

# Genotype x Environment Interaction and Yield Stability of Bread Wheat Genotypes in Oromia, Ethiopia

Berhanu Sime<sup>1,\*</sup>, Gudeta Nepir<sup>2</sup>, Bedada Girma<sup>1</sup>, Alemu Dabi<sup>1</sup>

<sup>1</sup>National Wheat Research Program, Kulumsa Agricultural Research Center, Assela, Ethiopia

<sup>2</sup>Colleges of Agriculture and Veterinary Sciences, Ambo, Ethiopia

## Email address:

[birhanume2006@gmail.com](mailto:birhanume2006@gmail.com) (B. Sime)

\*Corresponding author

## To cite this article:

Berhanu Sime, Gudeta Nepir, Bedada Girma, Alemu Dabi. Genotype x Environment Interaction and Yield Stability of Bread Wheat Genotypes in Oromia, Ethiopia. *American Journal of Life Sciences*. Vol. 10, No. 4, 2022, pp. 72-77. doi: 10.11648/j.ajls.20221004.13

Received: June 13, 2022; Accepted: July 12, 2022; Published: July 22, 2022

**Abstract:** Bread wheat is one of the most important cereal crops of Ethiopia grown over wider agro- ecologies mainly between 1900 to 3000 above sea level, Study on genotype by environment interaction and stability of 25 bread wheat genotypes was conducted across six locations 2019/2020 main growing season by Alpha lattice design using three replications at six locations in Oromia, Ethiopia. The main objectives of the present study are to interpret genotype main effect and GE interactions obtained by Additive mean-effect and multiplication Interaction analysis and group the genotypes having similar response pattern over all environments. The AMMI analysis also revealed that bread wheat grain yield was significantly affected by the environment at  $p < 0.01$  and explained 82.44% of the total variation. This indicated existence of high variability among the environments. Comparatively, genotype and GEI captured 6.23% and 11.33% of the total variation, respectively. On the other hand, genotypes BW174463, ETBW9193 and ETBW9087 genotypes are located closer to the origin of the biplot, and this implies that these bread wheat genotypes are stable across environments. In the first quadrant genotypes ETBW9066, ETBWBW174459, ETBW9193, ETBW9087, LEMMU and ETBW9185 are positively associated with locations kulumsa, Debre-Zeit, Holeta and Arsi-Robe are considered adaptable. The genotype with low YSI is considered as high yielding and stable genotypes. Accordingly, BW174466, BW174463, ETBW9094, ETBW9315 and, ETBW9089 were the most stable genotypes which were determined by YSI with mean grain yield of 5.33 t/ha, 5.11 t/ha, 5.41 t/ha, 5.14 t/ha and 6.29 t/ha, respectively.

**Keywords:** Genotype, Environment, GEI, AMMI, IPCA

## 1. Introduction

Bread wheat is a self-pollinating annual plant in the grass family, *Gramineae*. It is extensively grown as staple food source in the world [1]. Wheat is one of the most important cereal crops cultivated in Ethiopia. It ranks 4<sup>th</sup> after maize (*Zea mays* L.), tef (*Eragrostis tef*) and sorghum (*Sorghum bicolor* L.) in area coverage, and 2<sup>nd</sup> in productivity (tons/ha) next to maize [2]. Wheat is grown annually on 1.75 million hectares of land in Ethiopia with a total grain production of 4.84 million tons and average productivity of 2.77 tons/ha, which makes the country the second largest wheat producers in sub-Saharan [2].

Wheat has been selected as one of the target crops in the

strategic goal of attaining national food self-sufficiency, income generation, poverty alleviation and achieving socio-economic growth of Ethiopia [3]. It is one of the most important small cereal crops in Ethiopia widely cultivated in wide range of altitudes. Most wheat producing areas in Ethiopia are between 6° and 16° N latitude and 35° and 42° E longitude and altitudes ranging is from 1500 to 3000 m.a.s.l. But with proper irrigation, wheat has been grown successfully in the Awash and Wabe-Shebelle River Basins which lie below 1000 m.a.s.l. The most suitable agro-ecological zones, however, fall between 1900 to 2700 meters above sea level [4]. Wheat in Ethiopia is produced mainly under rain fed conditions with rainfall amounts ranging from 600 mm to 2000 mm. Grain yield is a function of genotype, environment and genotype x environment interaction (GEI)

as expressed by different authors [5-7]. An understanding of the effects of environment, genotype and Genotype by environment interaction is important at all stages of crop improvement programs as they have crucial effects on selection and cultivar adaptation trials. GEI studies thus provide a basis for selection of genotypes that are suitable for wider or specific cultivation.

