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Genotype x Environment Interaction and Stability Analysis of Bread Wheat (*Triticum aestivum* L) Varieties under irrigation for Mid to Highland Ecological Zones of Oromia

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Abstract

A multi-location trial was carried out across mid to high moisture areas of Oromia Region during off season 2021 under irrigation to estimate the magnitude of genotype x environment interaction and to select high yielding and adaptable genotype/s across the tested environments under irrigation. The varieties consisted of 12 bread wheat varieties arranged in randomized complete block design with two replications. The varieties were tested in seven environments. The combined analysis of variance showed significant differences (P<0.01) among varieties for grain yield. Harato was the highest yielding (4.95 t ha^{-1}) while Arjo was the lowest yielding (1.96 t ha^{-1}) environment. The mean grain yield of the varieties across seven environments was 3.56 t ha^{-1} with the range of 3.16 t ha^{-1} for Sofumer to 4.38 t ha^{-1} for Hibist. GGE biplot analysis explained 69.09% of G+GEI and divided the seven environments into two major groups: Group 1 includes three environments Adami Tulu, Shambu and Gechi and Group 2 includes four environments Arjo, Dodola, Lume and Harato .Environments within the same group were more correlated and provided redundant information about the varieties. Variety Hibist and Wane were identified as the most stable and high yielding varieties, however Deka and Ogolcho were identified as the least stable and low yielding varieties across seven environments. The environment Harato was the ideal environment to select widely adapted bread wheat varieties, whereas, Adami Tulu and Dodola were far from the ideal environment and considered as unstable. Generally the ideal varieties were Hibist and Wane for irrigated wheat production throughout Oromia under irrigation during off season and the ideal environment was Harato for selecting widely adaptable bread wheat Genotypes under irrigation during off season.

Keywords: Adaptation, AMMI, Bread Wheat, GGE biplot, Stability,

Introduction

Bread wheat (*Triticum aestivum* (L.) Moench, 2n=2x=20] is an important cereal crop cultivated globally for multiple uses (FAO, 2021). Wheat production and productivity is affected by various constraints notably by biotic stresses such as diseases, weeds (*Striga* species) and insect pests. Wheat is the most important cereal crop of the family Poaceae (Gramineae) and is the second most important staple food crop after rice grown in 89 countries comprising temperate, subtropical and tropical climates. It was cultivated in more than 221 million hectares of land producing 728.9 million tons of food grains with a productivity of 3.62 t ha^{-1} in the world (FAO, 2014).

Ethiopia ranks first in wheat production followed by Sudan and Kenya in East Africa, and second in sub Saharan Africa after South Africa (FAO, 2021). Wheat is the third largest produced cereal crop after maize and tef (*Eragrostis tef*) in Ethiopia. Wheat is grown >1500 m.a.s.l. in mid and highland areas as a rain-fed crop in Ethiopia. Irrigation contributes 1.1% of the total cultivated land. In Ethiopia cereal crops cover 81.46% of total area and 88.52% of total production, of which wheat covers 13.91% and 15.86% total area and total production during meher season (CSA 2019/2020).

Wheat research for irrigated areas is recently established for the development of wheat varieties that can give high yield with better quality under irrigated conditions. The diversity of released wheat varieties for the area is limited and their adaptability across different location is not investigated. Unlike the rain-fed agro-ecologies, off-season irrigated wheat production can be constrained mainly by inadequate number of released wheat varieties. However, there are still technological challenges that need to be addressed through research such as getting the right variety to the targeted environments in using the technologies.

Therefore, in order to promote production and productivity of wheat in irrigated areas within short time, it is necessary to identify best adapted and better yielding improved varieties and recommend. Evaluating potential varieties existed in wheat research program is the best approach to find prominent suited for irrigable areas instead of commencing breeding program from the grass root level. Multi-location variety adaptation trial of bread wheat for mid to highland areas using irrigation during off season is critical issue to be considered in this study. Therefore, this experiment was initiated to determine the nature and magnitude of genotype x environment interaction and identify superior and stable wheat varieties for the different environments.

Materials and methods

Plant materials

The study used released bread wheat varieties sourced from different National and Regional research centers in Ethiopia. Improved bread wheat varieties included are presented in Table 1.

Table 1: List of released varieties used in the experiment from different research centers

No	Variety Name	Released by	Year of Release
1	Deka	Kulumsa	2018
2	Hibist	Sirinka	2018
3	Shorima	Sinana	2019
4	Liben	Bako	2015
5	ETBW 9554	Kulumsa	2020
6	Kakeba	Kulumsa	2010
7	Wane	Kulumsa	2016
8	Ogolcho	Kulumsa	2012
9	Obora	Sinana	2015
10	Sofumar	Sinana	1999
11	Balcha	Kulumsa	
12	Dendea	Kulumsa	2010

Study sites and experimental design

The varieties were evaluated for adaptability at West Arsi (Dodola), Horro Guduru Welega (Harato and Shambu), East Welega (Arjo and Gechi) and East Shoa Zone (Adami Tulu & Lume (Koka Nagawo)) Zones in Oromia Regional State of Ethiopia. The varieties were planted using randomized complete block design with two replications. Each plot consisted of 10 rows of 5 m long with inter-row spacing of 0.3 m.

Table 2: Profile of the study area

No	Description	Seven test environments						
		Adami Tulu	**Lume**	**Dodola**	**Gechi**	**Arjo**	**Harato**	**Shambu**
1	**Altitude**	1650 m	1608 m					
3	**Rainfall**	760.9 mm	896.3mm					
4	**Temperature**	12.6 & 27^0C	11^0C & 33^0C					
5	**Soil type**	Silty loam	Clay loam					
6	**Zone**	East Shoa	East Shoa	West Arsi	East Welega	East Welega	Horro Guduru Welega	Horro Guduru Welega

Trial Management

In all test locations, appropriate seedbed was prepared to facilitate uniform distribution of seed, fertilizer and irrigation water. Each entry was planted on 15m^2 (5m x 3m plot dimension) keeping standard distance between rows (30cm) and 1m between blocks/replications. Design used was randomized complete block design with two replications. Seed rate of 150 kg ha^{-1} and Fertilizer rate of 100, 150 kg ha^{-1} NPS was applied at planting. UREA applied at the rate of 150 kg ha^{-1} and NPS @100kg/ha was applied based on previous recommendations in the irrigable areas of the country. Urea (N) application was on split basis; half at planting and the remaining half at tillering stage. NPS was applied all at planting. Other management practices were performed as per previous recommendations. All the experimental plots were irrigated uniformly commencing at planting in 8-10 days interval and all the crop protection mechanisms were applied until the wheat crop reaches physiological maturity.

