	Osk 251/02	CRO
9	Preslav	BUL	31	Osk 236/01	CRO
10	Progres	BUL	32	Osk 244/04	CRO
11	Milena	BUL	33	Renata	CRO
12	Mizaja	BUL	34	Lucia	CRO
13	Slaveja	BUL	35	Pipi	CRO
14	Bajka	SRB	36	Felix	CRO
15	Anastasija	SRB	37	Verbunkos	HUN
16	Stamena	SRB	38	Suveges	HUN
17	Sonata	SRB	39	Suba	HUN
18	Vizija	SRB	40	Codman	HUN
19	Matica	SRB	41	Mambo	HUN
20	KG-100	SRB	42	Edison	AUS
21	Mihalica	CRO	43	Equizit	AUS
22	Prima	CRO	44	Exclusive	AUS

Experimental layout was a randomized complete block design with five replications in each location. The plot size per cultivar was 5 x 1 m, with 8 rows per plot. The distance between rows, was 12.5 cm. At the maturity stage, the central six rows from each plot were harvested for grain yield calculation for each genotype, at each test environment.

Statistical analysis

The GGE biplot analysis was performed using R statistical package GGE biplot GUI (Bernal and Villardon, 2012). It was used to generate graphs which are showing (i) relationships among environments (ii) "which-won-where" pattern, (iii) ranking of cultivars on the basis of yield and stability, (iv) environment vectors, and (v) comparison of environment to ideal environment (Yan and Kang, 2003). The GGE biplot represents the first two principal components (PC1 and PC2, referred as primary and secondary effects, respectively) derived from subjecting environment centered yield data (yield variation due to GGE), to singular value decomposition (Yan *et al.*, 2000).

Results and discussion

Relationships among test environments

Genotype (G) plus genotype by environment interaction (GE) denotes GGE. These two sources of variation that are relevant to genotype evaluation, for appropriate genotype evaluation, must be considered simultaneously (Yan, 2002).

The relationships between the environments performed in this study are shown in Fig. 1. The test locations are connected to the biplot origin by lines, called environment vectors. The cosine of the angle between the vectors of two locations approximates the correlation between them (Kroonenberg, 1995; Yan, 2002). The size of the angle between the individual locations shows the similarity or dissimilarity between the environments. Strumica had the longest vector, thus it was the best location for genetic differentiation of analyzed cultivars. Prilep was the least representative environment in this study. The small angle between the vectors of Strumica and Skopje indicated that they had a strong relationship.

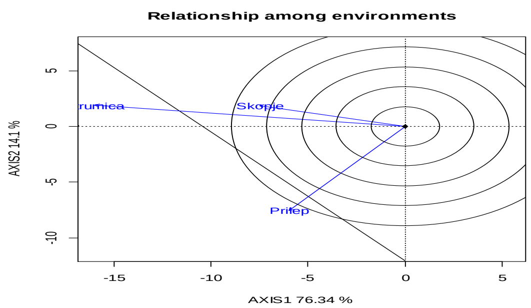

Fig. 1. GGE biplot based on relationships among test environments.

Best Cultivar in each Environment

GGE biplot technique proved successful in assessing the stability of the wheat cultivars and identification of the locations and mega external environments for testing wheat in many studies (Hagos and Abay, 2013, Mohammed *et al.*, 2013).

One of the best possibilities that the GGE biplot methodology offers, is showing the which-won-where pattern of a genotype by environment dataset (Fig. 2). It graphically addresses important concepts such as crossover GE, mega environment differentiation, particular adaptation, etc. (Yan and Tinker, 2005). The polygon is created by linking the markers of the genotypes that are the furthest away from the biplot origin such that all other genotypes are positioned in the polygon. Genotypes located on the vertices of the polygon performed either the best or the poorest in one or more environments. The vertex genotype(s) for each sector has higher (sometimes the highest) yield than the others in all environments that fall in that sector (Yan, 2002). The perpendicular lines are equality lines between adjacent genotypes on the polygon, which facilitate their visual comparison.

