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Genotype X Environment Interaction of Food Barley (Hordeum vulgare L.)

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Abstract
The objective of this experiment was to estimate the magnitude of genotype X environment interaction on grain yield and yield related traits. Twelve food barley varieties were included in the study planted in randomized complete block design (RCBD) with three replications. The ANOVA of combined and individual location revealed significant differences among the food barley genotypes for grain yield and other traits. The results of ANOVA for grain yield showed highly significant ($p \leq 0.01$) differences among genotypes evaluated for grain yield at Maychew and significant ($p \leq 0.05$) differences in Korem, Alage and Mugulat. The ANOVA over locations showed a highly significant ($p \leq 0.01$) variation for the genotype effect, environment effects, GEI effect and significant ($p \leq 0.05$) variation for GEI effect of yield and for most of the yield related traits of food barley genotypes. Haftysene, Yidogit, Estayish and Basso were the genotypes with relatively high mean grain yield across all locations and they are highly performing genotypes to the area. Among locations, the highest mean grain yield was recorded at Korem and it was a suited environment to all the genotypes whereas Mugulat is unfavoured one.
Keywords: ANOVA, GEI, RCBD, Significance, variation

Introduction
Barley was first domesticated about 10,000 years ago from its wild relative, in the area of the Middle East known as the Fertile Crescent (Badr *et al*., 2000).
The progenitor of cultivated barley has a brittle two-row spike and a hulled grain. Six-row barley appeared about 8000 years ago. The small, one seed arrow-like spikelets of barley are adapted to reach the soil through stones and pebbles. However the spontaneous six-row mutants, which produce larger three seed spikelets, do not have this evolutionary advantage and do not reach the soil as easily therefore they are naturally eliminated from wild barley populations. Thus, six-row barley occurs primarily as cultivars weeds in agricultural systems (Komatsuda *et al*., 2007).

Barley is cultivated in every region of Ethiopia and demonstrates wide ecological plasticity and physiological amplitude throughout the country (Lakew *et al*., 1996). This may lead to greater genotype X environment interaction (GEI). Barley is believed to have been cultivated in Ethiopia as early as 3000BC (Hailu and Leur, 1996). Ethiopia is generally considered as a secondary center of diversity for barley because of the presence of great genetic diversity and endemic forms (Birhane, 1991). The most important barley production regions are Oromia, Amhara, S.N.N.P.R and Tigray (CSA, 2010). Remarkably, over 90% of the barley produced by subsistence farmers is landraces (Alemayehu, 1995) with no or very little external inputs.

Over the past decade, the area planted to barley has declined by 31% in Tigray due to the abiotic (water logging) and biotic (diseases and insects) and the low priority given to barley in agricultural development, conservation and research programs, as compared to the emphasis placed on higher-valued export crops (Abay *et al.,* 2009*).* It was also replaced by bread wheat as wheat is yielder than barley genotypes used by farmers so, these genotypes needed to replaced by six row genotypes.

There is limited information on the GEI study in Tigray region with a highly varied micro-environments that differ in rainfall, topography, soil type, temperature and soil fertility (Bekele, 1984; Hagos *et al*., 1999). So the identification of superior and stable genotype is difficult. Mekbib (2003) also indicated that performance stability of common bean genotypes is of special importance under rainfed conditions in Ethiopia, where environmental conditions vary considerably and the means of modifying the environment are inadequate. Thus there is a need to study GEI to determine the response of different genotypes to varying environments and identify high yielding barley varieties in the region. This study was undertaken with the objective of estimating the magnitude of genotype X environment interaction for grain yield and yield related traits.

Materials and Methods
Experimental Materials
Twelve food barley varieties were included in the trial (Table 1). 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.

Table 1. 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

Description of Locations

Four locations were taken for testing the varieties in the year of 2010 main cropping season. These locations represent the varying agro ecologies of the major six-row barley growing areas of northern Ethiopia namely. Lists of the testing locations which were used in experiment with their climatic, soil type and global position are presented in Table 2.

