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Assessment of Yield Stability and Disease Responses in Ethiopian Barley (*Hordeium vulgare* L.) Landraces and Crosses

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ABSTRACT

The aim of this study was to assess yield stability and disease responses of barley landraces and crosses. Sixteen barley landraces including crosses were tested across eleven environments in randomized complete block design in four replications in Bale highlands of Southeastern Ethiopia. GGE (i.e., G = Genotype, GE = genotype x environment, interaction) biplot procedure was used for graphical display of yield data after subjecting genotype means of each environment to GGE biplot software. The severity of barley leaf rust disease reaction was measured from 0-100 scale, while net blotch disease was scored using double digit scoring (00-99) system. Analysis of variance revealed that barley yields were significantly ($p<0.01$) influenced by environment (71.3%) followed by GEI (9.0%) and genotype (4%). Barley cross lines (G13, G9, G12, G7 and G8) were desirable in high yielding and stability. G13 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21) which showed superior performances in yield and other desirable agronomic traits have been released in 2011 with a common name 'Abdanne' for commercial production in Mid highlands of Bale. None of the breeding materials showed resistance to net blotch and barley leaf rust diseases whereas landrace selections showed poor yield performance as compared to the barley crosses. The result indicates that the use of local cultivars in barley crossing program as sources of genes is highly important to improve the yielding potential of barleys.

Key words: Barley landraces, crosses, yield stability, net blotch, barley leaf rust, yield

INTRODUCTION

Plant breeders assess the performance of their genotypes across environments specifically to identify high yielding, stable genotypes with better resistant to disease and insect pests. However, commonly the performance of genotypes across environments is inconsistent due to the presence of Genotype by Environment Interaction (GEI). Estimation of GEI is useful in determining the relative stability of genotypes. Genotypes with stable yields are important in reducing crop failure and optimize crop production. Understanding GEI helps to design better breeding strategy in such a way that GEI can be avoided by selecting widely adapted cultivars to the entire range of environments or exploit GEI through selection of different cultivars for each specific 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 in to univariate and multivariate (Lin *et al.*, 1986). Among univariate stability methods, joint regression analysis (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Crossa, 1990) was popularly used in analysis of adaptation due to its simplicity (Ramagosa and Fox, 1993). On the other hand, the multivariate methods such as the additive main effects and Multiplicative Interaction (AMMI) have also been used as the major alternative to joint regression analysis in many plant breeding programs for GEI investigation and varietal adaptability (Annicchiarico, 1997; Ebdon and Gauch, 2002). However, recently developed multivariate analytical tool, GGE biplot (Yan *et al.*, 2000) was reported to be superior to 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). Eventhough, environment variation is said to cause about 80% of yield variation, 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). GEI has been studied by Ceccarelli (1989), Ceccarelli and Grando (1991), Jackson *et al.* (1993) and Van Oosterom *et al.* (1993) in barley. Barlay yields performance is also influenced by diseases. Thus, Yitbarek *et al.* (1996) indicated leaf rust as important barley disease in Ethiopia. Getaneh and Fekadu (2001) reported a yield loss of 28% by barley leaf rust, whereas Bekele *et al.* (2001) showed a yield loss of 28-29% by net blotch and leaf rust in Ethiopia.

Barley (*Hordeum vulgare* L.) is the most important staple food crops in the highlands of Ethiopia. Bale highlands situated in Southeastern Ethiopia being one of the major barley producing regions, however, constrained with lack of improved varieties, disease and insect pests. The local cultivar commonly grown is known as Aruso. Nationally released high yielding potential varieties did not perform well because of the presence of barley shoot fly. Sinana barley breeding program has been intensively working for the development of improved varieties with better agronomic traits, better resistance to disease and barley shoot fly insect pests. But, to make selection decision, the nature and magnitude of GEI, yield stability and responses of these barley landraces and crosses to diseases were not known. In view of this, the present study was conducted with the objectives of:

- Estimating GEI and stability performances of barley landraces and crosses
- Assessing the response of barleys to some major barley diseases
- Suggest effective breeding strategies for future barley improvement

MATERIALS AND METHODS

Study area and testing genotypes: Including one local check (Aruso) and two standard varieties (Harbu and Dimtu), 16 barley landraces and crosses were tested at 11 environments in Bale Mid-highlands {2300-2400 m above sea level (m.a.s.l)} of Southeastern Ethiopia from 2004-2007 cropping season. These breeding materials were developed from Ethiopian barley landrace collections and barley crossing program of 1999 *Ganna* (season from March to July) through pure line selection. During crossing program, high yielding potential but shoot fly susceptible advanced line (EH956/F2-8H-6) and HB42 variety were crossed with the local cultivar (Aruso) which is resistant to shoot fly, early but low yielding with the objective of developing high yielding and shoot fly resistant varieties. Segregating generations of barley crosses were handled through select and bulk method and at F_6 individual head selection was conducted on the crosses to develop pure lines. Many barley cross lines were screened at different stages and eventually seven best lines were included in this experiment (Table 4). The testing locations were Agarfa with altitude of 2300 m.a.s.l, while Adaba, Sinana and Robe locations had similar altitude of 2400 m.a.s.l. These areas are major barley testing sites commonly used by Sinana Agricultural Research Center barley breeding program. Except Adaba location, the remaining locations receive bimodal type of rainfall.

