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# GGE Biplot for Grain Yield and, Estimation of Variance Components and Heritability of Agronomic Traits for Early Maturing Sorghum (*Sorghum bicolor L.* Moench) Genotypes

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**Genotypes are grown in trials across multiple locations and years, known as multi-environment trials (METs). Genetic performance across these locations is measured as genotype by environment interaction (GEI). Combined analyses of variance showed significant differences for genotypes, environments and genotype by environment (GE). The genotypes G54, G76, G52 and G41 were early flowering and high yielding, and possessed other desirable agronomic traits. The highest heritability was recorded for plant height (PHT), days to 50% flowering (DTF) and grain yield (GY). Among the test locations the most discriminating and representative locations were Sheraro and Meisso stations, respectively. The vertex genotypes in this investigation were G74, G28, G64, G19, G16, G22, G5, G30 and G76. G74 is the winning genotype for the mega-environment which consists of Humera in 2015 (15HM), Meisso in 2015 (15MI) and Sheraro in 2016 (16 SH), while G14 is the winning genotype for Erer in 2116 (16ER) and Meisso in 2016 (16MI) mega-environment and G30 winning genotype for the 15SH mega-environment. Genotypes G41, G54 and G76 are stable and high yielding than the commercial sorghum varieties, G90 (Melkam) and G87 (Dekeba); hence, can be selected as the most favorable genotypes. Thus, based on the graphical interpretation, genotypes G54 and G76 followed by G25, G41 and G74 with high mean yield and stability performances can be considered as ideal genotypes. The G76 had higher than average yield in all environments, whilst it had the highest yield in Sheraro. It was concluded that genotype G76 showed the best stable performance in all locations, suggesting that it is a promising breeding material in future breeding programs of sorghum in Ethiopia. The results obtained through the study provide valuable information on understanding GxE interaction, genotypic variation in response to different diverse environments and application of GGE biplot to analyze GxE interaction to sorghum breeding in Ethiopia. The development of varieties with broad adaptation is strongly supported, rather than location-specific varieties.**

**Key words:** Sorghum, Genotype × environment interaction, GGE biplot, stability, ideal testing environment.

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## INTRODUCTION

Sorghum is a widely adaptable crop though its production has been limited to water and heat-stress areas within subtropics and tropical regions of the world. Sorghum is the main staple food in Ethiopia, ranking fourth after tef, maize, and wheat, both in area coverage, and production (CSA, 2016). The ability of the crop to withstand drought stress with early maturing and give reasonable yields under adverse environmental conditions has secured its importance as a food security crop in arid and semi-arid lowlands (Chalachew *et al*., 2017). Moisture stress contributes to poor crop performance and low yield. Inadequate, unequally distributed, and unpredictable rainfall are usually experienced in drier parts of Ethiopia. Consequently, sorghum productivity is still far below developed countries due to several production constraints and among which lack of appropriate agronomic production packages are detrimental (EIAR, 2014). The effect of moisture stress on crop yield is dependent on the stage of plant development. Anthesis and grain filling stages appear to be most susceptible. Occurrence of drought at these stages may result in reduced yield and/or complete crop failure (Khanna-Chopra *et al*., 1988). Although drought stress at the beginning of the growing season (seedling stage) will severely affect plant establishment, plants will recover soon after the rain falls. Moreover, recently the prevalence of drought has increased, and hence, farmers are increasingly growing early maturing sorghum varieties rather than late maturing sorghum landraces. The populations of growers have a habit of to like high-yielding and early-maturing sorghums that are less susceptible to moisture stressed. In most cases, this wide-ranging of traits is highly correlated genetically, making their immediate improvement easy (Gasura *et al*. 2014). GEI decreases the association between phenotype and genotype, and thus decreases responses to selection during breeding. Besides, GE confounds the recommendation of new varieties from MET and identification of the best testing environment (Yan and Kang, 2002).

The objective of this study was to conducted and analyzed genotype x environment interaction (GEI) for yield and other traits in early maturing sorghum genotypes at four locations within Ethiopia during two cropping seasons. Also, GGE biplot analysis for grain yield was applied to determine the superior genotypes with adaptability to diverse environments and the suitable location for selecting genotypes with better performance.

## MATERIALS AND METHODS

### Description of Study Areas

The experiments were conducted at Sheraro, Miesso and Erer during the cropping season of 2015-2016 (July-November) and in one location (Humera) for one cropping season in 2015. The field experiments were carried out during kiremt season in 2015 to 2016 at Sheraro (14º24’N, 37º56’E, 1006 m elevation), Meisso (9º13’N, 40º45’E, 1400 m elevation), Humera (14° 17' 26N, 36° 36' 29E, 573m elevation) and Erer (8°10'N, 42°15'E,1297 m elevation) in the dry lowland of Ethiopia. The average annual rainfall of Sheraro, Meisso, Humera and Erer were 615, 572, 611 and 500 mm, respectively; whereas the average annual temperature Sheraro, Meisso, Humera and Erer are 26.4ºC, 22.8ºC, 27.7 ºC and 26.5ºC, respectively.

### Genetic Materials

The 90 experimental genotypes were developed for high yield and early maturing are suitable for either food or biomass yield for animal feed. These sorghum genotypes were selected during the early stages of breeding based on these highly heritable traits. The two genotypes (Melkam and Dekeba) are the released commercial sorghum varieties grown in Ethiopia. The commercial variety Melkam is known for its high yield (5.8 t ha$^{-1}$) under optimal conditions. The variety Dekeba is suitable for drought areas, where it can maintain a guaranteed yield of about 4.5 t ha$^{-1}$. (Table 1)

**Table 1**. Description of the 90 sorghum genotypes evaluated in seven environments during 2015 and 2016 cropping seasons.

| No | Genotype | Pedigree | No | Genotype | Pedigree |
|---|---|---|---|---|---|
| 1 | 12MW6146 | WSV 387 X E-36-1 | 46 | 14MWLSDT7145 | WSV387/E-36-1 |

**Table 1**. Continuation

| | | | | | |
|---|---|---|---|---|---|
| 2 | 12MW6161 | WSV 387 X E-36-1 | 47 | 14MWLSDT7157 | WSV387/E-36-1 |
| 3 | 12MW6243 | WSV 387 X 76T1#23 | 48 | 14MWLSDT7176 | WSV387/E-36-1 |
| 4 | 12MW6251 | WSV 387 X 76T1#23 | 49 | 14MWLSDT7177 | WSV387/E-36-1 |
| 5 | 12MW6253 | WSV 387 X 76T1#23 | 50 | 14MWLSDT7191 | WSV387/E-36-1 |
| 6 | 12MW6296 | WSV 387 X 76T1#23 | 51 | 14MWLSDT7193 | WSV387/E-36-1 |
| 7 | 12MW6299 | WSV 387 X 76T1#23 | 52 | 14MWLSDT7196 | WSV387/76T1#23 |
| 8 | 12MW6302 | WSV 387 X 76T1#23 | 53 | 14MWLSDT7201 | WSV387/76T1#23 |
| 9 | 12MW6398 | LocalBulk(White)/SRN-39/B-35 | 54 | 14MWLSDT7207 | WSV387/76T1#23 |
| 10 | 12MW6420 | LocalBulk(White)/SRN-39/E36-1 | 55 | 14MWLSDT7209 | WSV387/76T1#23 |
| 11 | 12MW6427 | LocalBulk(White)/SRN-39/E36-1 | 56 | 14MWLSDT7234 | Macia/E-36-1 |
| 12 | 12MW6429 | LocalBulk(White)/SRN-39/E36-1 | 57 | 14MWLSDT7238 | Macia/E-36-1 |
| 13 | 12MW6437 | LocalBulk(White)/SRN-39/76T1#23 | 58 | 14MWLSDT7241 | Macia/E-36-1 |
| 14 | 12MW6440 | LocalBulk(White)/SRN-39/76T1#23 | 59 | 14MWLSDT7251 | Macia/E-36-1 |
| 15 | 12MW6444 | LocalBulk(White)/SRN-39/76T1#23 | 60 | 14MWLSDT7253 | Macia/E-36-1 |
| 16 | 12MW6447 | CR:35:5/ICSV-1005/76T1#23 | 61 | 14MWLSDT7278 | Macia/E-36-1 |
| 17 | 12MW6454 | CR:35:5/ICSV-1005/76T1#23 | 62 | 14MWLSDT7279 | Macia/E-36-1 |
| 18 | 12MW6457 | CR:35:5/ICSV-1005/76T1#23 | 63 | 14MWLSDT7308 | Teshale/B-35 |
| 19 | 12MW6460 | CR:35:5/ICSV-1005/76T1#23 | 64 | 14MWLSDT7310 | Teshale/B-35 |

