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STABILITY ANALYSIS OF FOOD BARLEY GENOTYPES IN NORTHERN ETHIOPIA

W. GEBREMEDHIN, M. FIREW[1] and B. TESFYE[2]
College of Agriculture & Natural Resources, Adigrat University, P. O. Box 50, Adigrat, Tigray, Ethiopia
[1]College of Agriculture, Haramaya University, P. O. Box 50, Dire Dawa, Ethiopia
[2]Mekele Research Center, Mekele, Ethiopia
Corresponding author: gwtgere@gmail.com

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ABSTRACT

Barley (*Hordeum vulgare* L.) is one of the founder crops of the old world agriculture and was one of the first domesticated cereals. The objective of this study was to estimate the magnitude of genotype x environment interaction and stability for barley grain yield and yield related traits in the growing areas of Tigray. Eight nationally released varieties, together with four farmers' varieties, were planted in randomised complete block design, with three replications. The additive main effects and multiplicative interaction analysis of grain yield showed that environment, and GEI were highly significant (P<0.01), whereas variations due to genotypes were not significant. They accounted for 72.21, 9.16, and 4.47% 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 multiplicative variance of the treatment sum of squares due to GEI was partitioned into the interaction principal component axes IPCA1, IPCA2 and IPCA3, which explained 58.06, 27.11 and 14.82% of the interaction sum of squares, respectively; but only the IPCA1 was highly significant. Atena, Shediho, Basso and Agegnehu with a lower IPCA1 score, were stable genotypes; whereas HB-1307, Estayish, Himbilil and Yidogit with relatively higher IPCA1 scores were unstable genotypes. The same was observed in ASV as AMMI stability. Maychew, with a low IPCA value was favourable environment for all genotypes; whereas Korem with a high IPCA score was unfavourable one.

Key Words: AMMI, GEI, *Hordeum vulgare*

RÉSUMÉ

L'orge (*Hordeum vulgare* L.) est une culture de l'agriculture antique et était l'une des premières céréales domestiquées. Un essai était fait pour estimer le niveau d'interaction génotype x environnement et la stabilité du rendement en grains et autres traits de rendement de l'orge dans les milieux de Tigray. Huit variétés diffusées dans le pays et les variétés locales des fermiers, étaient plantées en bloc complet randomisé avec trois répétitions. Les effets principaux additifs et l'analyse de l'interaction multiplicative du rendement en grains a montré que l'l'interaction environnement et GEI étaient hautement significatif (P<0.01), pendant que les variations dues aux génotypes n'étaient pas significatives. Elles comptaient pour 72.21, 9.16, et 4.47% de la somme totale des carrés, respectivement. Une large somme des carrés pour les environnements indiquait que les environnements étaient divers, causant ainsi la plupart des variations dans le rendement en grain. La variance multiplicative de la somme des carrés des traitements due au GEI était partitionnée dans l'interaction des axes des composantes IPCA1, IPCA2, et IPCA3 expliquant les 58.06, 27.11 et 14.82% d'interaction de la somme des carrés, respectivement, mais seul le IPCA1 était hautement significatif. Atena, Shediho, Basso et Agegnehu dotés d'un IPCA1 plus bas constituaient des génotypes stables, alors que HB-1307, Estayish, Himbilil et Yidogit avaient enregistrés un IPCA1 plus élevé et constituaient des génotypes instables. Ceci était observé sur ASV comme stabilité de l'AMMI. Maychew avec une valeur basse de l'IPCA constituait un environnement favorable pour tous les génotypes alors que Korem avec son IPCA plus élevé était défavorable.

Mots Clés: AMMI, GEI, *Hordeum vulgare*

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the founder crops of the old world agriculture and was one of the first domesticated cereals. It is also a model experimental plant because of its short life cycle and morphological, physiological and genetic characteristics (Komatsuda *et al*., 1999).

The total area covered by barley in Ethiopia is about 1.04 million hectares, with total production of 1.59 million tonnes; though the yield of the crop is still low with national average of 1.52 t ha^{-1} (CSA, 2010). It is the fifth important crop among the cereals, after maize, sorghum, tef and wheat, in area coverage as well as production. It accounts for about 10.55% of the total growing area of major cereal crops and about 9.21% of the total annual cereal production in Ethiopia.

