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STABILITY AND ADAPTABILITY OF RELEASED BREAD WHEAT (*TRITICUM AESTIVUM* L.) VARIETIES FOR YIELD AND YIELD RELATED TRAITS AT HIGHLANDS OF SOUTHWESTERN PART OF ETHIOPIA

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ABSTRACT

Bread wheat *(Triticum aestivum L.)* is the most important cereal crop in Ethiopia. Lack of genotypes with wide stability across environments has been one of the most important constraints of wheat production in the highlands of Southwestern part of Ethiopia. The objectives of the trial was to estimate the magnitude of GEI and to select high yielding and stable bread wheat varieties for the highlands of Southwestern Ethiopia using different stability analysis. Twelve nationally released bread wheat varieties were obtained from Kulumisa Agricultural Research Center (KARC) used for the study. The varieties were evaluated in three environments, over two main growing seasons (2021 and 2022), in the highlands of Southwestern Ethiopia. The experiment was laid out in randomized complete block design (RCBD) with three replications. The experimental plot for each variety consisted of six rows of 2.5m length and rows were spaced 20cm apart. Spacing between rows, plots and replications 25cm, 30cm and 1m respectively. The seed rate was 125kg/ha. Fertilizer was applied at rate of 100kg NPS and 150kg of urea was applied in spilt: half at the time of planting and the remaining half at the tillering stage. In addition, other relevant field trial management practices were carried out uniformly for all experimental units. The analysis of variance (ANOVA) revealed that there was a highly significant difference ($p<0.001$) among grain yield across locations. The mean grain yield of wheat varieties ranged from 3.5t/ha (Ogolocho) to 4.6t/ha (Danda'a) with mean grain yield of 3.8t/ha. The combined ANOVA over environments for grain yield was highly significant ($p<0.001$) for genotypes, environments and interaction effects. The effect of environment, genotype and GEI accounted for 77.6%, 3.87% and 10.57% of the total sum squares. According to both univariate and AMMI stability model analysis, bread wheat variety ETBW9089 was stable and recommended for high scale production.

Key Words: Grain yield, Stability analysis, Southwestern, wheat varieties

1. BACKGROUND AND JUSTIFICATION

Wheat is the second most produced cereal crop after maize in the world. It is the staple food for millions of people and cultivated all over the world except the Antarctica continent and is grown at a wide range of elevation varying from 260 meter below sea level up to 4,000 meter above sea level [1]. Bread wheat was originated recently as compared to other wheat species. However, it has wider adaptation than any other wheat species and other crops due to its sufficient genetic diversity which enables to survive in wider range of environments [2]. The major wheat producing countries were European Union, China, India, Russia, USA and Canada. These countries together contribute more than half of the global wheat production [3].Ethiopia is the largest wheat producer in the Sub-Saharan Africa with about 0.75 million ha of durum and bread wheat. Wheat is one of the major cereal crops in the Ethiopian highlands, which range between 6 and 16^{o}N, 35 and 42 ^{o}E, and from 1500 m to 2800 m. At present, wheat is produced solely under rain-fed conditions. About 60% of wheat area is covered by durum and 40% by bread wheat. Of the current total wheat production area 75.5% is located in Arsi, Bale, and Shewa regions. Forty-six percent of the 13 million ha classified as highly suitable for wheat production is located in Arsi, Bale, and Shewa.

Altitude plays an important role in the distribution of wheat production through its influence on rainfall, temperature and diseases. In Arsi, Bale, and Shewa regions, the soil, moisture and disease conditions in the 1900-2300 m altitude zone are favorable for the production of early- and intermediate maturing varieties of bread wheat. This is estimated to comprise 25% of the total wheat area, while the remaining 75% falls in the 2300-2700m zone. There, early, intermediate and late varieties are grown. Soil types used for wheat production vary from well-drained fertile soils to water-logged heavy vertisols [4].In Ethiopia, bread wheat is an introduced crop, although its time of introduction is immemorial [4]. Bread wheat is one of the most important cereal crops of Ethiopia grown over wider agro-ecologies mainly at intermediate and high land areas, commonly known as the east African wheat-belt [5].