They also provide information about the effect of environment on cultivar performance [8]. Further, the yield plateau in wheat productivity is now of great concern. It necessitates the development of high-yielding genotypes with wide or specific (local) adaptation to the environments within a target area [9].

The measured yield of each cultivar in each test environment is a function of genotype main effect (G), environment main effect (E) and genotype x environment (G x E) interaction [10]. Though, environment mostly accounts for the major portion of the total yield variation, only genotype and genotype x environment interaction are relevant to cultivar evaluation and mega environment classification [11-15]. AMMI and Genotype main effect and Genotype x Environment interaction (GGE) models are singular value decomposition (SVD) based statistical methods and they have been applied to yield trial studies for visualizing the data. The methods help in understanding complex genotype x environment interactions (GEI) and

determining which genotype has been in which environments and also helping in grouping environments with the same winner (or similar winners) into mega-environments. Evaluating genotypes over diverse environments is a universal practice to ensure the stability of performance of genotypes. It provides breeder with better strategy for selecting high yielding and consistently performing varieties over diverse environmental conditions [16]. GEI in multi-environment trials shows differential responses of wheat genotypes across ranges of environments. Grain yield is quantitative in nature and routinely exhibits GEI [17]. The main objectives of the present study are to interpret genotype main effect and GE interactions obtained by AMMI analysis and group the genotypes having similar response pattern over all environments.

## 2. Materials and Methods

The experiment was conducted during the 2019/20 main cropping season across six locations. The locations were Kulumsa (L1), Bekoji (L2), Assasa (L3), Arsi-Robe (L4), Debre-Zeit (L5) and Holeta (L6). The description of the testing locations is presented in Table 1. These locations represent different agro-ecologies of the major wheat growing areas in Oromia, Ethiopia.

**Table 1.** Location descriptions and weather conditions of experimental sites.

| Location   | Geographic position |           | Altitude | Soil type | Temperature (°C) |      | Rainfall (mm) |
|------------|---------------------|-----------|----------|-----------|------------------|------|---------------|
|            | Latitude            | Longitude |          |           | Min              | Max  |               |
| Kulumsa    | 08°02'N             | 39°10'E   | 2200     | Luvisol   | 10.5             | 22.8 | 820           |
| Bekoji     | 07°32'N             | 39°15'E   | 2780     | Nitosol   | 7.9              | 18.6 | 1020          |
| Assasa     | 07°07'N             | 39°11'E   | 2340     | Gleysol   | 6.6              | 21.9 | 642           |
| Arsi-Robe  | 07°53'N             | 39°37'E   | 2420     | Vertisol  | 6.0              | 21.1 | 890           |
| Debre-Zeit | 08°44'N             | 38°58'E   | 1900     | Vertisol  | 8.9              | 28.3 | 851           |
| Holeta     | 09°00'N             | 38°30'E   | 2400     | Nitosol   | 6.2              | 22.1 | 1044          |

Source: Kulumsa Agricultural Research Center, experimental site description, 2013.

The trials were conducted at six locations using 5 x 5 Alpha Lattice design replicated three times during the 2019/20 cropping season. Each treatment was planted on six rows of 2.5m length with 20cm distance between any two rows. The sowing dates were at the onset of the main rainy season as usual. Seed rate of 150 kg/ha was used. Fertilizer

was applied at the rate of 100 kg/ha of NPS and 100 kg/ha Urea at each location. Recommended rate of NPS was applied at planting, while urea was applied in two splits, half at planting and the remaining half at tillering stage. In addition, other relevant field trial management practices were carried out across all locations as per the recommendations.