Along with sorghum, tef and wheat, barley is the most widely grown and consumed crop in the Tigray region. At the same time, the total area covered by barley in Tigray region is about 0.1 million hectares, with total production of 0.14 million tonnes and yield average of 1.43 t ha^{-1} (CSA, 2010). Over 90% of the barley produced by subsistence farmers is landraces (Alemayehu, 1995) with no or very little external inputs.

The GEI limits yield estimation because it is associated with change in ranks of genotypes in addition to average performance (Gauch and Zobel, 1997). So, the identification of superior and stable genotype is difficult. Large GEI is known in barley and lentil (Ceccarelli and Grando, 1991). Similarly, Abay and Bjornstad (2008) indicated that there is a high degree of GEI in northern Ethiopia farmers' fields. Even though Tigray is one of the major barley growing areas in Ethiopia, the task of large scale GEI evaluation of six row barley released varieties is lacking. Hence, it is important to identify genotypes that are adapted to different barley growing environments in northern Ethiopia. The objective of this study was to estimate the magnitude of genotype x environment interaction for grain yield and to evaluate the stability for yield and yield related traits of food barley varieties grown in Ethiopia.

MATERIALS AND METHODS

Description of locations. The experiment was conducted during the 2010 main cropping season at four rainfed locations. These locations represent the varying agro ecologies of the major six-row barley growing areas of northern Ethiopia namely; Muglat 20 km to the south west of Addigrat, Korem 15 km to the north of the town, Alage 15 km to the east of Addi-shu town, and Maychew 17 km to the south of the town. Lists of the testing locations which were used in experiment with their climatic, soil type and global position are presented in Table 1.

Experimental materials. Eight nationally released food barley varieties, together with four farmers' varieties, were included in the trial (Table 2). The varieties were selected based on year of release, average performance and agro-ecological adaptation. Varieties were obtained from Srinka Agricultural Research Center, Debrebirhan Agricultural Research Center, Holetta Agricultural Research Center and from farmers for the farmers' varieties.

Experimental design and management. Randomised complete block design (RCBD) with

TABLE 1. Agro-ecological characterisation of test sites

Location	Altitude (m.a.s.l)	Mean annual rainfall (mm)	Soil texture	Global position	
				Latitude	Longitude
Muglat	2675	548	Clay	14^{0}16'47"N	39^{0}28'29"E
Korem	2490	946	Clay/clay loam	12^{0}30'21" N	39^{0}31'22" E
Alage	2458	729	Loam	12^{0}56'13"N	39^0 30' 58"E
Maychew	2419	657	Sandy loam	12^{0}46'47"N	39^{0}32'23"E

Sources: Agriculture Bureau of Tigray (2010)

TABLE 2. Six row food barley genotypes included in the experiment

Variety name (Acc. No.)	Origin/description	Year of release
Shoa	Dominant farmers' variety	-
Atena	Dominant farmers' variety	-
Haftysene	Dominant farmers' variety	-
Himblil	Dominant farmers' variety	-
Shedeho(3381-01)	SRARC/ARARI	2003
Trit (215235-2)	SRARC/ARARI	2004
Estayish(218963-4)	SRARC/ARARI	2004
Mezezo (4748-16)	DBARC/ ARARI	2004
Basso(4731-7)	DBARC/ ARARI	2004
Yedogit(BI 95 IN 198)	SRARC/ARARI	2005
HB-1307(EH-1700/F_{71}.B_1.63)	HARC/EIAR	2006
Agegnehu(218950-08)	SRARC/ARARI	2007

Source: MoARD, 2007. Crop variety registration 2004, 2005, 2006, 2007

three replications was used in all locations. Each experimental plot had six rows of 2.5 m long spaced and 20 cm apart with a plot area of 1.2 m x 2.5 m.

Drill planting by hand was used with the same rate at all locations. Fertiliser was applied at 41 and 46 kg ha^{-1} of N and P_2O_5, respectively, in the form of Urea and DAP. All P_2O_5 and one-third of N were applied during planting, while the second and the third one-third splits were applied at tillering and at panicle initiation stages, respectively. A seeding rate of 85 kg ha^{-1} was used. First weeding was carried out 35 days after emergence and the second one at 30 days after the first weeding. Weeding was done up to four times at some of the locations. Four middle rows were used for data collection.