Data collected

Days to heading, days to maturity, spike length (cm), plant height (cm), grain yield (t ha^{-1}) were collected and subjected to statistical analysis using appropriate software.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) for each environment separately; and also combined analysis of variance was conducted to determine the effect of environment (E), genotype (G) and GE interaction on the expression of traits. The PBSTAT and R Software Version 4.1.0 were used for combined ANOVA and GGE biplot. The data were graphically presented for interpreting GE interaction using the GGE biplot software (Yan, 2001).

Stability analysis

The stability analysis among genotypes over environments was done using GGE biplot multivariate analysis methods as described below.

GGE biplot analysis

The GGE biplot is a biplot that displays the GGE part of MET data. The basic model for a GGE biplot is:

$$Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \epsilon_{ij}$$

where Y_{ij} is the mean for the i^{th} genotype in the j^{th} is the environment, μ is the grand mean, β_j is the main effect of environment, λ_1 and λ_2 are the singular values of the 1st and 2nd Principal Components (PC1 and PC2), ξ_{i1} and ξ_{i2} are the PC1 and PC2 scores, respectively, for genotype i^{th}, η_{j1} and η_{j2} are the eigenvectors for the j^{th} environment for PC1 and PC2 and ϵ_{ij} is the residual error term.

Results and Discussion

Combined analysis of variance concerning all the five traits is presented in (Table 3). The variances due to environment was highly significant for days to heading, days to maturity, plant height, spike length and grain yield, indicating the distinct and differential effects of different environmental conditions. The variances due to genotypes were significant for days to maturity and plant height and highly significant for days to maturity spike length and grain yield indicated the genetic differences of the genotypes in the environments. This result was in line with the finding of (Kifle *et al.* 2016) who reported that the combined analysis of variance over the two locations showed highly wheat genotypes in all studied traits. The variance due to GEI was highly significant for days to maturity; spike length and grain yield, showing the differential response of the varieties with different environments.

Table 3: Combined analysis of variance for different agronomic parameters of 12 bread wheat varieties tested over seven locations during 2021 off season under irrigation

Source of variations	**Df**	**DH**	**DM**	**PH(cm)**	**SL**	**GY(ton/ha)**
Replications	**1**	63.14**	3.42ns	2.47ns	0.38ns	0.02ns
Locations	**6**	1492.52***	6027.44***	2044.06***	56.65***	39.02***
Genotypes	**11**	78.99***	56.07**	2.14**	3.58***	1.97***
GXE	**66**	11.55ns	19.53**	103.25ns	1.48***	0.78***
R		0.93	0.97	0.76	0.90	0.91
CV (%)		4.56	2.63	10.46	9.09	16.48

Where, ** = highly signifcant at $P \leq 0.001$; *****= significant at $P \leq 0.05$; **ns** = not signifcant at P= 0.05, **Df**: degrees of freedom, **DH**: Days to Heading, **DM**: Days to Maturity, **PH**: Plant height in cm, **SL**: Spike length (cm) and **GY**: Grain yield in ton/ha, **GXE**: Genotype by environment interaction, **CV**: Coefficient variation

Mean grain yield performance of genotype

The result displayed that there was a significant differences among bread wheat varieties for grain yield across test environments indicating that there is a possibility to select good performing genotype/s. The mean grain yield of the varieties across seven environments was 3.56 t ha^{-1} which ranged from 3.16 t ha^{-1} (Sofumer) to 4.38 t ha^{-1} (Hibist) (Table 4). The observed environmental mean grain yield ranged from 1.96 t ha^{-1} for Arjo to 4.95 t ha^{-1} for Harato. In general, the ranking of varieties changes from one environment to another and this is also an indication of the existence of cross over GEI due to variation among the testing environments and this result is in agreement with the findings of (Gadisa *et al*., 2020; Temesgen *et al.*, 2015) who reported that the GEI was highly significant reflecting the differential response of bread wheat varieties in various environments.

Table 4. Mean performance for grain yield (t ha^{-1}) of 12 varieties across 7 environments

	Variety	Adami Tulu	Arjo	Dodola	Gechi	Harato	Lume	Shambu	Mean
1	Balcha	4.37	2.10	2.40	4.62	5.43	3.98	3.67	3.79
2	Deka	4.57	1.28	2.38	4.66	4.80	3.43	3.79	3.56
3	Dendea	3.83	1.78	1.93	3.70	5.06	4.58	2.09	3.28
4	ETBW 9554	3.87	2.36	1.89	5.24	5.63	5.15	1.58	3.67
5	Hibist	3.95	2.17	2.57	5.67	6.81	5.73	3.79	4.38
6	Kakaba	3.76	1.66	2.25	3.47	4.87	5.16	1.92	3.30
7	Liben	4.00	2.13	1.77	4.79	3.96	4.69	2.42	3.39
8	Obora	3.89	2.20	2.33	4.15	3.86	4.07	2.07	3.22
9	Ogolcho	4.81	1.34	2.52	3.91	4.92	5.07	0.77	3.33
10	Shorima	4.49	2.16	2.50	5.37	3.42	4.79	2.10	3.54
11	Sofumer	3.52	1.98	2.80	3.80	5.05	3.82	1.17	3.16
12	Wane	4.47	2.48	2.90	4.46	5.69	5.63	3.19	4.12
	Mean	4.13	1.97	2.35	4.48	4.96	4.67	2.38	3.56
	LSD 0.05	0.92	0.46	0.71	1.29	1.61	0.76	0.86	0.35
	CV (%)	12.44	13.01	16.70	16.05	18.10	9.10	20.18	15.80

Table 5. Combined analysis of variance of 12 bread wheat varieties evaluated in Oromia

Source of variations	Degree of freedom	Sum squares	Mean squares	F.value	Pr..F.
Replication	7	4.26	0.61^{ns}	1.92	0.077448
Genotype(G)	11	21.77	1.98***	6.25	2.95E-07
Location(L)	6	234.12	39.02***	64.15	9.17E-06
G x L	66	51.52	0.78***	2.46	7.94E-05
Residuals	77	24.38	0.32	NA	NA