Planting: Barley seeds were planted at each location in a randomized complete block design with four replications on a plot size of 3 m^2 with six rows of 2.5 m 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.

Statistical analysis: Grain yield data in kg $plot^{-1}$ was taken from four central rows (2 m^2) and converted into t ha^{-1}. 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). 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). Barley leaf rust (*Puccinia hordei* Otth) and net blotch (*Pyrenophora teres* Drechs) disease data were recorded for all landraces and crosses including checks, across environments. Data was taken at 51-69 plant growth stages (Zadoks *et al.*, 1974) across environments. Barley leaf rust disease was scored based on Stubbs *et al.* (1986) method, whereas, net blotch disease was scored using 00-99 double digit scale (Saari and Prescott, 1975) in such a way that the first digit indicate the spread of disease in a plot (% of incidence) and the second digit shows the percentage of leaf area infected (% of severity), i.e., 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%. The important management and cultural practices was applied uniformly.

RESULTS

Analysis of variance and yield stability of barleys based on Biplot analysis: The pooled analysis of variance indicated that genotype, environment and genotype x environment interaction showed significant ($p<0.001$) difference among barley landraces and crosses tested (Table 1). Though, most of the barley genotypes and crosses performed differently in different environments, however, some showed consistent yield performance at some environments, viz, G13 {in E2 (Sinana-04), E10 (Agarfa-07) and E11 (Robe-07)} and G16 at {E1 (Adaba-04) and E9 (Sinana-07)} environments (data not shown). The result revealed that barley yields were greatly affected by environment which explained 71.3% of the variation followed by GEI (9.0%) and genotype (4.0%)

Table 1: Analysis of variance for barley grain yield (t ha^{-1}) across 11 environments in Bale high lands of Southeastern Ethiopia, 2004-2007 cropping season

Source of variation	Degree of freedom	Sum of squares	Mean squares	Explained variation (%)
Total	703	845.324		
Replication	3	2.063	0.688	
Environment (E)	10	602.690	60.269**	71.3
Genotype (G)	15	34.540	2.302**	4.0
G x E	150	76.810	0.512**	9.0
Error	525	132.507	0.252	

Repeatability (R^2): 0.840, Broad sense heritability (H^2): 0.842, Coefficient of variation (%): 20.60 and grand mean: 2.43 t ha^{-1}, **significance at p<0.01 probability level

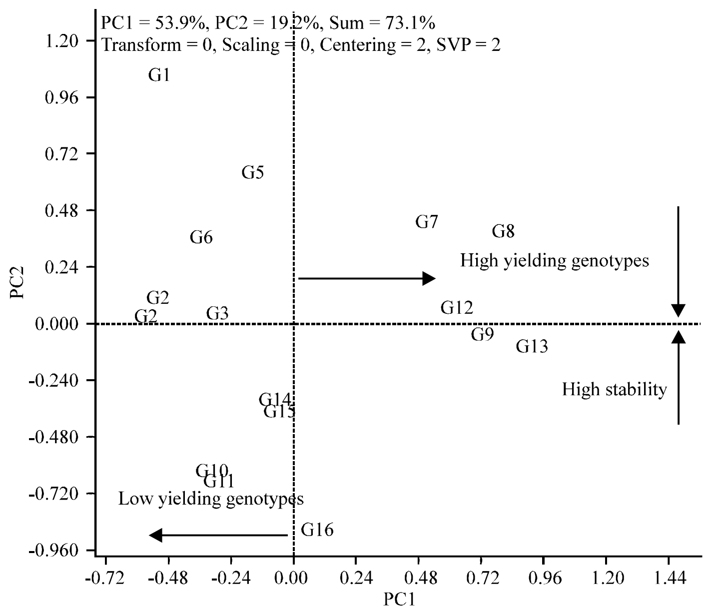

Fig. 1: GGE-biplot based on genotype focused scaling for genotypes. PC represent principal component and G: Genotypes

variations (Table 1). The magnitude of GEI was more than double that of genotype signifying the importance of GEI which is relevant in cultivar evaluation. The partitioning of GGE through biplot analysis showed that PC1 and PC2 were significant factors accounting 53.9 and 19.2% GGE sum of squares, respectively, explaining a total of 73.1% of the yield variation.