**Table 1**. Continuation

| | | | | | |
|---|---|---|---|---|---|
| 20 | 12MW6467 | IESV92084/E36-1 | 65 | 14MWLSDT7311 | Teshale/B-35 |
| 21 | 12MW6469 | IESV92084/E36-1 | 66 | 14MWLSDT7322 | SDSL2690-2/76T1#23 |
| 22 | 12MW6471 | IESV92084/E36-1 | 67 | 14MWLSDT7324 | SDSL2690-2/76T1#23 |
| 23 | 12MW6474 | IESV92084/E36-1 | 68 | 14MWLSDT7325 | SDSL2690-2/76T1#23 |
| 24 | 13MWF6#6035 | 2001 MS 7007 X SRN-39 | 69 | 14MWLSDT7329 | SDSL2690-2/76T1#23 |
| 25 | 13MWF6#6037 | 2001 MS 7007 X SRN-39 | 70 | 14MWLSDT7332 | SDSL2690-2/76T1#23 |
| 26 | 13MWF6#6045 | 2001 MS 7007 X Framida | 71 | 14MWLSDT7354 | MR812/76T1#23 |
| 27 | 13MWF6#6077 | ICSR 24010 X Brihan | 72 | 14MWLSDT7356 | MR812/76T1#23 |
| 28 | 14MWLSDT7026 | WSV387/76T1#23 | 73 | 14MWLSDT7362 | 2005MI5060/B-35 |
| 29 | 14MWLSDT7029 | WSV387/76T1#23 | 74 | 14MWLSDT7364 | 2005MI5060/B-35 |
| 30 | 14MWLSDT7031 | WSV387/76T1#23 | 75 | 14MWLSDT7388 | WSV387/76T1#23 |
| 31 | 14MWLSDT7033 | WSV387/76T1#23 | 76 | 14MWLSDT7395 | MR812/76T1#23 |
| 32 | 14MWLSDT7034 | WSV387/76T1#23 | 77 | 14MWLSDT7400 | WSV387/76T1#23 |
| 33 | 14MWLSDT7035 | WSV387/76T1#23 | 78 | 14MWLSDT7401 | WSV387/76T1#23 |
| 34 | 14MWLSDT7036 | WSV387/76T1#23 | 79 | 14MWLSDT7402 | WSV387/76T1#23 |
| 35 | 14MWLSDT7040 | WSV387/76T1#23 | 80 | 14MWLSDT7405 | Macia/76T1#23 |
| 36 | 14MWLSDT7042 | WSV387/76T1#23 | 81 | 14MWLSDT7410 | ICSR24010/B-35 |
| 37 | 14MWLSDT7060 | Macia/76T1#23 | 82 | 14MWLSDT7413 | WSV387/E-36-1 |
| 38 | 14MWLSDT7073 | SDSL2690-2/76T1#23 | 83 | 14MWLSDT7425 | MR812/B-35 |
| 39 | 14MWLSDT7074 | SDSL2690-2/76T1#23 | 84 | 2005MI5064 | WSV387/P9404 |
| 40 | 14MWLSDT7098 | MR812/76T1#23 | 85 | 2005MI5065 | WSV387/P9405 |

**Table 1**. Continuation

| | | | | | |
|---|---|---|---|---|---|
| 41 | 14MWLSDT7100 | MR812/76T1#23 | 86 | 2005MI5069 | M36121/P9402 |
| 42 | 14MWLSDT7114 | 2005MI5060/E-36-1 | 87 | Dekeba | ICSR24004 |
| 43 | 14MWLSDT7115 | ICSR24010/B_35 | 88 | ETSC300001 | Teshale/B35//Teshale |
| 44 | 14MWLSDT7129 | ICSR24010/E-36-1 | 89 | ETSC300002 | Teshale/E36-1//Teshale |
| 45 | 14MWLSDT7138 | WSV387/E-36-1 | 90 | Melkam | WSV387 |

## Experimental Design and Crop Management

The 90 sorghum genotypes were planted in Randomized Complete Block Design (RCBD) in row column arrangement with two replications. A plot consisted of three rows of 5 m length and inter-row spacing of 0.75 m. The sorghum genotypes were planted at the rate of 10 kg ha$^{-1}$ (88,888 plants ha$^{-1}$). Phosphorus and nitrogen fertilizers were applied at the recommended rates of 100 kg-ha$^{-1}$ and 50 kg-ha$^{-1}$ in the form of diammonium phosphate (DAP) and Urea, respectively. The DAP was applied during planting in the seed furrow. All plots were top-dressed with Urea when the plants were 30 cm tall. The experiments were conducted in rain fed seasons in all tested sites. Weeds were controlled using hand weeding.

## Data Collection

Data were collected on days to 50% flowering, plant height, days to physiological maturity and grain yield. Plant height was measured in centimeters from the base of the plant up to the last flag leaf. Days to 50% flowering were recorded from the date at which 50% of plants in the plot give flower. Days to physiological maturity were recorded from the date of planting until the formation of the black layer on the sorghum grain. Grain yield was measured in grams per plot and then converted to kilogram per hectare and 1000 kernel weights (TKW) (g) were recorded as an average weight of one thousand counted kernels obtained from a composite grain sample harvested from a plot at base moisture (12.5%) adjustment in quantity due to a change in moisture content (Schulz *et al.*, 1995).

## Data Analyses

GE analysis of variance (ANOVA) was done on grain yield and related agronomic traits using a mixed model (where genotypes and years were fixed while locations, replications, blocks and error were random) in Genstat software version13 (Genstat, 2010). The following model for the combined ANOVA was used:

$$Y_{ijkm(l)=}\ \mu + r_l(pt)_{jk} + b_m(ptr)_{jkl} + g_i + p_j + t_k + (gp)_{ij} + (gt)_{ik} + (pt)_{jk} + (gpt)_{ijk} + e_{ijkm(l)}$$

where $Y_{ijkm(l)}$ is the yield of the $i$th genotype in the $j$th location and the $k$th year in the $m$th block within the $l$th replication, $\mu$ is the grand mean ,$r_l\ (pt)_{jk}$ is the effect of the $l$th replication within locations and years, $b_m(ptr)_{jkl}$ is the effect of the $m$th block within the $l$th replication that is also within locations and years, $g_i$, $p_j$ and $t_k$ are the main effects of the genotype, locations and years, $(gp)_{ij}$, $(gt)_{ik}$, $(pt)_{jk}$ are the first order interactions and $(gpt)_{ijk}$is the second order interaction, and finally $e_{ijkm(l)}$ is the pooled error term. The terms $i$ =1, 2, 3 . . . 90; j=1, 2, 3, 4; k =1, 2; l = 1, 2, 3 and m = 1, 2, 3.

The suitable F-test for a mixed model that involves fixed genotypes and years, and location comparison biplot for classifying the most discriminating and representative locations were produced using the suitable SVP methods (Yan and Kang, 2002).

The statement used for the combined trials is that the effect of random interactions sums to zero across each level of a fixed factor (Moore and Dixon 2014). The mean squares for genotypes, environments and GE were tested compared to the pooled error mean square, while locations, years and locations×years were tested compared to the mean square of replications within locations and years (McIntosh, 1983).

## RESULTS AND DISCUSIONS

### Combined ANOVA

The combined analysis of variance (ANOVA) for all traits was showed significant differences ($P < 0.01$) for environments, genotypes and genotypes x environments interaction (Table 2).

The results of analysis of variance for the effects of G, E and their interactions G x E, selected sorghum agronomic traits pooled across environments are presented in Table 2. Mean of squares of all the characters study showed highly significant difference ($P < 0.01$) among the tested sorghum genotypes and environments. This study showed the sorghum genotypes were significantly more affected by interactions.

**Table 2**. Mean square values of grain yield and related traits of sorghum genotypes, environments and interaction tested.

| Source | DF | DTF | PHT | TSW | GY |
|---|---|---|---|---|---|
| Genotype(G) | 89 | 60.15** | 3692.71** | 29.21** | 2029001** |
| Environment(E) | 6 | 11747.34** | 251805.55** | 9318.06** | 69887520** |
| Replication/E | 7 | 79.36** | 1614.05** | 27.86ns | 2925900** |
| G*E | 534 | 38.03** | 1013.42** | 24.91** | 678796** |
| Residuals | | 8.82 | 412.74 | 17.73 | 460653 |

**, *: significant probability at 1 and 5% levels, respectively.

DF= Days to 50% flowering, PHT= Plant height (m), TSW= 1000 seed weight (g), GY= Grain yield (kg ha$^{-1}$).

### Mean performance, Variance Components and Heritability Estimates of Genotypes across the environments

Genotypes significantly varied for all the parameters. The study was shown that 11 genotypes (G29, G39, G40, G42, G52, G54, G69, G71, G72, G77, G85) were found to have higher mean grain yield and earlier flowering time than from the high yielder standard check Melkam in combined environments in Table 3, and this indicate positive relationship between grain yields with days to 50% flowering. These types of genotypes are very important in moisture stressed sorghum growing areas. Hence, there is an opportunity to find genotypes, among the tested entries, that perform better than the existing grain sorghum varieties in moisture stressed areas and/or to use them as parents for hybridization program. The genotypes G9, G12, G16, G17, G19 and G44 had late flowering time and least grain yield among the tested sorghum genotypes, these types of genotypes are not important for drought stressed environments (Table 3).

Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were observed higher for grain yield (60.98 % and 53.62%, respectively) followed by plant height (24.69% and 23.27%, respectively). PCV and GCV had lower days to 50% flowering (7.14% and 6.59%, respectively). In general, the PCV values were greater than the GCV values for all characters studied (Table 3). This indicates that high contribution of the environmental variance to the phenotypic variance. According to Deshmukh *et al.* (1986) PCV and GCV values greater than 20% are regarded as high, whereas values less than 10% are considered to be low and values between 10% and 20% to be medium.

Heritability in broad sense was high for plant height, days to 50% flowering and grain yield (88.82%, 85.34% and 77.30%, respectively). According to Singh (2001), if heritability (broad sense) of a character is very high, say 75% or more, selection for such characters could be fairly easy. This may indicate that the genotypes have a broad base genetic background as well as the potential to respond positively to selection for plant height, days to 50% flowering and grain yield. Thus, in the present study, selection of genotypes based on plant height, days to flowering and grain yield traits would be more satisfactory to increase the earliness, biomass and grain yield of sorghum.

The GE variation in this study was due to expectable factors (location) and changeable factors (years). In this study, the GE could be attributed to diverse factors like soil types, rainfall patterns, and temperatures. The economical option is to develop sorghum varieties adapted to the target environments. However, the locations have no clearly defined boundaries and farmers have of influencing each other in the choice of variety that is grown, the development of varieties with broad adaptation is strongly supported, rather than location-specific varieties (Chhetri *et al.*, 2012).