AMMI Model for ANOVA

The AMMI analysis can be used to diagnose whether a specific sub-case provides a more appropriate analysis. AMMI has no specific experimental design requirements, except for a two way data structure. The results of AMMI model for grain yield are presented in Table 4. Mean square of the two IPCA were highly significant ($p<0.001$) and significant for PC3. The first PC axis (PC1) score explained 38.4% of the variation in GEI, while the second PC axes accounted for 29% of the variability. Many researchers witnessed that the best accurate AMMI model prediction can be made using the first two IPCA. Therefore, the dataset obtained from the interaction of 12 varieties tested at 7 environments was best predicted by the first two IPCAs. On the other hand, the IPCA scores of a genotype in the AMMI analysis are reported as indication of the stability of a genotype across environments (Yan, 2007). Accordingly, the closer the IPCA scores are to zero (origin), the more stable the varieties are across all their testing environments (Mukti *et.al,* 2020)

Table 6: The analysis of variance for grain yield using AMMI model

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Explain (%)
Environment (E)	6	234.1215	39.02025	64.14676	9.17E-06	
Replication/E	7	4.258075	0.608296	1.921142	0.077448	
Genotype (G)	11	21.76748	1.978862	2.535124	0.009832	
GxE	66	51.51814	0.780578	2.465247	7.94E-05	
PC1	16	19.76474	1.235297	3.9	0	38.4
PC2	14	14.92866	1.066333	3.37	0.0003	29.0
PC3	12	8.051179	0.670932	2.12	0.0249	15.6
Residuals	77	24.38073	0.316633			

In AMMI biplot (Figure 1) the environmental scores are joined to the origin by sidelines. Environments Adami Tulu, Arjo, Dodola, Gechi, Harato, Lume and Shambu are connected to origin. The varieties occurring close to the origin on the plot tend to have similar in yield in all environments, while genotype far apart may either differ in yield or show a different pattern of response over environments. Varieties with a smaller vector angle in between and have similar projection, designate their proximity in the grain yield. Those varieties that are clustered closer to the center tend to be stable and those plotted far apart are unstable in yield. Hence the genotype near the origin is not sensitive to environments and those distant from the origin are sensitive and have large interaction. Accordingly, varieties Shorima, Ogolcho, Hibist and Deka were unstable as they were located far apart from the other varieties in the biplot when plotted on the IPCA1 and IPCA2 scores. Many researchers witnessed that the best accurate AMMI model prediction can be made using the first two IPCA (Yan et al., 2000). Varieties Wane, Dendea, Kakaba, Sofumer, and ETB9554 were located near to the origin of the biplot which implies that they were stable bread wheat varieties across environments. The rest of the bread wheat varieties (Balcha, Liben and Obora) were unstable and were located distant from the origin.

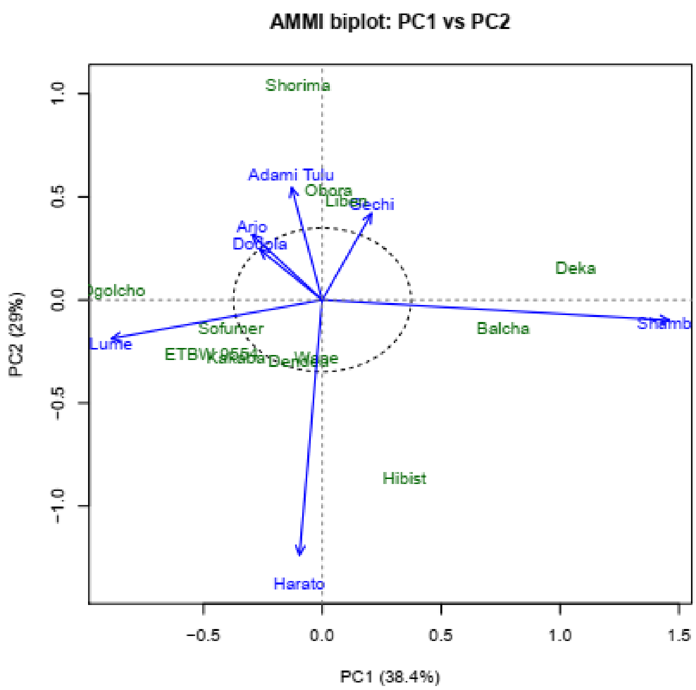

Figure 1: AMMI Biplot: PC1 vs. PC2

AMMI Stability Value (ASV)

In ASV method, a genotype with least ASV score revealed the most stable (Yan, 2003). Variety Wane is the most stable followed by Dendea and Sofumer and Deka and Ogolcho were unstable (Table 4). This was in agreement with the works (Farshadfar *et al.* 2012) that has used ASV as one method of evaluating grain yield stability of bread wheat varieties. Similar reports were also observed in (Mukti *et.al*, 2020) who has studied adaptability and stability pattern of spring wheat using ASV and other stability parameters. The significant mean square for location showed that genetic effects were influenced by the environments, which is a consequence of environmental diversity.

Yield stability index (YSI)

Stability is not the only parameter for selection, because the most stable varieties would not necessarily give the best yield performance, hence there is a need for approaches that incorporate both mean yield and stability in a single index, that is why various authors introduced different selection criteria for simultaneous selection of yield and stability: rank sum, modified rank-sum and the statistics yield stability In this regard, ASV takes into account both IPCA1 and IPCA2 and justifies most of the variation in the GEI. The least YSI is considered as the most stable with high mean grain yield. By using these measures, suitable wheat variety can be identified for varying existing environmental conditions. Based on YSI the most stable variety with high grain yield is variety Hibist with the YSI value 9 followed by Liben and ETB 9554 with YSI value 10 and 11, respectively. While most unstable varieties are Ogolcho with YSI value of 19 followed Deka with YSI value of 17. This result was in line with the works of (Mukti *et.al*, 2020) who classified 20 elite wheat lines into stable and unstable lines based on the distances they far from the origin for bread wheat.

