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Genotype by Environment interaction of food barley (Hordeum vulgare L.) genotypes in Southern Ethiopia

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Abstract

Multi-environment trials are essential to evaluate the genetic potential of the testing materials. The objective of this paper was to determine the magnitude and pattern of the genotype by environment interaction and stability of the varieties. Fifteen nationally released food barley varieties were planted in randomized complete block design with four replications. The additive main and multiplicative interaction effects analysis for grain yield showed that environment, GEI and variations due to genotypes were highly significant ($p<0.01$). They accounted for 55.76, 13.77, and 7.53% of the total sum of squares, respectively. Large sum of squares indicated that the environments were diverse; causing most of the variation in grain yield. The most stable genotypes with lowest ASV value were Gabulla, Ardu-12-60B, Agegnehu and Dimtu, whereas the most unstable genotypes were HB-1307, Cross-41/98, Estayish and Yedogit. In GGE bi plot for grain yield of food barley genotypes, the first and second components captured 73.4% and 18.8% of the G+GE sum of square, indicates different genotypes win in different sectors. Therefore, the result of this experiment might be used to recommend unstable genotypes for study areas.

Keywords: AMMI analysis, ASV, Genotype x Environment Interaction, GGE

Introduction

Barley (Hordeum vulgare L.) is one of the oldest and first domesticated cereal crops and is believed to have originated in the Fertile Crescent region of the near east around 8000 BC (Gebremedhin et al., 2014). In Ethiopia, out of the total area under cereals, barley covered 7.56 % (9,974,316 ha) and the grain produced was 6.96 % (23,128,797 tons) with average national productivity of 1.96 t ha-1. At the same time, in terms of the area coverage and production, Southern Nations Nationalities and Peoples Regional State (SNNPRS) contributes 7.22% (80861.37 ha) and 6.5 % (142,437 tons), respectively, to the nation with average productivity of 1.76 t ha-1. In SNNPR State the two zones, Guraghe and Siltie, contributes 12.8% (10345.86 ha) and 7.5% (6085.3 ha) in terms of area coverage, 19.6% (27,962.78 tons) and 10.1% (14,419.99 tons) in production with averages zonal yield of 2.68 tons/ ha and 2.37 tons/ ha (CSA, 2016), respectively, which is lower than the potential yield of the crop, which is 6 t ha-1 (Berhane et al., 1996; Hasan, 2014) in Ethiopia. This is due to constraints including poor soil fertility, limited supply of production inputs (fertilizer and improved seed) and biotic and abiotic factors.

Multi-environment trials are essential to evaluate the genetic potential of group of materials and recommend selected ones for production by farmers. However, it is not an easy job to get material(s) with high yield and stable across environments due to the occurrence of GEI that causes difference between genotypes in their performance across environments (Delacy et al., 1996) that hinders variety recommendation for wider environments. The GEI limits yield estimation because it is associated with change in ranks of genotypes in addition to average performance (Gauch and Zobel, 1997). Environment is a general term that covers condition under which crops grow and may involve locations, years, management practices or a combination of these factors. Targeting variety selection on to its growing environments is the prime interest of a plant-breeding program.

Even though SNNPRS is one of the major barley growing region in Ethiopia, the task of large scale GEI evaluation of six row barley varieties is limited. Hence, it was important to identify varieties that are adapted to different barley growing environments in SNNPRS, Ethiopia. Therefore, this paper addresses the magnitude of contribution of environment, genotype and their introduction in major barley growing zones of SNNPR State, Ethiopia.

Materials and Methods:

Description of the Locations

The experiment was conducted during the 2016 main growing season (June to December) at Mierab-Azerinet, Alicho wuriro, Geta and Gumer. These experimental sites are being used by Worabe Agricultural Research Centre and represent the major agro-ecologies of food barley growing areas of SNNPRS. Characteristics of the testing locations are

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indicated in Table 1.