For the detection of the location of barley genotypes and crosses on biplot, GGE biplot based on genotype focused scaling was portrayed (Fig. 1). The yielding potential of barley landraces and crosses can be visualized on a graphical display using GGE biplot, The presence of near perfect correlation (r = 0.974) (data not shown) between genotype PC1 scores and genotype main effects of the data set showed the yielding ability, genotype stability, discriminating and representativeness of environments can be viewed effectively by the GGE biplot graph (Yan *et al.*, 2000). Thus, genotypes that had PC1>0 were identified as high yielding, whereas, the genotypes that had PC1<0 were classified as low yielding. Figure 1 indicates that most of the barley crosses

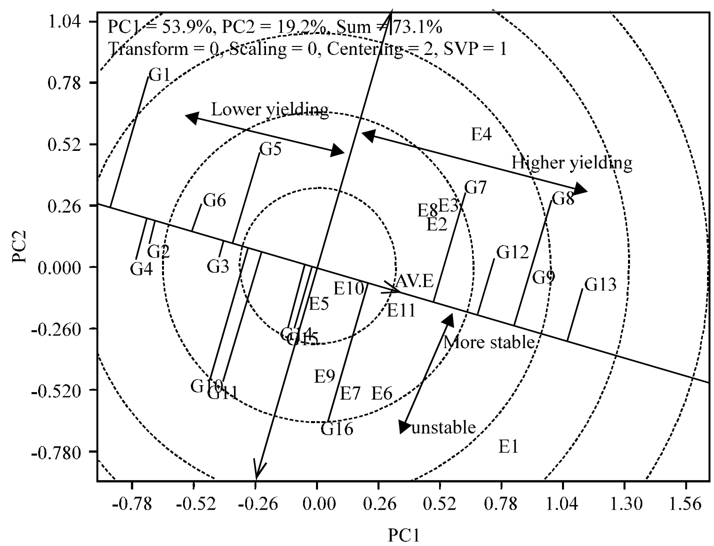

Fig. 2: Mean performance and stability of genotypes view based on genotype focused scaling. AV.E: Average environment

{G7 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-10), G8 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-12), G9 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-13), G12 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-19) and G13 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21)} showed high yielding potential. However, all landrace selections were low yielding. Genotypic stability and instability is associated with PC2 on the biplot graph. A genotype with PC2 near (absolute) 0 is more stable while genotypes with larger absolute PC2 is considered as unstable. Stability is meaningful when only related with high yielding performance (Yan and Tinker, 2006). Thus, G9, G12 and G13 were the most high yielding and stable cross lines. But, G7 and G8 can be regarded as high yielding but relatively unstable crosses whereas G16 (Dimtu cultivar) was the most unstable.

Figure 2 shows the Average Environment Coordination (AEC) view of the GGE biplot which indicate the mean performance and stability of genotypes. The single arrowed line on the graph is the AEC abscissa which points to a greater genotype main effect and the AEC ordinate is indicated by double arrows in either direction away from the biplot origin which shows greater GEI effect and reduced stability (Kaya *et al.*, 2006; Yan and Tinker, 2006). Thus, G13 had greatest genotype main effect or showed highest mean yield across environments followed by G9 and G8. Relatively the genotype vector of these crosses was shorter than the other high yielding genotypes indicating better stability. Though G3 was the most stable genotype, however, it can not be selected as the mean yield performance is low as described by Yan and Tinker (2006). G16 showed relatively longer vector showing instable. The AEC ordinate also divided genotypes with below average means from above average means. In this case, barley crosses (G13, G9, G8, G12 and G7) and G16 showed better than the average yield performance so that they could be used in future breeding programs.

Whereas, genotypes having below average means should be discarded. Most of the barley lines obtained from crosses showed better than average yield performance. But, as compared to barley crosses, the landrace selections showed below average yield performance. The distance from biplot origin and the average environment marker relative to the biplot size, is a measure of the relative

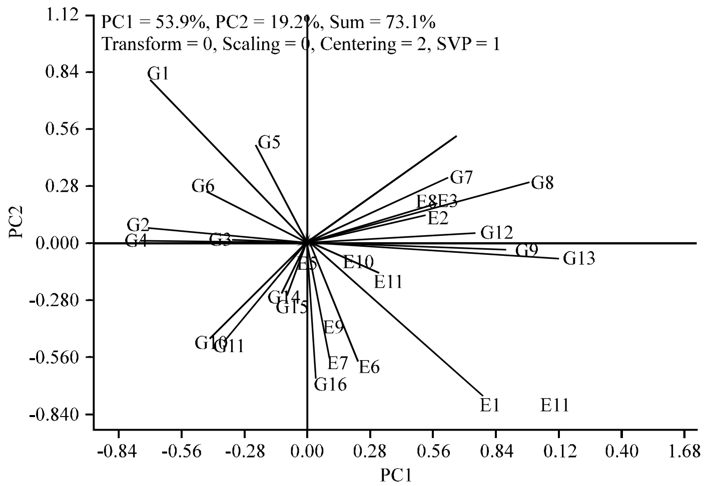

Fig. 3: The GGE-biplot view showing the performance of each genotype in each environment. Environments are designated as, E1 = Adaba-04, E2 = Sinana-04, E3 = Robe-05, E4 = Agarfa-05, E5 = Adaba-05, E6 = Sinana-06, E7 = Agarfa-06, E8 = Robe-06, E9 = Sinana-07, E10 = Agarfa-07 and E11 = Robe-07

importance of genotype main effect and GEI. The longer it is, the more important is the genotype main effect and the meaningful the selection based on mean performance (Kaya *et al*., 2006). In this study, the length of average environment vector enable us to select genotype based on mean performance.