**Table 2.** The Entry code, Genotype code and pedigree selection history of the genotypes were evaluated in the experiment in 2019/20 cropping season at six locations.

| Entry Code | Genotype code | Pedigree   |
|------------|---------------|--|
| G1         | WANE          | Check (SOKOLL/EXCALIBUR)   |
| G2         | ETBW9185      | KISKADEE#1/5/KAUZ*2/MNV//KAUZ/3/MILAN/4/BAV92/6/WHEAR//2*PRL/2*PASTOR                      |
| G3         | ETBW9193      | CHWINK/GRACKLE #1//FRNCLN  |
| G4         | ETBW9086      | MINO/898.97/4/2*PFAU/SERI.1B//AMAD/3/KRONSTAD F2004  |
| G5         | ETBW9087      | ATTILA/3/URES/PRL//BAV92/4/WBLL1/5/CHYAK1/6/NAVJ07   |
| G6         | ETBW9089      | BABAX/LR42//BABAX/3/ER2000/4/BAVIS   |
| G7         | ETBW9109      | PFAU/MILAN/3/BABAX/LR42//BABAX/8/JUP/ZP//COC/3/PVN/4/TNNU/5/TNNU/6/SITE/7/TNNU             |
| G8         | ETBW9284      | PRL/2*PASTOR//WAXWING*2/KRONSTAD F2004/4/PBW343*2/KUKUNA//KRONSTAD F2004/3/PBW343*2/KUKUNA |
| G9         | ETBW9299      | WHEAR/SOKOLL/4/WBLL1/KUKUNA//TACUPETOF2001/3/UP2338*2/VIVITSI                              |
| G10        | ETBW9304      | CROC_1/AE.SQUARROSA(205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2*2/5/WHEAR/SOKOLL            |
| G11        | ETBW9313      | ROLF07/YANAC//TACUPETOF2001/BRAMBLING*2/3/WHEAR//2*PRL/2*PASTOR                            |

| Entry Code | Genotype code | Pedigree   |
|------------|---------------|--|
| G12        | ETBW9094      | THELIN/3/BABAX/LR42//BABAX/4/BABAX/LR42//BABAX*2/5/KIRITATI/2*TRCH   |
| G13        | ETBW9066      | PRL/2*PASTOR/4/CHOIX/STAR/3/HE1/3*CNO79//2*SERI/5/KIRITATI/2*TRCH  |
| G14        | ETBW9102      | CETA/AE.SQUARROSA (174)//2*MU  |
| G15        | ETBW9315      | BABAX/LR42//BABAX/3/ER2000/11/CROC_1/AE.SQUARROSA(213)//PGO/10/ATTILA*2/9/KT/BAGE//FN/U/3/BZA/4/TRM/5/ALDAN/6/SERI/7/VEE#10/8/OPATA/12/BAVIS |
| G16        | BW174459      | THELIN/WAXWING//ATTILA*2/PASTOR/3/INQALAB91*2/TUKURU 9Y-0B   |
| G17        | BW174460      | PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA,  |
| G18        | BW174461      | PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA,,   |
| G19        | BW174462      | PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA   |
| G20        | BW174463      | SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE/5/SITTA/BUCHIN//CHIL/BOMB  |
| G21        | BW174464      | PFAU/MILAN//FUNG MAI 24/3/ATTILA*2/CROW  |
| G22        | BW174465      | FLORKWA-2/85 Z 1284//ETBW 4920/3/LOULOU-18   |
| G23        | BW174466      | SHARP/3/PRL/SARA//TSI/VEE#5/5/VEE/LIRA//BOW/3/BCN/4/KAUZ/6/HUBARA-5  |
| G24        | BW174467      | CHEN/AEGILOPSSQUARROSA(TAUS)//BCN/3/VEE#7/BOW/4/PASTOR/5/HUBARA-1  |
| G25        | LEMMU         | Check (WAXWING*2/HEILO)  |

Data collection: Data was collected on the following traits: days to heading, days to maturity, grain filling period, number of grains per spike, number of spikelets per spike, plant height, number of tillers per plant, spike length, Number of spikelets per spike, thousand kernel weight (TKW) and grain yield per plot.