Data collection. Data were collected on plant base and plot base as follows

Plot basis. The following plant parameters were determined:

(a) Days to heading (DH): The number of days from date of sowing to the stage where 75% of the spikes have fully emerged;
(b) Days to maturity (DM): The number of days from the date of sowing to a stage where 90% of plants have reached their physiological maturity;
(c) Biomass (BM): The total above ground biological yield in kg obtained from each plot at harvest;
(d) Harvest index (HI): The fraction of dry kernel in the above ground biological yield;
(e) Thousand kernel weight (TKW): The weight in grammes of 500 kernels sampled from each plot and multiplied by two; and
(f) Grain yield (GY): Kernel yield per plot was measured in kilograme.

Plant basis. The following plant parameters were determined:

(a) Plant height (PH): The height of plants in each plot measured in centimeters from the ground surface to the top of the main stem at maturity from five randomly taken plants;
(b) Spike length (SL): Average length (cm) of spikes from five randomly taken plants from the four central rows of each plot;
(c) Number of kernels per spike (NKS): were estimated from five randomly taken plants from the four central rows of each plot. The kernels were threshed; number of kernels were counted by hand and averaged per head;
(d) Tillers/plant (TIPP): The average number of effective tillers;
(e) Spikelets per spike (SLEPP): The average number of fertile spikelets per spikes of five randomly taken plants.

Data analysis. Different statistical software packages were used to analyse the data; Agrobase 2000 for AMMI analysis of variance; Genstat (12th edition) for biplot of GEI.

AMMI analysis. The Additive Main effect and Multiplicative Interaction (AMMI) (Zobel *et al*., 1988; Crossa, 1990) model analysis was performed for grain yield.

The AMMI model equation is given as:

$$Y_{ge} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda_n \gamma_{gn} \delta_{en} + \theta_{ge} + E_{ge}$$

Where:

Y_{ge}= the mean yield of genotype g in environment e;
μ = the grand mean;
α_g = the deviation of the genotype mean from the grand mean;
β_e = the deviation of the environment mean from the grand mean;
λ_n = the singular value for the IPCA n;
N = the number of PCA axis retained in the model;
γ_{gn}= the PCA score of a genotype for PCA axis n;
δ_{en}= the environmental PCA score for PCA axis n;
θ_{ge} = the AMMI residual; and
E_{ge}= the residuals

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 n^{th} axis of IPCA;

Stability analysis

AMMI Stability Value (ASV). AMMI stability value (ASV), which is stability value based on the AMMI model's IPCA1and IPCA2 values for each genotype and each environment, was calculated as suggested by Purchase *et al*. (2000). ASV is the effect of distance from the coordinate point to the origin in a two dimensional scatter diagram of IPCA1 scores against IPCA2 scores. IPCA1 score contributes more to the GE interaction sum of square, and a weighted value is needed. 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:

$$ASV_i = \sqrt{\left[\frac{SS_{IPCA1}}{SS_{IPCA2}}(IPCA1score)\right]^2 + (IPCA2score)^2}$$

Where, $\frac{SS_{IPCA1}}{SS_{IPCA2}}$ is the weight given to the IPCA1-value by dividing; and the IPCA1 sum of squares by the IPCA2 sum of squares.

RESULTS AND DISCUSSION

AMMI analysis for grain yield. The additive main effects and multiplicative interaction analysis (Table 3) of grain yield showed that environment, and genotype by environment interaction were highly significant (P<0.01). On the other hand, genotype was non-significant, and accounted for 72.21, 9.16 and 4.47% of the total sum of squares, respectively. The total sum of squares of the model (72.21%) was largely attributed to the main effects of environment; while 13.63% was due to the genotype and interaction effects. A large sum of squares for environments indicates that the environments were diverse; with large differences among environmental means causing most of the variation in grain yield (Rodriguez *et al*., 2007; Bahrami *et al.,* 2009). The significance exhibited by GEI indicates that each of the genotype interacted differently at each location (Anandan *et al.,* 2009; Asfaw *et al*., 2009).