To visualize the performance of each genotype in each environment, both the genotype and environmental vectors are drawn (Fig. 3). The performance of genotype in an environment is better than average if the angle between its vector and the environment's vector is less than 90°. It is less than average if the angle is greater than 90° and near average if the angle is about 90° (Yan and Tinker, 2006). Hence, the high yielding barley lines obtained from crosses performed better than average in E4, E3, E2, E8, E10 and E11. Whereas, G16 (Dimtu cultivar) performed greater than mean in all environments except in E4, E3, E2 and E8. Landraces such as G1, G2, G3, G4, G5 and G6 showed less than average yield performance in all test environments. G7 and G8 lines performed best in E3, E2 and E8 environments. A genotype located nearer to the biplot origin has an average value in each of the environments. Thus, G14 and G15 were relatively nearer to the biplot origin and performed average yield performance in all environments. In addition to this, the length of genotype vector measures the contribution of the genotype to either G or GEI or both (Yan and Tinker, 2006). Based on this, G13 and G1 showed opposite performances; G13 which had large positive PC1 scores had more genotype main effect and stable, as its PC2 value is nearer to 0 indicating less contribution to GEI. Whereas, G1 had PC1 scores in the negative direction showing poor performance as well as had large PC2 scores showing highly unstable.

Discriminating power and representativeness view of the GGE- biplot is an important measure of testing environment (Dehghani *et al*., 2006). Test environment with longer vectors are more discriminating of the genotypes while in the test environment with very short vector, all genotypes performed similarly in it and therefore, provides little information about the genotype differences (Yan *et al*., 2007). Thus, test environment E1 (Adaba-04) (Fig. 4) was the most discriminating followed by E4 (Agarfa-05). In contrast to this, E5 (Adaba-05) was the least discriminating, i.e.,

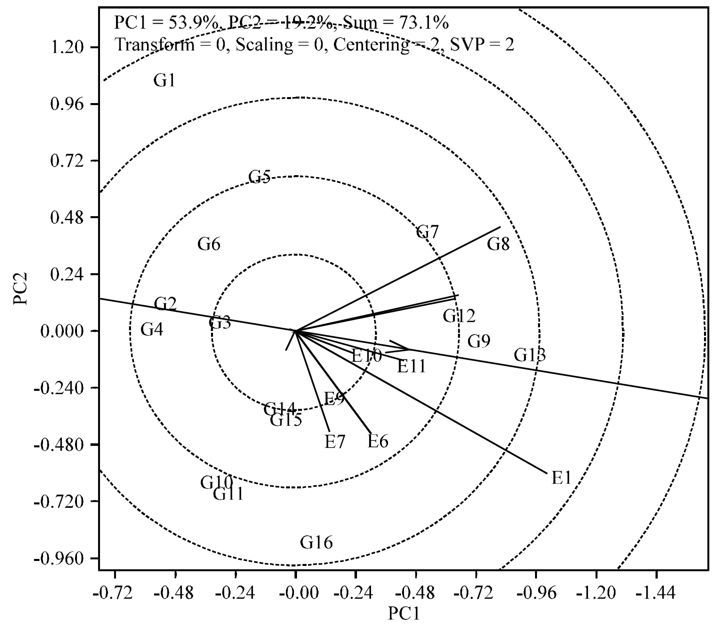

Fig. 4: Discriminating power and representativeness view of test environments. AV.E: Average environment

genotypes performed uniformly in it. Since the AEC abscissa is the "average environment axis" test environment that have small angle with it are more representative of the mega environment than those that have larger angle with it (Yan *et al.*, 2007). Thus, E11 (Robe-07) and E10 (Agarfa-07) were representative environments (Fig. 4).

An ideal genotype must have the highest mean yield and absolutely stable. These types of genotypes are described as having the longest vector length of the high yielding genotypes and zero GEI. In reality such genotypes does not exist but used as a reference in genotype evaluation. Ideal genotypes are located at the center of concentric circles as starting reference and desirable genotypes are located closer to the ideal genotypes. The concentric circles are used to visualize the distance between each genotype and ideal genotype (Kaya *et al.*, 2006). Figure 5 showed that G13 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21) and G9 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-13) were ideal genotypes in terms of higher yielding and stability as compared with the remaining genotypes. In addition, G12, G8 and G7 were desirable cross lines. Surprisingly, all barley landraces developed from barley landrace selections were situated in undesirable region of the biplot. In genotype evaluation, genotype ranking based on genotype focused scaling assumes that stability and mean yield are equally important (Yan, 2002) in comparison of landraces and crosses with ideal genotypes.

