Research Article

www.ekinjournal.com

Ekin
Journal of Crop Breeding and Genetics

2(1):90-99, 2016

Ekin International biannual peer-reviewed journal

GGE Biplot Analysis of Multi-Environment Yield Trials in Barley (*Hordeum vulgare* L.) Cultivars

Enver Kendal

Artuklu University, Kızıltepe Vocational College, Department of Crops and Animal Production, Kızıltepe, Mardin, Turkey

Corresponding author e-mail: enver21_1@hotmail.com

Citation:
Kendal E., 2016. GGE biplot analysis of multi-environment yield trials in barley (*Hordeum vulgare* L.) cultivars. Ekin J. 2(1):90-99.

Received: 11.05.2014 ***Accepted: 17.07.2015*** ***Published Online: 29.01.2016*** ***Printed: 29.01.2016***

ABSTRACT

Identification of the genetic stability and adaptation of released varieties are very important for breeding programs. Genotype x Environment Interaction (GEI) is extensively observed by breeders as differential ranking of variety yields among environments or years. Therefore, four spring barley varieties, registered in different years, were evaluated at eight environments in different years. The experiments were performed according to a complete randomized block design with four replications. Stability and genotypic superiority for yield was determined using ANOVA and GGE biplot analysis. Genotype x environment interaction was found to be highly significant ($P < 0.01$) for grain yield. The GGE biplot indicated that three mega-environment were occurred in terms of varieties. Kendal and Altikat, took place in same mega-environment, while Samyeli in the second, Sahin 91 in third. On the other hand, Kendal and Altikat showed general adaptability (E1, E2, E5, E7 and E8), while Samyeli and Sahin 91 exhibited specific adaptation to E4 and E3 respectively. Considering both techniques, Samyeli and Sahin 91 came forward with low yielding, while Kendal and Altikat with high yielding and stability. Results indicated that GGE biplot is illuminant methods to discover stability and adaptation pattern of varieties in practical recommendations.

Keywords: spring barley, genotype x environment interaction, GGE biplot, grain yield, stability.

Introduction

Barley is an excellent feed grain, fall and winter pasture, and forage crop in South-eastern Anatolia Region of Turkey. Barley has a wide range of adaptation, growing best on fertile, well-drained soils. Spring or winter and two- or six- row varieties are available. Spring barleys are grown in majority of region, while winter types only north of region. Basically this region is divided into three sub-regions. The first sub-region includes the Syrian border having low rainfall and drought conditions. Therefore, barley is one of a few plants that are grown without irrigation in this sub-region. The second sub-region have good conditions for barley and consisting of four province broadcast (Adıyaman, Diyarbakır, Batman, Siirt). The third sub-region includes north of South-eastern Anatolia Region. Many factors of barley wheat are affected depending on agro-ecologicical conditions of these sub-regions (Mizrak 1986).

The cultivars which are used in South-eastern Anatolia Region are different depending on sub-regions, as three main sub-regions have different conditions to cultivate barley cultivars. So it is very important to identify cultivars for specific sub-region. For that matter multi-environment trials (MET) are conducted to evaluate stability performance of genotypes under different environmental conditions *via* biplot analysis (Farshadfar *et al.* 2012; Yan 2000). Any genotype cultivated in varying environments show significant fluctuations in yield and yield components performance. These problems are affected by the different agro-ecological conditions and are referred to as genotype-by-environment (GE) interaction (Allard and Bradshow 1964). Furthermore, GE interaction decreases the genetic advance in plant breeding programs through minimizing the relation between phenotypic and genotypic values (Comstock and Moll 1963). Therefore, GE interaction must be either exploited by selecting superior genotype for each specific target environment or avoided by selecting widely adapted and stable genotype across wide range of environments (Ceccarelli 1989).

The breeding program of GAP International Agricultural Research and Training Center released five varieties between 1993-2013 years. The varieties, which released (2008-2013) in South-eastern Anatolia Region have different genotype features with superior grain yield, quality and other desirable characteristics over a wide range of different environmental conditions. Genotype by environment interaction (GxE) makes it difficult to recommend the best performing and most stable genotypes. Plant breeding programs should take GEI into consideration as well as an estimate of its magnitude, relative to the magnitude of G and E effects, which affects yield and yield components. The objective of this investigation was to use GGE Biplot to evaluate genetic improvement of varieties and detects in performance and stability of new varieties in eight diverse environments in South-eastern Anatolia Region with higher precision by removing the noise caused by E or genotypes.

Material and method

Plant genetic materials

The experimental material comprising of three new and one old barley varieties which were evaluated in eight rain-fed environments in different growing season (Table 1). The experiment was conducted in a randomized block design with four replications. The seeding rate was used 450 seeds m^{-2}. Plot size was 7.2 m^{-2} (1.2 × 6 m) consisting of 6 rows spaced 20 cm apart. Sowing was done by Wintersteiger drill. The fertilization rates for all plots were used 60 kg N ha^{-1} and 60 kg P ha^{-1} with sowing time and 60 kg N ha^{-1} was applied to plots at the early stem elongation. Harvest was done using Hege 140 harvester up on 6 m^2.