The genotype x environment interaction (GEI) has been an important and challenging issue among plant breeders, geneticists, and agronomists engaged in performance testing. The GEI reduces association between phenotypic and genotypic values and leads to bias in the estimates of gene effects and combining ability for various characters that are sensitive to environmental fluctuations. Such traits are less amenable to selection. Both yield and stability performance should be considered simultaneously to reduce the effect of GEI and useful for selecting varieties in a more precise and refined way (Yan 2006)

Table 7: AMMI-estimates per Varieties (yield (ton/ha) across environments) (ASP and YSI)

	ASV	YSI	rASV	rYSI	Means
Balcha	1.02005	12	9	3	3.793571
Deka	1.422636	17	12	5	3.555
Dendea	0.324919	12	2	10	3.277857
ETBW 9554	0.668993	11	7	4	3.671429
Hibist	0.976639	9	8	1	4.382857
Kakaba	0.554496	15	6	9	3.296429
Liben	0.503768	10	3	7	3.392857
Obora	0.531571	16	5	11	3.222143
Ogolcho	1.166172	19	11	8	3.332143
Shorima	1.053726	16	10	6	3.544286
Sofumer	0.526463	16	4	12	3.160714
Wane	0.282355	3	1	2	4.115

Relationship among test environments

Further information about the discriminating power of environments, together with a representation of their mutual relationships can be obtained by the environment-vector view of the GGE-biplot. The distance between two environments measures their dissimilarity in discriminating against the varieties. Thus, the seven environments fell into two apparent groups. Group 1 contains three environments viz. Adami Tulu, Shambu and Gechi, Group 2 had four environments viz. Arjo, Dodola, Lume and Harato. Obtaining reliable information on the similarity of environments and their subdivision into groups can enable breeders to use fewer test environments reducing the cost of testing and increasing breeding efficiency. In GGE-biplot, the cosine of the angle between any two environments' vectors stands for correlation intensity. Less than 90° indicates a positive correlation, more than 90° a negative correlation, and close to 90° no correlation (Yan and Kang 2003; Shiri, 2013). Accordingly, there were positive relationships between Dodola and Arjo; Dodola and Gechi; Dodola and Harato; Dodola and Lume; Dodola and Shambu; Arjo and Harato; Arjo and Lume; Arjo and Gechi; Lume and Harato; Shambu and Adami Tulu; Shambu and Gechi. There is no Correlation between Adami Tulu and Harato; Gechi and Lume. On the other hand there is negative correlation between Adami Tulu and Lume.

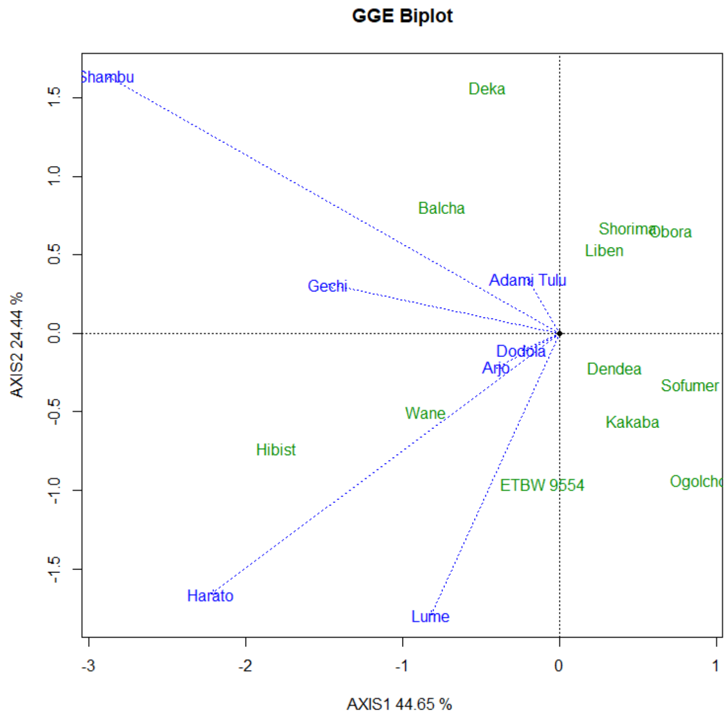

Figure 2: The Environment Vector View of GGE BIPLOT

Discriminating ability and representativeness of environments

Discriminating power and representativeness view of the GGE biplot is an important measure of testing environments (Dehghani *et al*., 2006). The length of concentric circles on the biplot help to visualize the length of the environment vectors which is proportional to a standard deviation within the respective environments on the biplot and also shows the discriminating ability of the environments (Yan 2006).

The GGE biplot revealed the discriminating ability and representativeness of test environments (Fig. 3). The similarity (covariance) between two environments is determined by both the length of their vectors and the cosine of the angle between them. In this case, a long environmental vector reflects a high capacity to discriminate the varieties. The environments Shambu and Harato had the good discriminating ability as shown by a long environmental vector and were the most discriminating environments and give more information on the performance of the varieties, while Dodola was the least discriminating environment, as was indicated by its short environment vector. This means if the study is carried out for several seasons and same sites continue to be non discriminating (less informative); it means the locations can be dropped and not be used as test locations. The representativeness of the test environments with a small angle to the average environmental axis (AEA) is more representative than other test environments. This means that Dodola and Arjo were the most representative test environment but with poor discriminating ability**,** whereas Gechi and Harato had good discriminating ability and less representativeness. Environments viz. Adami Tulu and Lume are the least representative. This may be due to their agro ecology of those two environments which is midland while the others were relatively highland areas. Test environments which are discriminating but non representative like Gechi and Dodola are important under circumstances when selecting varieties that are specifically adapted if the target environments can be divided into mega-environments.