### 3. Data Analysis

Analysis of variance (ANOVA) was made for the six locations separately using SAS software and then combined over six locations for all characters since all showed homogeneity of error variance. Prior to running combined analysis of variance, homogeneity of variance was checked using Bartlett's test. ANOVA was carried out using AMMI model to partition the total variance into genotype, environment and genotype by environment interaction, replication within environment and block within replication. The AMMI analysis was performed using the model suggested by [18]. as:

$$Y_{ijk} = \mu + G_i + E_j + \sum_{n=1}^{\infty} \lambda_n \alpha_{in} y_{jn} + e_{ijk}$$

Where  $Y_{ij}$  is the yield of the  $i^{th}$  genotype in the  $j^{th}$  environment,  $\mu$  is the grand mean,  $G_i$  is the mean of the  $i^{th}$  genotype minus the grand mean,  $E_j$  is the mean of the  $j^{th}$  environment minus the grand mean,  $\lambda_n$  is the square root of the Eigenvalue of the principal component analysis (PCA) axis,  $\alpha_{in}$  and  $y_{jn}$  are the principal component scores for PCA axis  $n$  of the  $i^{th}$  genotype and  $j^{th}$  environment and  $e_{ijk}$  is the error term.

### 4. Ammi Stability Value (Asv)

The AMMI stability value (ASV) as described by [19]. Was calculated as follow

$$ASV = \sqrt{\frac{IPCA1_{sum of square}}{IPCA2_{sum of square}} (IPCA1_{score})^2 + (IPCA2_{score})^2}$$

Where, ASV = AMMI stability value.

IPCA1 = the first interaction principal component analysis.

IPCA2 = the second interaction principal component analysis.

SSIPCA1 = sum of square of the first interaction principal component.

SSIPCA2 = sum of square of the second interaction principal component.

$\frac{IPCA1_{sum of square}}{IPCA2_{sum of square}}$  Is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. Larger the IPCA score, either negative or positive, the more indicates more specific adaptation of a genotype to a certain environment. Smaller ASV score for a given genotype indicates that a given genotype has broad adaptation across variable environments.

### 5. Yield Stability Index (YSI)

The yield stability index was calculated as:

$$YSI = RASV + RGY.$$

Where RASV is the rank of the AMMI stability value and RGY is the rank of the mean grain yield of genotypes across environments.

### 6. Results and Discussion

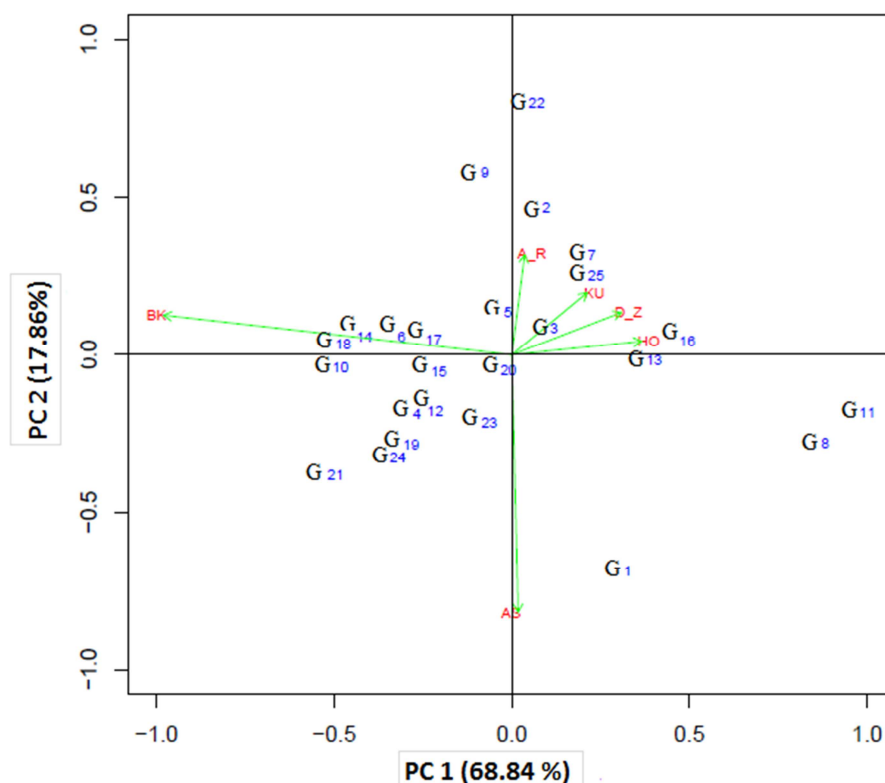
AMMI model showed highly significant main effects ( $P < 0.01$ ) for environment, genotype and their interactions (Table 3). The AMMI analysis also revealed that bread wheat grain yield was significantly affected by the environment at  $p < 0.01$  under (Table 3) and explained 82.44% of the total variation. This indicated existence of high variability among the environments. Comparatively, genotype and GEI captured 6.23% and 11.33% of the total variation, respectively.

