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Research Article

Evaluation of ICARDA Barley genotypes for yield stability and lodging resistance in southeastern Ethiopia highlands

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Abstract
The aim of this study was to evaluate the genotype yield stability and identify lodging resistant ICARDA barley genotypes for future breeding. Fifteen semi-dwarf ICARDA barley genotypes were tested across 11 environments in randomized complete block design in four replications in Bale highlands of Southeastern Ethiopia. The analysis of variance showed that total yield variation has been significantly (P<0.01) influenced by environment (72.9%), genotype by environment interaction (GEI) (11.4%) and genotype (2.1%), signifying the importance of GEI effect as compared to genotype effect. From high yielding and stable ICARDA barley genotypes, *27th IBON 73/99, F2 (S X S) 237/99* and *F2 (S X S) 222/99)* showed about 35% yield advantage over the lowest yielding checks (*Aruso* and *Dimtu*), and about 15% better yield than the higher yielding check, *Dinsho*. The result reveals that the ICARDA barley genotypes were shorter in height and better lodging resistant than checks. And, the ICARDA semi-dwarf material would be useful in crossing program with local barley landraces to develop promising genotypes for high yielding potential, lodging resistance and better adaptability.

Key words
Genotype-environment interaction, stability, lodging resistance, semi-dwarf, yield

Introduction

The performance of genotypes is usually assessed across environments to select superior performing genotypes in high yielding, stable genotypes and other agronomic performances. However, the performance of genotypes across environments is inconsistent due to the interaction of genotype with the environment. Thus, the knowledge of genotype by environment interaction (GEI) is useful in determining the relative stability of genotypes which is important in reducing crop failure and optimize crop production. Understanding GEI helps to design better breeding strategy in selecting widely adapted cultivars to the entire range of environments or exploit GEI by selection of cultivars specifically adapted to target environments (Ceccarelli, 1989). Many statistical methods have been developed to analyze GEI and yield stability over environments (Piepho, 1998). These methods can be grouped into univariate and multivariate (Lin *et al*., 1986). Among multivariate methods, recently developed multivariate analytical tool, GGE biplot (Yan *et al*., 2000) was reported to be superior to for instance AMMI in many aspects (Yan *et al*., 2007). GGE biplot is important for graphical display of GEI pattern of yield trial data with many advantages (Yan *et al*., 2000). The measured yield of each cultivar in each test environment is a result of genotype main effect (G), an environment main effect (E) and genotype x environment (GE) interaction (Yan and Kang, 2003). Though environmental variation is said to cause about 80% of yield variation, but it is only G and GE interaction that are relevant to cultivar evaluation (Yan, 2002; Yan and Rajcan, 2002; Kaya *et al*., 2006). The GGE-biplot combines two concepts: First, although the measured yield is the combined effect of G, E and GE-interaction, only G and GE-interaction are relevant to, and must be considered simultaneously, in genotype evaluation, hence the term GGE. Secondly, the biplot technique developed by Gabriel (1971) was employed for graphical display of the GGE of a yield trial data, hence the term GGE biplot. Thus, it can be possible to determine the pattern of genotypic responses across environments graphically (Yan *et al*., 2001; Yan and Tinker, 2006). Cross over GE-interaction across environments has been reported by Ceccarelli (1989), Ceccarelli and Grando (1991), Jackson *et al*.(1993);Van Oosterom *et al*. (1993); Sinebo (2005); Abay and Bjørnstad (2008) in barley.

Bale highlands which are situated in Southeastern Ethiopia are one of the major barley (*Hordeium vulgare* L.) producing regions in Ethiopia. However, barley production is constrained with lack of improved varieties with improved agronomic traits. Specifically, in Ethiopian barley landraces, identification of lodging resistant genotypes is not common. Thus, varieties and landraces are susceptible to lodging which reduces grain yield and causes seed quality deterioration. Yet no

reported improvement has been made in this regard in our country. Other countries experience showed that estimated yield loss of 15-20% and serious deterioration of grain quality have been reported due to lodging in for instance in Turkey (Akar *et al*., 1999). Another report by Briggs *et al*. (1999) also indicted a decrease in grain yield by 4-20%; while Pinthus (1973) reported 30% yield loss due to lodging and Easson *et al*.(1993) showed a loss of 40% grain yield in wheat. On the other hand, semi-dwarf barley cultivars are reported to be resistant to lodging. Short stature barleys are resistant to lodging which increase grain yield potential (Dahleen *et al*., 2005). For instance, in China semidwarf barley yield about 5-fold increase over landraces (Zhang and Zhang, 2003). In view of this, some ICARDA (International Center for Agricultural Research in Dry Areas) semi-dwarf barley genotypes were evaluated in Bale highlands for improved yield potential, stability and lodging resistance. However, the nature of GEI performance of barley genotypes and lodging resistance were not investigated for further breeding. Thus, the present study was conducted with the objective of:
estimating GEI and stability performance of ICARDA barley genotypes, identify and recommend semi-dwarf barley genotypes for lodging resistance and, suggest better barley breeding strategy