**Table 3**. Combined mean, variance and heritability performance of the 90 genotypes studied for four characters.

| Code | Genotype | DTF | PHT | TSW | GY |
|---|---|---|---|---|---|
| G1 | 12MW6146 | 75.58 | 147.57 | 26.85 | 1828.98 |
| G2 | 12MW6161 | 76.50 | 177.86 | 25.60 | 1967.12 |
| G3 | 12MW6243 | 76.00 | 143.79 | 27.60 | 1785.23 |
| G4 | 12MW6251 | 78.75 | 184.71 | 31.31 | 2133.40 |
| G5 | 12MW6253 | 74.58 | 174.43 | 29.88 | 1944.89 |
| G6 | 12MW6296 | 77.50 | 140.57 | 29.50 | 1367.29 |
| G7 | 12MW6299 | 81.67 | 145.07 | 25.90 | 2014.59 |
| G8 | 12MW6302 | 78.08 | 137.07 | 28.90 | 1986.06 |
| G9 | 12MW6398 | 78.83 | 183.43 | 31.39 | 937.85 |
| G10 | 12MW6420 | 79.92 | 173.71 | 30.78 | 1925.71 |
| G11 | 12MW6427 | 79.08 | 176.64 | 30.65 | 1285.82 |
| G12 | 12MW6429 | 82.58 | 190.36 | 26.40 | 984.03 |
| G13 | 12MW6437 | 77.08 | 165.57 | 27.35 | 1638.18 |
| G14 | 12MW6440 | 79.42 | 194.21 | 26.45 | 1899.21 |
| G15 | 12MW6444 | 80.25 | 188.36 | 26.60 | 1909.34 |
| G16 | 12MW6447 | 80.42 | 161.14 | 30.94 | 655.16 |
| G17 | 12MW6454 | 78.42 | 179.57 | 28.28 | 744.00 |
| G18 | 12MW6457 | 79.33 | 177.57 | 28.10 | 1248.78 |
| G19 | 12MW6460 | 78.33 | 192.71 | 28.75 | 755.31 |
| G20 | 12MW6467 | 79.17 | 180.14 | 26.85 | 1054.41 |
| G21 | 12MW6469 | 80.50 | 183.50 | 33.00 | 1042.13 |
| G22 | 12MW6471 | 79.75 | 178.00 | 31.38 | 969.40 |
| G23 | 12MW6474 | 78.58 | 173.43 | 28.87 | 1168.06 |
| G24 | 13MWF6#6035 | 77.42 | 159.93 | 27.40 | 1980.96 |
| G25 | 13MWF6#6037 | 78.00 | 157.43 | 25.99 | 2287.29 |
| G26 | 13MWF6#6045 | 75.08 | 152.07 | 27.40 | 1397.03 |
| G27 | 13MWF6#6077 | 76.92 | 148.00 | 25.90 | 1657.67 |
| G28 | 14MWLSDT7026 | 74.83 | 176.79 | 28.90 | 1977.01 |
| G29 | 14MWLSDT7029 | 74.00 | 169.36 | 29.65 | 1811.89 |
| G30 | 14MWLSDT7031 | 75.30 | 174.86 | 30.95 | 2121.79 |
| G31 | 14MWLSDT7033 | 76.33 | 170.21 | 28.45 | 1870.76 |
| G32 | 14MWLSDT7034 | 78.25 | 182.14 | 27.70 | 1915.66 |
| G33 | 14MWLSDT7035 | 77.42 | 184.50 | 29.28 | 1700.44 |
| G34 | 14MWLSDT7036 | 75.33 | 172.07 | 31.11 | 1871.31 |
| G35 | 14MWLSDT7040 | 76.33 | 178.29 | 28.35 | 1523.32 |
| G36 | 14MWLSDT7042 | 75.00 | 167.79 | 27.05 | 1603.37 |
| G37 | 14MWLSDT7060 | 75.42 | 144.36 | 27.40 | 1834.83 |
| G38 | 14MWLSDT7073 | 76.50 | 187.29 | 26.15 | 1400.64 |
| G39 | 14MWLSDT7074 | 72.33 | 168.00 | 29.75 | 1802.05 |
| G40 | 14MWLSDT7098 | 73.58 | 171.64 | 29.00 | 1705.31 |
| G41 | 14MWLSDT7100 | 74.58 | 187.21 | 29.00 | 2176.44 |
| G42 | 14MWLSDT7114 | 72.08 | 162.50 | 35.44 | 2008.02 |
| G43 | 14MWLSDT7115 | 76.33 | 158.36 | 28.30 | 1597.78 |
| G44 | 14MWLSDT7129 | 81.42 | 201.21 | 29.50 | 928.61 |
| G45 | 14MWLSDT7138 | 76.67 | 160.79 | 30.38 | 1954.28 |

**Table 3.** Continuation

| | | | | | |
|---|---|---|---|---|---|
| G46 | 14MWLSDT7145 | 79.67 | 187.57 | 28.44 | 1437.06 |
| G47 | 14MWLSDT7157 | 78.00 | 190.57 | 29.25 | 1663.86 |
| G48 | 14MWLSDT7176 | 78.08 | 216.86 | 30.33 | 1871.72 |
| G49 | 14MWLSDT7177 | 75.42 | 177.00 | 31.44 | 1690.28 |
| G50 | 14MWLSDT7191 | 76.60 | 162.50 | 29.50 | 1204.47 |
| G51 | 14MWLSDT7193 | 75.00 | 165.00 | 29.75 | 1909.66 |
| G52 | 14MWLSDT7196 | 71.75 | 142.71 | 27.40 | 2167.01 |
| G53 | 14MWLSDT7201 | 79.08 | 200.71 | 27.40 | 1768.61 |
| G54 | 14MWLSDT7207 | 74.17 | 182.64 | 28.45 | 2264.52 |
| G55 | 14MWLSDT7209 | 75.42 | 170.50 | 29.95 | 1323.62 |
| G56 | 14MWLSDT7234 | 79.75 | 165.29 | 28.28 | 1806.94 |
| G57 | 14MWLSDT7238 | 78.17 | 177.86 | 31.71 | 1587.88 |
| G58 | 14MWLSDT7241 | 76.58 | 169.64 | 30.19 | 1326.31 |
| G59 | 14MWLSDT7251 | 78.00 | 180.86 | 28.50 | 1552.97 |
| G60 | 14MWLSDT7253 | 79.50 | 180.43 | 29.85 | 1028.98 |
| G61 | 14MWLSDT7278 | 74.75 | 162.64 | 30.80 | 1852.47 |
| G62 | 14MWLSDT7279 | 75.33 | 191.93 | 28.80 | 1467.09 |
| G63 | 14MWLSDT7308 | 76.50 | 193.00 | 29.80 | 1393.81 |
| G64 | 14MWLSDT7310 | 78.08 | 174.07 | 29.70 | 1309.35 |
| G65 | 14MWLSDT7311 | 79.08 | 193.21 | 29.00 | 1615.31 |
| G66 | 14MWLSDT7322 | 74.58 | 184.93 | 27.50 | 1699.55 |
| G67 | 14MWLSDT7324 | 76.08 | 206.00 | 28.55 | 2139.81 |
| G68 | 14MWLSDT7325 | 77.92 | 192.50 | 29.00 | 1609.99 |
| G69 | 14MWLSDT7329 | 73.92 | 187.07 | 29.25 | 1995.31 |
| G70 | 14MWLSDT7332 | 76.25 | 175.29 | 31.50 | 1994.73 |
| G71 | 14MWLSDT7354 | 73.42 | 150.79 | 28.35 | 1951.96 |
| G72 | 14MWLSDT7356 | 73.20 | 162.43 | 25.65 | 1812.87 |
| G73 | 14MWLSDT7362 | 77.42 | 157.50 | 29.40 | 1415.09 |
| G74 | 14MWLSDT7364 | 78.00 | 184.43 | 30.45 | 2247.20 |
| G75 | 14MWLSDT7388 | 77.67 | 176.21 | 30.35 | 1746.69 |
| G76 | 14MWLSDT7395 | 75.58 | 176.64 | 30.85 | 2351.44 |
| G77 | 14MWLSDT7400 | 73.33 | 178.21 | 30.05 | 1696.77 |
| G78 | 14MWLSDT7401 | 75.17 | 181.36 | 30.65 | 1921.15 |
| G79 | 14MWLSDT7402 | 74.92 | 202.93 | 28.85 | 1122.46 |
| G80 | 14MWLSDT7405 | 75.75 | 202.21 | 29.10 | 1780.35 |
| G81 | 14MWLSDT7410 | 77.50 | 159.50 | 29.00 | 1784.48 |
| G82 | 14MWLSDT7413 | 79.92 | 156.57 | 35.45 | 1791.30 |
| G83 | 14MWLSDT7425 | 75.67 | 179.79 | 28.65 | 1544.80 |
| G84 | 2005MI5064 | 79.08 | 180.07 | 30.90 | 1899.95 |
| G85 | 2005MI5065 | 74.42 | 163.57 | 29.70 | 1614.87 |
| G86 | 2005MI5069 | 75.17 | 177.50 | 31.00 | 1887.20 |
| G87 | Dekeba | 72.08 | 149.07 | 27.10 | 1407.26 |
| G88 | ETSC300001 | 78.67 | 175.36 | 25.90 | 1188.30 |
| G89 | ETSC300002 | 76.17 | 187.00 | 30.20 | 1945.39 |
| G90 | Melkam | 74.50 | 149.79 | 30.65 | 1485.05 |
| | **Mean** | **76.83** | **174.07** | **29.12** | **1651.64** |
| | LSD(5%) | 2.41 | 15.08 | 3.78 | 503.77 |
| | $\sigma^2$g | 25.67 | 1639.98 | 8.11 | 784174.00 |
| | $\sigma^2$p | 30.08 | 1846.36 | 16.98 | 1014500.50 |
| | $\sigma^2$e | 4.41 | 206.37 | 8.87 | 230326.50 |
| | PCV% | 7.14 | 24.69 | 14.15 | 60.98 |
| | GCV% | 6.59 | 23.27 | 9.78 | 53.62 |
| | H% | 85.34 | 88.82 | 47.79 | 77.30 |

$\sigma^2$g, $\sigma^2$p, $\sigma^2$e, PCV, GCV and H are variances due to genotype, phenotype and error, phenotypic coefficient of variation, genotypic coefficient of variation and broad sense heritability, respectively.