Wheat (*Triticum aestivum*) is one of the major cereals grown for use as food and industrial raw materials in Ethiopia. It is an important staple food in the diets of many Ethiopians, providing an estimated 12% of the daily per capita caloric intake for the country’s over 90 million population [6]. Wheat is the most important staple crop in temperate zones and is in increasing demand in countries undergoing urbanization and industrialization. In addition to being a major source of starch and energy, wheat also provides substantial amounts of a number of components which are essential or beneficial for health, notably protein, vitamins (notably B vitamins), dietary fiber, and photochemical [7].

Southwestern highland part of the country, Yem special district, Jimma and Buno Bedele zones, are among major wheat producing areas that cover 2823.3,29,257 and 1751 ha and with the productivity of 29.2, 31.4 and 28.5qt/ha respectively [8].The production and productivity of wheat at the highlands of Southwestern part of Ethiopia was below from national productivity which 31qt/ha mainly due to lack of high yielding and adaptable varieties, diseases, soil acidity and other biotic and abiotic factors. Grain yield is the most important trait in wheat however; this character is polygenic and sensitive to the exposed environmental changes [9].The genotype by environment interaction (GEI) has greater influence on grain yield of wheat in Ethiopia. The purpose of conducting adaptation test is to determine the genetic potential and adaptability of varieties in the targeted environments. This test involves the evaluation of a number of various varieties in several environments using the same experimental design. A better understanding of GEI is helpful to evaluate genotype stability and adaptability across environments, and assess the ability of test environments to discriminate the tested genotypes [10].

Several models of stability analysis are provided to elucidate the complex nature of GEI phenomena under stressed environments [11] and to utilize the obtained information for varietal selection [12].The parametric methods themselves are divided into two groups: multivariate (AMMI and GGE bi-plot analysis) and univariate stability parameters [13], which most of these methods will be considered here.[14] suggested using GEI for each genotype as a stability measure, which he termed as ecovalance (Wi). [14] suggested that the contribution of each genotype to GEI sum of squares as ecovalence (Wi) and genotypes with the least/zero ecovalence are considered as stable.[15] developed an unbiased estimate using stability variance ($\sigma^2 i$) of genotypes and a method to test the significance of the ($\sigma^2 i$) for determining stability of a genotype. According to [15], a genotype is stable when Shukla stability variance is equal to environmental variance *i.e.* Shukla stability variance is zero.[16], used the environmental variance ($S^2 i$) and the coefficient of variation (CVi) and [17], used coefficients of determination (Ri^2) of each genotype as stability parameter.

According to [18] a stable genotype is a genotype with the least AMMI Stability Value (ASV), because the lower the ASV of the genotype, the lower the contribution of a genotype to GEI. Genotype selection index (GSI), was used by taking into consideration the AMMI stability value and mean yield for yield stability [19].The additive main effects and multiplicative interaction (AMMI) model is a powerful multivariate method to multi-environmental trial. This technique incorporates both additive and multiplicative components into an integrated, powerful least square analysis [20]. Hence, the objectives of the experiment was to estimate the magnitude of GEI and to select high yielding and stable bread wheat varieties for the highlands of southwestern Ethiopia using different stability model analysis.

2. MATERIALS AND METHODS

Experimental materials

Twelve nationally released bread wheat varieties were obtained from Kulumisa Agricultural Research Center (KARC) used for the study (Table 1).The varieties were evaluated in three environments, over two growing seasons (2021 to 2022), in the highlands of Southwestern

Ethiopia. The experiments were conducted at Dedo, Yem and Gechi districts of Southwestern part of Ethiopia during the main cropping seasons (Table 2).