Material and methods

Study area and testing genotypes: Including one local check (*Aruso*) and three standard varieties (*Shage*, *Dimtu* and *Dinsho*), 15 ICARDA semidwarf barley genotypes were tested across 11 environments in Bale highlands covering from 2400-3200 meters above sea level (m.a.s.l)} from 2004-2006 *Bona* (season from July to December) cropping season. The test locations were Sinana (2400 m.a.s.l), Gasara (2400 m.a.s.l),Sinja (2520 m.a.s.l), and Upper Dinsho (3200 m.a.s.l). These areas are major barley testing sites commonly used by Sinana Agricultural Research Center barley breeding program. The semi-dwarf materials were pure line genotypes initially introduced from ICARDA (International Center for Agricultural Research in Dry Areas).

Planting: Barley seeds were planted at each location in a randomized complete block design with four replications on standard plot size of 3m^2 with six rows of 2.5 meter long with spacing of 20 cm between rows. The central four rows were considered for all data recording to avoid border effects. The recommended fertilizer rate of 50 kg ha^{-1} DAP (Diammonium phosphate) and 125 kg ha^{-1} seed rate was used at each location.

Data collection and statistical analysis: Grain yield data in kg plot^{-1}was taken from four central rows (2m^2) and converted into tons hectare^{-1}. Plant height was measured in cm from the ground to the tip of spike, excluding the awn. Days to maturity was the number of days from planting to stage when 75% crops in a plot reached physiological maturity. Whereas, lodging percent (%) was scored on (1-9 scale). e.g.1=<10%, 2=10-20%, 3=20-30%, 4=30-40%, 5=40-50%, 6=50-60%, 7=60- 70%, 8=70-80% and 9= >80%. Analysis of variance was done using system analysis software (SAS 2004). The GGE Biplot methodology, which is composed of two concepts, the Biplot concept (Gabriel, 1971) and the GGE concept (Yan *et al*., 2000), was applied for visual examination of the GEI pattern of yield trial data by using GGE-biplot software (GGE-biplot, 2009) to determine genotypic stability. The GGE biplot uses the first 2 principal components (PC1 and PC2) derived from subjecting environment centered yield data (Yan *et al*., 2000) for graphical display of data, and genotype- focused scaling was used for genotypic comparison (Yan, 2002).

Results and Discussion

Analysis of variance:
Plant characteristics are important in determining agricultural production and productivity of crops. In barley, a crop ideotype with a short plant starture is said to be associated with increasing yield and suitable for mechanization. Thus, the present study was mainly concerned with the evaluation of introduced semi-dwarf ICARDA barley genotypes for high yielding potential, stability and lodging resistance. The analysis of variance for grain yield data revealed that genotype (G), environment (E), and genotype x environment interaction (GEI) were significant (P<0.01) among barley genotypes tested. Environment explained 72.9% of total yield variation followed by GEI and G, accounting for 11.4% and 2.1%, respectively (Table 1). The result indicated that the effect of GEI was more than five times that of the effect of genotype indicating the importance of GEI.

Yield stability analysis of ICARDA barley genotypes based on GGE-Biplot:
ANOVA describes the main effects and determines if GEI is a significant source of variation, but it does not provide insight into the genotypes or environments that give rise to the interaction (Samonte *et al*., 2005).Thus further investigation through GGE-Biplot analysis is required. Maximum yield was obtained from different genotypes in different environments. High yield was obtained from *27th IBON 133/99* and *27th IBON 71/99* (3.0 t ha^{-1}) in E1, *F2 (S X S) 222/99* (7.6 t ha^{-1}) in E2, *Shage* (3.4 t ha^{-1}) in E3, *Dinsho* (3.1 ha^{-1}) in E4, *F2 (S X S) 168/99* (5.0 t ha^{-1}) in E5, *8th EMBSN 3/99* (5.2 t ha^{-1}) in E6, *Dinsho* (3.1 t ha^{-1}) in E7, *F2 (S X S) 237/99* (2.8 t ha^{-1}) in E8, *27th IBON 71/99* (3.2 t ha^{-1}) in E9, *27th IBON 71/99* (5.4 t ha^{-1}) in E10 and *Dinsho* (1.4 t ha^{-1}) in E11 (Table 2). Hence, superior yielding genotypes differed in each environment except *27th IBON 71/99* which showed superior performance in two environments {E1 (Sinana-04) and E9 (Sinja-06)} (Table 2) indicating the presence of high cross over GEI. The performance of most genotypes was superior at E2 (Sinja-04) with maximum yielding genotype, *F2 (S X S) 222/99*) (7.6 t ha^{-1}) than in other environments. Whereas, as opposed to this, most genotypes showed

uniformly minimum yield performance in E11 (Gasara-06) with the same genotype *F2* (*S X S) 222/9)* yielded 0.6 t ha-^{1}(Table 2).