DF= Days to 50% flowering, PHT= Plant height (m), TSW= 1000 seed weight (g), GY= Grain yield (kg ha$^{-1}$).

**Table 4**. Mean yield (kg ha$^{-1}$) of 90 early sorghum genotypes tested at seven environments in 2015 and 2016.

| Code | *Genotype* | 15ER | 15HM | 15MI | 15SH | 16ER | 16MI | 16SH | Mean |
|---|---|---|---|---|---|---|---|---|---|
| **G1** | ***12MW6146*** | 1288.65 | 1569.33 | 1934.2 | 3068.67 | 730 | 1765.33 | 2446.67 | 1828.98 |
| **G2** | ***12MW6161*** | 916 | 1393.67 | 1622.4 | 3146 | 1100 | 2235.13 | 3356.67 | 1967.12 |
| **G3** | ***12MW6243*** | 1314 | 2125.67 | 1282.4 | 1920 | 1130 | 2534.53 | 2190 | 1785.23 |
| **G4** | ***12MW6251*** | 822 | 1741.67 | 2110.2 | 2525.34 | 1320 | 2767.93 | 3646.67 | 2133.40 |
| **G5** | ***12MW6253*** | 504 | 1464 | 1776.8 | 4571.34 | 1200 | 2724.73 | 1373.33 | 1944.89 |
| **G6** | ***12MW6296*** | 1746.65 | 2222 | 774.47 | 899.33 | 1210 | 1378.6 | 1340 | 1367.29 |
| **G7** | ***12MW6299*** | 650 | 1493 | 1046.8 | 4330.67 | 1320 | 2525 | 2736.67 | 2014.59 |
| **G8** | ***12MW6302*** | 1016 | 1038.33 | 1656 | 3563.33 | 1940 | 1762.07 | 2926.67 | 1986.06 |
| **G9** | ***12MW6398*** | 128 | 160.67 | 596.13 | 1668.67 | 1190 | 1471.47 | 1350 | 937.85 |
| **G10** | ***12MW6420*** | 1027.35 | 1416.67 | 782.53 | 2874 | 1890 | 3052.73 | 2436.67 | 1925.71 |
| **G11** | ***12MW6427*** | 520 | 736 | 1993.07 | 1519.34 | 500 | 2082.33 | 1650 | 1285.82 |
| **G12** | ***12MW6429*** | 914.7 | 836.33 | 553.8 | 1908 | 920 | 1282.07 | 473.33 | 984.03 |
| **G13** | ***12MW6437*** | 739.3 | 901 | 2481.6 | 1605.34 | 1560 | 1886.67 | 2293.33 | 1638.18 |
| **G14** | ***12MW6440*** | 1414.65 | 850 | 1333.93 | 3913.33 | 1370 | 2642.53 | 1770 | 1899.21 |
| **G15** | ***12MW6444*** | 662 | 1119.67 | 1489.47 | 3511.34 | 1200 | 2469.6 | 2913.33 | 1909.34 |
| **G16** | ***12MW6447*** | 610 | 97 | 195.07 | 1890.67 | 950 | 736.73 | 106.67 | 655.16 |
| **G17** | ***12MW6454*** | 394.65 | 774.33 | 261.87 | 2258.67 | 510 | 781.8 | 226.67 | 744.00 |
| **G18** | ***12MW6457*** | 352.65 | 949.33 | 434.27 | 1776 | 1100 | 935.87 | 3193.33 | 1248.78 |
| **G19** | ***12MW6460*** | 506 | 325.67 | 823.87 | 726.67 | 910 | 828.27 | 1166.67 | 755.31 |
| **G20** | ***12MW6467*** | 817.3 | 392.67 | 855.33 | 2291.34 | 890 | 1664.27 | 470 | 1054.42 |
| **G21** | ***12MW6469*** | 648 | 0 | 796.33 | 992 | 800 | 2975.27 | 1083.33 | 1042.13 |
| **G22** | ***12MW6471*** | 203.35 | 37.33 | 331.67 | 3687.34 | 230 | 1069.47 | 1226.67 | 969.40 |
| **G23** | ***12MW6474*** | 1522 | 253.07 | 1341.73 | 1779.34 | 1230 | 1863.6 | 186.67 | 1168.06 |
| **G24** | ***13MWF6#6035*** | 1061.3 | 2144.33 | 958.8 | 2436.67 | 1510 | 2488.93 | 3266.67 | 1980.96 |
| **G25** | ***13MWF6#6037*** | 1034 | 1787.67 | 2100.73 | 4014 | 1410 | 2327.93 | 3336.67 | 2287.29 |
| **G26** | ***13MWF6#6045*** | 1180.7 | 1208 | 872.67 | 1757.33 | 1410 | 1627.2 | 1723.33 | 1397.03 |
| **G27** | ***13MWF6#6077*** | 564 | 725 | 1333.07 | 2022.67 | 1580 | 2332.27 | 3046.67 | 1657.67 |
| **G28** | ***14MWLSDT7026*** | 846 | 1753.67 | 2017.33 | 1499.33 | 1130 | 2456.07 | 4136.67 | 1977.01 |
| **G29** | ***14MWLSDT7029*** | 1209.3 | 1419.67 | 2117.47 | 2119.34 | 1250 | 2570.8 | 1996.67 | 1811.89 |
| **G30** | ***14MWLSDT7031*** | 978 | 994 | 1575.87 | 4754.67 | 1510 | 2576.67 | 2463.33 | 2121.79 |

**Table 4.** Continuation

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **G31** | ***14MWLSDT7033*** | 1052 | 1532.33 | 1565.8 | 3019.33 | 1590 | 2412.53 | 1923.33 | 1870.76 |
| **G32** | ***14MWLSDT7034*** | 1601.3 | 1044.77 | 1767.93 | 2976.67 | 920 | 2712.27 | 2386.67 | 1915.66 |
| **G33** | ***14MWLSDT7035*** | 991.3 | 339 | 2076.8 | 2880.67 | 590 | 1985.33 | 3040 | 1700.44 |
| **G34** | ***14MWLSDT7036*** | 948 | 1373.33 | 2239.53 | 2530.67 | 1070 | 2541 | 2396.67 | 1871.31 |
| **G35** | ***14MWLSDT7040*** | 650 | 867.33 | 2393.33 | 1167.34 | 1500 | 2331.93 | 1753.33 | 1523.32 |
| **G36** | ***14MWLSDT7042*** | 932.65 | 779.33 | 1558.53 | 1294 | 1460 | 2195.73 | 3003.33 | 1603.37 |
| **G37** | ***14MWLSDT7060*** | 890 | 1319 | 2316.93 | 2018.67 | 1330 | 3022.53 | 1946.67 | 1834.83 |
| **G38** | ***14MWLSDT7073*** | 864.65 | 1158.67 | 1837.07 | 1837.34 | 790 | 1523.4 | 1793.33 | 1400.64 |
| **G39** | ***14MWLSDT7074*** | 830.65 | 1807.67 | 1488.67 | 2497.33 | 1210 | 2406.73 | 2373.33 | 1802.05 |
| **G40** | ***14MWLSDT7098*** | 873.3 | 1334.67 | 1727.6 | 1445.34 | 1320 | 2092.93 | 3143.33 | 1705.31 |
| **G41** | ***14MWLSDT7100*** | 847.35 | 1943 | 1284.07 | 3374.67 | 1830 | 2329.33 | 3626.67 | 2176.44 |
| **G42** | ***14MWLSDT7114*** | 1674 | 1148.67 | 1510.6 | 2461.34 | 1110 | 2648.2 | 3503.33 | 2008.02 |
| **G43** | ***14MWLSDT7115*** | 151.3 | 1069.33 | 956.8 | 1888.67 | 1750 | 2445 | 2923.33 | 1597.78 |
| **G44** | ***14MWLSDT7129*** | 876.65 | 791.33 | 967.2 | 800.67 | 1420 | 1194.4 | 450 | 928.61 |
| **G45** | ***14MWLSDT7138*** | 1048 | 1166 | 1891.6 | 3850.67 | 1210 | 2870.33 | 1643.33 | 1954.28 |
| **G46** | ***14MWLSDT7145*** | 1572.65 | 947.33 | 1191.73 | 1255.34 | 800 | 2012.4 | 2280 | 1437.06 |
| **G47** | ***14MWLSDT7157*** | 803.3 | 1559.33 | 1290.13 | 2638 | 1180 | 2579.6 | 1596.67 | 1663.86 |
| **G48** | ***14MWLSDT7176*** | 1398.7 | 564.67 | 1992.67 | 2821.34 | 1710 | 1994.67 | 2620 | 1871.72 |
| **G49** | ***14MWLSDT7177*** | 866.7 | 1567.67 | 2240.27 | 1694 | 1320 | 2243.33 | 1900 | 1690.28 |
| **G50** | ***14MWLSDT7191*** | 584.65 | 711 | 166.87 | 1996.67 | 1400 | 1452.13 | 2120 | 1204.47 |
| **G51** | ***14MWLSDT7193*** | 854.65 | 988.67 | 1363.4 | 3717.34 | 1400 | 2150.2 | 2893.33 | 1909.66 |
| **G52** | ***14MWLSDT7196*** | 1056.65 | 2102 | 1754.4 | 2003.34 | 1500 | 2866 | 3886.67 | 2167.01 |
| **G53** | ***14MWLSDT7201*** | 726 | 1426.67 | 1133.27 | 3062 | 1210 | 3392.33 | 1430 | 1768.61 |
| **G54** | ***14MWLSDT7207*** | 1376 | 918.67 | 1974.47 | 3696 | 1780 | 2303.13 | 3803.33 | 2264.51 |
| **G55** | ***14MWLSDT7209*** | 310.65 | 1243.33 | 1197.87 | 1794 | 1480 | 2196.13 | 1043.33 | 1323.62 |
| **G56** | ***14MWLSDT7234*** | 788 | 299.33 | 1628.67 | 2966.67 | 1720 | 3112.6 | 2133.33 | 1806.94 |
| **G57** | ***14MWLSDT7238*** | 140 | 1583.33 | 1748.73 | 2076 | 900 | 2443.73 | 2223.33 | 1587.87 |
| **G58** | ***14MWLSDT7241*** | 949.3 | 361.33 | 713.2 | 2309.34 | 1850 | 2604.33 | 496.67 | 1326.31 |
| **G59** | ***14MWLSDT7251*** | 618 | 838.67 | 1856.2 | 2582 | 1810 | 1742.6 | 1423.33 | 1552.97 |
| **G60** | ***14MWLSDT7253*** | 1009.35 | 780.33 | 1019.07 | 1050.67 | 660 | 1646.8 | 1036.67 | 1028.98 |
| **G61** | ***14MWLSDT7278*** | 1582.7 | 1455 | 2080.73 | 3251.33 | 640 | 1984.2 | 1973.33 | 1852.47 |