The multiplicative variance of the treatment sum of squares due to GEI was partitioned into the IPCA1, IPCA2 and IPCA3; which explained 58.06, 27.11 and 14.82% of the interaction sum of squares, respectively. However, the IPCA1 mean square was highly significant. The first interaction principal component was highly important in explaining the interaction sum of squares; while the rest IPCAs were not significant (P>0.05) and remained in residual component. This is similar

TABLE 3. AMMI analysis of variance for grain yield (t ha^{-1}) of food barley genotypes tested at four locations in northern Ethiopia

Sources of variation	Degree of freedom	Sum of squares	Mean squares	Sum of square explained	
				% total	% GXE
Environment	3	220.91	73.64**	72.21	
Bloc.within E	8	10.28	1.29		
Genotype	11	13.69	1.24^{ns}	4.47	
GXE	33	28.01	0.85**	9.16	
IPCA1	13	16.26	1.25**	5.31	58.06
IPCA2	11	7.59	0.69^{ns}	2.48	27.11
IPCA3	9	4.15	0.46^{ns}	1.36	14.82
Residuals	88	33.06	0.38		
Total	143	305.94			
Grand mean	3.19		CV (%)=19.23		

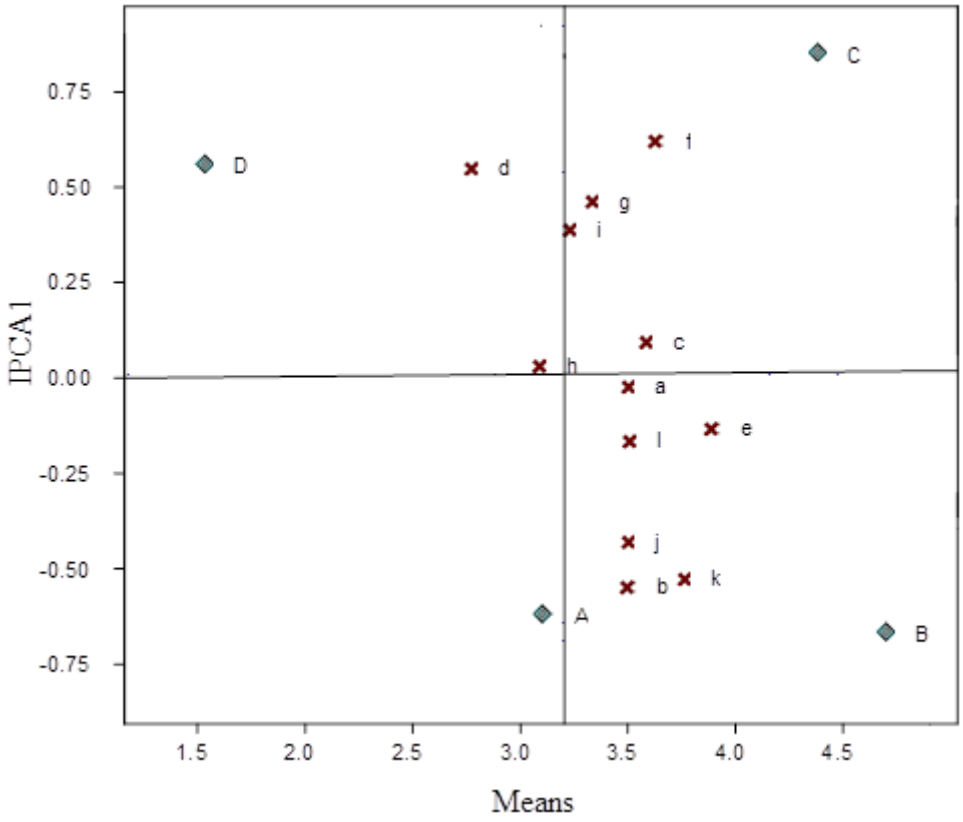
** = significant (P < 0.01), ns = non significant, GXE= genotype by environment interaction, IPCA = interaction principal component axis

to the report of Ntawuruhunga *et al*. (2001). This indicates that one fundamental factor that affects GEI could either be genotypic or environmental in nature (Debelo *et al.,* 2000). Anandan *et al.* (2009) also reported that 74.3% of the interaction sum of squares was explained by IPCA1.