The result showed that the performance of barley genotypes were highly inconsistent across environments indicating high cross over GEI. The comparison between GEI and genotype effect is important in cultivar evaluation (Yan, 2002) indicating that the effect of GEI was by far greater than genotypic effect showing differences in the performances of genotypes. Such variation is usually caused by predictable or unpredictable factors. Thus, in this study, the differences in location, rainfall, temperature, soil variations, and shoot fly damage may be suggested as main causes of GEI. In another report, Baker (1988), Crossa (1990), Yan and Hunt ((2001) and Kaya *et al*.(2006) indicated that the presence of GEI causes variation in the performance of genotypes across environment complicating selection. Specific adaptation or cross over GEI has been reported in barley by Ceccarelli (1989), Ceccarelli and Grando (1991), Jackson *et al.*(1993), Van Oosterom *et al*.(1993), Dehghani *et al*.(2006), Sinebo (2005) and Abay and Bjørnstad (2008). The partitioning of GGE through biplot analysis showed that PC1 and PC2 were important factors accounting 53.4% and 14.8% GGE sum of squares, respectively, explaining a total of 68.2% of the yield variation.

GGE-biplot based on genotype focused scaling (Fig.1) indicated that most of the ICARDA semi-dwarf barley genotypes tested showed high yielding potential and stable performance in Bale highlands. According to Yan *et al*.(2000), high yielding and stable genotypes should have large PC1 scores but near 0 absolute PC2 scores and such genotypes are more easily identified at environment with large PC1 scores but near 0 PC2 scores. And genotypes that had PC1 scores greater than 0 were high yielding while genotype that had less than 0 PC1 scores are low yielding genotypes. Thus, the high yielding genotypes were classified as stable and unstable. Hence, genotypes ‘J’ (*F2 (S X S) 168/99*), *‘*E*’* (*F2 (S X S) 213/99*), ‘G’ (*F2 (S X S) 222/99*), ‘F’ (*F2 (S X S) 237/99*), *‘*C’ (*27th IBON 133/99*) and ‘I’ (*F2 (S X S) 238/99*) were relatively stable, while ‘A’ (*8th EMBSN 3/99*) and ‘D’ (*27th IBON 73/99*) (Fig.1) genotypes were relatively less stable. The other genotypes were low yielding potential except cultivar ‘O’ (*Dinsho*). The high yielding genotypes gave an average grain yield of 2.7-3.1 t ha^{-1} as compared to the *Aruso* and *Dimtu* (2.3 t ha^{-1}) and *Shage* (2.5 t ha^{-1}) checks (Table 2). All checks except ‘O’, were situated in low yielding region of the GGE-biplot (Fig.1).

On the GGE biplot, the performance of two genotypes can be visually compared by connecting their markers with a straight line and drawing perpendicular equality line that passes through the biplot origin. The distance between two genotypes estimates the euclidean distance between them which is a measure of the overall dissimilarity. Genotypes had better yield in environments that are located on its side of the equality line (Yan *et al*., 2000;Yan and Tinker, 2006). Thus, genotype ‘G’ (*F2 (S X S) 222/99*) have shown better performance in most of the environments except in E4, E11 and E7 environments. However, cultivar ‘O’ (*Dinsho*) on the other hand showed better performance in E4, E7 and E11 (Fig. 2). Thus, the comparison of the two genotypes ‘G’ and ‘O’ across environment showed opposite performances in the three environments (at E4, E7 and E11) showing cross over GEI. This may be due to their difference in response to environmental and biological variables. Specifically it may be partially attributed to their response to waterlogging as Gasara soil exhibit clayey but cultivar ‘O’ (*Dinsho*) showed better performance to this water logging condition. Kang (1998) indicated large GEI can be expected when there is wide variation between genotypes for morpho-physiological characters possessing resistance to stresses. Hence these two genotypes have contributed to cross over GEI.

An ideal genotype should have both high mean yield performance and high stability across environments. And it is a genotype to be on average environment axis (AEA) on positive direction having a vector length equal to the longest vectors of the genotypes on the positive side of AEA and indicated by an arrow pointed to it (Kaya *et al*., 2006;Yan and Tinker, 2006). Thus, genotype “G” (*F2 (S X S) 222/99*) is an ideal genotype. Comparison of genotypes with ideal genotype showed that genotype ‘J’, ‘D’, ‘C’, ‘E’, ‘A’ and ‘B’ were desirable in high yielding and stability performance (Fig. 3). Whereas the other genotypes which were found below the double arrow in the negative direction were undesirable. The superior performance of barley genotypes at E2 may be due to favorable growing condition.