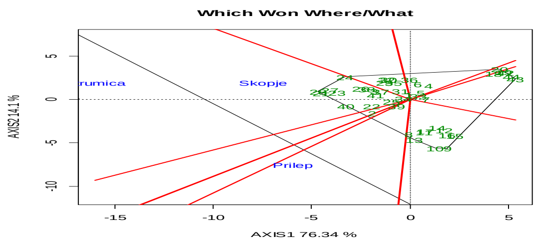

Fig. 2. Which-won-where pattern of genotypes and environments.

Considering this, the cultivars 27 and 28 had the best performance in Skopje, cultivar 21 in Strumica, while none of the cultivars was positioned in the same sector with the location Prilep, meaning that none of the evaluated varieties will give its maximum yield at this location. Many cultivars did not fall in the same sector with each of locations, indicating that these cultivars are less suitable for growing at these locations. Locations Skopje and Strumica are located at the same sector, indicating that they can be regarded as one mega-environment and there is no need for evaluation of varieties at both locations as they will perform similarly.

Average Yield and Stability of Cultivars

The ranking of 44 cultivars based on their grain yield and yield stability for 3 environments is shown in Fig. 3. Genotypes positioned on the axis in the direction of the arrow, are characterized by a high average yield, while those that are positioned closer to the axis regardless of the direction, characterized by higher stability (Yan, 2002). Considering this, the hybrid 28 has the highest average grain yield (9.31 t ha^{-1}), as having the highest projection on the performance line, followed by 21 (9.09 t ha^{-1}) and 27 (9.04 t ha^{-1}) (Table 2). The hybrid 43 had the lowest grain yield (3.29 t ha^{-1}).

Table 2. Average yields of the wheat cultivars (t ha^{-1}).

Code	Strumica	Skopje	Prilep	Mean	Code	Strumica	Skopje	Prilep	Mean
1	6.95	8.21	4.39	6.52	23	9.92	10.72	5.68	8.77
2	7.86	9.92	6.14	7.97	24	10.32	9.64	4.6	8.19
3	8.9	8.53	4.76	7.40	25	7.44	8.92	5.1	7.15
4	7	6.2	3.36	5.52	26	8.9	10.12	5.02	8.01
5	7.1	6.64	3.92	5.89	27	10.12	11.28	5.72	9.04
6	7.47	6.58	3.52	5.86	28	10.84	11.16	5.94	9.31
7	6.76	6.5	4.16	5.81	29	8.08	9.22	4.24	7.18
8	6.68	7.2	6.36	6.75	30	7.9	9.26	4.04	7.07
9	4.42	6.64	6.46	5.84	31	6.34	10.5	4.6	7.15
10	4.14	8.58	6.86	6.53	32	7.62	9.96	4.14	7.24
11	5.5	7.82	6.08	6.47	33	6.62	7.68	4.26	6.19

Code	Strumica	Skopje	Prilep	Mean	Code	Strumica	Skopje	Prilep	Mean
12	4.5	7.56	5.66	5.91	34	7.52	7.58	4.6	6.57
13	5.58	8.54	672	6.95	35	8.76	6.92	3.84	6.51
14	5.28	6,84	5.54	5.89	36	7.3	8	3.56	6.29
15	4.64	5.78	5.56	5.33	37	8.06	9.4	4.8	7.42
16	4.5	7.02	5.8	5.77	38	8.72	9.78	4.9	7.80
17	5.72	7.32	5.96	6.33	39	7.1	8.86	5.24	7.07
18	2.52	7.86	1.97	4.12	40	9.54	9.96	6.14	8.55
19	1.96	7.78	1.73	3.82	41	8.48	9.02	5	7.50
20	2.5	7.38	1.6	3.83	42	2.28	7.02	1.63	3.64
21	11.1	10.26	5.9	9.09	43	1.94	6.21	1.72	3.29
22	8.68	8.62	5.58	7.63	44	2.04	6.64	1.7	3.46