The environment and the genotype means were plotted against IPCA1 (Fig. 1). This biplot helped in the interpretation of the interaction effects among genotypes and environments; and in the assessment of the adaptability of genotypes. Atena, Shediho, Basso and Agegnehu with a lower IPCA1 score were stable genotypes, but Atena did not perform well, whereas genotypes HB-1307, Estayish, Himbilil and Yidogit had relatively higher IPCA1 scores and greater mean than grand mean of grain yield (Table 4). Genotypes which are characterised by means greater than grand mean and the IPCA scores nearly zero are considered as generally adaptable to all environment. However, the genotype with high mean performance and with large value of IPCA scores are considered as having specific adaptability to the environments (Singh, 2009). Bantayehu (2009) reported that the larger the IPCA scores, either negative or positive, the more specifically adapted a genotype is to a certain environments; yet the smaller the IPCA scores, the more stable the genotype is over all environments.

Genotypes Yedogit, Agegnehu and Basso had grain yield above the grand mean; and similar IPCA1 scores with locations Alage and Mugulat implying that their interactions were positive; the higher yields of these genotypes were found, particularly, at these locations. Hence, they were the best adapted genotypes for these locations. Crossa (1990) also indicated that Genotype and location combinations with IPCA1 scores of the same sign produced positive specific interaction effects; whereas combinations of opposite sign had negative specific interactions.

In AMMI biplot (Fig. 1), genotypes showed more variation for interaction than for the main effects. This was manifested by relatively wider distribution of genotypes in the vertical than in the horizontal direction. There were also a difference among genotypes and environments both for the interaction effects and mean grain yields. Even though the ranges were different from one to the other, all the locations had IPCA1 scores far from zero (Fig. 1). This indicates that all the environments had potential for large GEI in grain yield (Sanni *et al.,* 2009). Similarly, Anandan *et al.* (2009) reported that locations with IPCA1 scores far from zero had high interaction effect and discrimination among genotypes and vice-versa.



a = Shediho, b = Himbilal, c = Basso, d = HB1307, e = Haftysene, f = Yedogit, g = Shoa, h = Atena, i = Trit, j = Mezezo, k = Estayish, l = Agegnehu, A = Maychew, B = Korem, C = Alage, D = Mugulat IPCA-interaction principal component axis, AMMI- additive main effect and multiplicative interaction

Figure 1. AMMI1 biplot for grain yield (t ha^{-1}) and IPCA1of food barley genotypes grown in northern Ethiopia.

Stability analysis for genotypic performance

AMMI Stability Value (ASV). Table 5 shows AMMI stability values for important agronomic traits. Considering the AMMI stability value (ASV) that takes into account the scores of the IPCA2, genotypes with least ASV scores are the most stable, whereas genotypes with high ASV score are unstable (Farshadfar, 2008; Bantayehu, 2009; Issa, 2009). Accordingly, genotypes Basso, Atena, Trit, Agegnehu and Shediho appeared to be among those showing low ASV and were the most stable. On the contrary, genotypes Yidogit, Himbilil, Estayish and HB-1307 showed the highest ASV and were thus deemed to be unstable. With regard to environments, Mugulat gave the lowest ASV score, whereas Korem scored a high value.

Stability in itself should, however, not be the only parameter for selection, as the most stable genotype would not necessarily give the best yield performance (Mohammadi *et al*., 2007). In this study, for example, Atena which had the lowest ASV (Table 5), had lower yield (2.84 kg ha^{-1}) than the grand mean (3.19 kg ha^{-1}). So if we select Atena based on ASV *per se*, there will be a risk of yield reduction.