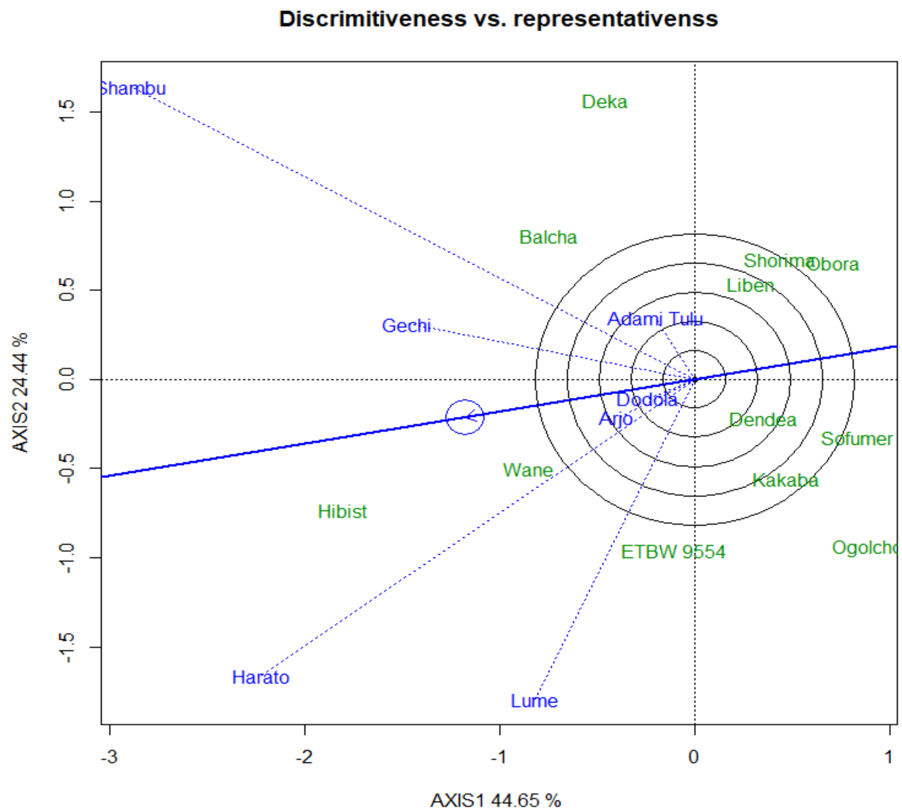

Figure 3: Discriminating ability and representativeness of environments

GGE analysis

Genotype main effect plus genotype by-environment interaction (GGE) biplot produces a graphical display of results that facilitates a better understanding of complex genotype by environment interaction in multi environment trials of breeding.

Which Won Where Pattern

Dividing the target environment into meaningful mega-environments and deploying different cultivars for different mega-environments is the only way to utilize positive GE and avoid negative GE and the sole purpose for genotype by environment interaction analysis (Yan *et al.*, 2007). A mega-environment is defined as a group of environments that consistently share the same best cultivar(s) (Yan and Rajcan, 2001). The present results showed that the first two principal components (PC1 and PC2) obtained by singular value decomposition of the environment centered data explained 69.09% of the total variability attributable to G+GE of yield data (Fig. 4). Similarly, Agegnehu *et al.*, 2019 and Gadisa *et al.*, 2020 reported that the two IPCAs explained 69.01% of the total GE interactions on the study of bread varieties evaluation for grain yield.

The biplot enabled visual comparison of the locations and varieties studied and their interrelationships. The vertices of the polygon were the genotype markers located farthest away from the biplot origin in various directions, such that all genotype markers were contained within the resulting polygon.

The vertex varieties were Obora for quadrant I; Deka for quadrant II; two varieties Hibist and ETB9554 for quadrant III and Ogolcho for quadrant IV. Mega environment may have more than one winning cultivar. These varieties were the best or worst in some or all environments because they are farthest from the origin of the biplot (Yan and Kang, 2003) and are more responsive to environmental changes and are considered as specifically adapted varieties.

The environments fall into two quadrants while the varieties fall into four quadrants (Fig. 4). The first quadrant contains no environment and 3 varieties Obora, Shorima and Liben and the vertex genotype for this section was Obora, being the highest yielding genotype at this quadrant within the same sector share the same winning genotype. The second quadrant contains three environments: Adami Tulu, Gechi and Shambu and two varieties namely; Deka and Balcha and the vertex genotype for this section was Deka. The third quadrant contains four environments: Arjo, Dodola, Harato and Lume and three varieties namely: Wane, ETB9554 and Hibist and the vertex varieties for this section were two namely Hibist and ETB9554. The fourth quadrant contains no environment and four varieties Dendea, Sofumer, Kakaba and Ogolcho and the vertex genotype for this section was Ogolcho. This result is in agreement with the findings of (Gadisa *et al*., 2020).

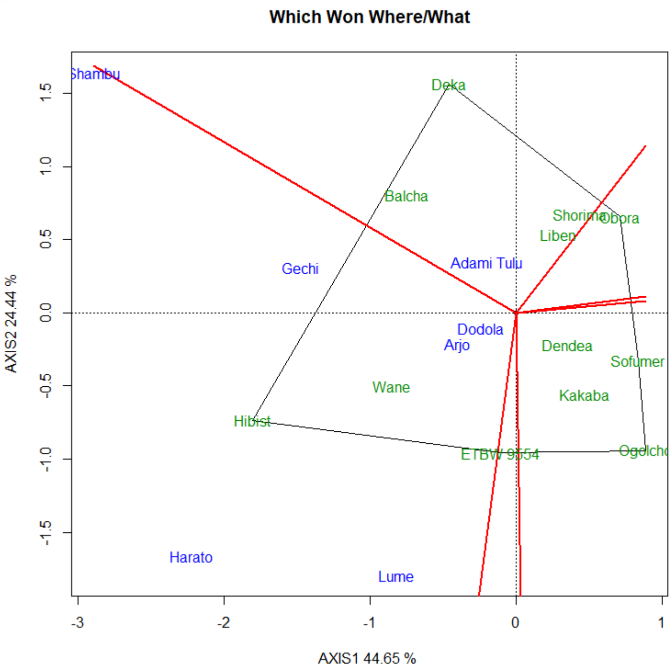

Figure 4. The which-won-where view of the GGE biplot to show which bread wheat genotype performed better in which environment for grain yield

Grain yield performance and stability of bread wheat varieties

The stability and grain yield performance of twelve bread wheat varieties were evaluated using average environment coordination (AEC) method (Fig. 5). In GGE biplot the estimation of yield and stability of varieties are done by using the average environment coordinate (AEC) methods (Yan, 2001). The best genotype can be defined as the one with the highest yield and stability across environments. In the GGE biplot, genotypes with high PC1 scores have high mean yield and those with low PC2 scores have stable yield across environments (Yan and Tinker, 2006).

Within a single mega-environment, genotypes should be evaluated on both mean performance and stability across environments. Therefore, in the present study, varieties Hibist, Wane and Balcha showed highest average yielding, respectively. On the other hand, besides to the genotypic grain yield performance stability of varieties across the testing environments is very important. A genotype which has shorter absolute length of projection in either of the two directions of AEC ordinate (located closer to AEC abscissa), represents a smaller tendency of GEI, which means it is the most stable genotype across different environments or vice versa. Hence, genotype Hibist and Wane were identified as the most stable and high yielding varieties across seven environments. Deka and Ogolcho were identified as the least stable and low yielding varieties.

