

## Genotype x Environment Interaction and Yield Stability of Maize

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**Abstract:** Maize cultivars vary in their response to variable environmental conditions. Twenty maize cultivars were tested at nine locations in Ethiopia (1100 – 2240 masl) in randomized complete block design with three replications for two years to study the nature and magnitude of genotype x environment (G x E) interaction and phenotypic yield stability of the cultivars. Analysis of variance and stability analysis were computed. Variances due to genotypes, years, locations, genotype x year, genotype x location and genotype x year x location interaction were significant ( $P < 0.01$ ). Most of the cultivars had significant deviation mean square ( $S^2_{di}$ ), implying that these cultivars had unstable performance across the testing environments. However, Additive Main Effect and Multiplicative Interaction (AMMI) analysis showed Gibe-1 (mean yield, 7.40 t ha<sup>-1</sup>) had relatively stable performance across the environments. None of the cultivars were the best for grain yield in all environments. BH-660 (mean grain yield, 8.14 t ha<sup>-1</sup>) had a relatively good performance in the mid- to high-altitude (1650 – 2240 m above sea level) areas whereas BH-140 (mean grain yield, 6.65 t ha<sup>-1</sup>) had a good performance in the low-mid to mid-altitude (1100 – 1650 m above sea level) areas, indicating the possibility of developing specific cultivars adapted to mid- and high- or low-mid and mid-altitude areas. However, the top yielding cultivars at each maize agro-ecology were specifically adapted, indicating that, for high yield potential in each maize agro-ecology, a specific breeding program is necessary.

**Keywords:** Environment; Cultivar; Interaction; Stability; *Zea mays*

### 1. Introduction

Changes in relative rankings appear to be an inevitable consequence of growing a set of plant genotypes in even a few locations or seasons. This is especially true in tropical regions where, not only are environmental fluctuations greater, but crops also lack the protection conferred by purchased inputs; thus for plant breeders, large genotype by environment (G x E) interactions impede progress from selection and have important implications for testing and cultivar release programs (Smithson and Grisley, 1992).

In fact, G x E interaction is as much a function of the genotype as they are of the environment and so are partly heritable (Hill, 1975). Statistically, G x E interactions are detected as significantly different patterns of response among the genotypes across environments and biologically, this will occur when the contributions (or level of expression) of the genes regulating the trait differ among environments (BASFORD and COOPER, 1998).

As it is a common phenomenon in the East of Africa (Birhane and Bentayehu, 1989), Ethiopia is a country of great environmental variation (EMA, 1988). Where environmental differences are greater, it may be expected that the G x E interaction will also be greater. As a result, it is not only average performance that is important in genotype evaluation programs but also the magnitude of the interactions (Fehr, 1992; Gauch and Zobel, 1997). Stability of performance is also of special importance in Ethiopia and similar countries where environmental conditions vary considerably and means of modifying the environment are far from adequate. Benti *et al.* (1996) studied G x E interaction and grain yield stability of twelve maize composites and three locally-adapted Kenyan hybrids at six locations in Ethiopia with altitude

ranges of 1100 – 1750 meters above sea level (masl) with sufficient rainfall for two years and found G x E interaction. Wende *et al.* (2004) also studied the G x E interaction of ten locally-developed maize cultivars at five locations (1650 – 2240 masl) in Ethiopia for three years and reported G x E interaction. However, it is not possible to get information on the performance of the maize cultivars across the altitude ranges of 1100 – 2240 masl, the major sub-humid maize growing areas of Ethiopia. Thus, this study intended to study the nature and magnitude of G x E interaction and grain yield stability of twenty maize cultivars at nine locations (1100 – 2240 masl) in Ethiopia for two years.

### 2. Materials and Methods

Twenty different maize cultivars of East African and CIMMYT origin were tested at nine locations situated between 7° 09' N and 11° 16' N latitudes and 36° 00' E and 42° 02' E longitudes in the 1997 and 1998 main cropping seasons. The altitude and annual rainfall of the locations ranged from 1100 – 2240 meters above sea level (masl) and 900 – 1595 mm respectively. The testing locations were: Pawe (1100 masl), Bako (1650 masl), Awassa (1700 masl), Jimma (1750 masl), Areka (1800 masl), Arsi-Negelle (1960 masl), Alemaya (1980 masl) and Adet (2240 masl). The locations represent three of the four major maize-producing mega-environments in Ethiopia; *viz.* low (low-mid) altitude sub-humid zone, mid-altitude sub-humid zone and high altitude sub-humid zone (Birhane and Bentayehu, 1989; Benti *et al.*, 1993).