Experimental materials, design and management

Nationally released 15 food barley varieties were included in the trial which were selected based on year of release; performance in previous trials and the agro-ecological adaptation. The varieties (HB-1307, Shege, HB-42, Ardu-12-60B, Dimtu, Cross-41/98, EH-1493, Yedogit, Estayish, Tiret, Shedeho, Harbu, Agegnehu, Abdane and Gabulla) were obtained from Hawassa and Holetta Agricultural Research Centers. The experimental layout was randomized complete block design with four replications. Seed was hand drilled on plot consisting of six rows (spaced 0.2m) with 2.5m length. Spacing between blocks and plots was 1m and 0.4 m, respectively. The middle four rows were used for data collection. Seed rate was 125 kg ha-1 while fertilizers rate was 38/19/7 kg/ha N/P2O5/S, respectively for all locations. Planting was done at early July, at the onset of the main rainy season. Weed management and all other agronomic practices were carried out uniformly for all plots.

Table 1. Agro-ecological characteristics of test sites

Location	Altitude (masl)	Mean annual rainfall (mm)*	Average temp (°C)*	Soil texture	Global position	
					Latitude	Longitude
Mierab-Azerinet	2612	750.27	17.25	Loam	7^0 44′ 46″	37^0 53 ′ 43″
Gumer	2980	895.83	13.45	Loam	8^0 00′ 62″	38^0 09′53″
Geta	2974	910	11.75	Black clay	7^0 47′ 52″	37^0 43′ 36″
Alicho	2984	1021	9.50	Clay loam	7^0 58′ 23″	37^0 29′ 49″

Table 1. Agro-ecological characteristics of test sites

Statistical Analysis

Stability analysis: Ecovalence (Wi2) suggested by Wricke (1962) and cultivar/environmental superiority measure were computed to further describe stability. It was measured by combining the mean yield and coefficient of variation (CVi) (Francis and Kannenberg, 1978). The method of Eberhart and Russell (1966) was used to calculate the regression coefficient (bi) and deviation from regression (Sdi2).

AMMI analysis: Percentage of the total treatment sum of squares accounted by the three components (Genotype, Environment and GxE) was assessed. For parameter where the GEI was significant the nature of the interaction is explained using graphical and other methods. The Additive Main and Multiplicative Interaction effects (AMMI) (Gauch, 1988; Zobel et al., 1988) model analysis was performed for grain yield using the following formula:

Yijr-αi_βj+μ=∑_(n=1)^N▒(λnᵞinδjn + ρij + εijr)

Where: Yijr is the observed yield of the ith genotype in the jth environment,

μ is the grand mean; αi is the genotype mean and βj is the environment mean.

Summation was carried out over the components n = 1 to N, where N is the number of interaction principal component axes (IPCAs) retained in the AMMI model.

The multiplicative parameters are: λn, the singular value (eigenvalue) of the nth principal component axis; ᵞin and δjn, the genotype and environment scores (eigenvectors) for the nth principal component axis; ρij, the residual (remains if not all axes are used); and εijr, the random error, which is the difference between the Yij mean and the single observation for environment j.

The degrees of freedom (df) for the IPCA axes were calculated based on the following method (Zobel et al., 1988): df = G + E -1- 2n, Where: G = the number of genotypes; E = the number of environments; and n = the nth axis of IPCA.

AMMI stability value (ASV): is stability value based on the AMMI model's IPCA1 and IPCA2 values for each genotype and each environment, was calculated as suggested by Purchase et al. (1997). Since the IPCA1 score contribute more to GEI sum of squares, it has to be weighted by the proportional difference between IPCA1 and IPCA2 to total GEI sum of squares. This weight is calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction SS as follows:

ASV = √(([((SS IPCA1)/SSIPCA2)(IPCA1 score)]^2+(IPCA2 score))^2)

Where: SS IPCA1/SS IPCA2 is the weight given to the IPCA1 value by dividing the sum of square of IPCA1 by sum of square of IPCA2; and the IPCA1 and IPCA2 scores are the genotypic scores in the AMMI model. GGE biplot analysis was used to identify genotypes which have high productivity and well adapted to an agronomic zone including test sites (Gauch and Zobel, 1997).