The average environment coordination (AEC) view of the GGE biplot is important to evaluate genotypes based on both mean performance and stability across environments. The single arrowed line is the AEC abscissa which points to higher mean yield across environments or to greater genotype main effect and the AEC ordinate is indicated by double arrows in either direction away from the biplot origin indicating greater GEI effect and reduced stability (Kaya *et al*., 2006;Yan and Tinker, 2006). And stability is meaningful only when associated with high mean performance (Yan and Tinker, 2006). High yielding and stable genotypes should have large PC1 scores but near zero absolute PC2 scores and such genotypes are more easily identified at locations with large PC1 scores but near zero PC2 scores (Yan *et al*., 2000). Thus, genotype ‘G’ had the highest mean yield performance across environments followed by ‘D’, ‘I’, ‘C’, ‘J’, ‘A’ and ‘E’. Genotype ‘B’ and ‘H’ showed nearly an average yield performance which is found closest to the AEC ordinate line. On the other hand, genotypes 'G', 'J', 'I', 'C' and 'E' had relatively short genotype vectors showing more stable (Fig.4.). Whereas, genotype 'D' and 'A' had long genotype vector indicating less stable. The AEC ordinate separates genotypes with above average means from below average means. So, genotypes which are located above AEC ordinate toward a positive direction on the abscissa axis showed above average yield performance whereas genotypes which were found on the negative direction and below the double arrow line yielded below average. The length of concentric circles on the biplot helps to visualize the length of the environment vectors which is proportional to standard deviation within the respective environments on the biplot; and also shows the discriminating ability of the environments (Yan and Tinker, 2006).

Average environment axis (AEA) (Yan *et al.,* 2001) view is the line that passes through the average environment (represented by small circle) and biplot origin. The average environment has the average coordinates of all test environments. A test environment that has a smaller angle with the AEA is more representative of other test environments (Yan and Tinker, 2006). A test environment with longest vector is powerful in discriminating genotypes. Thus, E10 (Upper Dinsho-06) showed powerful in discriminating genotypes as well as it is also representative test environment (Fig.5). Test environments that are both discriminating and representative is good test environment for selecting generally adapted genotypes (Yan and Tinker, 2006).Thus, E10 test environment is important in selecting widely adapted genotypes. However, the test environments which are consistently non-discriminating provide little information on genotype differences and non-discriminating testing environments are those with very short vectors and are less useful (Yan and Tinker, 2006).Hence, E8 (Sinana-06), E11 (Gasara-06) and E9 (Sinja-06) can be regarded as non-discriminating environments (Fig.5).

The ideal test environment (the center of concentric circles) should be both highly discriminating and most representatives of the target environments. Test environment that is located at the centre of concentric circle is ideal tester (Kaya *et al*., 2006; Yan and Tinker, 2006). Favorable test environments must have large PC1 scores (more discriminating genotypes) and near zero PC2 scores (more representative of an average environment) (Yan *et al*., 2001).Hence, E10 (Upper Dinsho-06) was ideal environment. Whereas, the concentric circles following ideal test environment are favorable environments;E6 (UpperDinsho-05) and E2 (Sinja-04) were more favorable than E5 (Sinja-05). However, test environments such as E7(Gasara-05), E4(Gasara-04) and E11(Gasara-06) were regarded as unfavorable environment since their PC1 scores are small (Fig.6).The three unfavorable environments were surprisingly the effects of the same location (Gasara) in the three different seasons or years. Relatively the two varieties, 'O' and 'M' showed better performance than others in these unfavorable environments (Fig.5 and Table 2).

<u>Evaluation of ICARDA barley genotypes for lodging resistance:</u>

In small cereals like barley, a crop ideotype with a short plant stature is associated with increasing yield due to reduction in lodging and suitable for mechanization. One weakness of Ethiopian barley landraces is their susceptibility to lodging which reduce their yield potential. Thus, this experiment was conducted in Bale highlands to identify lodging resistant and high yielding potential barleys from ICARDA breeding materials. Thus, the plant heights of ICARDA genotypes were shorter than the standard checks which indicates its potential for better lodging resistance (Table 3). The plant height of barley genotypes varied from 46 cm to 67 cm but most of the ICARDA materials showed about 10cm shorter in plant height than the checks indicated. As well as the lodging score recorded for the ICARDA genotypes was almost 1 except genotype 'I' which was 2, while the lodging score recorded for the checks and varieties was 3. Hence, the ICARDA semidwarf genotypes showed better resistance to lodging. Dahleen *et al*.(2005) indicated that the semidwarf trait is desired in cereal breeding programs for increased lodging resistance. They reported an average height of 64.8 cm for the semi-dwarf genotypes. However, in this study, most of the barley genotypes showed an average of plant height ranging from 46-52 cm which is shorter than Dahleen *et al*. (2005) report. Most of the lodging resistance genes are related to shorter plant stature. Plant height and culm stiffness are reported to be the two most important traits determining lodging resistance in cereal plants (Keller *et al*., 1999). With the development of semi-dwarf varieties, yield loss was largely overcome and the plant utilized its resources in increasing harvest index rather than its biomass (Chloupek *et al*., 2006). Many studies showed that plant height is the single trait that influences lodging more than any other. Selection for lodging-resistant genotypes can be done *via* indirect selection based on the morphological traits of plant height and culm stiffness before flowering. Short varieties show better lodging resistance in barley (Murthy and Rao, 1980).In Shehata *et al*.(2009) report mutant rice variety was developed from Egyptian Yasmine with short stature associated with better yield potential by using mutation breeding and as a result the average yield potential of rice varieties in Egypt increased to 10 t ha^{-1}. Kandemir (2004) indicated that semi-dwarf genes usually result in 10-30 cm shorter plants and do not cause losses from potential yields and allow combine harvesting. In China, breeders achieved about 5-fold yield increase over landraces and older cultivars (Zhang and Zhang, 2003) and most European barley cultivars are similarly semi-dwarf (Hellewell *et al*., 2000).