The cultivars were planted at each location in randomized complete block design with three replications. The experimental unit was a two row plot 5.1 meters long, spaced 75 cm apart and with a plant-to-plant

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distance of 30 cm. All trial management practices were based on the recommendations of each location. Field weight was recorded from all ears in the harvest area. Then grain yield per hectare was calculated using average shelling percentage of 80% and adjusted to 12.5% moisture.

Analysis of variance for each environment and combined analysis of variance over years and locations were computed for grain yield. Bartlett's test, as cited in Gomez and Gomez (1984), was also computed to assess homogeneity of variances prior to combined analysis. The statistical significance of analysis of variance was determined using the F-test.

The stability of yield performance for each cultivar was calculated by regressing the mean yields of individual cultivar on environmental index and calculating the deviations from regression as suggested by Eberhart and Russell (1966). However, regression coefficient ( $b_i$ ) was considered as an indication of the response of the cultivar to varying environments while mean square for deviations from regression ( $S^2_{di}$ ) was used as the criteria of stability as suggested by some authors (Gupta *et al.*, 1974; Becker and Leon, 1988). In addition, the G x E interactions were analyzed using Additive Main effect and Multiplicative Interaction (AMMI) analysis (Crossa *et al.*, 1990; Gauch, 1992) to assess similarity and dissimilarity among testing environments and interaction patterns.

The regression coefficients ( $b_i$ ) were tested for significant difference from unity using t-tests while the significance of the deviations from regression ( $S^2_{di}$ ) from zero was tested by the F-test. The SAS computer program (SAS, 2001) and the AGROBASE software computer program (Agronomix software INC. and AGROBASE, 2000) were used for the analysis of the data.

### 3. Results and Discussion

Analysis of variance for grain yield revealed significant differences ( $P < 0.01$ ) among the cultivars in each environment. Variances due to genotypes (G), years (Y), locations (L), genotype x year, genotype x location and genotype x year x location were significant ( $P < 0.01$ ) (Table 1). The significance of the interaction effects showed that the cultivars had inconsistent performance across the years and locations. A similar result was reported by Lothrop (1989) in which he indicated that environmental changes cause G x E interaction for grain yield.

The partitioning of variance components showed that 53.64% was due to Y x L interaction, 13.84% was due to location, while 8.06% was due to the genotypes (cultivars) (data not shown). This indicated that environment was the greatest source of variation. AMMI analysis also showed that the G x E interaction was significant ( $P < 0.01$ ) and the best-fit model was AMMI2 (Table 1). Interaction Principal Component Analysis score (IPCA1) was significant ( $P < 0.01$ ) and explained 29.06% of the G x E interaction sum of squares. Similarly, the Interaction Principal Component Analysis score (IPCA2) was significant ( $P < 0.01$ ) and explained 22.82%. This showed

that the two IPCAs accounted for the larger portion (51.88%) of the total interaction.

AMMI biplots for grain yield (Figure 1) showed distinct patterns for the testing environments. The high-yielding environments, Alemaya 1997 (AL97), Hirna 1997 (HR97), Awassa 1998 (AW98), Adet 1998 (AD98), Pawe 1998 (PW98) and Bako 1997 (BK97), were in quadrants two and three while the low-yielding environments, Hirna 1998 (HR98), Alemaya 1998 (AL98), Adet 1997 (AD97), Areka 1998 (AR98) and Awassa 1997 (AW97) were in quadrants one and four. AMMI biplots showed that AD98 and AL97 were the most favorable environments for realizing the yield potential of the cultivars while HR98 was the poorest yielding environment. This showed that the performance of the cultivars varied from season to season in some locations.