Table 2. Agro-ecological characterization 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)

Experimental Design

The experiment was used Randomized Complete Block design (RCBD) with three replications in all locations. Each experimental plot had six rows of 2.5 m long spaced 20 cm apart with a plot area of 3m^2 (1.2mX2.5m), 1.5m distances between replications and 0.4 m between plots. Drill planting by hand was used with the same rate at all locations. The fertilizer rate was 41/46 $kgha^{-1}$ of N/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 seed rate of 85 $Kgha^{-1}$ was used. All agronomic managements performed as recommended and four middle rows were used for data collection.

Data Collection

Data were collected on the following parameters: Days to heading (DH), Days to maturity (DM), Biomass (BM) Harvest index (HI) Thousand kernel weight (TKW), Grain yield (GY), Plant height (PH), Spike length (SL), Number of kernels per spike (NKS), Tillers/plant (TIPP), Spikelets per spike (SLEPP)

Data Analysis

Different statistical software packages were used to analyze the data; SAS (2002) was used for analysis of variance and LSD test.

Analysis of variance combined data over locations

The combined analysis was done using mixed linear model as outlined (Table 3) to examine the additive and interaction effects of genotypes and environments following the standard procedure given by Gomez and Gomez (1984).

Table 3. Combined analysis of variance over locations

Sources of variation	Degrees of Freedom	Mean square	Expected mean squares
Environment (E)	$l-1$	MS_E	$\sigma^2 e + g\sigma^2_l$
Blocks within sites [R (E)]	$l(r-1)$	MSr	---
Genotype (G)	$g-1$	MSg	$\sigma^2 e + r\sigma^2_{gl} + lr\sigma^2_g$
G x E	$(g-1)(l-1)$	MS_{GxE}	$\sigma^2_e + r\sigma^2_{GxE}$
Error (e)	$l(g-1)(r-1)$	MSe	σ^2_e

l = no of locations, g = no of genotypes, r= no of blocks, MSE=environment mean square, MSr= block mean square, MSg= genotype mean square, MSGxE= GxE mean square, MSe= error mean square, σ^2 = Variance

Results

Analysis of variance over locations

The analysis of variance over locations showed a highly significant (p≤0.01) variation for the genotype effect, environment effects, GEI effect and significant (p≤0.05) variation for GEI effect of yield and for most of the yield related traits of food barley genotypes (Table 4).

Grain yield

Haftysene, Yidogit, Estayish and Basso were the leading genotypes having relatively high mean grain yield across locations whereas HB-1307, Atena, Trit and Shoa were from the base side of the genotypes and recorded mean grain yield below the grand mean (Table 5). When locations were compared in terms of grain yield, there was highly significant difference (Table 4) and, it was at Korem where the highest mean grain yield was recorded followed by Alage (Table 6). The total grain yield averaged over locations was 3.19tha^{-1} whereas grain yield recorded at Mugulat and Maychew was below the grand mean.

Yield related traits

Combined ANOVA over locations for all the yield related traits, have shown statistically significant differences among genotypes (Table 4). Estayish, Shedho, Trit, Atena and Agegnehu were with high mean for stand count m^{-2} whereas Himblil and Yidogit highest in tillers per plant. Haftysene, Shoa and Himbilil had the highest number of kernels per spike. Comparing their maturity period Basso was early maturing genotype followed by Agegnehu and Shedeho whereas HB-1307 was late maturing one over all locations. This may reduce its chance to introduce the variety in areas having moisture stress.

In terms biomass and grain yield Estayish and Haftysene showed the highest mean performance. These genotypes also have relatively high harvest index which helped for selection of varieties with increased biomass and grain yield. HB-1307 a variety preformed less in all locations had the highest thousand kernel weight (Table 5).

Table 4. Combined analysis of variance for twelve genotypes for twelve traits grown in 2010.