Statistical analysis

The grain yield data were subjected to combined analysis of variance (ANOVA) to determine the effects of environment (E), genotype (G), and their interactions. The data were graphically analyzed for interpreting GE interaction using the GGE biplot software (Yan 2001). GGE biplot methodology, which is composed of two concepts, the biplot concept (Gabriel 1971) and the GGE concept (Yan *et al.* 2000), was used to visually analyze the wheat-barley disomic addition lines MET data. This methodology uses a biplot to show the factors (G and GE) that are important in genotype evaluation and that are also the sources of variation in GE interaction analysis of MET data (Yan 2001). The graphs generated based on (1) relationships between testing environments based on the angles between the vectors of the environments. (2) Ranking of cultivars on the basis of yield and stability, (3) ranking of test environment relative to the highest yielding cultivar, (4) comparison of cultivars to an ideal cultivar, (5) ranking of cultivars relative to the test environment with highest yielding performance and (6) "which-won-where" pattern to identify the best genotypes in each environment for four genotypes of South-eastern Anatolia Region.

Results and discussion

Analysis of variance showed that the impacts of Environments (E), Genotypes (G) and Genotype × Environment Interaction (GEI) are highly significant. The percentage of the total sums of squares accounted for by G, E, and GE interactions were used as an indicator of variation attributed to grain yield. The biplot analysis of variance of grain yield of the four cultivars tested in eight environments showed that 82.89% of the total sum of squares was attributable to environmental effects, only 4.39% to genotypic effects and 12.7% to GEI effects (Table 3). Because environment accounted for 82.89% of the total variation for grain yield/ha, the effect of environmental sites was expected to be high. Majority of grain yield variation, explained by environments, showed that the environments were diverse and a major part of variation in grain yield can be resulted from environmental changes. But notional addition of GE constituent variance was very high as compared to the G component of variance showing that genetic improvement of this study is low. Yan and Kang (2003) reported high magnitude of E constituent to the extent of 80% in wheat and 59% in soybean. Also, Brar *et al.* (2010), Mohammadi and Amri (2011), reported more than 78% estimates for E components in *Taramira* and wheat through the environment and years. The heritability of genotype estimates were 7.67 to 18.53%, for seed yield (Letta *et al.* 2008; Brar *et al.* 2010). On the other hand, some researchers reported heritability of environment estimates between 40.5 to 84.8% for grain yield (Dash and Pandey 2009; Singh *et al.* 2009).

Interrelationship among cultivars and environments

Summary of the interrelationships among the environments for different cultivar is presented in Figure 1. The lines linking the biplot origin with the markers for the environments are called environment vectors. The angle between the vectors of two environments is related to the correlation coefficient between them. The cosine of the angle between the vectors of two environments approximates the correlation coefficient between them (Yan 2002; Yan *et al.* 2007; Brar *et al.* 2010). Based on the cosine of angles of environment vectors, the eight environments for grain yield were grouped into three groups. The presence of wide obtuse angles i.e. strong negative correlations among the environments is marker of strong cross-over genotype by environment interactions (Yan and Tinker 2006). The distance between two environments measures their dissimilarity in discriminating the genotypes. Therefore, eight environments for grain yield/ha were resolved into three groups. E1, E2, E5, E6, E7, E8, clustered in one group; E4 involved in second group; E3 included in third group. The concentric circles on the biplot help to visualize the length of the environment vectors, which is proportional to the standard deviation within the respective environments and is discriminating ability of the environments (Kroonenberg 1995). Thus, among the eight environments E2, E4 and E7 were the most discriminating (informative) while E3 and E5 were the less discriminating for grain yield. The

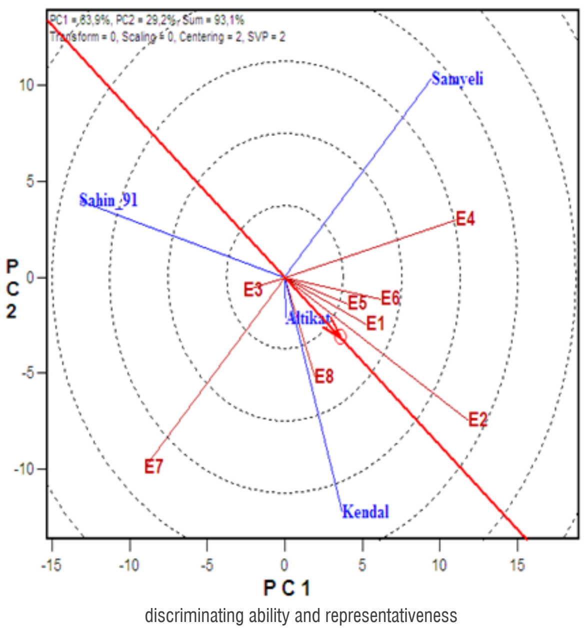

Figure 1: GGE biplot showing the performance of each cultivar at each environment

test environment which have length vector and narrow angles environments that mean it is both discriminating and representative environment and good for selecting widely adaptive genotypes (Yan 2001). This concept showed that E1, E5 and E6, had very narrow angle with AEA, but the environmental conditions at these environments were not much discriminating as E2 and E4 have sufficient vector length. Thus, E2 and E4 are suitable environments for selecting high yielding cultivars having wider adaptability in South-eastern Anatolia Region (Figure 1 & Table 4).