The result of this experiment showed that the elevation rainfall distribution during the growing period (data not shown) had a great impact on the performance of maize cultivars. For example, Alemaya and Hirna were among the high yielding environments in 1997 whereas they were among the poor yielding environments in 1998 (Figure 1). This could be attributed to the continuous moisture stress after emergence due to shortage of rain in eastern Oromia in 1998. The stress occurred during the vegetative growth period while there was good distribution of rain during the grain filling period. This implied that the data obtained from the two locations in 1998 may not represent the actual yield potential of the normal years. The year effect was also observed at Adet and Awassa in 1997 (Figure 1). Thus, cultivars were exposed to different environments at the same location in different years. Similar results were reported by other authors (Fox and Rosille, 1982; Becker and Leon, 1988). This indicated the necessity of testing elite maize cultivars at least for two years before recommending them for commercial production, especially in areas where rainfall distribution is unreliable.

The mean grain yield of the cultivars across the 18 environments (year-location combination) ranged from 5.71 t ha<sup>-1</sup> in Beletech RC-2 to 8.14 t ha<sup>-1</sup> in BH-660 (Table 2). The ranking of the cultivars varied across the seasons in some locations and altitudinal ranges (data not shown). For example, BH-540 was among the low-yielding in 1997 at Alemaya, while it was the highest yielding in 1998, indicating G x Y interaction. BH-660 was the top-yielding at high altitude and had relatively good performance at mid-altitude testing locations. However, it was out-yielded by BH-530, BH-140 and Gibe-1 at Pawe, low-mid altitude sub-humid zone. Although, BH-530 was the top-yielding at Pawe, it was one of the low-yielding cultivars at the other testing locations, mid- and high-altitude sub-humid zones, whereas BH-140 and Gibe-1 had relatively good performances at low-mid and mid-altitude testing locations. This indicated that the rank of the cultivars varied from one testing location to another testing location, confirming the presence of G x L interaction. Similarly, Wende Abera *et al.* (2004) found

Table 1. Combined analysis of variance and AMMI analysis for grain yield of 20 maize cultivars tested at nine locations over two years in Ethiopia (1997-1998).

Source	df	Mean square
Year (Y)	1	127.54 **
Location (L)	8	80.89**
Y x L	8	313.61**
Replication (L x Y)	36	1.88**
Genotype (G)	19	19.84**
Y x G	19	2.71**
L x G	152	2.05**
Y x L x G	152	1.65**
Error	684	0.49
AMMI		
G x E	323	1.90**
IPCA1	35	4.22**
IPCA2	33	3.52**

\*\*-. Significant at  $P < 0.01$ .

crossover interaction in maize cultivars tested in the mid- and high-altitude areas of Ethiopia (1650 – 2240 masl). This showed that for high yield potential, a specific breeding program is necessary for the low- and high-altitude maize growing areas of Ethiopia. This is similar to the report of Rathore and Gupta (1994) who stated that the presence of crossover interaction is substantial evidence in favor of breeding for specific adaptation.

The superior performance of BH-660 at high elevations could be attributed to its genetic background as its parental lines are developed from Kitale Synthetic- II and Eucador-573, which are adapted to high-altitude transition zones (Benti *et al.*, 1993). On the other hand, BH-530 with CIMMYT tropical maize germplasm in its genetic background (Benti *et al.*, 1997) had a better performance at the lower elevations.

Analysis of responsiveness as measured by regression coefficients (bi) indicated that most of the cultivars had average responsiveness (Table 2). The high-yielding cultivars, BH-660 and Gibe-1 were more responsive ( $b_i > 1$ ) to favorable environmental conditions than the other cultivars. The better response of Gibe-1, as compared to the other open-pollinated cultivars, indicated the possibility of developing open-pollinated cultivars with high mean grain yield under favorable environmental conditions. The old composites, Alemaya composite, UCB and Bako composite, had regression coefficients below unity ( $b_i < 1$ ), indicating their average responsiveness to favorable environmental conditions. In addition, their grain yield means were less than the grand mean, which indicated their inferior performance compared to Gibe-1.

The simple correlation coefficient between mean yields and regression coefficients was calculated and it showed a positive relationship ( $r = 3$ ) indicating the possibility of

breeding responsive cultivars along with high grain yield. Abebe *et al.* (1984) also found a positive relationship between mean grain yields and regression coefficients in sorghum.

Most of the cultivars had significant deviation mean square from linear regression ( $S^2_{di}$ ), implying that these cultivars were unstable across the environments (Table 2). BH-530 had the highest  $S^2_{di}$ . The high yielding cultivars, BH-660 and Gibe-1 also had significant  $S^2_{di}$ , implying unstable performance across the testing environments. In general, when the three adaptability parameters, i.e. mean yield, regression coefficient and deviation mean square from the linear regression were considered, none of the cultivars exhibited general adaptability. Additive Main effect and Multiplicative Interaction (AMMI) analysis also showed differences among the cultivars in their stability performance for grain yield across the testing environments (Table 2).