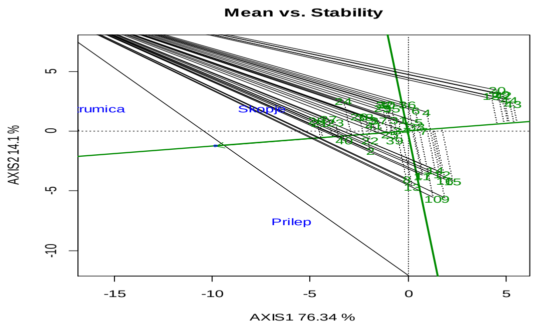

Fig. 3. GGE biplot representing mean performance and genotypes stability.

In the ranking of the tested cultivars according to the yield and stability, the best ranked is the genotype that is closest to the center of the concentric circles of biplot (Fig. 4). In this study, the cultivar 28 was the closest to the "ideal" genotype, and it should be considered for cultivation on all locations evaluated within this study.

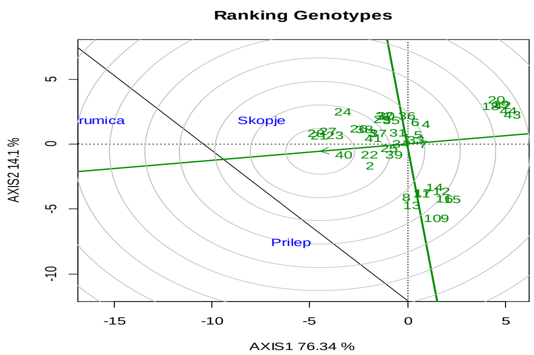

Fig. 4. Ranking of the tested cultivars according to the yield and stability.

Environment Ranking

Discriminating ability and representativeness of the environments is presented in Fig. 5. An ideal environment is the one that is most discriminating for genotypes (longest distance between the marker of the environment to the plot origin, is a measure of its discriminating ability) and is representative (shortest projection from the marker of location onto the ATC Y-axis is the measurement of its representativeness) of all other environments (Yan, 2001; Yan and Kang, 2003). According to Tonk *et al.* (2011), those are the best environments for genetic differentiation of experimental genotypes. Based on it, Strumica was the most discriminating as well as most representative location, as it is far away from the plot origin and had the shortest projection onto ATC Y-axis, respectively. It should be considered as one of the best locations for wheat stability testing and shoud be included as an experimental site in future studies.

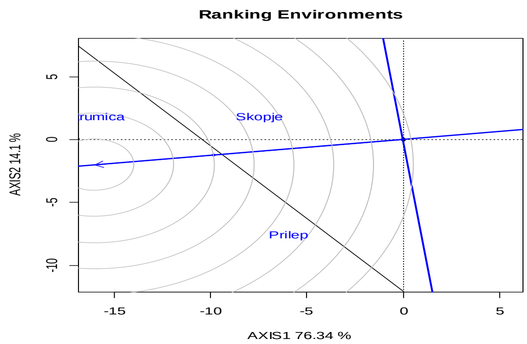

Fig. 5. GGE biplot based on environment-focused scaling.

Conclusions

The analyzed 44 wheat cultivars showed high variability for grain yield. The locations Skopje and Strumica can be considered as on mega-environment. Genotypes 27, 28 and 21 had the highest average yield and were the most stable genotypes. Genotype 27 had the best performance in Skopje region and 21 in Strumica. The tested varieties did not express high yield and stability in location Prilep, as in Skopje and Strumica. The location Strumica is an ideal environment for testing wheat genotypes.

References

Benin G, Lindolfo S, Volmir SM, Matheus HT, Anderson SM, Leomar GW. 2014. Effects of years, locations and sowing date on the spring wheat yield performance. Review Faculty Agronomy **113(2)**, 165-173.

Bernal EF, Villardon PG. 2012. Package 'GGE Biplot-GUI'. http://cran.r-project.org/...ages/ GGEBiplotGUI/GGEBiplotGUI. pdf

Castillo D, Matus I, del Pozo A, Madariaga R, Mellado M. 2012. Adaptability and genotype × environment interaction of spring wheat cultivars in Chile using regression analysis, AMMI, and SREG. Chilean Journal of Agricultural Research **72(2)** 167-174.