Reports showed that lodging can cause significant yield loss in barley and wheat. For instance, estimated yield loss of 15-20% has been reported due to lodging in Turkey (Akar *et al*., 1999). Another report by Briggs *et al*. (1999) also indicated a decrease in grain yield by 4-20%, while Pinthus (1973) reported 30% yield loss. Easson *et al*.(1993) showed loss of 40% grain yield in wheat. However, in Ethiopia, the extent of yield loss due to lodging in barley has not been documented yet and needs research priority.

With regard to maturity, all ICARDA barley genotypes were late in maturity as compared to local and cultivar *Dinsho* (Table 3) which can affect farmers' preferences in Bale. Bale farmers prefer for early maturing types and early types are mainly preferred because of their fitness to the two short cropping seasons, *Bona* (season from July to December) and *Ganna* (season from March to July). In this study, *27th IBON 73/99* (3.1 t ha^{-1})), *F2 (S X S) 237/99* (3.0 t ha^{-1}) and *F2 (S X S) 222/99* (3.0 t ha^{-1}) semidwarf ICARDA genotypes have been selected as the best superior yield performing over *Aruso*, *Dimtu* and *Shage* checks. However, the limitation of ICARDA genotypes is their late maturity and susceptibility to shoot fly damage in intermediate altitudes (like Gasara, Sinana, Robe and Agarfa areas) in Bale which reduce their adaptability. Nevertheless, these semidwarf barley genotypes are extremely important as source of genes in developing high yielding and lodging resistant. Therefore, to effectively utilize these semidwarf genotypes, hybridization with the local landraces or shoot fly resistant varieties may be the remedy to improve the adaptability of the crop in Bale highlands.

Conclusion

The result showed that the two important factors, GEI and genotype effect caused a total yield variation of 11.4% and 2.1%, respectively, indicating high influence of GEI than genotypic effect. Most of the ICARDA semi-dwarf genotypes showed high yielding performance and stability in Bale high lands of Southern eastern Ethiopia. Genotypes *27th IBON 73/99* (3.1 t ha^{-1}), *F2 (S X S) 237/99* (3.0 t ha^{-1}) and *F2 (S X S) 222/99* (3.0 t ha^{-1}) were the best high yield performing semidwarf barleys across environments and showed about 35% yield advantage over the lowest yielding *Aruso* and *Dimtu* checks, and about 15% better yielder than the higher yielding check, *Dinsho.* ICARDA semi-dwarf genotypes shorter in height and with lower lodging score indicating better lodging resistance. It is uncommon for exotic barley genotypes to adapt to Ethiopian environmental condition due to susceptibility to stresses. Hence, hybridization of the semidwarf ICARDA genotypes with local landraces and/or varieties would be better to transfer dwarfing genes to Ethiopian barleys for better lodging resistance and/or to improve shoot fly resistance and early maturity traits of ICARDA semidwarf barley genotypes for better adaptability and yielding performance.

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Table 1. Analysis of variance for barley grain yield (t ha^{-1}) across 11 environments in Bale high lands of Southeastern Ethiopia, 2004-2006 cropping season.

Source of variation	Degree of Freedom	Sum of Squares	Mean squares	Explained variation (%)
Total	659	1910.398		
Replication	3	0.0955	0.03	
Environment (E)	10	1391.943	139.19**	72.9
Genotype (G)	14	39.249	2.803**	2.1
GxE	140	216.770	1.548**	11.4
Error	492	264.3533	0.537	

Repeatability (R^2) =0.861, Broad sense heritability (H^2) = 0.581, CV (%) = 26.934

Table 2. Genotype code and mean grain yield (t ha^{-1}) of 15 barley genotypes tested across 11 environments in Bale highlands of Southeastern Ethiopia, 2004-2006.