Mean performance of cultivars at different environments

Both vectors for genotype and environment, as drawn in Fig 1, are helpful to visualize the specific interactions between a genotype and an environment, as well as, the performance of each genotype in each environment (Yan and Tinker 2006). The performance of a genotype at a specific environment is better, when the angle is <90° between genotype vector and environment vector; it is poorer than average if the angle is >90° ; and it is near average if the angle is about 90°, which is based on the "inner product property" principle of biplot (Gabriel 1971). Therefore, the potential grain yield of Sahin 91 is under average at majority environments without E3 and E7. However the performance of Samyeli is above average at E4 and E6, while it was near average at E2. Similarly Kendal gave better yield than average at E5 and E7, also it was adapted in E2 and E8 environments. Altikat was well adapted to E1 and E3, while it took place above average for grain yield in E2, E4, E5 and E7 environments (Fig 1 and Table 4).

Stability of cultivars through the environments

The ideal genotype should have high mean performance coupled with high stability to give wide adaptability in the target region, As shown in Figure 2, the single-arrowed line called average–environment coordination abscissa (or AEA) points to higher mean yield through the environments. Thus, Kendal had the highest mean yield, followed by Altıkat and Samyeli. Sahin 91 had low yield for overall mean yield through all environment. The double-arrow line is the AEC ordinate and it points to greater variability (poor stability) in either direction.

The instability index calculated as *per* Eberhart and Russel (1966) model has the same magnitude as depicted by GGE biplot (Fig. 2). Therefore, to rows barley cultivars Altikat and Kendal are highly stable genotypes, whereas two rows cultivar of

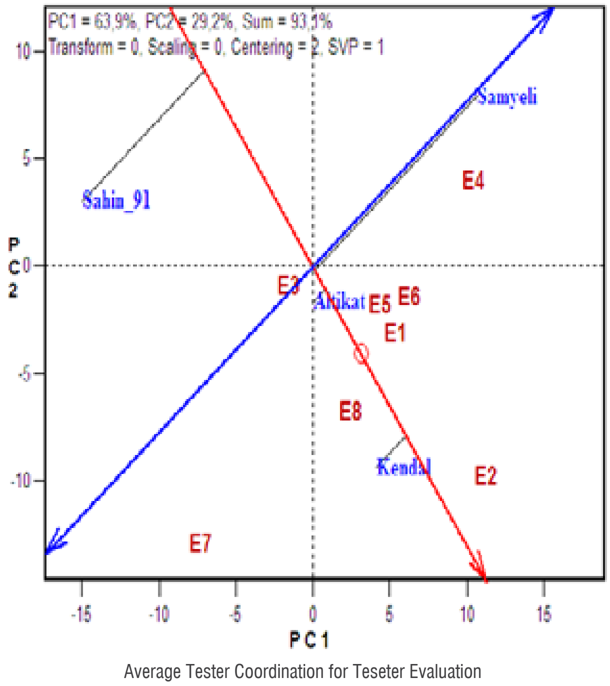

Figure 2: Average- environment coordination (AEC) show the mean performance and stability of cultivars

Samyeli and Sahin 91 were most unstable through all environments for grain yield. Kendal cultivar is stable for grain yield as it has performed better than average at E2 and E8 environments. Samyeli strain is also unstable as its performance was opposite to Sahin 91 at different sites; also it has performed better than average at E4, E6 and E5 and poor at E8 and E7 (Fig. 2).

Ranking of cultivars based on performance in a specific environment and across environments

Conjecture, we wanted to see the yield potential of different genotypes at E2 environment, the line will be drawn that passes through the biplot origin and E2 environment (Fig 3). The Kendal, Altıkat and Samyeli gave highest yield, while Sahin 91 provided the lowest yield. On the other hand, some environments (E3 and E7 as well as E8) the ranking of cultivars were just across to especially E2 and other environments. The graph indicates the clear-cut presence of cross-over interaction (COI). This warrants exploitation of GEI (Yan *et al.* 2000). It is pertinent to mention that these environments are conducting breeding program of spring barley in South-eastern Anatolia Region of Turkey.

The adaptability of cultivars to these environments showed opposite points on Figures 3, 4 & 5. The conditions of these environments are different; because these environments consist of three Sub-regions in South-eastern Anatolia Region The environment of E8 located in south of region which is very dry ; E2, E1, E4 and E5 located in central of region which are normal; E3and E7 located in north of region is colder than other environments. This means that specific adaptability of cultivars at these environments is entirely different and GEI can be exploited for selecting cultivars rather than ignoring it. We can also visualize biplot for best adaptability of cultivar in a specific environment or sub-region as well.