Results and Discussion

Regarding Wricke's (Wi2) stability parameter, Genotypes Ardu-12-60B, Gabulla and Dimtu with lowest Wricke's ecovalence were considered to be stable as they contribute 0.10, 0.11 and 0.31 % to the interaction sum of squares, showed wider adaptation and they were not ranked best mean grain yield and were 8th, 15th and 6th, respectively; whereas HB-1307 and Cross-41/98 with higher Wricke's ecovalence value were unstable and made the highest contributions 4.45 and 2.57 % to GEI with higher average grain yield than grand mean and shows specific adaptation. However, cultivar superiority measure (Pi) depicted EH-1493, Cross-41/98, HB-1307 and HB-42 as stable, indicating wider adaptation across the environments; whereas Estayish, Harbu, Gabulla and Agegnehu were the most unstable genotypes, respectively that showed limited adaptation. Parameter CVi, genotypes Ardu-12-60B, HB-42 and Agegnehu were stable and Ardu-12-60B and Agegnehu had the lowest CVi and low grain yield than grand mean, whereas HB-1307 and Cross-41/98 with the highest CVi values had high yield performances but EH-1493 had the lowest CVi, ranked 1st for mean grain yield. Genotypes with the lowest bi; Yedogit, Agegnehu, Ardu-12-60B and Shege were more adapted to marginal environments, whereas EH-1493, Cross-41/98 and Tiret were input sensitive adapted to ideal environments for selecting genotypes with specific adaptation.

Genotypes HB-1307, Harbu, Dimtu and Shedeho were relatively stable as they had small deviation from regression value (S2di) (Table 2).

Genotype name	Mean grain yield (t ha^{-1})	Wi	Pi	CV	(bi)	(S^2d)	ASV
G1(HB-1307)	3.79	4.45	0.37	45.82	1	0	8.04
G2(Shege)	2.97	0.65	1.15	40.07	0.89	0.05394	2.27
G3(HB-42)	3.39	0.43	0.88	35.36	0.93	0.02583	2.17
G4(Ardu)	3.1	0.10	1.05	34.2	0.86	0.09325	0.25
G5(Dimtu)	3.24	0.31	0.95	40.59	1.03	0.00431	1.43
G6(Cross-41/98)	3.61	2.57	0.34	46.77	1.15	0.10925	5.98
G7(EH-1493)	3.88	0.50	0.15	38.54	1.18	0.14711	2.15
G8(Yedogit)	3.15	1.68	0.90	37.94	0.78	0.21387	4.72
G9(Estayish)	2.68	1.61	2.08	55.36	1.05	0.00999	4.78
G10(Tiret)	3.31	1.38	1.13	46.42	1.12	0.07011	4.34
G11(Shedeho)	2.91	0.67	1.53	43.92	0.96	0.0062	3.12
G12(Harbu)	2.74	1.24	1.92	51.64	1.02	0.00231	4.27
G13(Agegnehu)	2.71	0.43	1.74	37.24	0.79	0.20753	1.04
G14(Abdane)	2.91	0.85	1.35	56.73	1.30	0.41953	2.15
G15(Gabulla)	2.56	0.11	1.83	45.47	0.93	0.02134	0.12

Table 2. Stability estimates for six parameters of barley varieties tested across four locations in 2016

Wi = Wricke's ecovalence, (Pi) Lin and Binns's cultivar performance measure, regression coefficient (bi), deviation from regression (S2d), CV = Coefficient Variability, ASV= AMMI Stability Value

AMMI Stability Value (ASV)

Purchase et al. (1997) developed a quantitative stability value to rank genotypes through the AMMI model, named the AMMI Stability Value (ASV). According to the ASV ranking, the most stable varieties with lowest ASV value were Gabulla, Ardu-12-60B, Agegnehu and Dimtu, whereas the most unstable varieties were HB-1307, Cross-41/98, Estayish and Yedogit. Ardu-12-60B, Dimtu and Agegnehu with a lower VIPC1 score, were stable varieties; whereas HB-1307, Cross-41/98, Estayish and Yedogit with relatively higher VIPC1 scores were unstable varieties.

Table 3. AMMI Stability Value (ASV) and ranking with the IPCA1 and IPCA2 scores of grain yield (t ha-1) for barley genotypes across four environments in 2016