Genotype code	Genotype	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	Genotype Mean
A	8th EMBSN 3/99	2.48	6.33	2.21	1.46	3.60	5.21	2.10	1.29	2.56	3.61	0.86	2.9
B	27th IBON 97/99	2.45	6.25	1.53	1.43	4.56	3.47	0.81	0.57	2.40	3.37	0.92	2.5
C	27th IBON 133/99	2.95	6.30	1.87	1.25	4.23	3.88	1.04	1.44	2.60	4.62	0.81	2.8
D	27th IBON 73/99	2.68	6.88	3.03	1.52	4.07	5.01	1.93	1.17	2.57	4.57	0.79	3.1
E	F2 (S X S) 213/99	2.85	6.16	2.12	1.58	4.10	3.57	1.54	0.89	3.06	4.01	0.93	2.8
F	F2 (S X S) 237/99	2.81	6.26	2.13	1.20	4.51	3.95	1.35	2.83	3.01	4.41	0.81	3.0
G	F2 (S X S) 222/99	2.39	7.62	1.54	1.30	3.69	5.09	1.38	0.89	3.08	5.00	0.57	3.0
H	27th IBON 71/99	2.97	6.28	1.35	1.69	4.14	3.66	2.03	1.03	3.20	3.51	1.00	2.8
I	F2 (S X S) 238/99	2.82	6.28	1.94	1.49	4.20	3.42	1.46	0.76	2.70	5.39	0.79	2.8
J	F2 (S X S) 168/99	2.43	6.10	2.06	1.38	4.96	4.21	1.66	0.69	2.50	4.50	0.65	2.8
K	F2 (S X S) 171/99	2.56	6.35	1.53	1.16	3.75	3.08	1.16	1.00	2.37	2.80	0.62	2.4
L	Aruso (Local Check)	2.45	4.62	1.14	2.75	3.50	1.98	2.36	1.11	2.34	1.93	1.24	2.3
M	Shage (standard check)	1.63	4.72	3.38	1.07	3.08	4.25	1.57	0.70	2.49	3.95	0.76	2.5
N	Dimtu (standard check)	1.58	5.08	1.98	1.74	3.37	3.12	0.95	1.08	2.39	3.31	1.14	2.3
O	Dinsho(standard check)	2.92	4.86	1.89	3.13	3.65	3.14	3.14	1.29	2.70	1.71	1.42	2.7
	Environment mean	2.5	6.0	2.0	1.6	4.0	3.8	1.6	1.1	2.7	3.8	0.9	

E1:Sinana-04),E2:Sinja-04, E3:Upper Dinsho-04,E4:Gasara-04,E5:Sinja-05, E6:UpperDinsho-05, E7:Gasara-05,E8:Sinana-06, E9:Sinja-06 , E10:Upper Dinsho-06 and E11:Gasara-06, and mean yield= 2.72 t ha^{-1}

Table 3. The average Days to maturity (DM), plant height (PH) in cm) and lodging percent (%) performance of ICARDA barley genotypes in Bale highlands.

Trait/Genotype code	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
DM	136	136	135	137	136	137	138	132	137	138	136	126	140	143	126
PH	51	51	52	52	52	50	50	46	67	48	47	60	55	66	62
Lodging (%)	1	1	1	1	1	1	1	1	2	1	1	3	3	3	3

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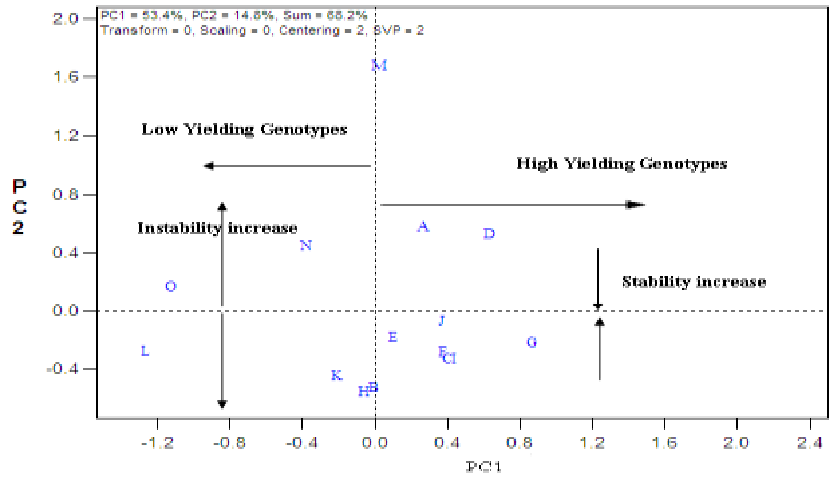