Ceccarelli S. 1989. Wide adaptation. How wide? Euphytica **40**, 197-205.

Cooper M, Podlich DW, Luo L. 2007. In: Varshney, R. and Tuberosa, R., Eds., Modeling QTL Effects and MAS in Plant Breeding. Genomics-Assisted Crop Improvement 1, Springer, Dordrecht, The Netherlands 57-96.

Hagos HG, Abay F. 2013. AMMI and GGE biplot analysis of bread wheat genotypes in the northern part of Ethiopia. Journal of Plant Breeding and Genetics **01**, 12-18.

Kaya Y, Akcura M, Taner S. 2006. GGE-Biplot Analysis of Multi-Environment Yield Trials in Bread Wheat. Turkish Journal of Agriculture and Forestry **30**, 325-337.

Kroonenberg PM. 1995. Introduction to biplots for G × E tables. Centre for Statistics. Research Report 51. The University of Queensland, Brisbane, Australia 22.

Mehari M, Tesfay M, Yirga H, Mesele A, Abebe T, Workineh A, Amare B. 2015. GGE biplot analysis of genotype-by-environment interaction and grain yield stability of bread wheat genotypes in South Tigray, Ethiopia. Communications in Biometry and Crop Science **10**, 17–26.

Mohamed NEM, Said AA, Amein KA. 2013. Additive main effects and multiplicative interaction (AMMI) and GGE-biplot analysis of genotype × environment interactions for grain yield in bread wheat (*Triticum aestivum* L.). African Journal of Agricultural Research **8(42)**, 5197-5203.

Mohammadi MR, Karimizadeh T, Hosseinpour M, Kalateharabi H, Khanzadeh N, Sabaghnia P, Hasanpour H. 2012. Analysis of genotype, environment and genotype × environment interaction in bread wheat in warm rainfed areas of Iran. Crop Breeding Journal **2(1)**, 63-70.

Rodriguez J, Sahagún J, Villaseñor H, Molina J, Martínez A. 2002. Estabilidad de siete variedades comerciales de trigo (*Triticum aestivum* L.) de Temporal. Revista Fitotecnia Mexicana **25**, 143–151.

Sabaghnia N, Mohammadi M, Karimizadeh R. 2013. Interpreting genotype x environment interaction of bread wheat genotypes using different nonparametric stability statistics. Agriculture & Forestry **59(2)**, 21-35.

Tonk FA, Ilker E, Tosun M. 2011. Evaluation of genotype x environment interactions in maize hybrids using GGE biplot analysis. Crop Breeding and Applied Biotechnology **11**, 1-9.

FAO (Food and Agriculture Organization of the United Nations). 2012. FAOSTAT. www.faostat.fao.org

Yan W. 2001. GGE Biplot - A windows application for graphical analysis of multi-environment trial data and other types of two-way data. Agronomy Journal **93**, 1111–1118.

Yan W. 2002. Singular-value partitioning in biplot analysis of multi-environment trial data. Agronomy Journal **94**, 990-996.

Yan W, Hunt LN. 2001. Interpretation of Genotype x Environment Interaction for Winter Wheat Yield in Ontario. Crop Science **41**, 19-23.

Yan W, Tinker NA. 2005. An integrated system of biplot analysis for displaying, interpreting, and exploring genotype by environment interactions. Crop Science **45,** 1004-1016.

Yan W, Hunt LA, Sheng Q, Szlavnics Z. 2000. Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Science **40**, 597-605.

Yan W, Cornelius PL, Crossa J, Hunt LA. 2001. Two types of GGE biplots for analysis of multi-environment trial data. Crop Science **41**, 565- 663.

Yan W, Kang MS. 2003. GGE biplot analysis: a graphical tool for breeders, geneticists and agronomist. CRC Press, Boca Raton, FL, 271.