The closer the IPCA scores (Interaction Principal Component Analysis scores, IPCA1 and IPCA2) to zero, the more stable the cultivars are across the environments (Crossa *et al.*, 1990; Purchase, 1997). When the IPCA scores were considered, Gibe-1 had relatively stable performance across the environments among the high-yielding cultivars (Figure 1).

However, the good performance of BH-660 in the mid- and high-altitude areas and good performance of BH-140 and Gibe-1 in the low-mid and mid altitude areas indicated the possibility of developing maize cultivars adapted to mid- and high-altitude or low-mid and mid-altitude areas. Crossa *et al.* (1990) have also reported similar observations about the performance of specific maize genotypes across altitude ranges.

IPCA1 score (-1.290, 1.757)

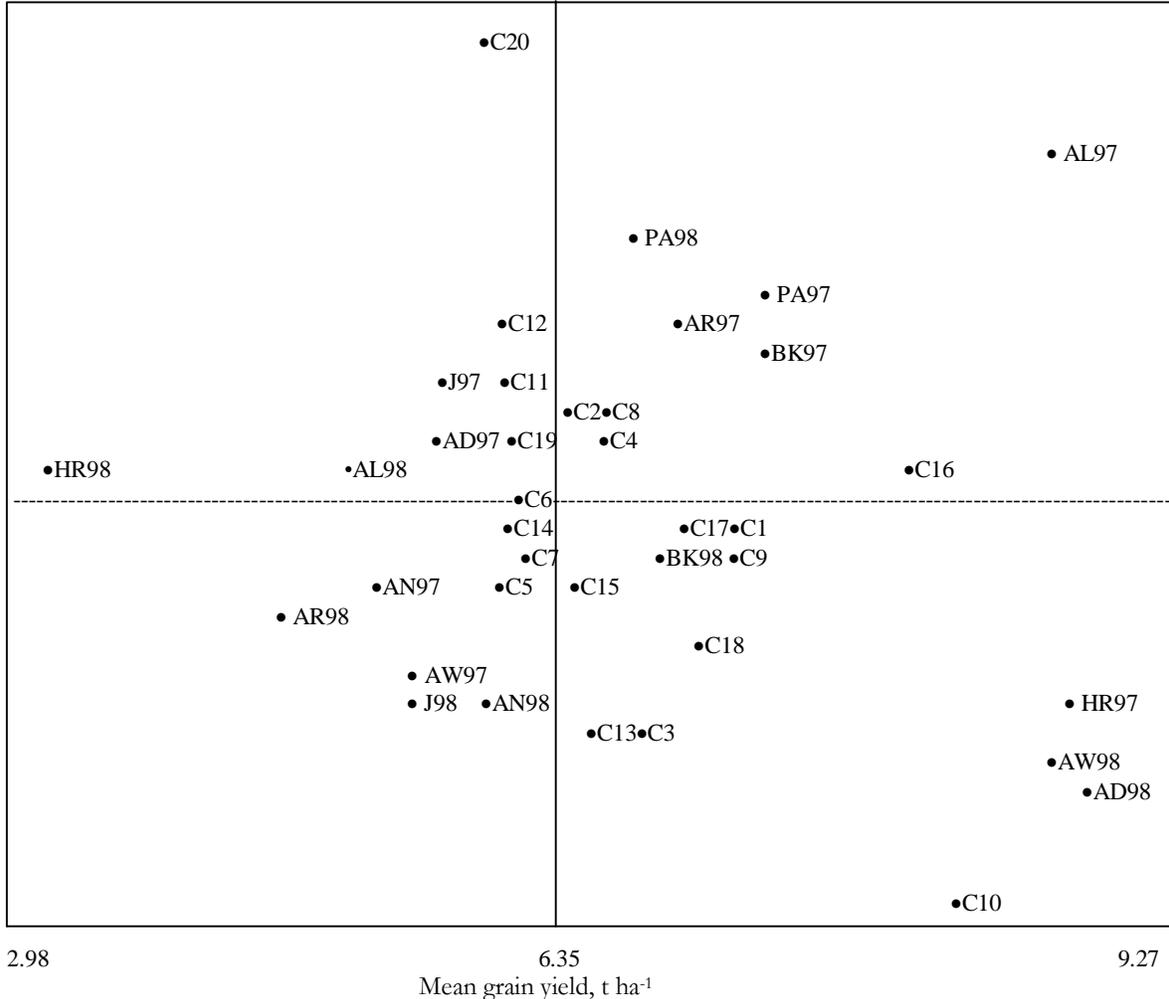


Figure 1. AMMI biplot for grain yield of 20 maize cultivars tested across 18 environments of Ethiopia (9 location, 2 years). Dots on the biplot indicate the correct spot. C=Cultivar, AL=Alemaya, AD=Adet, J=Jimma, BK=Bako, AN=Arsi-Negele, AW=Awassa, HR=Hirna, AR=Areka, PA=Pawe.

The present results demonstrate that, even in areas with sufficient rainfall, elevation has a great impact on the performance of maize cultivars in Ethiopia. It also showed that some specific cultivars, which are adapted to mid- and high- or low-mid and mid-altitude areas, could be developed. However, for high yield potential, a specific breeding program is necessary for each maize-producing agro-ecology of Ethiopia.

The results also indicated that, in some areas, distribution of rainfall during the growing period is the determining factor for the performance of maize cultivars. Thus, in those areas with abnormal distribution of rain in some years, the testing of maize cultivars across the years may help in selecting cultivars which give good yield during the years with even distribution of rain and relatively good performance in a year of uneven distribution of rain.