Trait	Mean squares (MS)			
	Genotype (G) (11)	Environments (E) (3)	GXE (33)	Pooled (94)
DTH	206.60**	311.67**	12.60*	7.37
STC	2989.35**	3484.30*	1249.69*	766.42
SLEPP	15.49**	143.86**	4.14**	1.77
TIPP	3.42**	2.77 ^{ns}	2.22*	1.33
PLH	429.86**	14132.24**	61.33*	36.22
SL	5.57**	17.72**	0.92*	0.57
KPS	153.69**	1567.67**	37.6*	23.6
DTM	129.99**	911.49**	13.97**	6.49
BY	3.19*	1.53**	3.6**	1.51
GY	1.10**	74.73**	0.62*	0.35
HI	0.02**	0.45**	0.008*	0.0048
THKW	88.69**	257.88**	30.61**	12.53

*ns - non significant, * - significant (P≤0.05) and **- highly significant (P≤0.01),* numbers in parentheses indicates d.f.

Where: BY= above ground dry biomass weight (t/ha), DTH= days to head, DTM= days to maturity, GY= grain yield (t/ha), HI= harvest index, KPS= kernels per spike, PLH= plant height (cm), SL= spike length (cm), SLEPP= no. of spikelets per spike, STC= stand count per m^2, THKW= thousand kernel weight (g), TIPP= no. of effective tillers per plant

In this study high kernel weight was associated with low yielding genotype but Abay (2008) reported the association of high thousand kernel weights was with low yielding environments. At Mugulat, the relatively high days to maturity, days to heading and stand count, the lower tiller per plant, number of spikelets per spike, spike length, plant height, kernels per spike, biomass and grain yield and low thousand kernel weight was because of the scarcity of rainfall (Table 6).

Genotypes matured earlier in Maychew, as it has lower elevation and relatively high temperature which facilitated the physiological activity of the crop and increased spike length. The other traits are lower in their mean at this location. The mean number of spikletes per spike, grain yield, harvest index thousand kernel weight were highest at Korem. The major factor in this location was suitable rainfall distribution during the growing period. However, mean tillers per plant, plant height and biomass yield were higher in Alage (Table 6).

Discussion

Analysis of variance over locations

The analysis of variance over locations showed a highly significant ($p\leq0.01$) variation for the genotype effect, environment effects, GEI effect and significant ($p\leq0.05$) variation for GEI effect of yield and for most of the yield related traits of food barley genotypes. This indicated that the phenotypic expression of one genotype might be superior to another genotype in one environment but inferior in a different environment (Falconer and Mackay, 1996; Bahrami *et al*., 2008)

The presence of variation between environments point out the presence of dissimilarity and provide a baseline information to categorize high potential, low potential and intermediate potential yielding agro ecologies. The association between the environment and the phenotypic expression of a genotype constitute the GEI. The GEI determines if a genotype is widely adapted for an entire range of environmental conditions or separate genotypes must be selected for different sub-environments. When GEI occurs, factors present in the environment (temperature, rainfall, etc.), as well as the genetic constitution of an individual (genotype), influence the phenotypic expression of a trait (Bondari, 1999). Generally, larger interaction component cause difficulties in selection of widely adapted and high yielding genotypes under diverse environments.

Table 5. Mean values of agronomic traits of food barley genotypes tested at four locations in the 2010.