Fig.1. GGE- biplot based on genotype focused scaling for genotypes

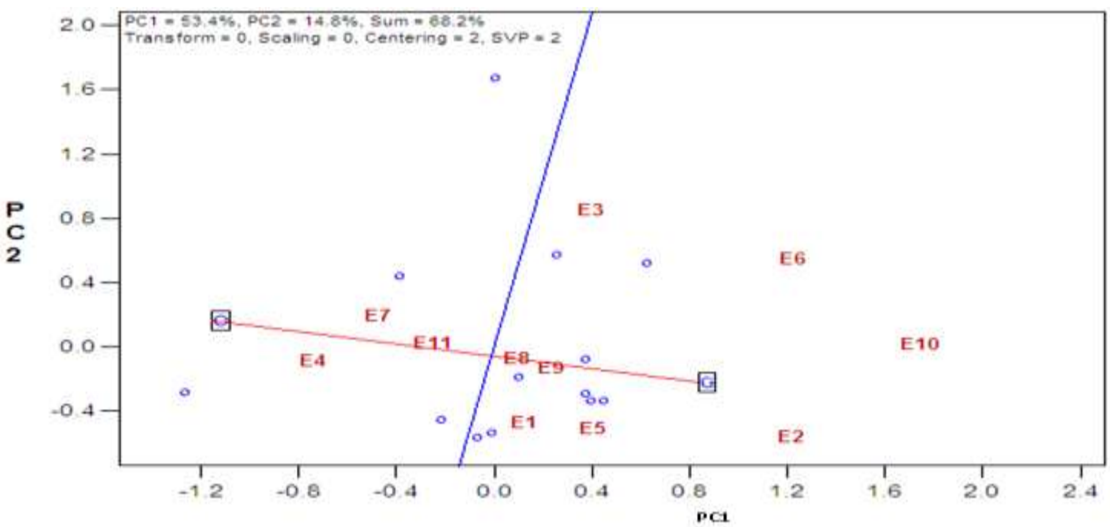

Fig.2. Comparing two barley genotypes 'G' and 'O' of their performances in different environments.

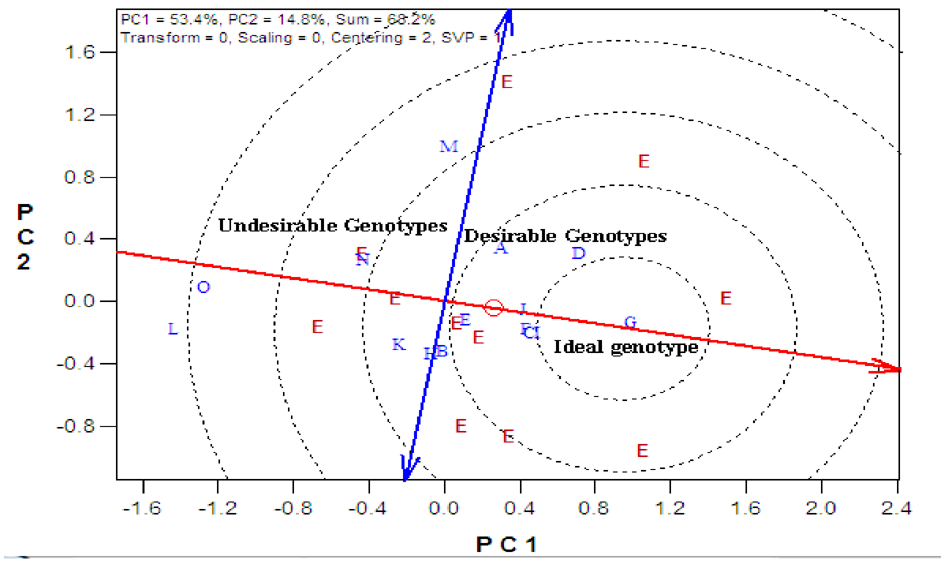

Fig.3. GGE-biplot based on genotype-focused scaling for comparison of the genotypes with ideal genotype.