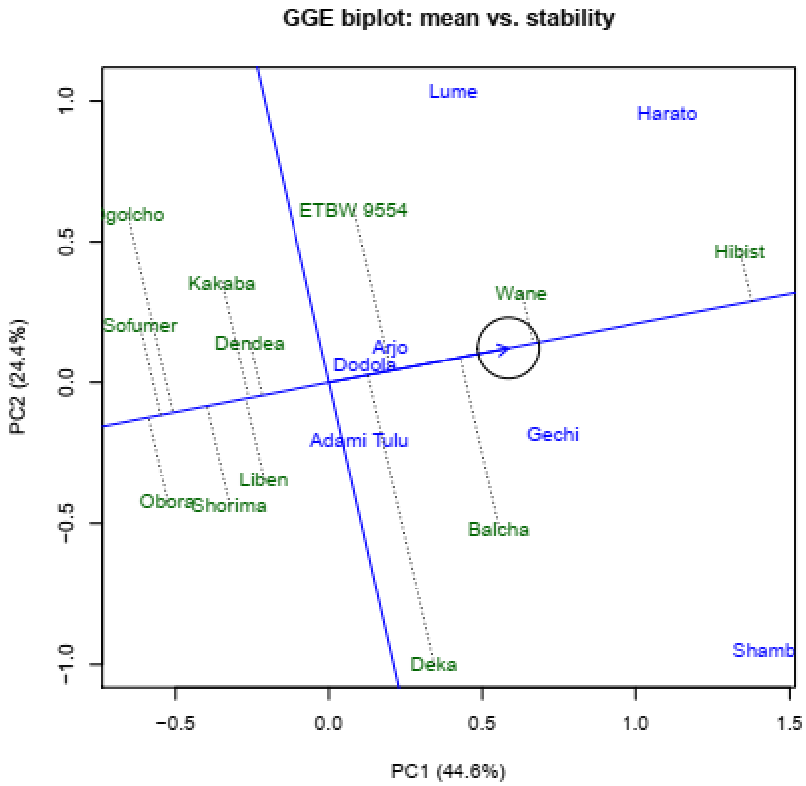

Figure 5: Grain yield performance and stability of bread wheat varieties

Evaluation of environments relative to the ideal environments

An ideal environment is one which highly discriminating the tested varieties and at the same time be representative of the target locations (Yan and Kang, 2003) and desirable environments are close to the ideal environment. Accordingly, nearest to the first concentric circle, the environment Harato was the ideal environment to select widely adapted bread wheat varieties, whereas, Adami Tulu and Dodola were far from the ideal environment and considered as unstable and it is, therefore, not a representative environment for the other five environments included in this study (Fig. 6). This result was in line with the works of (Muez *et al*., 2015; Gadisa *et al*., 2019, Gadisa *et al*., 2020) who reported that the first concentric circle environment was the ideal environment to select the widely adapted bread wheat genotypes, where as the environments far from the concentric circle were considered as unstable and it is not representative environments.

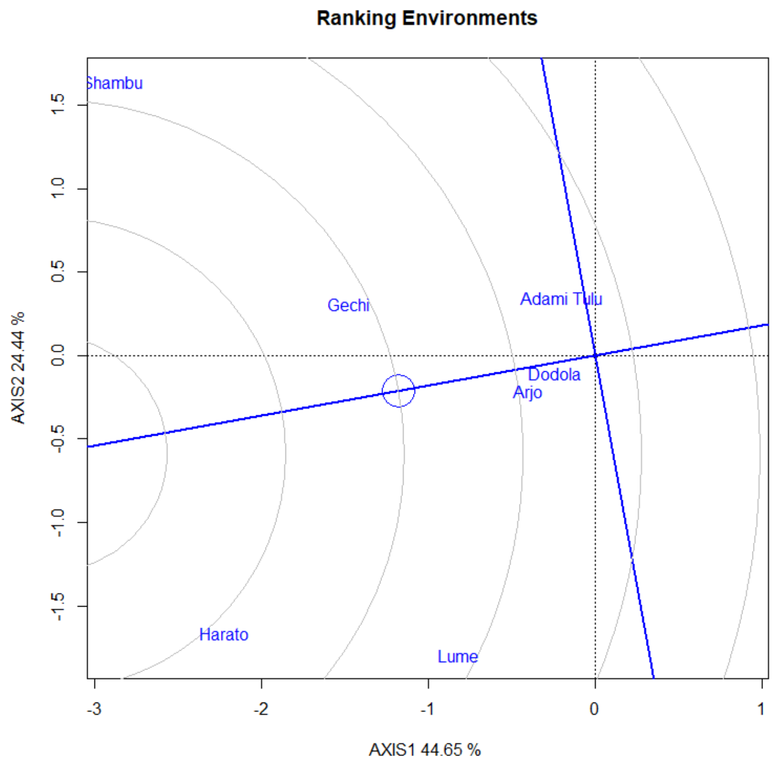

Figure 6: Ranking Environments Based on Ideal Genotype

Evaluation of varieties relative to the ideal varieties

An ideal genotype is defined as one that is the highest yielding across test environments and it's absolutely stable in performance (that ranks the highest in all test environments) (Yan and Kang, 2003; Farshadfar *et al.* 2012). Although such an "ideal" genotype may not exist in reality, it could be used as a reference for genotype evaluation and a genotype is more desirable if it is located closer to "ideal" genotype (Mitrovic *et al*., 2012). The varieties closer to the "ideal" were Hibist, Wane and Balcha. On the contrary, the lower yielding varieties Ogolcho, Sofumer and Obora were unfavorable because they are far from the ideal varieties (Fig. 7). The relative contributions of stability and grain yield to the identification of desirable genotype found in this study by the ideal genotype procedure of the GGE biplot in agreement with the report of Fan *et al.* (2007) for maize grain yield