In terms of the yield related traits, Haftysene in plant height, Shedho and Haftysene in tillers per plant, Atena in days to maturity and in thousand kernel weight, Tirit, Himbilil and Yedogit were stable genotypes as they had low ASV. On

TABLE 4. Grain yield (t ha^{-1}), and environment and genotype IPCA1 scores for twelve genotypes tested at four locations in northern Ethiopia

Genotype	Location				Genotype	
	Maychew	Korem	Alage	Mugulat	Mean	IPCA1
Shedeho	2.41	5.037	4.246	1.307	3.25	-0.1553
Himbilil	3.397	5.031	3.539	1.033	3.25	-0.6409
Basso 2.988	4.327	4.294	1.39	3.25	0.1148	
HB-1307	2.345	3.006	4.039	0.943	2.58	0.6169
Haftysene	2.937	5.636	4.464	1.629	3.67	-0.3533
Yedogit2.99	3.995	5.302	2.046	3.58	0.8016	
Shoa	2.262	4.299	4.44	1.332	3.08	0.2836
Atena	2.77	3.716	3.664	0.85	2.75	0.0620
Trit	2.378	4.021	4.143	1.125	2.92	0.2308
Mezezo	3.324	4.662	3.636	1.046	3.17	-0.4214
Estayish	3.605	5.304	3.804	1.287	3.50	-0.6381
Agegnehu	3.593	3.964	4.096	1.347	3.25	0.0993
Mean	2.92	4.42	4.14	1.28	3.187	-
Env. IPCA1	-0.3495	-1.0526	0.9411	0.4611	-	-

GxE = genotype by environment interaction, IPCA- interaction principal component axis, Env. = environment

TABLE 5. AMMI stability value of GY, PLH, TIPP, DTM, THKW for the 12 barley genotypes evaluated in northern Ethiopia

Attributes	GY	PH	TIPP	DTM	THKW
Genotypes					
Shedeho	0.69	1.34	0.68	5.28	10.44
Himbilil	1.38	0.96	4.03	2.14	1.48
Basso	0.25	3.32	2.45	5.07	5.93
HB-1307	1.34	4.41	4.36	8.36	12.99
Haftysene	0.94	0.55	0.76	1.38	6.65
Yedogit	1.72	1.97	1.40	1.34	1.92
Shoa	0.75	3.67	1.01	9.25	7.99
Atena	0.33	4.11	2.71	0.31	5.73
Trit	0.53	2.95	2.89	6.42	1.43
Mezezo	0.94	1.28	4.53	3.47	3.38
Estayish	1.37	1.57	1.48	6.83	10.11
Agegnehu	0.66	1.76	1.95	3.13	5.75
Environments					
Maychew	1.27	4.56	0.99	3.14	17.31
Korem	2.35	2.94	2.21	11.31	2.23
Alage	2.04	6.63	6.90	0.61	2.76
Mugulat	0.99	3.21	5.88	13.67	17.24

the other hand, HB-1307 in plant height, Mezezo and HB-1307 in tillers per plant, Shoa in days to maturity and HB-1307 in thousand kernel weight were genotypes with high ASV and unstable genotypes (Table 5).

CONCULSION

Although the GEI of grain yield partitioned in to different IPCAs using AMMI model analysis, the first principal component axis for interaction alone explains most of the interaction sum of squares. The sign and magnitude of IPCA scores reveal the relative contribution of each genotype and environment for the genotype and environment interactions and the biplot graph of AMMI scattered genotypes and environments based on their interaction. It helps to summarise the pattern and magnitude of GEI and main effects that reveal clear insight into the adaptation of genotypes to environments. This shows that genotypes Atena, Shediho, Basso and Agegnehu are less contributors to the interaction effect and have consistent performances across all locations whereas genotypes, HB-1307, Estayish, Himbilil and Yidogit relatively with higher IPCA1 scores are unstable genotypes. Genotypes Basso, Atena, Trit, Agegnehu and Shediho appear to be among those showing low ASV and are the most stable. On the contrary, genotypes Yidogit, Himbilil, Estayish and HB-1307 show the highest ASV and are unstable.

REFERENCES

Abay, F. and Bjornstad, A. 2008. Participatory varietal selection of barley in the highlands of Tigray in Northern Ethiopia. In: Thijssen, M.H., Bishaw, Z., Beshir, A. and de Boef, W.S. (Eds.). Farmers, seeds and varieties: supporting informal seed supply in Ethiopia. Wageningen, Wageningen International. 348p.

Anandan, A., Eswaran, R., Sabesan, T. and Prakash, M. 2009. Additive main effects and multiplicative interactions analysis of yield performances in rice genotypes under coastal saline environments. *Indian Journal of Advances Biological Research* 3(1-2): 43-47.