**Table 4.** Continuation

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **G62** | ***14MWLSDT7279*** | 1079.3 | 2143.33 | 909.53 | 875.34 | 690 | 2422.13 | 2150 | 1467.09 |
| **G63** | ***14MWLSDT7308*** | 640.7 | 456.67 | 797.47 | 2578 | 710 | 2587.2 | 1986.67 | 1393.82 |
| **G64** | ***14MWLSDT7310*** | 563.35 | 560.67 | 2182.8 | 641.34 | 610 | 2094 | 2513.33 | 1309.36 |
| **G65** | ***14MWLSDT7311*** | 1240 | 547 | 538.4 | 3840 | 880 | 1638.47 | 2623.33 | 1615.31 |
| **G66** | ***14MWLSDT7322*** | 500 | 773.67 | 1926.6 | 3607.33 | 1180 | 2789.27 | 1120 | 1699.55 |
| **G67** | ***14MWLSDT7324*** | 1652 | 1225.67 | 2328 | 2215.34 | 2500 | 2737.67 | 2320 | 2139.81 |
| **G68** | ***14MWLSDT7325*** | 408 | 817 | 1906.67 | 2173.34 | 830 | 2528.27 | 2606.67 | 1609.99 |
| **G69** | ***14MWLSDT7329*** | 1214 | 1560 | 1232.87 | 2799.34 | 1290 | 2781 | 3090 | 1995.32 |
| **G70** | ***14MWLSDT7332*** | 556 | 1350.33 | 1552.8 | 3770.67 | 1160 | 2763.27 | 2810 | 1994.72 |
| **G71** | ***14MWLSDT7354*** | 1389.35 | 1477.67 | 1893.53 | 2645.33 | 1510 | 2191.2 | 2556.67 | 1951.96 |
| **G72** | ***14MWLSDT7356*** | 1728.65 | 1374 | 1825.6 | 1220.67 | 1350 | 2141.2 | 3050 | 1812.87 |
| **G73** | ***14MWLSDT7362*** | 636 | 788.33 | 955.13 | 2122.67 | 600 | 3016.8 | 1786.67 | 1415.09 |
| **G74** | ***14MWLSDT7364*** | 1410.7 | 1170 | 2083.47 | 2969.33 | 1500 | 2450.2 | 4146.67 | 2247.20 |
| G75 | ***14MWLSDT7388*** | 1852 | 1083 | 2000.67 | 2616 | 740 | 2458.47 | 1476.67 | 1746.69 |
| **G76** | ***14MWLSDT7395*** | 1506.65 | 1173.33 | 2185.87 | 3917.34 | 1490 | 2396.87 | 3790 | 2351.44 |
| **G77** | ***14MWLSDT7400*** | 626 | 1188.67 | 1822.07 | 1203.33 | 1380 | 2410.67 | 3246.67 | 1696.77 |
| **G78** | ***14MWLSDT7401*** | 1306.65 | 1701.33 | 2986.13 | 2893.33 | 700 | 2393.93 | 1466.67 | 1921.15 |
| **G79** | ***14MWLSDT7402*** | 822.65 | 406.67 | 555.73 | 2571.33 | 890 | 1480.87 | 1130 | 1122.46 |
| **G80** | ***14MWLSDT7405*** | 1120 | 1222.33 | 1514.53 | 3321.34 | 1080 | 2460.93 | 1743.33 | 1780.35 |
| **G81** | ***14MWLSDT7410*** | 490 | 1277.33 | 2198.2 | 2502.67 | 1260 | 2506.47 | 2256.67 | 1784.48 |
| **G82** | ***14MWLSDT7413*** | 772.7 | 517 | 2008.27 | 2254.67 | 1100 | 2933.13 | 2953.33 | 1791.30 |
| **G83** | ***14MWLSDT7425*** | 732 | 1046.33 | 1753.87 | 1580 | 1140 | 1998.07 | 2563.33 | 1544.80 |
| **G84** | ***2005MI5064*** | 1173.3 | 641 | 2083.07 | 3734 | 1400 | 2308.27 | 1960 | 1899.95 |
| **G85** | ***2005MI5065*** | 853.35 | 452.67 | 1645.27 | 3353.33 | 1000 | 2316.13 | 1683.33 | 1614.87 |
| **G86** | ***2005MI5069*** | 820.65 | 1570.33 | 1010.87 | 3128 | 1190 | 2450.53 | 3040 | 1887.20 |
| **G87** | ***Dekeba*** | 1281.35 | 1013.33 | 1186.93 | 1193.34 | 960 | 2142.53 | 2073.33 | 1407.26 |
| **G88** | ***ETSC 300001*** | 573.3 | 1164 | 672.87 | 1704 | 370 | 1777.27 | 2056.67 | 1188.30 |
| **G89** | ***ETSC 300002*** | 1496.65 | 1845 | 1259.93 | 3360 | 1110 | 2016.13 | 2530 | 1945.39 |
| **G90** | ***Melkam*** | 368 | 2124.33 | 947.87 | 2230 | 1170 | 2358.47 | 1196.67 | 1485.05 |
| | **Mean** | 925.25 | 1106.92 | 1470.54 | 2455.66a | 1191.67 | 2220.01 | 2191.41 | |

15ER= Erer 2015; 15HM= Humera 2015; 15MI= Meisso 2015; 15SH= Sheraro 2015; 16ER= Erer 2016; 16MI= Mieso 2016; 16SH= Sheraro 2016.

## Genotype by Environment Interaction for grain yield

The average grain yield performance of sorghum genotypes was showed in 2015 and 2016 cropping season (Figure 1). In 2015 cropping season the terminal drought was happened in the sorghum growing regions in Ethiopia, in this case the sorghum trial was affected by terminal moisture stress in all tested locations and it was likely to had low performance and average grain yield of sorghum genotypes. Notice that the combined average grain yield of sorghum genotypes in 2015 had lower than 2016. This variation was showed due to diverse factors like rainfall patterns and temperatures. The environments in 2015 and 2016 years have a wide difference between their average grain yields of genotypes. A difference in yield of 0.4 t/ha means something different depending on weather conditions, however, it is clear that there was some genotype by environment interaction that means some genotypes did well in some environments but poorly in other environments.