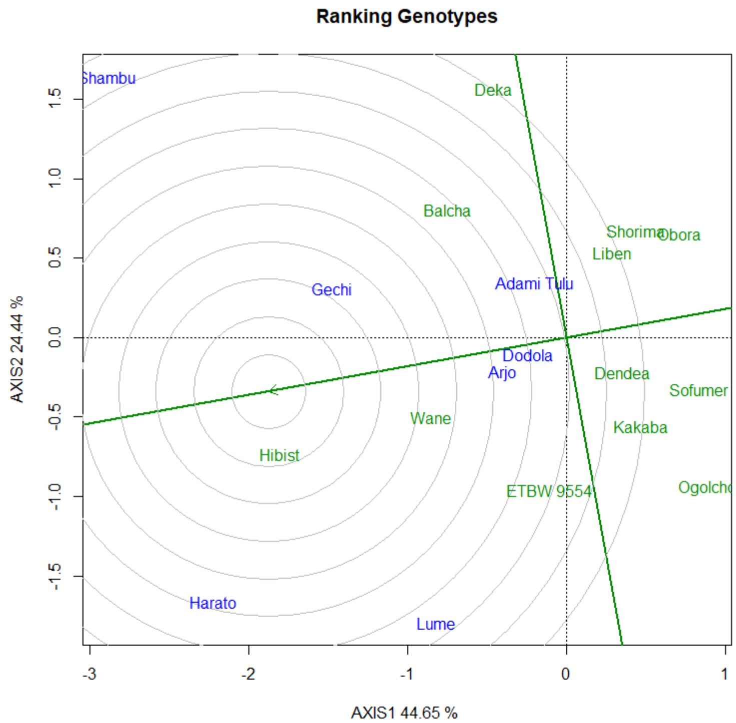

Figure: 7 Ranking Genotypes Related to Ideal Genotype

Conclusion

The GGE biplot analysis showed that both year and location are important for studying stability and adaptability of bread wheat varieties for grain yield in optimum moisture areas of Ethiopia. The contribution of the environment to the total treatment sum of square was higher than the G and GEI sum of squares indicating the test environments are more diverse and important to consider for evaluation of bread wheat varieties. The discriminating ability and representativeness of the test environments for the test varieties were good to identify stable and high yield varieties. Moreover, the information generated regarding the test environments for bread wheat breeding and MET analysis is useful for the future works.

The model identified the following varieties; Hibist, Wane and Balcha are the most stable and high yielding across the seven environments. Based on other desirable agronomic performance and wide adaptability, the genotype Hibist was selected as best variety for irrigated wheat production throughout Oromia. The environment Harato is ideal for selecting widely adaptable bread wheat Varieties under irrigation during off season.

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References

Agegnehu M., Firew M., and Arega G. 2019. AMMI and GGE biplot analysis of grain yield of bread wheat (*Triticum aestivum* L.) genotypes at moisture deficit environment of Wollo, Ethiopia. *Journal of Agricultural Science and Practice* 4(1), 9-19.

CSA (Central Statistics Agency). Agricultural Sample Survey 2019/2020 (2012 E.C.). Report on Area and Production of Major Crops (Private Peasant Holdings, *Meher* Season). Volume I Addis Ababa, Ethiopia (2020).

Dehghani, H., Ebadi, A. and Yousefi, A. 2006. Biplot analysis of genotype by environment interaction for barley yield in Iran. *Agronomy J*ournal, 98: 388-393

Fan, X.M., Kang, M.S., Chen, H., Zhang, Y., Tan, J. and Xu, C. 2007. Yield stability of maize hybrids evaluated in multi-environment trials in Yunnan, China. *Agronomy Journal* 99:220-228.

FAO, 2019. Strategic analysis and intervention plan for wheat and wheat products in the Agro-Commodities Procurement Zone of the pilot Integrated Agro-Industrial Park in Central-Eastern Oromia, Ethiopia

Farshadfar. E., Mohammadi. R, Aghaee, M. & Vaisi, Z. 2012. GGE biplot analysis of genotype x environment interaction in wheat-barley disomic addition lines. *Australian Journal of Crop Science*. 6: 1074–1079

Food and Agricultural Organization of the United Nations (FAO). 2014. Crop Prospects and Food Situation. Rome, Italy.

Food and Agricultural Organization of the United Nations (FAO). 2021. Crop Prospects and Food Situation. Rome, Italy.

Gadisa A., Alemu D., Negash G., Tafesse S., Abebe D., Rut D., Habtemariam Z., Dawit A., Abebe G., Bayisa A., Demeke Z., Bekele G., Ayele B.; and Bedada G. 2020. Development of Bread Wheat (*Triticum aestivum* L.) Varieties for High Moisture areas of Ethiopia: A G x E Interaction and Stability Analysis for Grain Yield. *Ethiopian Journal of Crop Science 8(1): 84-104.*

Gadisa A., Asnake, D. and Mohammed, H. 2019. GGE Biplot Analysis of Genotype by Environment Interaction and Grain Yield Stability of Bread Wheat Genotypes in Central Ethiopia. *Journal of Plant Breeding and Genetics*, *7*(2): 75-85.

Kifle Z, Firew M and Tadesse D. 2016. Genetic variability, heritability and genetic advance in bread wheat (*Triticum aestivum*.L) genotypes at Gurage Zone, Ethiopia. *International Journal of Microbiology and Biot*echnlogy 1(1): 1-9.

Mehari M., Tesfay M., Yirga H., Mesele A., Abebe T., Workineh A., Amare B. 2015. GGE biplot analysis of genotype-by-environment interaction and grain yield stability of bread wheat genotypes in South Tigray, Ethiopia. *Communications in Biometry and Crop Science* 10:7–26.

Mitrovic B, Stanisavljevi D, Treski S, Stojakovic M, Ivanovic M, Bekavac G & Rajkovic. M . 2012. Evaluation of experimental Maize hybrids tested in Multi-location trials using AMMI and GGE biplot analysis. Turkish Journal *of Field Crops:* 17(1):35-40

Muez M, Mizan T, Haddis Y, Adhiena M, Teklay A, Assefa W, Birhanu A 2015. GGE biplot analysis of genotype-by-environment interaction and grain yield stability of bread wheat genotypes in South Tigray, Ethiopia. *Communications in Biometry and Crop Science*.10.17–26.

Mukti R., Suryakant G., Madhav P., Krishnahari D., Dhruba Bahadur T., Hema and K.2020 Yield Stability Analysis of Wheat Genotypes at Irrigated, Heat Stress and Drought Condition. *Journal of Biology Today's World* 9(5): 220.

Naheif E., and Mohamed M. 2013. Genotype by environment interactions for grain yield in bread wheat (*Triticum aestivum* L.) *Journal of Plant Breeding and Crop Science* 5(7) :150-157

Shiri M. R. 2013. Grain yield stability analysis of maize (*Zea Mays* L.) hybrid under different drought stress conditions using GGE biplot analysis. *Crop Breeding Journal*, 3: 107–112.

Temesgen B, Sintayew A & Zerihun T. 2015. Genotype X environment interaction and yield stability of bread wheat (*Triticum Eastivum L*.) genotype in Ethiopia using the Ammi Analysis. *Journal of Biology, Agriculture and Healthcare*, 5(11): 129-139.