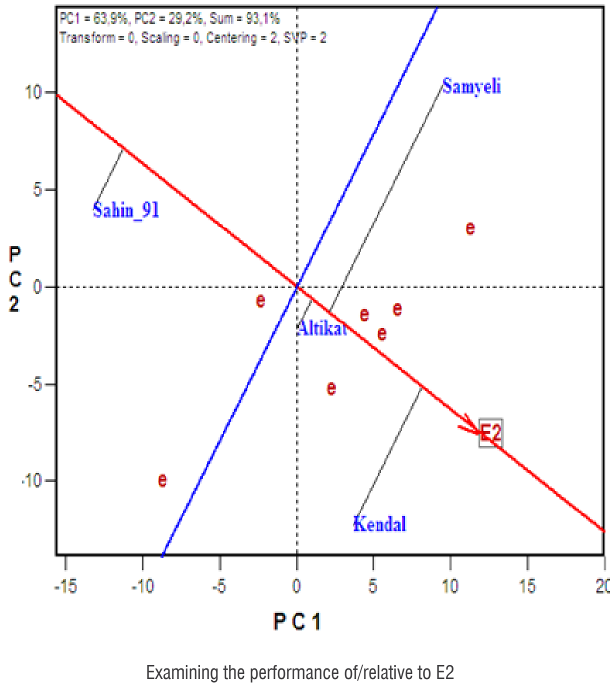

Figure 3: Ranking of cultivars performance based on *E2*

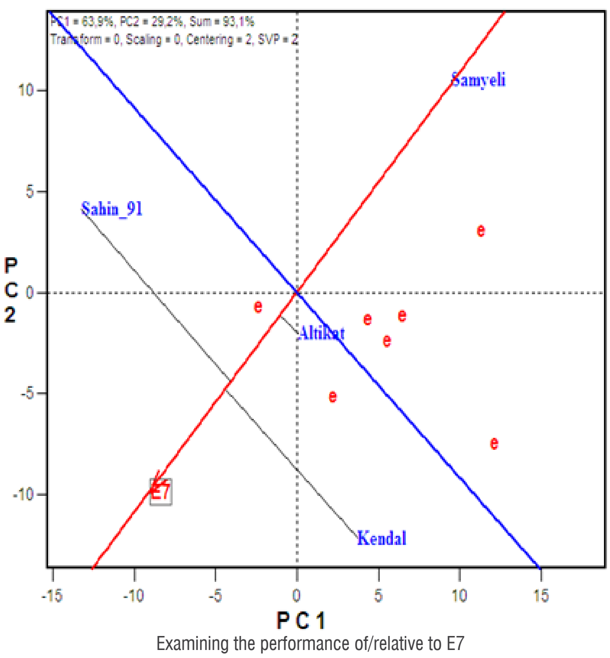

Figure 4: Ranking of cultivars performance of based on *E7*

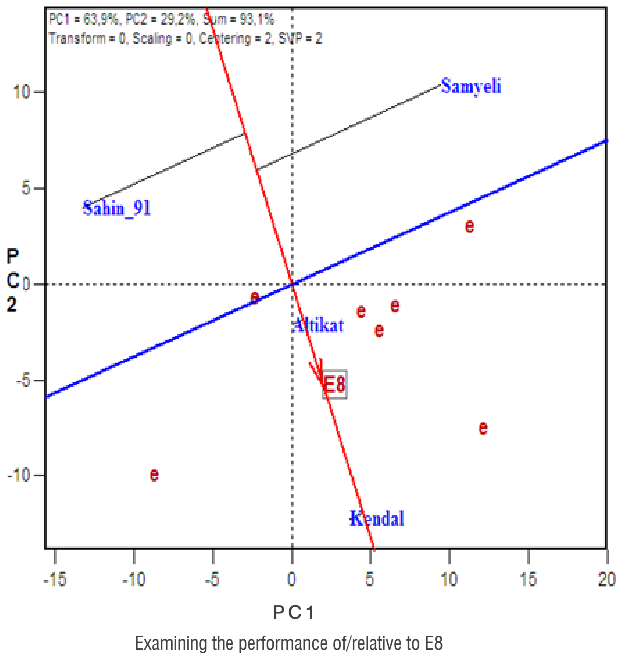

Figure 5: Ranking of cultivars performance based on *E8*

Ranking of environments in terms of the relative performance of cultivars

Based on the relative performance of the selected cultivar, the environments are ranked along the cultivar axis, with the arrow pointing to a better relative adaptation of cultivar. On this basis the adaptability of Kendal was highest at E2 followed by E7, E8, E1, E6, E5, E4 and least at E3 (Fig. 6). Similarly, Altikat possessed extreme adaptability at E1, E6, E5 and E3 environments, while it showed bad adaptation to E4 on grain yield (fig. 7). Samyeli was the best cultivar for E4, while it was least at E3,

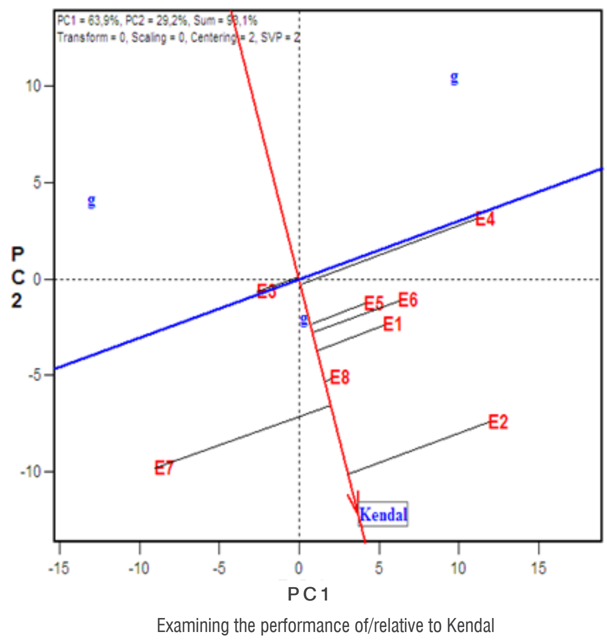

Figure 6: Ranking of environments in terms of the relative performance of *Kendal* variety