Genotype	DTH	STC	SLEPP	TIPP	PLH	SL	KPS	DTM	BY	GY	HI	THKW
Shedeho	65.42bdc	137.67ab	15.92de	3.35c	80.35cd	6.33cde	41.65cd	101.58fg	7.30ab	3.25abcd	0.43c	39.67ef
Himbilil	67.50b	121.42bc	19.05a	5.02a	85.35ab	5.85ef	46.18ab	105.83bc	7.26ab	3.25abcd	0.45bc	41.67def
Basso	61.75ef	118.25bc	16.65cde	4.22abc	86.38a	7.00b	39.63cd	99.83g	6.93abcd	3.33abc	0.47bc	42.33cde
HB-1307	71.58a	107.67cd	15.80e	3.60bc	71.13e	5.57f	39.03d	112.33a	6.82abcd	2.52e	0.37d	48.67a
Haftysene	66.92b	117.50bc	17.82b	4.22abc	84.98abc	6.37dce	49.17a	105.00cd	7.60ab	3.64a	0.46bc	43.00bcd
Yedogit	57.50g	108.00cd	16.15de	5.00a	67.67e	5.56f	40.90cd	104.33cde	6.23cd	3.38abc	0.55a	39.33f
Shoa	72.25a	91.33d	19.33a	3.73bc	79.33d	6.33cde	48.82a	107.33b	7.18abc	3.08bcd	0.42cd	44.17bcd
Atena	61.42f	132.00ab	16.93bcd	4.50ab	83.55abcd	6.70bc	40.60cd	103.17def	6.04d	2.84de	0.49b	45.67b
Trit	67.00b	133.58ab	16.48cde	4.03bc	80.37cd	6.62bcd	39.12d	106.08bc	6.64bcd	2.98cde	0.46bc	43.33bcd
Mezezo	66.08bc	120.92bc	17.48bc	4.33ab	86.57a	8.06a	40.63cd	103.08edf	7.47ab	3.25abcd	0.42cd	44.67bc
Estayish	64.67cd	149.83a	17.3bc	3.58bc	84.73abc	6.56bcd	43.56bc	102.58ef	7.67a	3.51ab	0.44bc	39.67ef
Agegnehu	63.83de	132.58ab	16.75bcde	4.37ab	80.55bcd	6.02def	42.37bcd	101.75fg	7.17abc	3.26abcd	0.43bc	43.00bcd
Mean	65.49	122.56	17.14	4.16	80.91	6.42	42.64	104.41	7.03	3.19	0.45	42.93
CV (%)	4.14	22.57	7.75	27.71	7.44	11.79	11.39	2.45	17.48	18.55	15.52	8.25
LSD	2.20	22.44	1.08	0.94	4.88	0.61	3.94	2.06	1.00	0.48	0.06	2.87

Values with the same letter in a column are not significantly different ($p\leq0.05$)

Where: BY= above ground dry biomass weight (t/ha), DTH= days to head, DTM= days to maturity, GY= grain yield (t/ha), HI= harvest index, KPS= kernels per spike, PLH= plant height (cm), SL= spike length (cm), SLEPP= no. of spikelets per spike, STC= stand count per m^2, THKW= thousand kernel weight (g), TIPP= no. of effective tillers per plant

Table 6. Mean values of agronomic traits of four locations in the 2010 season.

Lcation	DTH	STC	SLEPP	TIPP	PLH	SL	KPS	DTM	BY	GY	HI	THKW
Maychew	64.61c	127.17a	18.00a	3.07c	83.16c	7.34a	47.31a	98.92c	7.07b	2.87c	0.41b	39.56c
Korem	66.53b	123.00a	18.46a	4.69b	87.15b	6.27b	45.48ab	108.61a	7.58b	4.46a	0.61a	46.06a
Alage	61.94d	108.72b	17.93a	5.91a	100.10a	6.41b	44.89b	101.36b	9.78a	4.14b	0.43b	42.67b
Mugulat	68.89a	131.36a	14.16b	2.98c	53.24d	5.64c	32.86c	108.75a	3.68c	1.29d	0.35c	43.44b
Mean	65.49	122.56	17.14	4.16	80.91	6.42	42.64	104.41	7.03	3.19	0.45	42.93
CV (%)	4.14	22.57	7.75	27.71	7.44	11.79	11.39	2.45	17.48	18.55	15.52	8.25
LSD(5%)	1.27	12.96	0.62	0.54	2.82	0.35	2.27	1.19	0.57	0.28	0.03	1.66