Table 2. Mean grain yield, regression coefficient (bi), mean square of deviation (S<sup>2</sup>di) and Interaction Principal Component Analysis scores, IPCA1 and IPCA2, of 20 maize cultivars tested at 18 environments in Ethiopia (1997-1998).

	Cultivar	Yield (t ha <sup>-1</sup> )	bi	S <sup>2</sup> di	IPCA1	IPCA2
1	Alemaya Comp. RC-2 <sup>3</sup>	6.88	1.04	34.64**	-0.03	-0.70
2	Alemaya Comp. <sup>2</sup>	6.18	0.85	13.53*	0.40	0.50
3	UCB RC-2 <sup>3</sup>	6.45	0.71	58.61**	-0.71	1.04
4	UCB <sup>2</sup>	6.31	0.89	24.85**	0.18	0.39
5	Beletech RC-2 <sup>3</sup>	5.71	0.95	41.15**	-0.22	-0.54
6	Beletech S <sub>1</sub> C <sub>1</sub> RC-2 <sup>3</sup>	6.05	1.02	9.96	0.05	-0.22
7	Beletech <sup>2</sup>	5.99	1.09	17.46*	-0.17	-0.40
8	Late RC-5 <sup>3</sup>	6.33	0.98	15.23*	0.32	-0.11
9	Synthetic RC-3 <sup>3</sup>	6.67	1.21	52.36**	-0.18	-1.17
10	BH-660 <sup>1</sup>	8.14	1.12	101.70**	-1.29	-0.29
11	EAH-75 <sup>2</sup>	5.79	1.07	45.02**	0.49	0.15
12	Bako Comp. <sup>2</sup>	5.81	0.89	48.60**	0.58	0.64
13	Kuleni <sup>2</sup>	6.38	0.83	17.19*	-0.65	0.57
14	INT-A <sup>3</sup>	5.87	1.03	13.09	-0.09	-0.10
15	INT-B <sup>3</sup>	6.18	1.12	12.72	-0.27	-0.53
16	Gibe-1 <sup>2</sup>	7.40	1.21	30.79**	0.13	0.23
17	BH-140 <sup>1</sup>	6.65	1.03	31.83**	-0.05	0.48
18	BH-540 <sup>1</sup>	6.76	0.87	52.80**	-0.45	0.94
19	A-511 <sup>2</sup>	5.78	1.13	7.26	0.20	-0.21
20	BH-530 <sup>1</sup>	5.80	0.96	158.87**	1.76	0.09
	Mean	6.35				
	CV %	11.03				

\*, \*\* - Significant at  $P < 0.05$  and  $P < 0.01$ , respectively.

<sup>1</sup> - hybrids

<sup>2</sup> - open-pollinated cultivars

<sup>3</sup> - breeding populations

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