**Table 3.** Additive mean-effect and multiplicative Interaction analysis of variance for grain yield of 25 bread wheat genotypes across six locations.

| Source of Variation | df  | SS      | MS       | Explained% |
|---------------------|-----|---------|----------|------------|
| Total               | 449 | 1594.5  | 3.55     |            |
| E                   | 5   | 1261.90 | 252.38** | 82.44      |
| G                   | 24  | 95.35   | 3.97**   | 6.23       |
| G x E               | 120 | 173.38  | 1.44**   | 11.33      |
| IPCA1               | 28  | 111.78  | 3.99**   | 62.25      |
| IPCA 2              | 26  | 46.23   | 1.78**   | 25.74      |
| IPCA3               | 24  | 14.34   | 0.60**   | 7.99       |
| Error               | 300 | 63.87   | 0.21     |            |

The large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing variation in the grain yield of G across E. “Similar result was reported by Mehari. [20]”. Additive mean-effect and Multiplicative Interaction model demonstrated the presence of significant GEI and it was partitioned into IPCA. The first three principal component axes (IPCA1) were highly significant ( $p < 0.01$ ) accounting for 62.25, 25.74 and 7.99% of the total variation attributable to GEI, respectively. The Results from AMMI analysis also showed that

the first three principal component axes accounted about 96% of the GEI variation. When looking at the environments, it is clear that there is a good variation in different environments. Assasa and Bekoji were the most discriminating environments as indicated by the long distance between their marker and the origin (Figure 1). However, due to their large IPCA2 score, genotypic differences observed at these environments may not exactly show the genotypes with average yield over all locations. Closer relationships were observed between Kulumsa, Arsi-Robe, Debre-Zeit and Holeta.



**Figure 1.** AMMI 2 biplot of IPCA1 against IPCA2 for grain yield of 25 bread wheat genotypes tested across six locations (G stands for genotype as described in Table 2).

G1=WANE, G2=ETBW9185, G3=ETBW9193, G4=ETBW9086, G5=ETBW9087, G6=ETBW9089, G7=ETBW9109, G8=ETBW9284, G9=ETBW9299, G10=ETBW9304, G11=ETBW9313, G12=ETBW9094, G13=ETBW9066, G14=ETBW9102, G15=ETBW9315, G16=BW174459, G17=BW174460, G18=BW174461, G19=BW174462, G20=BW174463, G21=BW174464, G22=BW174465, G23=BW174466, G24=BW174467, G25=LEMMU  
A-R=Arsi-Robe, AS= Assasa, BK= Bekoji, D-Z=Debre-Zeit, HO=Holeta and KU=Kulumsa).

Closer IPCA Score to Zero, the more adaptable is the genotype across all test locations by [20]. Similarly location scores from AMMI analysis regarding to interaction also interpreted as location with large IPCA scores are more discriminating the genotypes. While locations with low IPCA scores or near zero revealed small interactions with the genotypes and have low discrimination power on the genotypes [21]. Accordingly, genotype BW174465, ETBW9313, ETBW2884 and WANE are considered unstable as they located far apart from the other genotypes in the biplot when plotted on the IPCA1 and IPCA2 scores (Figure 1). On the other hand, genotypes BW174463, ETBW9193 and ETBW9087 genotypes are located closer to the origin of the biplot, and this implies that these bread wheat genotypes are stable across environments. The rest of

the bread wheat genotypes are unstable as they are located distant from the origin. In the first quadrant genotypes ETBW9066, ETBWBW174459, ETBW9193, ETBW9087, LEMMU and ETBW9185 are positively associated with locations kulumsa, Debre-Zeit, Holeta and Arsi-Robe as indicated by the vector lines and are considered adaptable (Figure 1).