Response of barley to major diseases: Barley leaf rust (*Puccinia hordei* Otth) and net blotch (*Pyrenophora teres* Drechs) barley diseases data were recorded on barley landraces and crosses across environments. Thus, summary of leaf rust and net blotch diseases are indicated in Table 2 and 3. Regarding net blotch disease score of genotypes (Table 2), it showed that there was high net blotch disease incidence and severity recorded on barley genotypes and crosses at Agarfa location during 2006 *Ganna* followed at Adaba 2005 *Bona* (season from July to December). However, except

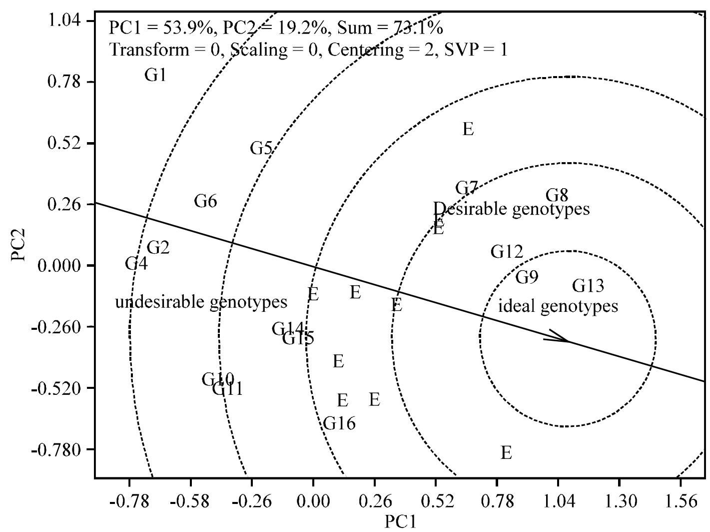

Fig. 5: GGE biplot based on genotype-focused scaling for comparison of genotypes with ideal genotypes

Table 2: The net blotch (*Pyrenophora teres* Drechs) disease score for sixteen barley landraces and crosses including checks across 11 environments in Bale highlands of Southeastern Ethiopia from 2004-2007 cropping season

	Agarfa			Robe			Sinana			Adaba	
	2005	2006	2007	2005	2006	2007	2005	2006	2007	Adaba	Adaba
Entry	*Bona*	*Gana*	*Bona*	*Bona*	*Gana*	*Bona*	*Bona*	*Gana*	*Bona*	-04 *Bona*	-05 *Bona*
Acc.3852-1(Sn01B)	81	96	27	0	85	92	86	84	85	77	96
Acc.1796-1(Sn01B)	61	96	37	0	83	86	86	82	84	81	96
Acc.1695-1(Sn01B)	81	96	37	0	84	84	86	84	84	75	94
Acc.3840-1(Sn01B)	81	94	39	0	84	87	84	84	84	74	92
Acc.3842-1(Sn01B)	82	96	48	0	84	91	92	84	84	81	96
Acc.3836-1(Sn01B)	71	96	34	0	83	94	84	86	84	77	96
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-10	81	96	48	0	85	87	84	84	85	77	94
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-12	71	96	49	74	96	91	84	86	83	77	94
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-13	71	96	56	42	96	96	84	86	83	81	94
Aruso/HB42SNRFBC99B0003-9	82	96	59	0	92	94	86	92	83	76	94
Aruso/HB42SNRFBC99B0003-10	82	94	36	0	94	97	86	86	83	77	96
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-19	81	96	57	48	96	92	82	86	84	77	94
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21	91	96	55	82	96	96	84	86	85	74	94
Harbu (standard variety)	81	96	58	0	96	91	86	86	84	74	96
Aruso (Local variety)	81	96	30	0	96	94	86	86	95	73	94
Dimtu (standard variety)	41	96	26	0	96	91	76	82	81	84	96

on few barley crosses, no net blotch disease has been recorded on barley genotypes and crosses at Robe during 2005 *Bona*. Field reactions of 16 barley genotypes and crosses to barley leaf rust was found to be 0 (no visible infection), MS (moderately susceptible) and S (susceptible) (Table 3). The barley leaf rust disease severity and reaction of these barley landraces and crosses were higher at Sinana (20-80% in 2005 *Bona*) and (5-80% in 2007 *Bona*) cropping season. Relatively low leaf rust severity was recorded at Agarfa during 2006 *Ganna* (season from March to July) cropping season.

Table 3: Leaf rust (*Puccinia hordie*) disease reaction and severity score for sixteen barley landraces and crosses including checks across 9 environments in Bale highlands of Southeastern Ethiopia from 2004-2007 cropping season