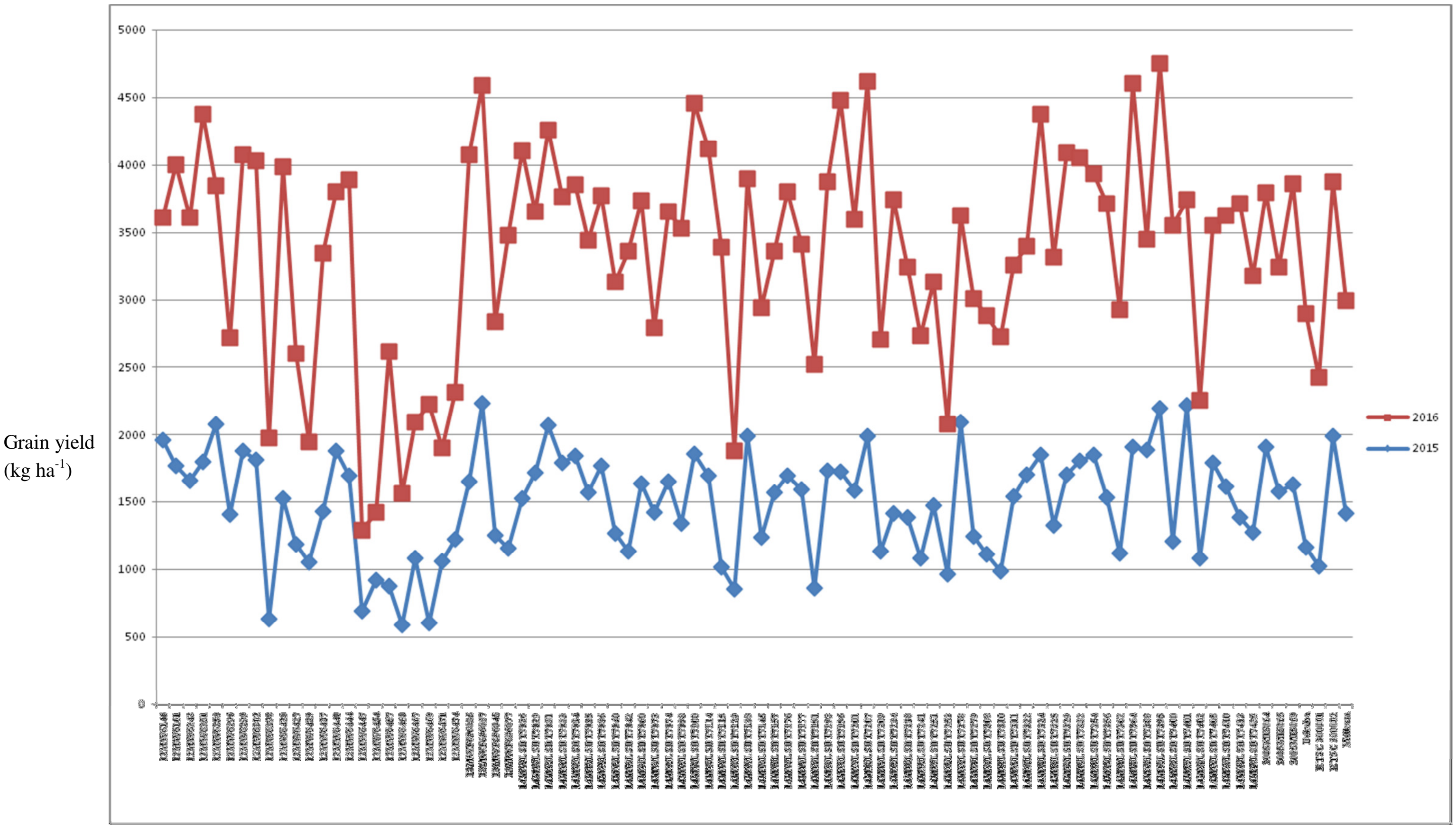

**Figure 1.** Performance of genotypes over the years.

## GGE BIPLOT ANALYSIS OF GxE FOR GRAIN YIELD DATA

### Test environment evaluation based on GGE biplots

Although MET data are used for genotype evaluation, they can also be used in environment evaluation. The line passing through the biplot origin is called the average environment coordinate (AEC) (Figure 2), which any test environments are closed to AEC that are more representative environments (Yan and Kang, 2002). 16MS had very short vectors, small angles and closed to AEC that means it is the most representative environment. The environment 16SH and 15SH (Sheraro) had the longest vectors from the biplot origin and they were also more discriminating but 16SH is closest to the ideal environment, therefore, best, whereas 15ER and 16ER (Erer) had very short vectors, small angles and far away from the ideal environment and poorest for selecting cultivars adapted to the whole regions (Figure 2).

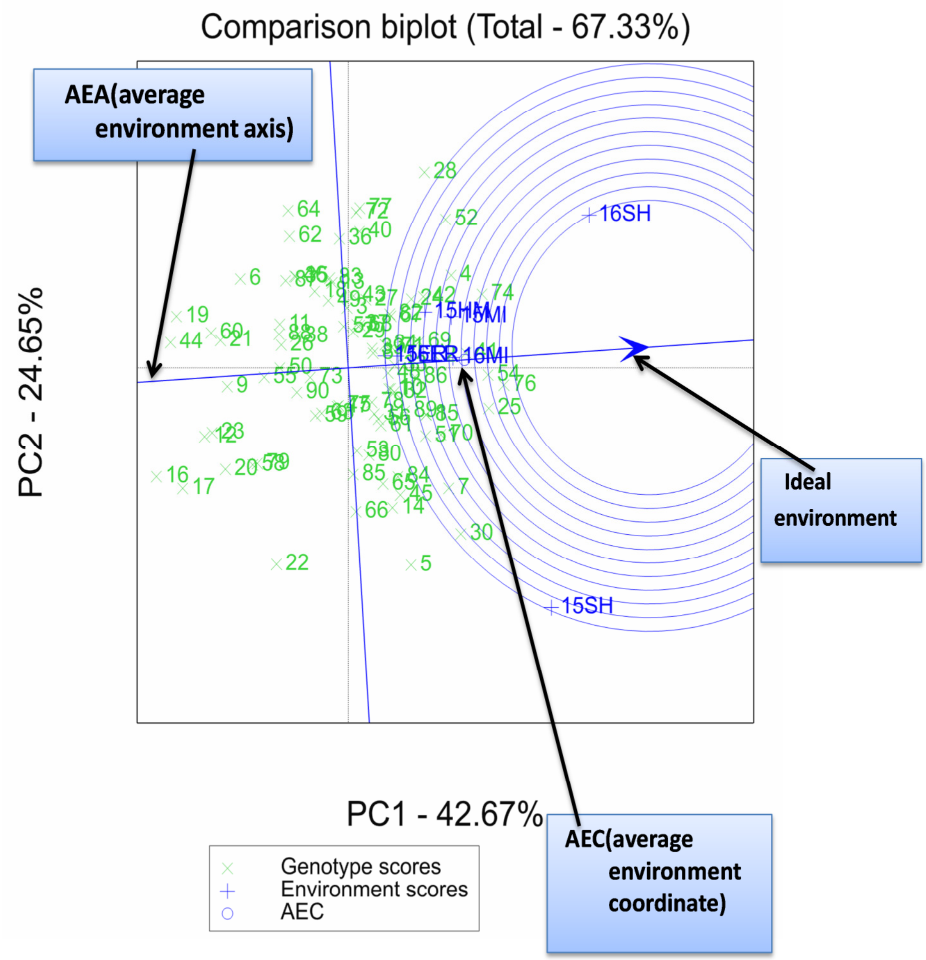

**Figure 2**. The environment-vector view of the GGE biplot to display test environments.

## Correlations of tested environments

The concentric circles on the biplot help to visualize the length of the environment vectors, which is relative to the standard deviation within the respective environments and is a measure of the discriminating ability of the environments. Therefore, among the seven environments, 15SH and 16SH (Sheraro) were most discriminating (informative), and 15ER and 16ER (Erer) least discriminating environments (Figure 3). Test environments that are consistently non-discriminating provide little information on the genotypes and, therefore, should not be used as test environments (Yan and Tinker, 2006). Discriminating but non-representative test environments (15SH and 16SH), Sheraro, northern part of Ethiopia is useful for selecting specifically adapted genotypes if the target environments can be divided into mega-environments.

The comparison between two environments is determined by the length of their vectors and the angle between them (Figure 3). Environment 16SH and 15SH (Sheraro) as shown by a long environmental vector and had almost a right angle between them that showed there is not any correlation. The unrelated correlation between two environments 15SH and 16SH indicated a crossover GE interaction; thus, the changes in ranking order of genotypes form one year to another in the same location, Sheraro, due to the change of environmental factors like rainfall and temperature. However, 16ER and 15ER (Erer, eastern part of Ethiopia) had short environmental vector. This means if the study is carried out for several seasons and same sites continue to be non-discriminating; it means the locations can be throw down and not to be used as test locations at Erer. Environments are fewer valuable because they bring little discriminating information about the genotypes as reported by Yan and Tinker (2006).

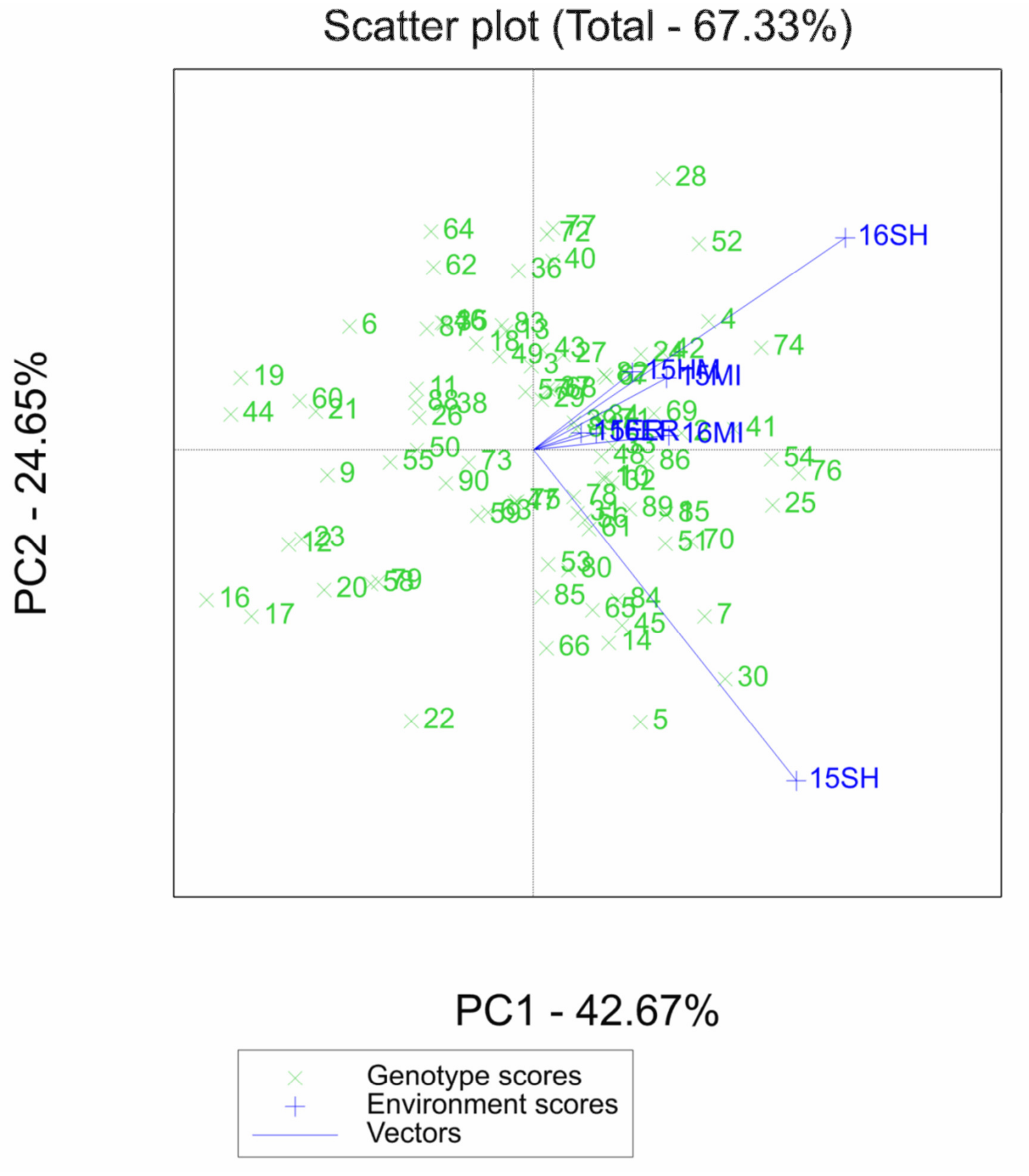

**Figure 3**. The discrimination view of the GGE biplot.

## Genotype evaluation based on GGE biplots

### Mega environment pattern of GE interaction (which-won-where)

The polygon view of a biplot provides the best way to imagine the interaction patterns between genotypes and environments and to effectively understand a biplot.