## 7. Additive Mean-Effect and Multiplicative Interaction Stability Value

Additive mean-effect and multiplication interaction stability values revealed variations in yield stability among

the 25 genotypes (Table 4). According to [22]. The genotype with least ASV score is the most stable across environments and the larger the ASV value, either negative or positive; the more specifically adapted a genotype is to certain environments. Consequently, genotypes with lower ASV values were BW174463, ETBW9087 and BW174466 which are considered more stable than the rest of the genotypes

(Table 4). On the other hand, genotypes which showed larger values were unstable, and only adaptable to specific areas. Hence, genotypes with larger ASV values include ETBW9313, ETBW9284, BW174461 and BW174459. Accordingly, these last three genotypes have been picked for the Debre-Zeit, Bekoji and Holeta types of specific environments by AMMI ranking.

**Table 4.** Mean grain yield, ASV and YSI of 25 bread wheat genotypes across six locations.

| SN | Genotype  | GY (t/ha) | RGY | RASV | YSI | ASV  | IPCA1   | IPCA2   |
|----|-----------|-----------|-----|------|-----|------|---------|---------|
| 1  | WANE      | 4.88      | 17  | 19   | 36  | 1.36 | 0.3255  | -0.6843 |
| 2  | ETBW 9185 | 4.83      | 19  | 5    | 24  | 0.60 | 0.0974  | 0.4707  |
| 3  | ETBW 9193 | 4.62      | 22  | 4    | 26  | 0.39 | 0.1183  | 0.0853  |
| 4  | ETBW 9086 | 5.08      | 13  | 11   | 24  | 0.81 | -0.2663 | -0.1874 |
| 5  | ETBW 9087 | 4.92      | 15  | 2    | 17  | 0.24 | -0.0114 | 0.1342  |
| 6  | ETBW 9089 | 6.29      | 1   | 15   | 16  | 1.05 | -0.3100 | 0.0580  |
| 7  | ETBW 9109 | 4.86      | 18  | 9    | 27  | 0.75 | 0.2253  | 0.3179  |
| 8  | ETBW 9284 | 4.54      | 23  | 24   | 47  | 2.82 | 0.8817  | -0.2810 |
| 9  | ETBW 9299 | 4.91      | 16  | 10   | 26  | 0.80 | -0.0751 | 0.5800  |
| 10 | ETBW 9304 | 5.58      | 4   | 21   | 25  | 1.56 | -0.4823 | -0.0401 |
| 11 | ETBW 9313 | 4.25      | 25  | 25   | 50  | 3.13 | 1.0000  | -0.1819 |
| 12 | ETBW 9094 | 5.41      | 7   | 7    | 14  | 0.63 | -0.2156 | -0.1790 |
| 13 | ETBW 9066 | 4.74      | 21  | 17   | 38  | 1.25 | 0.4003  | -0.0160 |
| 14 | ETBW 9102 | 5.87      | 2   | 18   | 20  | 1.36 | -0.4146 | 0.0571  |
| 15 | ETBW 9315 | 5.14      | 10  | 6    | 16  | 0.61 | -0.2057 | -0.0551 |
| 16 | BW174459  | 4.92      | 14  | 22   | 36  | 1.61 | 0.4933  | 0.0420  |
| 17 | BW174460  | 5.27      | 9   | 8    | 17  | 0.66 | -0.2203 | 0.0468  |
| 18 | BW174461  | 5.54      | 5   | 23   | 28  | 1.63 | -0.4746 | 0.0335  |
| 19 | BW174462  | 5.14      | 11  | 13   | 24  | 0.83 | -0.2835 | -0.2860 |
| 20 | BW174463  | 5.11      | 12  | 1    | 13  | 0.09 | -0.0095 | -0.0487 |
| 21 | BW174464  | 5.76      | 3   | 20   | 23  | 1.56 | -0.4958 | -0.3819 |
| 22 | BW174465  | 4.51      | 24  | 14   | 38  | 1.02 | 0.0695  | 0.8040  |
| 23 | BW174466  | 5.33      | 8   | 3    | 11  | 0.33 | -0.0633 | -0.2145 |
| 24 | BW174467  | 5.43      | 6   | 16   | 22  | 1.06 | -0.3203 | -0.3257 |
| 25 | LEMMU     | 4.75      | 20  | 12   | 32  | 0.82 | 0.2370  | 0.2520  |

Note: ASV = AMMI Stability Value, IPCA = Interaction Principal Component Axes, RASV = Rank of ASV, RGY = rank of grain yield of genotypes across environments and YSI = Yield Stability Index.