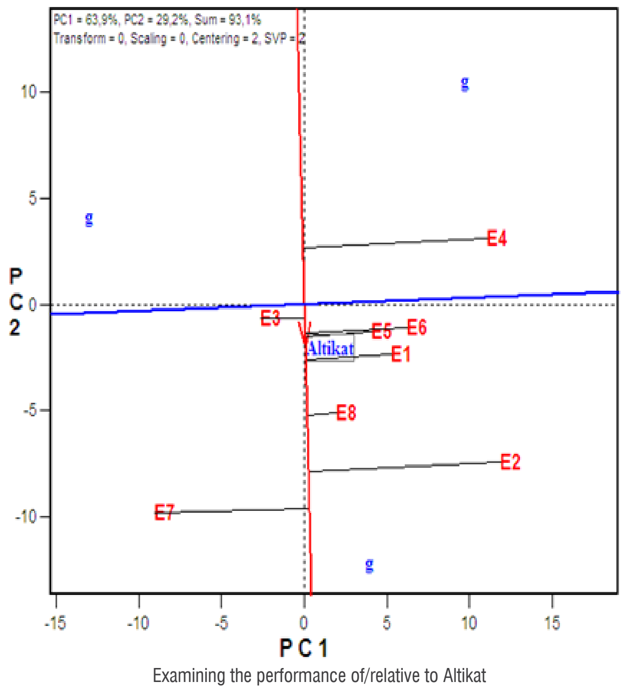

Figure 7: Ranking of environments in terms of the relative performance of *Altikat* variety

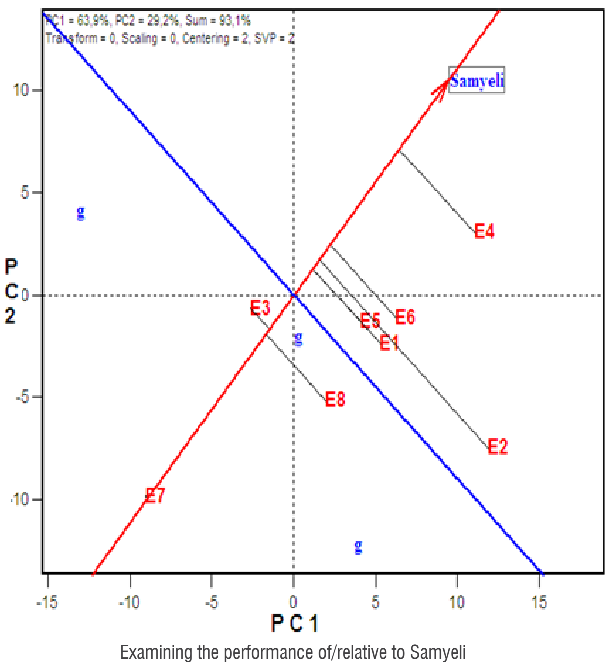

Figure 8: Ranking of environments in terms of the relative performance of *Samyeli* variety

E8 and E7 on grain yield (Fig. 8). Whereas other cultivars, Sahin 91 showed good adaptation to E7 and E4, while it had not good adaptation at environments which Kendal, Altikat and Samyeli cultivars showed good performance (Fig 9). Moreover, Kiliç (2014) explained that the study consist of 25 advanced line displayed that G17 (Altikat) and G21 (Samyeli) had high or moderate stability with high grain yield and desirable quality with acceptable morphological

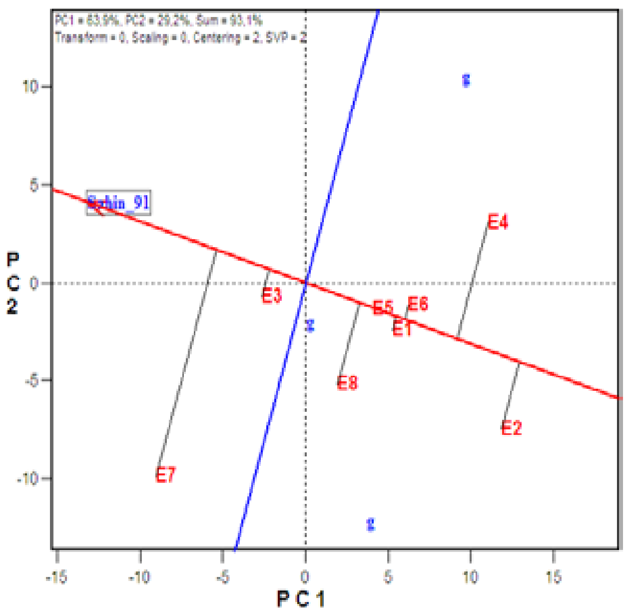

Figure 9: Ranking of environments in terms of the relative performance of *Sahin 91* variety