Yan W & Tinker K. 2006. Biplot analysis of multi-environment trial data: Principles and applications. *Canadian J. Plant Sci*, 86: 623–645. Yan, W. and Rajcan, I. 2002. Biplot evaluation of test sites and trait relations of soybean in Ontario. *Crop Science.* 42: 11–20.

Yan W S, Kang M, Baoluo M, Woods S & Cornelius, PL. 2007. GGE Biplot vs. AMMI analysis of genotype-by environment data. *Crop Science*. 47:643- 653.

Yan W, L A.Hunt, Q. Sheng and Z Szlavnics. (2000). Cultivar Evaluation and MegaEnvironment Investigation Based on the GGE Biplot. Crop Science, 40: 597.

Yan, W. 2001. GGE biplot: a Windows application for graphical analysis of multi environment trial data and other types of two-way data. *Agronomy*, 93: 1111-1118.

Yan, W. and Kang, M. S.. 2003. GGE biplot Analysis: a Graphical Tool for Breeders, Geneticists and Agronomists CRC Press LLC: Boca Roton, Florida *Crop Breeding Journal*, 3: 127–132

APPENDIX

Appendix Table 1: Mean agronomic performance of 12 bread wheat varieties tested at seven mid to highland areas of Oromia during 2021 off season under Irrigation.

	Genotypes	DH	DM	PH(cm)	SL	GY(ton/ha)
1	**Adami Tulu**	57.12^{e}	107.62^{e}	74.44^{d}	8.70^{c}	4.12^{c}
2	**Arjo**	76.91^{a}	124.41^{b}	79.05^{bcd}	8.4^{c}	1.96^{e}
3	**Dodola**	63.20^{c}	112.54^{d}	80.95^{bc}	5.75^{e}	2.35^{d}
4	**Gechi**	64.12^{c}	115.66^{c}	84.08^{b}	7.57^{d}	4.48^{b}
5	**Harato**	57.37^{e}	123.83^{b}	97.96^{a}	9.60^{b}	4.95^{a}
6	**Lume**	59.58^{d}	108.66^{bc}	77.33^{cd}	9.4^{b}	4.67^{ab}
7	**Shambu**	73.87^{b}	153.50^{a}	96.12^{a}	10.41^{a}	2.37^{d}
Mean		64.60	120.89	84.28	8.55	3.56
LSD(0.05)		2.95	3.18	8.82	0.77	0.58

Where, **LSD**: Least significant Difference, **DH**: Days to Heading, **DM**: Days to Maturity, **PH**: Plant height in cm, **SL**: Spike length (cm) and **GY**: Grain yield in ton/ha

Appendix Table 2: Combined mean values of 12 bread wheat varieties for grain yield and other agronomic characters at seven locations during 2021 off season under Irrigation

No	Genotypes	DH	DM	PH(cm)	SL	GY(ton/ha)
1	**Balcha**	65.76b^{cd}	119.78^{cde}	87.20^{a}	8.25^{cdef}	3.79^{bc}
2	**Deka**	62.35^{efgh}	121.85^{bc}	81.84^{ab}	8.27^{cdef}	3.55^{cde}
3	**Dendea**	66.42^{abc}	122.28^{b}	85.55^{a}	8.65^{bcd}	3.28^{de}
4	**ETBW 9554**	64.57^{cde}	121.35^{bcd}	84.20^{a}	8.76^{bcd}	3.67^{cd}
5	**Hibist**	61.85^{gh}	119.21^{de}	82.38^{a}	8.05^{ef}	4.38^{a}
6	**Kakaba**	62.21^{fgh}	118.00^{e}	84.34^{a}	8.20^{def}	3.29d^{e}
7	**Liben**	66.92^{ab}	119.07^{de}	82.05^{ab}	8.39^{cde}	3.39^{cde}
8	**Obora**	68.28^{a}	125.71^{a}	85.54^{a}	9.20^{ab}	3.22^{e}
9	**Ogolcho**	63.92^{defg}	121.07^{bcd}	87.12^{a}	9.58^{a}	3.33d^{e}

10	**Shorima**	67.42^{ab}	121.00^{bcd}	86.77^{a}	8.64^{bcd}	3.54^{dce}
11	**Sofumer**	64.21^{cdef}	121.6^{4bc}	87.71^{a}	8.80^{bc}	3.16^{e}
12	**Wane**	61.25^{h}	119.71^{cde}	75.62^{b}	7.75^{f}	4.11^{ab}
Mean		64.60	120.89	84.28	8.55	3.56
CV (%		4.56	2.63	10.46	9.09	16.48
LSD(0.05)		2.95	3.18	8.82	0.77	0.58

Where, **DH**: Days to Heading, **DM**: Days to Maturity, **PH**: Plant height in cm, **SL**: Spike length (cm) and **GY**: Grain yield in ton/ha, **LSD** : Least significant difference**, CV**: Coefficient variation

Appendix Table 3: Parameters Rank of genotypes

No	Genotypes	Yi	CVi	bi	s2di	Wi2	Di	StabVar	YSi	Si(1)	Si(2)	Si(3)	Si(6)	TOP	NPi(1)	NPi(2)	NPi(3)	NPi(4)
1	Balcha	3	3	7	7	6	7	6	2.5	3	3	3	4	8	4.5	5.5	6	6
2	Deka	5	5	8	12	12	12	12	9	11	11	12	9	4.5	9.5	7	8	8
3	Dendea	10	9	2	2	1	2	1	7	1	1	1	2	11.5	1	1	1	1
4	ETBW 9554	4	11	11	6	8	6	8	4	9	9	11	10.5	3	9.5	10	10	9
5	Hibist	1	7	9	9	9	9	9	2.5	12	12	8	12	1	12	12	12	12
6	Kakaba	9	10	3	5	4	5	4	6	5	6	4	3	8	2.5	2	2	2
7	Liben	7	4	4	4	5	4	5	5	4	4	5	5	11.5	4.5	5.5	4	4
8	Obora	11	1	10	1	3	1	3	8	6	5	2	1	8	6	3	3	3
9	Ogolcho	8	12	12	10	11	10	11	11	10	10	10	8	8	11	8	7	7
10	Shorima	6	6	6	11	10	11	10	10	7.5	7	9	7	4.5	7	9	9	10
11	Sofumer	12	8	5	8	7	8	7	12	7.5	8	6	6	8	8	4	5	5
12	Wane	2	2	1	3	2	3	2	1	2	2	7	10.5	2	2.5	11	11	11