Genotypes	Mean grain yield	VIPC1	VIPC2	ASV	Rank
G1 (HB-1307)	3.78700	1.07384	0.18604	8.04933	15
G2 (Shege)	2.96525	0.29738	-0.42094	2.26795	8
G3 (HB-42)	3.39313	-0.28673	-0.27529	2.16628	7
G4 (Ardu-12-60B)	3.09838	-0.02295	-0.18494	0.25256	2
G5 (Dimtu)	3.23494	-0.18942	-0.19467	1.43274	4
G6 (Cross-41/98)	3.61263	0.79781	0.25160	5.98394	14
G7 (EH-1493)	3.88238	0.28357	0.35026	2.15371	6
G8 (Yedogit)	3.14888	0.62958	-0.24458	4.72435	12
G9 (Estayish)	2.68244	-0.63678	0.17335	4.77512	13
G10 (Tiret)	3.31150	-0.57786	0.27764	4.33930	11
G11 (Shedeho)	2.91322	-0.41616	-0.06750	3.11938	9
G12 (Harbu)	2.74369	-0.57021	-0.01994	4.27309	10
G13 (Agegnehu)	2.71225	-0.12077	-0.52029	1.04391	3
G14 (Abdane)	2.91356	-0.27459	0.62994	2.15197	5
G15 (Gabulla)	2.55619	0.01328	0.05933	0.11587	1

ASV= AMMI Stability Value, VIPC = Variety interaction principal component

Additive main effects and multiplicative interaction (AMMI) analysis

The additive main effect showed a highly significant variance (p<0.01) for the environment, genotype by environment interaction and genotype sum of squares with 55.76, 13.77 and 7.53%, respectively (Table 4). The large environmental sum of square was reported by Gebremedhin et al. (2014) who found significant differences among the genotypes, environment and GEI effects variation in barley grain yield. The largest portion of the total sum of squares captured by environments implying significant influence of the environment in evaluating genotypes for grain yield performances and caused most of the variation in grain yield. A large portion of the total sum of squares taken by GEI, shown there is vulnerability of grain yield to the influence of GEI. Furthermore, the highly significant (p<0.01) value for the interaction between GxE indicated that inconsistent environmental conditions prevailed across locations (Gauch and Zobel, 1997).

Table 4. AMMI analysis of variance for grain yield (t ha-1) of food barley genotypes evaluated across four environments in 2016

Sources of variation	DF	SS	% SS	MS
Total	239	123.19		
GEN	14	9.28	7.53	0.66**
ENV	3	68.67	55.76	22.89**
REP(ENV)	12	2.43	2.03	0.032
GxE	42	16.96	13.77	0.065**
IPCA1	16	14.4503	70.42	
IPCA2	14	1.9283	11.37	
IPCA3	12	0.5804	3.42	
Error	168	25.85		0.154

** Significant at p<0.01, ns = not significant, Grand mean = 3.14, CV% = 15.3

AMMI1 Biplot Analysis

Each sector had a variety at the vertex of its polygon indicating that the variety had the largest positive interaction with that specific environment. Environment Mierab-Azerinet with variety Tiret, Environment Gumer with variety HB-1307 and Environment Alicho wuriro with variety Agegnehu were three sectors where the interaction pattern of varieties were independent. These varieties made the largest contribution to the GEI and were unstable. Environment Geta was correlated to both Mierab-Azerinet and Alicho wuriro, but had a very short vector contributing little to GEI. Varieties near the center of the biplot (Ardu-12-60B, Dimtu and Gabulla) contributed very little to the GEI and were stable based on AMMI. This result was in agreement with the work of (Zobel et al., 1988; Vargas and Zobel, 2000) who reported similar results on the GEI contribution of AMMI sectors on barley varieties. Also similar results were obtained by Naroui et al. (2013) who described the significant GEI in wheat by AMMI biplot analysis.

The environment Mierab-Azerinet was considered the most favorable environment where maximum mean grain yield was recorded and positively associated with Tiret variety. Gumer was the second highest yielding environment positively associated with varieties HB-1307, Cross-41/98, EH-1493 and Yedogit; with HB-1307 at the vertex, having the highest positive interaction. The least favorable environments for the performance of the varieties were Geta and Alicho wuriro where the lowest grain yields were recorded (Figure 1).

Purchase (1997) explained that IPCA1 is plotted against IPCA2, the closer the varieties score to the center of the biplot, the more stable they are. Based on their positions on the biplot, HB-42, Ardu-12-60B, Dimtu and Gabulla were scattered close to the origin, indicating minimal interaction with environments. Milan et al. (2014) had reported similar results from AMMI analysis when applied on multi-environmental trial data of barley. Varieties HB-1307, Yedogit, Shege, Agegnehu, Harbu, Estayish, Tiret, Abdane, EH-1493, and Cross-41/98 were the most unstable, since they were further from the biplot origin and were sensitive to the environment and had large interaction, indicating that these varieties had specific adaptations.