Alemayehu, F. 1995. Genetic variation between and within Ethiopian barley landraces with emphais on durable resistance. PhD Thesis. Landbouw Universiteit, Wageningen, The Netherlands.

Asfaw, A., Alemayehu, F., Gurum, F. and Atnaf, M. 2009. AMMI and SREG GGE biplot analysis for matching varieties onto soybean production environments in Ethiopia. *Scientific Research and Essay* 4(11):1322-1330.

Bahrami, S., Bihamta, M.R. and Solouki, M. 2009. Adaptation and stability analysis of hulless barley (*Hordeum vulgare* L.) genotypes in temperate regions of Iran. *Trakia Journal of Sciences* 7(2):8-17.

Bantayehu, M. 2009. Analysis and correlation of stability parameters in malting barley**.** *African Crop Science Journal* 17 (3):145-153.

Ceccarelli, S. and Grando, S. 1991. Selection environment and environmental sensitivity in barley. *Euphytica* 57:157-219.

Crossa, J. 1990. Statistical analysis of multi location trials. *Advances in Agronomy* 44:55-85.

CSA. 2010. Central Statistical Authority. Area and Production of crops (Private peasant holdings, Maher season). Statistical Bulletin Addis Ababa, Ethiopia.

Debelo, D., Girma, B., Alemayehu, Z. and Gelalcha, S. 2000. Drought tolerance of some bread wheat genotypes in Ethiopia. *African Crop Science Journal* 9 (2):385-392.

Farshadfar, E. 2008. Incorporation of AMMI stability value and grain yield in a single non-parametric index (GSI) in bread wheat. *Pakistan Journal of Biological Sciences* 11:1791-1796.

Gauch, H.G. and Zobele, R.W. 1997. Identifying mega environments and targeting genotypes. *Crop Sciences* 37 (2):21-32.

Issa, A.B. 2009. Genotype by environment interaction and yield stability of maize hybrids evaluated in Ethiopia. MSc. in Agriculture, Free State University, South Africa.121pp.

Komatsuda, T., Tanno, K., Salomon, B., Bryngelsson, T. and Von Bothmer, R.1999. Phylogeny in the genus *Hordeum* based on nucleotide sequences closely linked to the

vrs1 locus (row number of spikelets). *Genome* 42: 973-981.

MoARD, 2007. Crop development department; Crop variety registration. Issue No.10.June 2007 Addis Ababa, Ethiopia.

Mohammadi, R., Armion, M., Shabani, A. and Daryaei, A. 2007. Identification of stability and adaptability in advanced durum wheat genotypes using AMMI analysis. *Asian Journal of Plant Sciences* 6:1261-1268.

Ntawuruhunga, P.H., Rubaihayo, P., Whyte, J.B.A., Dixon, A.G.O. and Osiru, D.S.O. 2001. Additive main effects and multiplication interaction analysis for storage root yield of cassava genotypes evaluated in Uganda. *Africa Crop Sciences Journal* 9 (4):591-598.

Purchase, J.L., Hatting, H. and Vandenventer,C.S. 2000. Genotype by environment interaction of winter wheat in South Africa: II. Stability analysis of yield performance. *South Africa Journal of Plant and Soil* 17:101-107.

Rodriguez, M., Rau, D., Papa, R. and Attene, G.2007. Genotype by environment interactions in barley (*Hordeum vulgare* L.): different responses of landraces, recombinant inbred lines and varieties to Mediterranean environment. *Euphytica.* pp. 9635-9638.

Sanni, K.A., Ariyo, O.J., Ojo, D.K., Gregorio, G., Somado, E.A., Sanchez, I., Sie, M., Futakuchi, K., Ogunbayo, S.A., Guei, R.G. and Wopereis, M.C.S. 2009. Additive main effects and multiplicative interactions analysis of grain yield performances in rice genotypes across environments. *Asian Journal of Plant Sciences* 8(1):48-53.

Singh, D., Singh, S.K. and Singh, K.N. 2009. AMMI analysis for salt tolerance in bread wheat genotypes.www.cabdirect.org/abstracts/20093259042.html. Accessed on 10 February 2011.

Zobel, R.W., Wright, M.J. and Gauch, H.G. 1988. Statistical analysis of a yield trial. *Agronomy Journal* 80:388-393.