	Agarfa			Robe			Sinana		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
Entry	*Gana*	*Bona*	*Bona*	*Gana*	*Bona*	*Bona*	*Gana*	*Bona*	*Bona*
Acc.3852-1(Sn01B)	10MS	5MS	10MS	15MS	10MS	20S	80S	10MS	80S
Acc.1796-1(Sn01B)	15S	0	25MS	10MS	5MS	15MS	80S	10MS	80S
Acc.1695-1(Sn01B)	15S	5MS	25MS	15MS	5MS	20MS	80S	10MS	40S
Acc.3840-1(Sn01B)	15S	0	30MS	15MS	5MS	15MS	80S	10MS	40S
Acc.3842-1(Sn01B)	10MS	5MS	20MS	15MS	5MS	10MS	60S	10MS	40S
Acc.3836-1(Sn01B)	20S	5MS	5MS	15MS	5MS	15MS	80S	10MS	40S
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-10	15S	5MS	5MS	10MS	5MS	20MS	20MS	10MS	10MS
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-12	10MS	0	5MS	10MS	5MS	15MS	20MS	10MS	10MS
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-13	5S	0	9MS	10MS	5MS	15MS	30MS	10MS	5MS
Aruso/HB42,SNRFBC99B0003-9	10MS	5MS	55MS	20MS	5MS	10MS	80S	10MS	80S
Aruso/HB42SNRFBC99B0003-10	10MS	5MS	25MS	10MS	15MS	15MS	80S	10MS	60S
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-19	10MS	5MS	30MS	10MS	5MS	15MS	30MS	10MS	10MS
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21	10S	0	15MS	15MS	5MS	10MS	20MS	10MS	80S
Harbu (standard variety)	20S	5MS	45MS	15MS	5MS	10MS	80S	10MS	80S
Aruso (Local variety)	5S	5MS	30MS	15MS	10MS	10MS	80S	5MS	60S
Dimtu (standard variety)	15S	5MS	5MS	15MS	10MS	15MS	80S	15MS	10M

0: No visible infection, S: Susceptible, MS: Moderately susceptible, *Bona*: Season from July to December, *Ganna*: Season from March to July

The two barley diseases were the major diseases in the two main seasons. It has been observed that there was also high barley leaf rust disease incidence and severity recorded on barley genotypes and crosses more in *Bona* season than *Ganna*. Commonly barley leaf rusts occur during early growth stages of plants than net blotch disease which appear at later stages of plant growth.

DISCUSSION

Understanding GEI is useful to design better breeding strategy in such a way that GEI can be avoided by selecting widely adapted cultivars to the entire range of environments or exploited through selection different cultivars each specifically adapted to a subset of target environments (Ceccarelli, 1989). Yield stability is considered as the most important socioeconomic aim to minimize crop failure in marginal environments (Tarakanovas and Rusgas, 2006). Genetic improvement of different traits of crop is important for sustainable improvement in production and productivity. Because, the improvement in one aspect of the crop may not lead to improved yield. A high yielding potential variety may not give sustainably high yield as long as it is susceptible to diseases, insects, drought and others. Breeding barley for yield stability, resistance to disease and insect pests are among high priorities of barley breeding program in Bale highlands of Southeastern Ethiopia. The information on genotypic stability, disease responses of barley landraces and crosses is important to identify high yielding and adaptable cultivars with better resistance to diseases and to suggest future research directions.

The result of this study showed that the yield performance of different barley genotypes and crosses varied across environments (Table 1) due to the presence of cross GEI where as some barley crosses showed also consistent yield performance in some environments indicating the existence of non cross over GEI (data not shown). Similarly, cross over GEI has been reported in barley crop by Ceccarelli (1989), Ceccarelli and Grando (1991), Jackson *et al.* (1993), Van Oosterom *et al.* (1993) and Dehghani *et al.* (2006). Asfaw *et al.* (2008) reported a cross over GEI in small red beans. Barley yields were significantly affected by environment followed by GEI and genotypes, accounting for 71.3, 9.0 and 4.0% of yield variation, respectively. This could be mainly attributed to the difference in rainfall, disease, insect pests and genotypic differences.

The GGE biplot graph (Fig. 1) revealed that barley lines obtained from crossing program {G13 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21), G9 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-13) and G12 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-19)} were identified as high yielding and relatively stable. Whereas, the remaining crosses, G7 and G8 were high yielding but unstable. G16 (Dimtu) cultivar was the most unstable. The mean performance and stability view of the biplot (Fig. 2) showed G13 as the most superior line followed by G9, G8, G12 and G7 and yielded above average mean. However, the low yielding genotypes were ranked from G15 to G1 on the abscissa axis (Fig. 2). G16 with the longest genotype vector was the most unstable may be due to its susceptibility to shoot fly. It appears that some barley cultivars and crosses showed very similar mean grain yield performance and stability on the biplot graph Fig. 1 and 2. For instance, G14 and G15 had similar performance. This could be due to G14 (Harbu cultivar) was obtained from Aruso collections. Whereas, the similar performance of G10 and G11 may be attributed to both were developed from the same parents.

In addition to this, barley cross lines such as G13, G9, G12, G8 and G7 which were developed from common parents (Aruso and EH956/F2-8H-6) showed superior yield performance and above average performance in all environments. This indicates that there was better genetic recombination between the two parents for better agronomic traits than between other crosses. The performance of high yielding and stable cross lines such as G13, G9 and G12 was above average in all environments except at E5 where they showed about nearly average yield (Fig. 3). The contribution of G13 to GEI was minimum, but contributed high genotype main effect. As opposed to this, G1(Acc.3852-1(Sn01B)) contributed maximum GEI effect as well as poor performances in all environments. It appears that most of the six rowed barley crosses showed high yielding potential may be due to their effects of more number of kernels per spike, high kernel weight/spike and spike weight. Whereas, the two rowed genotypes showed low yield potential than the six rowed (Table 4). Generally the barley crosses combined better agronomic and stability performance than landraces. This suggests that the yielding potential of barley crosses have been improved through barley crossing program with the local, Aruso.