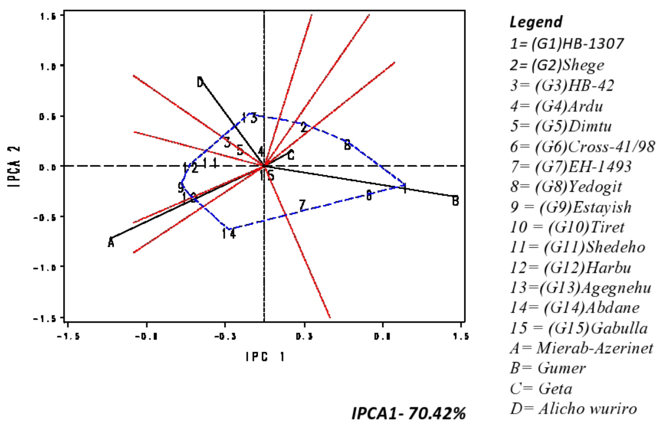

Figure 1. AMMI biplot of IPCA1 vs IPCA2 for grain yield (t ha-1) of food barley varieties at four locations plotted as G1, G2, G3… and environments plotted as A,B,C and D abbreviations in the biplot

Genotype main effects plus genotype by environment (GGE) biplot analysis

In GGE biplot for grain yield of food barley varieties, the first and second components captured 73.4 % and 18.8%, and the two together captured 92.2% of the G+GE sum of square, it means that different varieties won in different sectors (Yan et al., 2007). The correlation of Alicho wuriro with the other was also positive since it is located between Mierab-Azerinet and Gumer. Gumer and Geta were more correlated and found in the same polygon where HB-1307 was the winning, ranked first, specifically adapted and the highest yielding variety under these environments had gave mean grain yield of 6.21 and 2.71 t ha-1, respectively.

Yan et al. (2001) used GGE-biplot to illustrate the performance of barley genotypes over environments. Environments Geta and Alicho wuriro had short vectors and provide little information about the yield potential of the varieties and did not discriminate between the varieties. Gumer had the longest vector and was the most discriminating environment. Varieties HB-42, Ardu-12-60B, Dimtu and Abdane were stable and widely adapted and had above average grain yield except Abdane (Hussein et al., 2000)

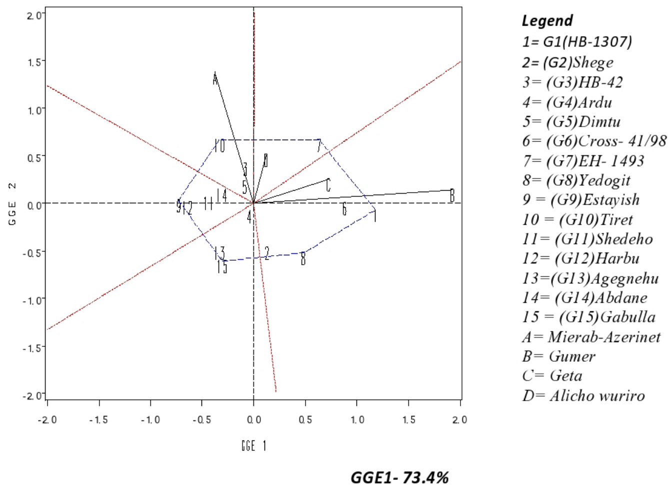

Figure 2. GGE biplot of GGE1 vs GGE2 for grain yield of genotypes at four locations plotted as G1, G2, G3… and environments plotted as A,B,C and D abbreviations in the biplot

Conclusion

Many stability parameters used in this study have quantified stability of the varieties with their yield. Therefore, yield and stability of the varieties should be considered to exploit useful effect of GxE interaction and to make selection of the varieties. Varieties HB-1307, EH-1493, and Cross-41/98 were the most unstable, sensitive to the environment and had large interaction, indicating that these varieties had specific adaptations. Based on the AMMI-1 biplot analysis, Mierab-Azerinet and Gumer districts were favorable testing environments. Therefore, the result of the study revealed, unstable varieties are recommended for favorable testing environments for production.

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