It is drawn by connecting the genotype markers located furthest from the biplot origin using straight convex hull to form a polygon such that all other genotype markers are contained within the polygon. Environments that fall in different sectors have different best genotypes. The which-won-where biplot showed different winning genotypes in different environments (Gasura *et al*., 2015).

Mega-environment idea needs multi-year data, in this study four mega environments were formed (Figure 4). Thus environments, 15ER, 16ER and 16MI formed one mega environment,15HM and 16SH formed one mega environment, while 15MI formed and 15SH formed single split mega-environment. The engaging genotypes for each segment are those located at the vertex. The vertex genotypes in this investigation were G74, G28, G64, G19, G16, G22, G5, G30 and G76.

Genotypes G74, G4 and G52 were the attractive genotypes for the 15HM and 16SH formed one mega-environment, and G74 was also the winning genotype for the 15MI mega environment. Genotypes G76, G54, G41 and G25 were the winning genotypes for the 15ER, 16ER and 16MI formed one mega environment, while G30 was the winning genotype for the 15SH formed mega-environment.

The convex hull is fairness lines between adjacent genotypes on the polygon, which facilitate graphic comparison of them. The equality line between G74 and G28 shows that the G74 was better than G28 in all environments. G52 are located on the convex hull that connects G74 and G28. This means that the three can be ranked G74, G52 and G28 in all the environments (Figure 4). This pattern recommends that the mark environment may contain of four different mega-environments and that dissimilar cultivars should be selected and organized for each. This allows the researcher to have specific and effective explanation to recommend genotypes which are best for that particular environment (Gasura *et al.,* 2015).

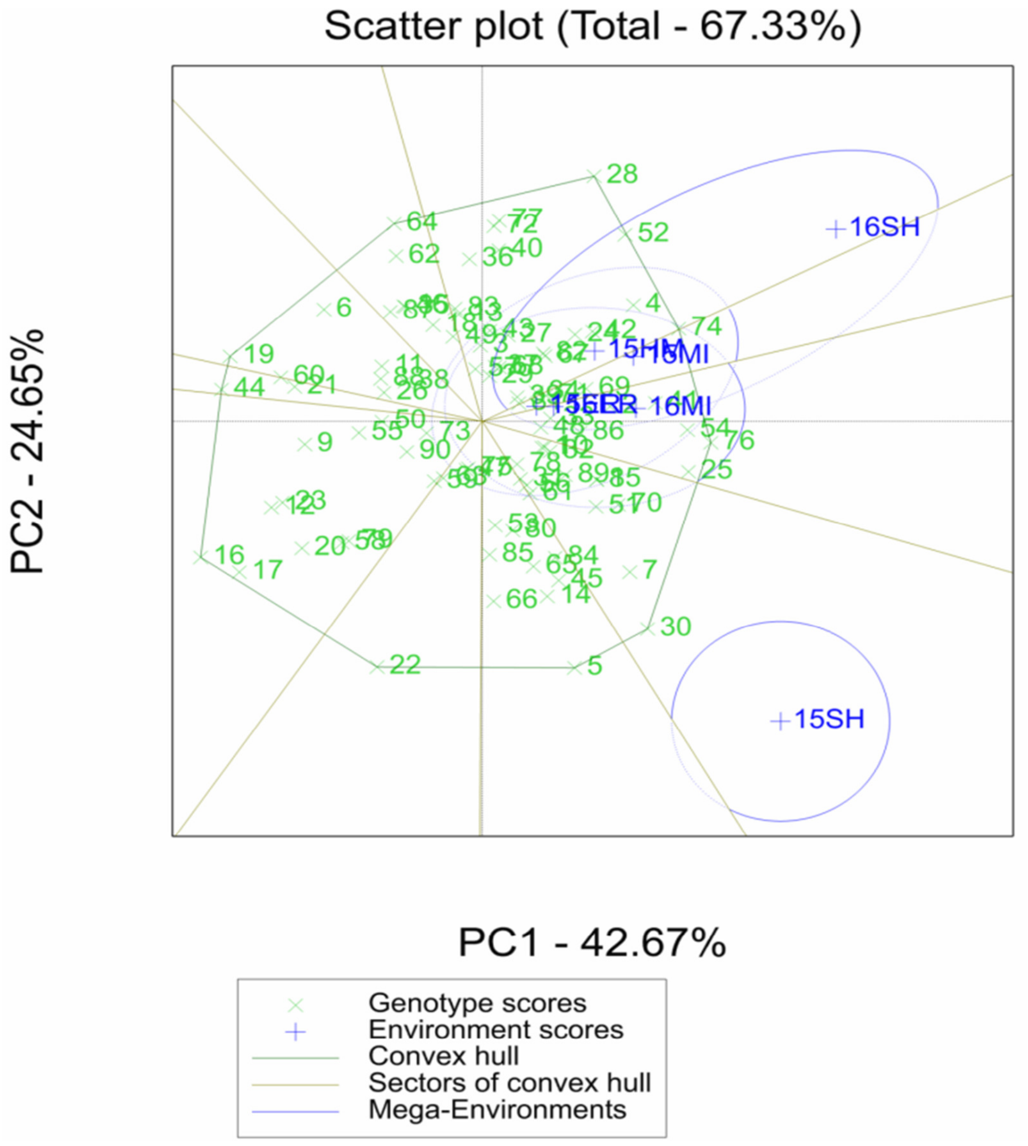

**Figure 4**. GGE biplot analysis showing the mega-environments and their respective hiegh yielding genotypes.

## Mean Performance and Stability of the Genotypes

Figure 5 illustrates the graphic evaluation of the comparative performance of tested genotypes in environment 16MI (represents the moderate environment in 2016 at Meisso), which produced high and stable yield among the seven environments. A line was drawn that passed through the biplot's origin and the 16MI marker to make an average environment axis (AEA), and then another line drawn vertical from each genotype toward the AEA. The genotypes were ranked on the basis of their projections onto the AEA, with rank increasing in the direction toward the positive end (Yan and Kang, 2002).

Genotypes should be evaluated on both mean performance and stability across environments. The average environment coordination (AEC) view of the GGE biplot origin (Figure 5). Lines vertical to average environment axis (AEA) measures the stability of genotypes in either direction. Genotypes with smallest vertical line and close to AEC are called stable genotype. In this study, the graph shows that G41, G25, G54, G74 and G76 had the highest mean yield, whereas G36, G66 and G85 gave a mean yield almost comparable to the grand mean and; G16, G17, G19 and G44 gave the lowest mean yield. Stability and high performance make a candidate the best genotype (Mare *et al*., 2017). In this biplot, G41, G2, G33 and G48 were most stable with the higher yield performances than the overall mean, whereas G73, G50, G9 and G55 were also most stable with the lower mean yield performances than the overall mean, as they were located almost onto the AEA, indicating that their ranks were highly consistent across environments. Genotypes G41, G54 and G76 are stable and high yielding; hence, can be selected as the most favorable genotypes. Genotypes were the best or the poorest genotypes in some or all of the environments since they had the greatest distance from the origin as reported by Yan and Kang (2002). These three genotypes yielded higher and were more stable than the commercial sorghum varieties, G90 (Melkam) and G87 (Dekeba). Based on their stability and high yield, these three genotypes were outstanding in the common of the environments. Such genotypes were showed stability and best yield performance in high yield environments, which was as reported by Finlay and Wilkinson (1963). However, G5, G28, G30, G52, G72 and G77 are the most unstable however genotypes had above mean yield.

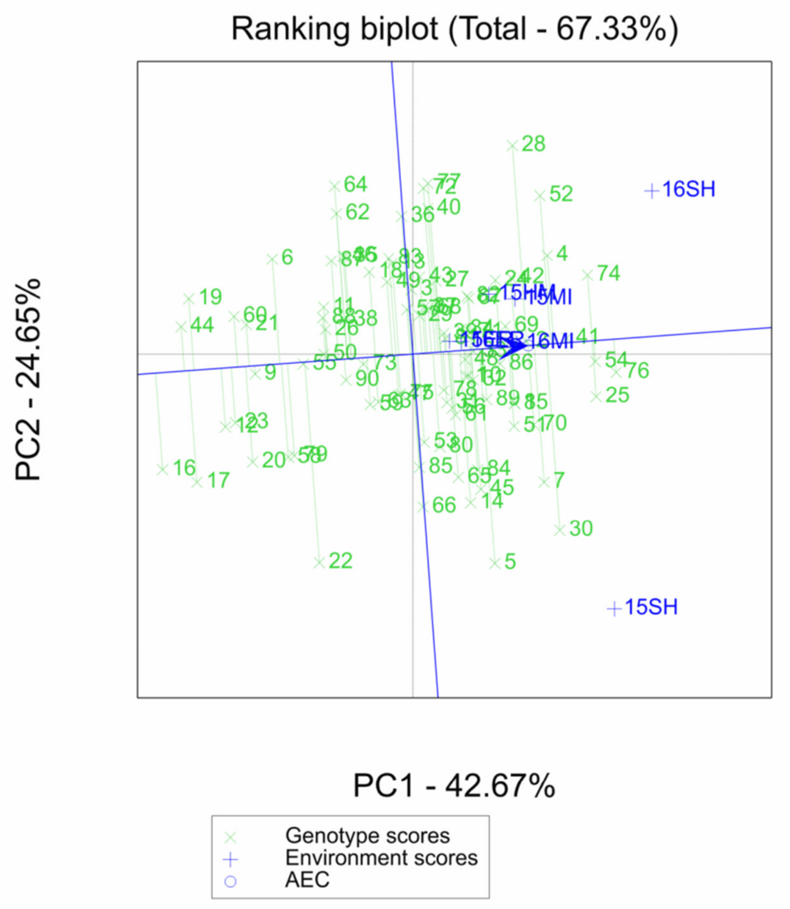

**Figure 5**. GGE for ranking of all genotypes relative to the test environments.

### Evaluation of genotypes based on an ideal genotype

An ideal genotypes should have the highest mean performance and be stable. Thus, using the ideal genotype as the center, concentric circles were drawn to help imagine the detachment between each genotype and the ideal genotype (Figure 6). An ideal genotype, which is located at the center of the concentric circles has high mean yield and high stability. Thus, based on the graphical understanding, the G76 and G54 followed by G25, G41 and G74 with high mean yield and stability performances can be considered as ideal genotypes. However, G16, G17, G19 and G44 are the poorest genotypes as their placed in the plot are located away from the concentric circle. The genotypes lying on the right side of the line was drawn vertical that passed through AEA had yield performance greater than the mean and the genotypes on the left side had yields lower than the mean (Rono *et al.*, 2016).