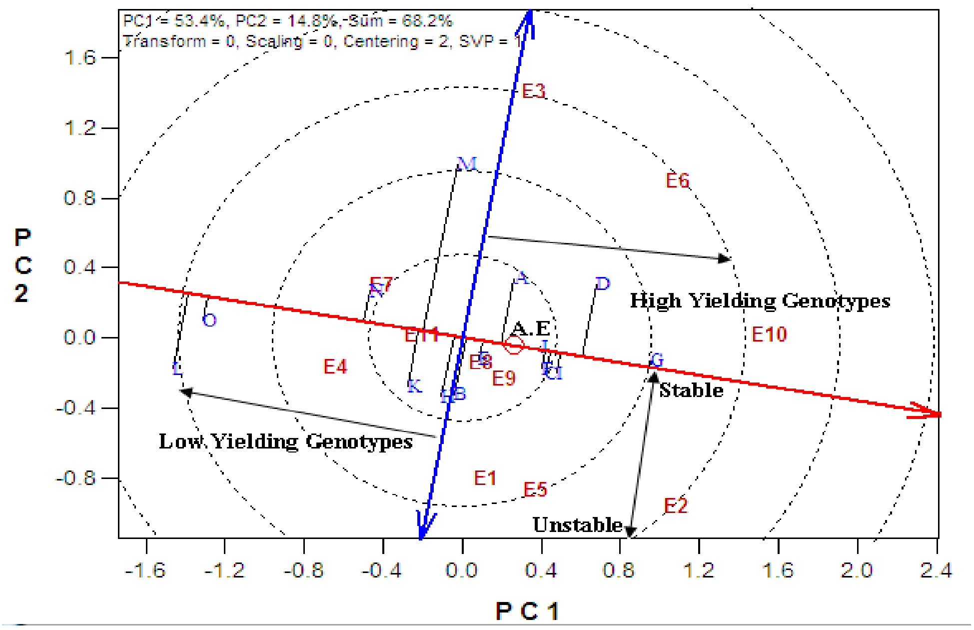

Fig.4. Average environment coordination (AEC) views of the GGE biplot based on environment focused scaling for the mean performance and stability of genotypes. A.E=Average environment.

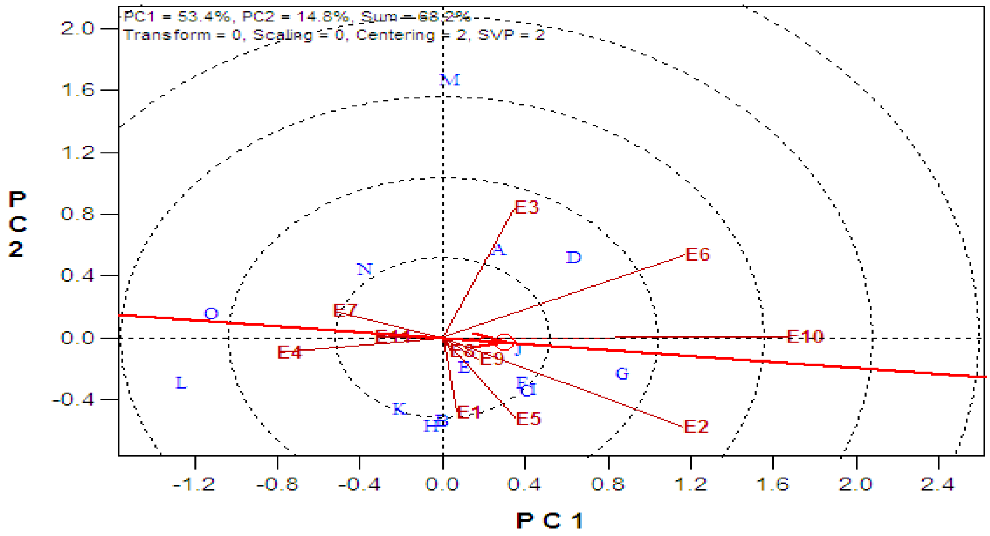

Fig. 5. The discriminability and representativeness view of the GGE-biplot to show the discriminating ability and representativeness of the test environments

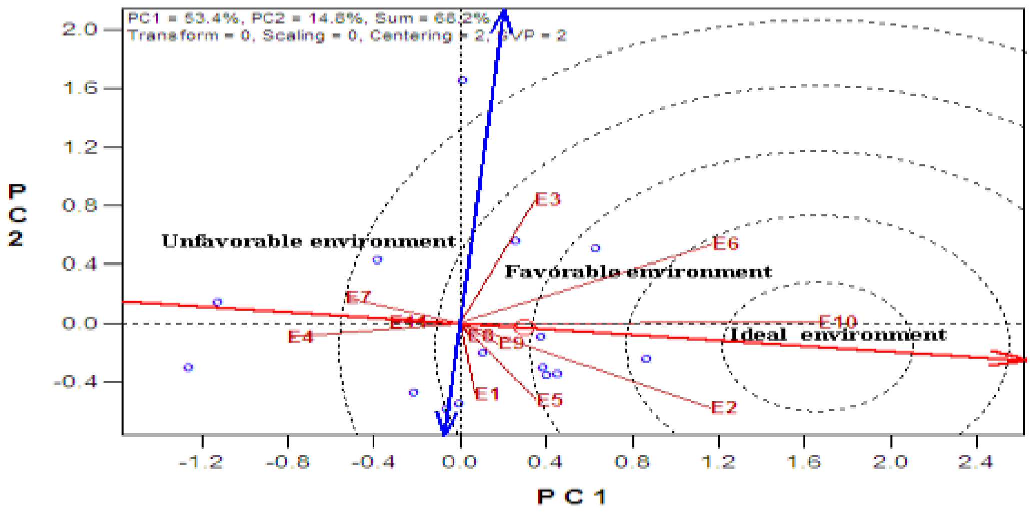

Fig.6. GGE-biplot based on environment focused scaling for comparison of the environments in relation to ideal tester