Values with the same letter in a column are not significantly different ($p\leq0.05$)

Where: BY= above ground dry biomass weight (t/ha), DTH= days to head, DTM= days to maturity, GY= grain yield (t/ha), HI= harvest index, KPS= kernels per spike, PLH= plant height (cm), SL= spike length (cm), SLEPP= no. of spikelets per spike, STC= stand count per m^2 , THKW= thousand kernel weight (g), TIPP= no. of effective tillers per plant

Grain yield

Grain yield is the product of number of tillers/plant, thousand kernel weights and number of kernels/spike when each of these characters is measured without error (Johnson *et al.,* 1955) which applies for Haftysene in this experiment. Haftysene, Yidogit, Estayish and Basso were the leading genotypes having relatively high mean grain yield across locations whereas HB-1307, Atena, Trit and Shoa were from the base side of the genotypes and recorded mean grain yield below the grand mean. When locations were compared in terms of grain yield, there was highly significant difference and, it was at Korem where the highest mean grain yield was recorded followed by Alage. The total grain yield averaged over locations was 3.19tha^{-1} whereas grain yield recorded at Mugulat and Maychew was below the grand mean.

Yield related traits

Merch (2000) demonstrate that environmental factors affect the important traits of both grain and biomass yields which produce variable harvest index of genotypes. Some of those main environment factors are water availability (moisture stress and /or water logging), high temperature variation, population density, fertilizer application, and soil acidity and salinity. Estayish, Shedho, Trit, Atena and Agegnehu were with high mean for stand count m^{-2} whereas Himblil and Yidogit highest in tillers per plant. Haftysene, Shoa and Himbilil had the highest number of kernels per spike. Comparing their maturity period Basso was early maturing genotype followed by Agegnehu and Shedeho whereas HB-1307 was late maturing one over all locations. This may reduce its chance to introduce the variety in areas having moisture stress. In terms biomass and grain yield Estayish and Haftysene showed the highest mean performance. These genotypes also have relatively high harvest index which helped for selection of varieties with increased biomass and grain yield. HB-1307 a variety preformed less in all locations had the highest thousand kernel weight. In this study high kernel weight was associated with low yielding genotype but Abay (2008) reported the association of high thousand kernel weights was with low yielding environments. At Mugulat, the relatively high days to maturity, days to heading and stand count, the lower tiller per plant, number of spikelets per spike, spike length, plant height, kernels per spike, biomass and grain yield and low thousand kernel weight was because of the scarcity of rainfal. Gholinezhad *et al.* (2009) also illustrated that increasing the intensity of drought stress reduces yield and yield components.

Kiliç and Yağbasanlar (2010) illustrates that drought stress reduced the number of days to heading, grain filling period, number of days to maturity, plant height, number of spike per m^2, peduncle length, spike length, number of grains per spike, 1000 kernel weight of genotypes. Similar results were obtained in this experiment, genotypes matured earlier in Maychew, as it has lower elevation and relatively high temperature which facilitated the physiological activity of the crop and increased spike length. The other traits are lower in their mean at this location. The mean number of spikletes per spike, grain yield, harvest index thousand kernel weight were highest at Korem. The major factor in this location was suitable rainfall distribution during the growing period. However, mean tillers per plant, plant height and biomass yield were higher in Alage.

Conclusion

The analysis of variance over locations showed a highly significant ($p \leq 0.01$) variation for the genotype effect, environment effects, GEI effect and significant ($p \leq 0.05$) variation for GEI effect of yield and for most of the yield related traits of food barley genotypes. Haftysene, Yidogit, Estayish and Basso were the genotypes with relatively high mean grain yield across locations and they are highly performing genotypes to the area. Among locations, the highest mean grain yield (4.46 tha^{-1}) was recorded at Korem and it was a suited environment to all the genotypes whereas the lowest at Mugulat (1.29 tha^{-1}).

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