In comparison of genotype with the ideal genotypes (Fig. 5), G13 and G9 were identified as ideal genotypes, whereas, G12, G8 and G7 were desirable in high yielding and stability. In genotype evaluation, an ideal genotype should have both high yield performance and high stability with in a mega-environment (Yan *et al.*, 2007). All genotypes developed from barley landraces collections were in undesirable region while most of the materials obtained from crossing were highly desirable in high yielding and stability. The discriminating power and representativeness view (Fig.4) indicated that test environment E1 (Adaba-04) was the most discriminating while E5 (Adaba-05) was the least discriminating. This may be due to the conducive environmental conditions in 2004 at Adaba which favored the discrimination of barley genotypes and crosses. On the other hand, unfavorable environmental conditions in 2005 made barley genotypes to respond uniformly at the same location. On the other hand, E11 (Robe-07) and E10 (Agarfa-07) with the smallest angle with average environment axis was the most representative test environment. The

Table 4: Mean grain yield (t ha^{-1}) performance, genotype code and collection site for 16 barley landraces and crosses tested across 11 environments in Bale highlands in South east Ethiopia, 2004-2007 cropping season

Variety	Genotype code	Collection site in Ethiopia	Row type	Altitude (m.a.s.l)	Mean	Rank
Acc.3852-1(Sn01B)	G1	Semen Omo	Two	2200	1.97j	16
Acc.1796-1(Sn01B)	G2	Jimma	Two	2010	2.20ij	14
Acc.1695-1(Sn01B)	G3	Arsi	Irregular	2400	2.46defg	8
Acc.3840-1(Sn01B)	G4	North Omo	Two	2180	2.19ij	15
Acc.3842-1(Sn01B)	G5	North Omo	Two	2000	2.27ghi	12
Acc.3836-1(Sn01B)	G6	North Omo	Two	2235	2.23hi	13
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-10	G7	*	Six	2400	2.59bcde	5
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-12	G8	*	Six	2400	2.61abcd	4
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-13	G9	*	Six	2400	2.68abc	2
Aruso/HB42SNRFBC99B0003-9	G10	*	Six	2400	2.43defg	9
Aruso/HB42SNRFBC99B0003-10	G11	*	Six	2400	2.38fghi	11
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-19	G12	*	Six	2400	2.64ab	3
Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21	G13	*	Six	2400	2.81a	1
Harbu	G14	Cultivar	Six		2.47defg	7
Aruso	G15	Local	Irregular		2.54cdef	6
Dimtu	G16	Cultivar	Six		2.41efgh	10

Coefficient of variation (%) = 20.60, LSD (p = 0.05) = 0.20, genotype mean in the column and followed by the different letters are significantly different, m.a.s.l: Meters above seas level. *Barley lines developed through crossing program at Sinana Agricultural Research Center

findings of this study also revealed that the repeatability (R^2 = 0.840) value was relatively high showing the reliability of the information generated and heritability (H^2 = 0.842) (Table 1) value for grain yield was also very high may be due to conducive environmental conditions during testing and genotypic reasons. Thus, the high heritability value indicates that the environments showed high yielding potential and there was high efficiency for selection of high yielding genotypes. Similar report has been indicated by Ceccarelli (1994) and Ceccarelli (1996) with regard to heritability in high potential environments which says heritability is higher in high yielding environment than low yielding environment in barley (*Hordeum vulgare* L.).

In addition, based on visual observations, barley landraces and crosses showed also better resistance to shoot fly, major insect pest of barley (data not shown) as experimental sites were hot spot areas for this insect. Jobie (2003) and Jobie *et al.* (2004) have recently identified barley shoot fly species, *Delia flavibasis* stein as a major insect pest of barley in Bale. Jobie (2007) has indicated that infestation on late maturing susceptible food barley varieties such as Shage, HB-42 and Ardu-12B-60 can reach up to 100%. The resistance mechanisms of barley to shoot fly reported by Jobie (2003) was a sort of compensatory growth after damage by shoot fly. G16 (Dimtu cultivar) which was indicated in this study was also late maturing susceptible check to shoot fly insect, but it showed better performance than expected. May be because of good rainfall conditions at test environments as shoot fly cause less damage under good rainfall conditions. Though not supported with data in this report, it is worth mentioning that, it is commonly impossible to grow shoot fly susceptible barley varieties in Bale. For instance, under severe moisture stress total yield loss may happen especially for exotic and malting barley varieties which were observed very susceptible. Barley lines are usually screened for shoot fly resistance starting at early stages in breeding in comparison to susceptible cultivars. In most cases, resistant genotypes were obtained from

Ethiopian landraces for which Aruso populations are good sources of genes for such resistance/tolerance and they are also early maturing. In view of this, efforts has been made in 1999 *Ganna* and 2003 *Bona* to develop better shoot fly resistant improved barley varieties through crossing advanced lines and high yielding potential susceptible cultivars with Arsuo (local) which is better resistant to shoot fly. From the observations of crossing, lines which were obtained from crossing of parents of susceptible cultivars (Shage, HB 42 and Ardu 12B-60) with Aruso showed better resistance than the susceptible cultivars showing inheritance of shoot fly resistance genes. Barley cross lines which were included in this report were the result of 1999 crossing program and the other cross lines are currently being evaluated in nurseries. Hence, we suggest for further separate investigation on genetics of resistance by plants, type of genes controlling the trait and mechanism of inheritance of the genes involved and other genetic aspects of the crop which is relevant for resistance breeding.