traits. When we rank cultivars across environments it should be done with respect to an ideal cultivar that lies on AEA (absolutely stable) in the positive direction and has a vector length equal to the longest vector of the cultivars on the positive side of AEA i.e., highest mean performance. Thus, cultivars which are closer to "ideal cultivar" are more desirable than others (Yan and Tinker 2006) and so, Kendal was high yielding with consistent of performance across the environments (Fig. 10). Altikat though moderate yielder, indicated highest stability among overall cultivars. Yan and Tinker (2006) are of the view that when we are interested to transfer "stability gene" to other genotypes it should be desirable to use a donor having high mean performances along with stability. Therefore, Kendal or Altikat can prove to be a better donor than Sahin 91 as far "stability genes" are concerned. On the other hand, new cultivars (Kendal, Altikat and Samyeli) had good stability than old cultivar (Sahin 91).Similarly, Kendal is the last cultivar which was registered by GAP International Agricultural Research and Training Center, it showed best performance among cultivars at majority environments.

Comparison among the cultivars

The distance between two genotypes approximates the Euclidean distance between them and hence, is measure of dissimilarity among the genotypes (Kroonenberg 1995). Therefore, Kendal and Samyeli and Sahin 91 are quite different in their genetic make-up with respect to grain yield. In that context Kendal and Altikat are very close to each other (Fig. 11). The biplot center also represents a "virtual" cultivar with grand mean value and zero contribution of additive effect of genotype (G) as well as multiplicative interactions (GE). The vector length of a cultivar of the center of biplot is due to the contribution of G and/or GE. The cultivar which located near to the biplot center have less contribution to G or GE (Altikat), while cultivars having longer vectors show the most contribution

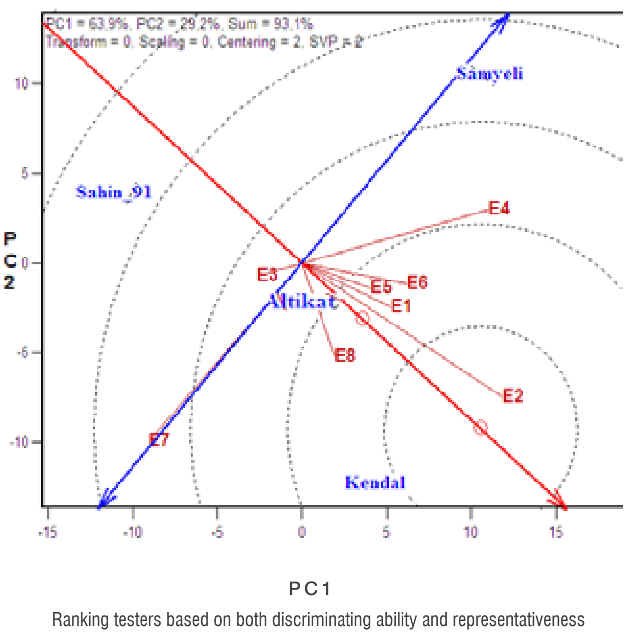

Figure 10: The average-environment coordination (AEC) view to rank cultivars relative to an ideal cultivar for grain yield per/ ha in SEA.

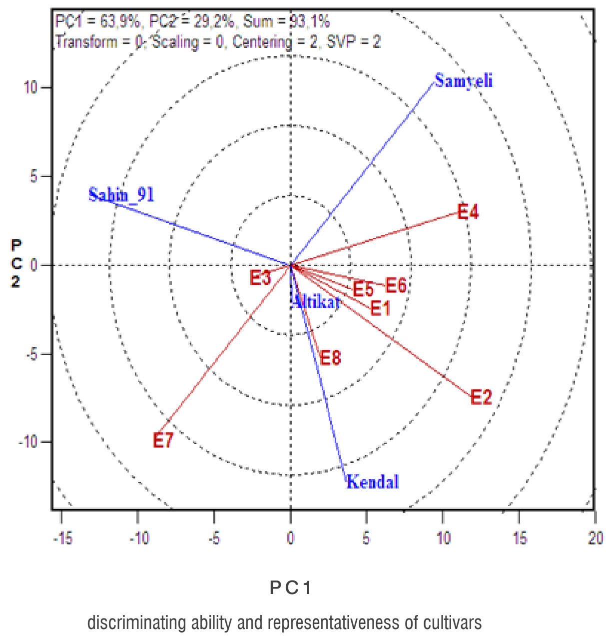

Figure 11: The cultivars-vector show similarities in their performance in individual environment for grain yield per/ ha.

of G and/or GE. So, cultivars with the longest vectors are either the best (Samyeli) or the poorest (Sahin 91) or most unstable (Kendal). Samyeli can be considered as the best cultivar as its angle is very close to the ideal cultivar coupled with longer vector length. Moreover, the angle between vector of a cultivar and the AEA partitions the vector length into components of G and GE. (Fig. 11). Therefore, there is major contribution of G for Samyeli and Sahin 91 and Kendal for grain yield, because they have opposite direction, so they can make up different genetic contribution. As Altikat took place of Center biplot, so it can't make up different genetic contribution.