## 8. Yield Stability Index (YSI)

Yield stability index (YSI) proposed by [23]. Includes both stability (ASV) rank and combined grain yield rank simultaneously. ASV takes into consideration both IPCA1 and IPCA2 which consider most of the variations in the GE interaction. Therefore, the genotypes with smallest ASV takes the rank one, while the genotype with the highest mean grain yield takes the rank one and then the ranks are summed in a single simultaneous selection index of yield and yield stability called yield stability index (YSI). The genotype with low YSI is considered as high yielding and stable genotypes. Accordingly, BW174466, BW174463, ETBW9094, ETBW9315 and, ETBW9089 were the most stable genotypes which were determined by YSI with mean grain yield of 5.33 t/ha, 5.11 t/ha, 5.41 t/ha, 5.14 t/ha and 6.29 t/ha, respectively. On the other hand, less stable genotypes, also with lower yields were ETBW9313, ETBW9284, ETBW9066, BW174465 and BW174459; these gave 4.25 t/ha, 4.54 t/ha, 4.74 t/ha, 4.51 t/ha and 4.92 t/ha, respectively.

## 9. Conclusion

Bread wheat genotypes are generally evaluated in multi-environment trials to test their performance across environments and to select the best genotypes for specific environments. The AMMI analysis for the additive main-effect and multiplicative interaction effect revealed significant variance for Genotype, location and genotype by location interaction. Genotypes BW174463, ETBW9193 and ETBW9087 genotypes are located closer to the origin of the biplot, and this implies that these bread wheat genotypes are stable across environments. Some selected genotypes showed similar ranking in different locations while other selected genotypes showed different rankings over different locations. For example, genotypes ETBW9089 ranked first at four of the six environments (Kulumsa, Bekoji, Debre-Zeit and Holeta), and 2<sup>nd</sup> at Arsi-Robe and 3<sup>rd</sup> at Assasa. ETBW9102 was picked by the AMMI model as 1<sup>st</sup> rank at Arsi-Robe and genotype, BW174464 ranked 1<sup>st</sup> at Assasa. Accordingly, ETBW9089 was 1<sup>st</sup> at Kulumsa, Bekoji, Debre-Zeit and

Holeta, 2<sup>nd</sup> at Arsi-Robe and 3<sup>rd</sup> at Assasa. It showed good performance in grain yield across most locations with variable performances and adaptation under two locations.

## Acknowledgements

The authors would like to acknowledge the financial support provided by Ethiopian Agricultural Research Institute for conducting the field trials. The authors also would like to acknowledge Kulumsa Agricultural Research Centre for the support in facilitating the field work and allocating the required labour and materials for field work and National wheat breeding program staff for all the assistance.