Disease summary for net blotch (*Pyrenophora* teres Drechs) and barley leaf rust (*Puccinia hordei* Otth) are indicated in Table 2 and 3, respectively. The presence of high net blotch disease severity at Agarfa in 2006 *Ganna* and Adaba 2005 *Bona* seasons may be due to the existence of conducive environmental conditions for the formation of disease epidemics (Table 2). On the other hand, the lowest net blotch scores recorded at Robe in 2005 *Bona* season showed unfavorable conditions for formation of net blotch disease. None of the barley landraces and crosses were immune to net blotch disease. Whereas, as indicated in Table 3, the reaction types of barley landraces and crosses to leaf rust were 0 (no visible reaction), MS (moderately susceptible) and S (susceptible). The high barley leaf rust disease incidence and severity at Sinana during 2005 and 2007 *Bona* seasons may be due to two main reasons: (i) The presence of favorable environmental conditions for the formation of rust formation in these seasons than others and, (ii) Sinana site has been frequently used season after season for conducting trials so that there could be accumulation of more disease spores than other locations. The barley leaf rust disease reactions also revealed that none of the materials were resistant or immune to leaf rust. At Agarfa (Table 3), in 2006 *Ganna* season did not promote barley leaf rust infection. It was observed that the two diseases (net blotch and leaf rust) had different environmental requirement. For instance, the favorable condition for high net blotch severity at Agarfa in 2006 *Ganna*, did not favor the barley leaf rust epidemics at the same location and season. The study showed that the breeding materials were observed not resistant to these diseases. One reason may be due to breeding materials were early maturing as earliness was considered as additional important trait starting from early screening. Similarly, Parlevliet and Moseman (1986) and Getaneh *et al.* (1999) also reported, early maturing barley lines as less resistant to leaf rust than late types. This study conforms with Yitbarek *et al.* (1998) report which indicated early maturing barley population as less resistant to net blotch due to escaping mechanisms of late maturing types. However, Michael *et al.* (1989) reported positive association of earliness and grain yield. Woldeab *et al.* (2006) reported that barley leaf rust (*Puccinia hordei*) was an important disease of barley in Ethiopia during main rainy season, residual and short rainy season production systems. Barley leaf rust has been reported to cause a yield loss of 28% on farmers' field (Getaneh and Fekadu (2001) in Ethiopia. Yitbarek and Wudneh (1985) indicated under severe condition, net blotch cause substantial grain yield loss from 27-34%. And another experiment by Bekele *et al.* (2001) revealed that, an on farm average yield loss of 28-29% was accounted for net blotch and leaf rust infection on barley in Ethiopia. This study showed that barley leaf rust and net blotch were the most important diseases in these Bale mid-highlands (except Upper Dinsho areas) in the two main seasons. Yitbarek *et al.* (1996) also concluded that net blotch and leaf rust are the most important barley diseases in Ethiopia. During testing, scald disease was not recorded on these barley landraces and crosses. It might be because it needs cooler environments than these environments like Upper Dinsho areas of Bale where the incidence and severity has been usually high.

CONCLUSION

This study revealed that barley yields were significantly influenced by the effect of environment followed by GEI and genotype. Barley cross lines were observed desirable in high yielding and stability. Among this, the six rowed, high yielding (2.81 t ha^{-1}) and early maturing advanced line G13 (Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21) was identified as the best candidate variety. Because of this, Aruso/EH956/F2-8H-6-4SNRFBC99G0003-21 was recently approved by the national variety releasing committee for official release in 2011 with a common name '*Abdanne*' (in *Afaan Oromo* language literary meaning 'future hope') for commercial production in Mid highlands of Bale in Southeast Ethiopia specifically where shoot fly is prevalent. The variety has got 14% (Harbu), 16.6% (Dimtu) yield advantage and 10.6% over local check, Aruso. Beside this, it has shoot fly resistance and early maturing traits which are compulsory for barley crop adaptation in the target environment and to fit in to crop production systems in the area (*Bona* and *Ganna*). The result of participatory barley variety selection conducted in 2008 in Bale also indicates this new variety was among farmers' best choice (Unpublished). With regard to barley diseases, barley leaf rust and net blotch were an important diseases occurring in the study area during *Bona* and *Ganna* seasons and none of the barley landraces and crosses showed resistance to these barley diseases. This needs future research attention. In general, the barley crossing program conducted by Sinana barley breeding program may be taken as good experience that can be adopted or applied by other research institutions in Ethiopia to improve barley yield by using the local cultivars/landraces as an important sources of genes for early maturity, resistance to insect pests, drought and for high yield potential.

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