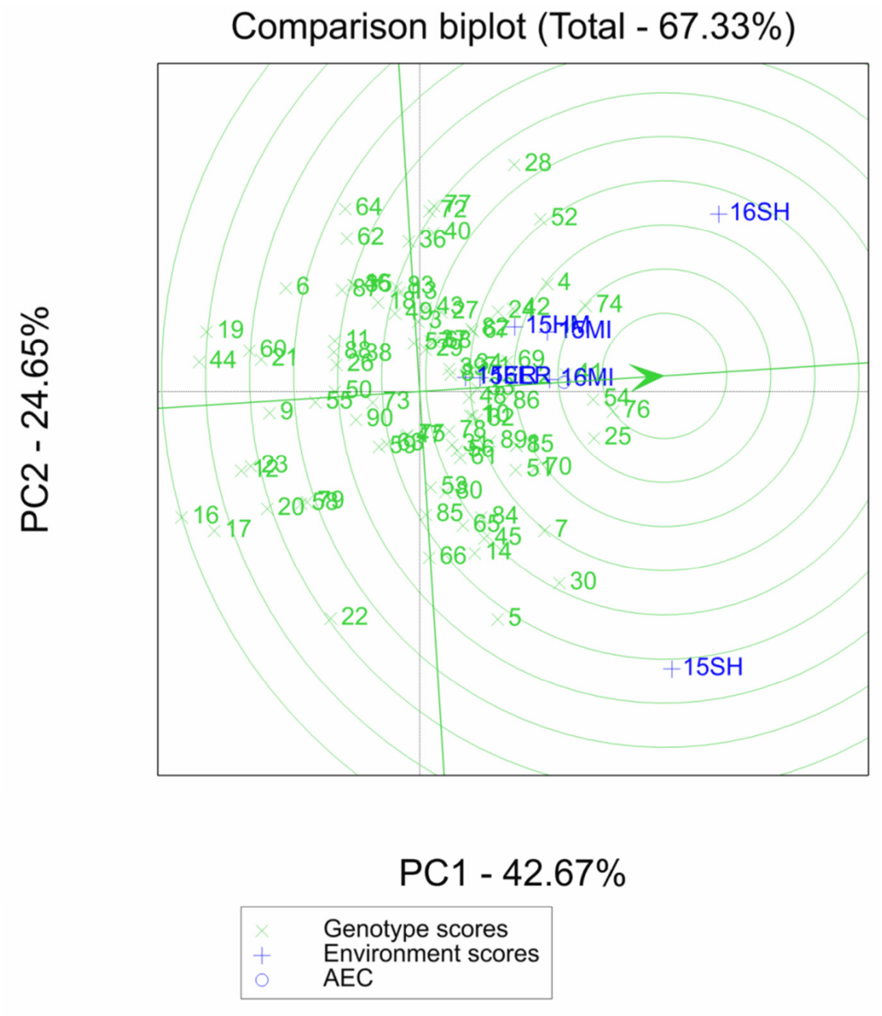

**Figure 6**. GGE-biplot, which shows the evaluation of genotypes based on an ideal genotype.

### Ranking environments based on the highest yielding genotype (G76-14MWLSDT7395)

The specific adaptation of agenotype, to rank the test environments on the comparative performance of a genotype, a line is drawn that passes over the biplot origin and the genotype. This line is called the axis for this genotype, and along it is the ranking of the environments. The axis in Figure 7 was drawn based the test environments based on the comparative performance of G76. This showed that G76 had higher than average yield in all environments, whilst it had the highest yield in 15SH and 16SH (Sheraro in both years).

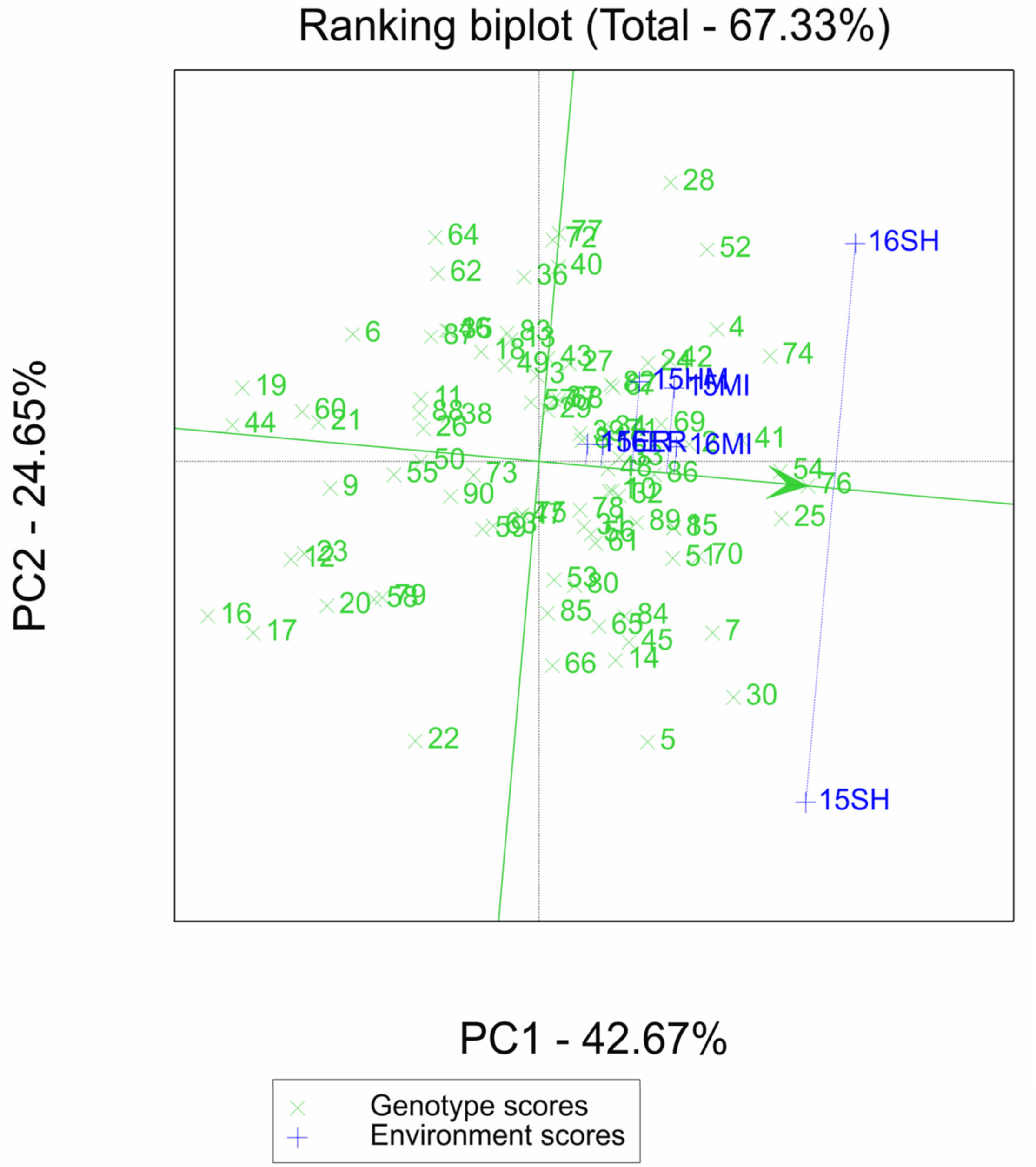

**Figure 7**. Ranking environments based on the performance of a genotype

## CONCLUSION

The significant GEI for DTF, PHT TSW and GY observed from analysis of variance in this study shows that early sorghum genotypes respond differently when grown in different environmental conditions. Environmental effects, as well as GEI, had strong effect on yield of early maturing sorghum genotypes; it means a breeder faces challenge of selection genotypes for improvement and or release, thus additional testing for genotypes with wider and specific adaptation and locations with good discriminating ability and representativeness were done.

The results from this study indicated that G41, G54 and G76 were stable and high yielding and best genotype across environments whereas environment Sheraro in both years (15SH and 16SH) has excellent potential for grain yield in areas. Environments 15ER and 16ER (Erer) are non-discriminating and least representative test environment which are less useful because they provide little discriminating information about the genotypes. The genotypes G16, G17, G19 and G44 were poor performance for grain yield to be found outside limits of any environments. It is evident that performance of early maturing sorghum is attributed to both genetic make-up and environment.

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## ABBREVIATIONS

E, environment; G, genotype; GE, genotype x environment interaction; GGE, genotype main effect plus genotype x environment interaction; MET, multi-environmental trial; PC, principal component.

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