## References

- [1] Mollasadeghi, V., and R. Shahryari. 2011. Important morphological markers for improvement of yield in bread wheat. *Advances Environ. Biol.* 5 (3): 538-542.
- [2] CSA. 2019. Report on Area and Crop Production forecast for Major Crops (for private Peasant Holdings 'Meher' season). Addis Ababa, Ethiopia.
- [3] Mulatu Kassaye. 2015. Effect of Mineral NP and Organic Fertilizers on the Productivity and Nitrogen Use Efficiency of Bread Wheat (*Triticum aestivum* L.) in Gozamin District, North Western Ethiopia. PhD Dissertation, Haramaya University, Haramaya.
- [4] Bekele, H., H. Kotu, W. Varkuijl, D. Mwangi, and G. Tanner. 2000. Adoption of improved Wheat technologies in Adaba and Dodola Woredas of Bale high land, Ethiopia. Mexico D. F.: CIMMYT.
- [5] Trethowan, R., and J. Crossa. 2007. Lessons learnt from forty years of international spring bread wheat trials. *Euphytica* 157: 385-390.
- [6] Sial, MA., MU. Dahot, SM. Mangrio, B. Nisa Mangan, MA. Arain, MH. Naqvi, M. Shabana. 2007. Genotype x environment interaction for grain yield of wheat genotypes tested under water stress conditions. *Sci. Int.* 19 (2): 133-13.
- [7] Hamam, K., A. Abdel-Sabour, and G. A. Khaled. 2009. Stability of wheat genotypes under different environments and their evaluation under sowing dates and nitrogen fertilizer levels. *Austr. J. Basic Appl. Sci.* 3 (1): 206-217.
- [8] Khan, A. J., F. Azam, A. Ali, M. Tariq, M. Amin, and T. Muhammad. 2007. Wide and specific adaptation of bread wheat inbred lines for yield under rain-fed conditions. *Pak. J. Bot.* 39: 67-71.
- [9] Rane, J., RK. Pannu, VS. Sohu, RS. Saini, B. Mishra, J. Shoran, J. Crossa, M. Vargas, AK. Joshi. 2007. Performance of yield and stability of advanced wheat genotypes under heat stress environments of the Indo-Gangetic Plains. *Crop Sci.* 47: 1561-1573.
- [10] Yan, W., and M. S. Kang. 2003. GGE biplot analysis: a graphical tool for breeders, *In* M.S. Kang, ed. Geneticists, and Agronomist. CRC Press, Boca Raton, FL.
- [11] Yan, W., LA. Hunt, Q. Sheng and Z. Szlavnic. 2000. Cultivar evaluation and mega-environment investigation based on the GGE biplot. *Crop Science* 40: 597-605.
- [12] Yan W. 2002. Singular value partition for biplot analysis of multi environment trial data. *Agronomy Journal* 94: 990-996.
- [13] Yan, W., and I. R. Rajcan. 2002. Biplot analysis of test sites and trait relations of soybean in Ontario. *Can. J. Plant Sci.* 42: 11-20.
- [14] Rao, A. R., and V. T. Prabhakaran. 2005. Use of AMMI in simultaneous selection of genotypes for yield and stability. *J. Indian Soc. Agric. Stat.* 59: 76-82.
- [15] Kaya, Y., M. Akcura, and S. Tanner. 2006. GGE-biplot analysis of multi-environment yield trials in bread wheat. *Turk J. Agric. For.* 30: 325-337.
- [16] Asnake, W. N., M. Henry, Z. Temesgen, and T. Girma. 2013. Additive main effects and multiplicative interactions model and genotype main effect and genotype by environment interaction (GGE) biplot analysis of multi environmental wheat variety trials. *African Journal of Agricultural Research*. Vol. 8 (12): 1033-1040.
- [17] Fan, X. M., M. S., Kang, H. Chen, Y. Zhang, J. Tan, and C. Xu. 2007. Yield stability of maize hybrids evaluated in multi environment trials in Yunnan, China. *Agronomy J.* 99: 220-228.
- [18] Crossa, J., P. L. Cornelius, W. Yan. 2002. Biplots of linear-bilinear models for studying cross-over genotype x environment interaction. *Crop Sci.* 42: 619-633.
- [19] Purchase, JL., H. Hatting, CS. Vandeventer. 2000. Genotype x environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: Stability analysis of yield performance. *South African Journal of Plant and Soil* 17 (3): 101-107.
- [20] Mehari, M., and A. Workineh. 2019. "Adaptation Study and Genotype by Environment Interaction of Bread Wheat Genotypes in Tigray." North Ethiopia. *Basic Research Journal of Agricultural Science and Review* 6 (2): 09-14.
- [21] Gauch, H. G., R. W. and Zobel. 1997. Identifying mega-environments and targeting genotypes. *Crop science* 37 (2): 311-326.
- [22] Purchase, L. J. 1997. Parametric analysis to describe genotype x environment interaction and yield stability in Winter Wheat. PhD. Thesis, Department of Agronomy, Faculty of Agriculture, University of the orange Free State, Bloemfontein, South Africa.
- [23] Farshadfar, E. 2011. Incorporation of AMMI Stability Value and Grain Yield in a Single Non-Parametric Index (Genotype Selection Index) in Bread Wheat. *Pakistan Journal of Biological Sciences* 11: 1791-1796 pp.