Mega environments "which-won-where or which is best for what"

Dividing the target environment into meaningful mega-environments and deploying different cultivars for different mega-environments is the only way to utilize positive GE and avoid negative GE and the sole purpose for genotype by environment interaction analysis (Yan *et al.* 2007). A mega-environment is defined as a group of environments that consistently share the same best cultivar(s) (Yan and Rajcan 2002). This definition explain the following biplot based on the multi-environment trials (MET) data of barley yield which illustrates two points: 1) A mega-

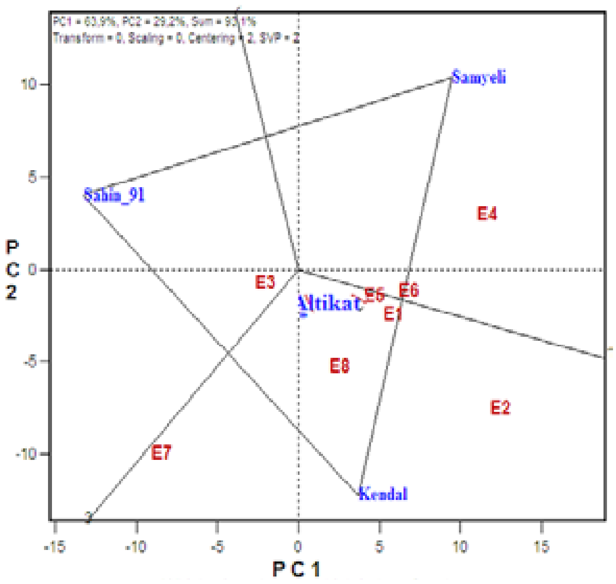

Figure 12: The which-won-where view of the GGE biplot to show which cultivars performed better in which Environment for grain yield of barley

environment may have more than one winning cultivar (sector 1), and 2) even if there exists a universal winner (Kendal), it is still possible, and beneficial, to divide the target environments into meaningful mega-environments (Fig 12). Mainly, these three lines divide the biplot into three sectors. Five environments fall in the one sector. Cultivars located on the vertices of the polygon reveal the best or the poorest in one or other environment (Gauch & Zobel 1997). Consequently, Kendal was high yielding at five environments (E1, E2, E5, E7 and E8), while Samyeli at E4 and E6, Sahin 91 at E3.

Conclusion

The results indicated that yield performance of barley cultivars were highly influenced by environment followed by GE interaction effect and genotype with the least effects. Because of the changing conditions of environments in SEA, the magnitude of environment effect was very high than that of cultivar effect. The Kendal cultivars, which are newly registered, showed best performance among genotypes tested across environments, while the oldest cultivar (Sahin 91) had least grain yield and adaptability. So, the new cultivars were desirable in terms of high mean yield and stability, this means that the study provided an indication of the genetic progress. According to the results, the specific cultivar was appropriate for specific environment (Samyeli-E4, Sahin 91-E3, Kendal-E2) and E1 was the best yielding, while E8 least. The GGE biplot analysis allowed a meaningful and useful summary of GE interaction data and assisted in examining the natural relationships and variations in genotype performance across test environments. As our results indicated, GGE biplot is illuminant methods to discover stability and adaptation pattern of varieties in practical recommendations.

Acknowledgements

This work is part of the barley breeding project financially supported by the Republic of Turkey Ministry of Food, Agriculture and Livestock. We express our sincerest gratitude to them for their support.

Table 1. The information's about varieties, used in experiment.

Name	Pedigree of cultivar	Origin	Approved year and institution	Spike rows
Kendal	Lent/Bllu//Pinon CBSS97M00698T-C-2M-1Y-0M	ICARDA	2013 GAPIARTC	6
Altikat	Arta/4/Arta/3/Hml-02//Esp/1808-4L ICB96-0601-0AP-10AP-0AP	ICARDA	2011 GAPIARTC	6
Samyeli	Hml-02//WI2291/Bgs ICB83-1554-1AP-1AP-6AP-0AP-22AP-0AP	ICARDA	2011 GAPIARTC	2
Sahin 91	YEA 1553-1/Eskişehir	TURKEY	1993 GAPIARTC	2

GAPIARTC: GAP International Agricultural Research and Training Center

Table 2. Years, sites, codes, coordinate status of environment long term of precipitation

Years	Sites	Code of sites	Altitude (m)	Latitude	Longitude	Annual rainfall (mm)
2011/12	Diyarbakir	E1	496	36° 97' N	38°42' E	550.6
	Kiziltepe	E2	483	37° 20' N	40^0 56' E	217.0
	Hazro	E3	895	38° 15' N	40° 49' E	891.9
2012/13	Diyarbakir	E4	496	36° 97' N	38°42' E	405.0
2013/14	Diyarbakir	E5	496	36° 97' N	38°42' E	363.0
	Adiyaman	E6	685	37° 46' N	380 17' E	592.0
	Hazro	E7	895	38° 15' N	40° 49' E	743.9
	Ceylanpinar	E8	363	36° 51' N	40° 20' E	260.3

Table 3. Combined analysis variance grain yield of barley cultivar tested across environments

Source	DF	SS	MS	F	LSD	Explained (%)
Environment(E)	7	3702452	528922	135.4261	45.6**	82.89
Rep(E)	24	93734.7	3905.61	1.0997		
Genotype(G)	3	196406	65468.8	18.4338	29.7**	4.39
GEI	21	567355	27016.9	7.607	84.0**	12.7
Error	72	255712.9	3551.6			
Total	127	4815661	37918.6			
CV(%)				13.53		

**Value significant for 0.01 probability level.

Table 4. Grain yield performance at different environment, average over environments (kg ha^{-1})

Cultivars	E1		E2		E3		E4		E5		E6		E7		E8		Mean	
Kendal	7070	bc	8180	a	3100	km	5240	ef	3880	jk	4740	fı	4250	gj	2520	m	4870	A
Altikat	7540	ab	6770	bc	3610	jl	5510	ef	3860	jk	4220	gj	3980	hj	1160	n	4580	A
Samyeli	6960	bc	7140	bc	2870	lm	6610	cd	3850	jk	4810	fh	1550	n	1340	n	4390	B
Sahin 91	5890	de	4930	fg	3490	jl	3900	ık	2990	lm	3480	jl	4220	gj	1260	n	3770	C
Mean	6870	A	6750	A	3270	D	5320	B	3650	D	4310	C	3500	D	1570	E	-	-

References

Allard RW and Bradshaw AD (1964). Implication of genotype-environmental interaction in applied plant breeding. Crop Sci 5: 503-506

Brar KS, Singh P, Mittal VP, Singh P, Jakhar ML, Yadav Y, Sharma MM, Shekhawat US & Kumar C (2010). GGE biplot analysis for visualization of mean performance and stability for seed yield in taramira at diverse locations in India. Jo of Oilseed Brassica. 1(2): 66-74.

Ceccarelli S (1989). Wide adaptation: How wide. Euphytica. 40: 197-205

Comstock RE and Moll RH (1963). G x E interactions. Symposium on Statistical Genetics and Plant Breeding. National Academy Science National Research Council. Washington. D.C.. pp: 164-196

Dash SS and Pandey A (2009). Genetic variability and association of yield and its components in toria, *Brassica rapa* L. *var* toria germplasm. J. Oilseeds Res. (Special issue) 26: 53-55.

Eberhart SA and Russel WA (1966). Stability parameters for comparing varieties. Crop Sci., 6: 36-40.

Farshadfar E, Mohammadi M, Aghaee M, Vaisi Z (2012). GGE biplot analysis of genotype × environment interaction in wheat-barley disomic addition lines. Australian Journal of Crop Science, 6(6):1074–1079.

Gabriel KR (1971). The biplot graphic display of matrices with application to principal component analysis. Biometrika 58: 453-467

Gauch HG and Zobel RW (1997). Identifying mega-environments and targeting genotypes. Crop., 37:311-326.

Kiliç H (2014). Additive main effects and multiplicative interactions (AMMI) analysis of grain yield in barley genotypes across environments, Journal of Agricultural Sciences, 20 (2014) 337-344.

(Letta *et al.* 2008: (Mizrak 1986). Mohammadi and Amri (2011). Singh *et al.* 2009).

Kroonenberg PM (1995). Introduction to biplots for G×E tables. Department of Mathematics, Research Report #51, University of Queensland, 22.

Letta TM, Egidio GD and Abinasa M (2008). Analysis of multi-environment yield trials in durum wheat based on GGE-biplot Journal of Food, Agriculture and Environment Vol.6 (2): 217 -221

Mizrak G (1986). Climate zones in Turkey. The Center of Agricultural Research. Technical Publication. No. 2. Ankara.

Mohammadi R and Amri A (2011). Graphic analysis of trait Relations and genotype evaluation in durum wheat, Journal of Crop Improvement, 25:680–696.

Singh MM, Shekhar RR and Dixit RK (2009). Genetic variability and character association in Indian mustard, (Brassica juncea) .J. Oilseeds Res 26: 56-57.

Yan W L, Hunt A, Sheng Q and Szlavnics Z (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Sci. 40: 597-605.

Yan W (2001). GGE biplot-a windows application for graphical analysis of multi-environment trial data and other types of two-way data. Agronomy J. 93. 1-11.

Yan W (2002). Singular value partition for biplot analysis of multi-environment trial data Agron. J., 94: 990-96.

Yan W and Kang MS (2003). GGE biplot analysis: A graphical tool for breeders, geneticists and agronomists. CRC Press, Boca.

Yan W S, Kang M, Baoluo M, Woods S & Cornelius PL (2007). GGE Biplot vs. AMMI Analysis of genotype-by-environment data. Crop Sci 47: 643-653.

Yan W and Rajcanw I (2002). Biplot analysis of test sites and trait relations of soybean in Ontario. Crop Science. 42. 11-20. doi:10.2135/cropsci 2002.0011-17

Yan W and Tinker NA (2006). An Biplot analysis of multi-environment trial data; Principles and applications. Canadian Journal of Plant Science 86. 623-645.