Table 1: Descriptions of experimental materials used in the study

#SN	Variety name	Year of Release	Breeder/ Maintainer
1.	ETBW9089	2021	*KARC/* EIAR
2.	Jajabo	2017	*KARC/* EIAR
3.	Liben	-	*KARC/* EIAR
4.	Lemu	-	*KARC/* EIAR
5.	Wane	-	*KARC/* EIAR
6.	Huluka	2012	*KARC/* EIAR
7.	Alidoro	2007	*KARC/* EIAR
8.	Hidasse	2012	*KARC/* EIAR
9.	Ogolcho	2012	*KARC/* EIAR
10.	Daka	-	*KARC/* EIAR
11.	Danda'a	2010	*KARC/* EIAR
12.	Boru	-	*KARC/* EIAR

Where;*EIAR; Ethiopian Agricultural Research Institute KARC: Kulumisa Agricultural Research Center*

Testing Environments

Table 2: Description of the Study Sites

Stations	Zones/Regions	Altitude (m.a.s.l.)	Temp (^{0}C)	Rainfall (mm)	Soil type
Dedo	Jimma	2284	22	1850	Nitosol
Yem special dist.	SNNPR	2470	22.5	1550	Nitosol
Gechi	Buno bedele	2087	20.7	1800	Nitosol

NB*: SNNPR=Southern Nation, Nationalities and peoples region*

Experimental Design and Crop Management

The experiment was laid out in randomized complete block design (RCBD) with three replications. The experimental plot for each variety consisted of six rows of 2.5m length and rows were spaced 20cm apart. Spacing between rows, plots and replications 25cm, 30cm and 1m respectively. The seed rate was 125kg/ha.Fertilizer was applied at rate of 100kg NPS and 150kg of urea was applied in spilt: half at the time of planting and the remaining half at the tillering stage. In addition, other relevant field trial management practices were carried out uniformly for all experimental units.

Data Collection

All the data were recorded based on the wheat descriptor list [21].Data were collected from the four middle rows of each plot on the plant and plot bases. For the data collected on a plant basis, five plants per plot were randomly selected for each of the traits; that is, number of tillers per plant, number of kernels per spike, plant height (cm), and spike length (cm) and data for number of days to heading (75%), number of days to maturity (90%), grain filling period, thousand kernel weight (gm), aboveground biomass (t/ha) and grain yield (t/ha) were collected on a plot basis.

Data Analysis

The agro-morphological data parameters of the three locations were subjected to the variance analysis using GenStat 16th edition statistical software package (VSN International Ltd., London, UK) following the standard procedures described by [22] to evaluate the performance of genotypes for each trait and location and calculate the error variances for each of the environments. For combined ANOVA over locations, the homogeneity of error variance was tested using [23] for homogeneity of variances using the same software. Difference between treatment means was compared using the least significant difference (LSD) test at 5% level of significance when the ANOVA showed a significant difference among genotypes.

Additive Main Effect and Multiplicative Interaction (AMMI) Statistical model, AMMI Stability Value (ASV) and Genotype Selection Index (GSI)

AMMI analysis was done by using Genstat version 16th software, according to the model suggested by [24] AMMI statistical model equation is: $\bar{Y}_{ijk} = \mu + G_i + E_j + \Sigma m\ k{=}1\ \lambda k\alpha ik\gamma jk + Y_{ij}$Where:$\bar{Y}_{ijk}$. = The yield of the ith genotype in the jth environment, $_I$ = The mean of the ith genotype minus the grand mean, E_j = The mean of the jth environment minus the grand mean, λ_k = The square root of the eigen value of the kth IPCA axis, αik and γjk = The principal component scores for IPCA axis k of the ith genotypes and the jth environment

AMMI Stability Value (ASV)

AMMI stability value (ASV) [25] would be essential in order to quantify and rank genotypes according to their yield stability. AMMI's stability value (ASV) was calculated using the following formula with Microsoft excel (2010).

$$ASV = \frac{\sqrt{[IPCA1\ sumofsquares(IPCA1\ score)]^2}}{IPCA2\ sum\ of square} + (IPCA2\ score)^2$$

Where: ASV = AMMI's stability value, SS = sum of squares, IPCA1 = interaction of principal component analysis one, IPCA2 = interaction of principal component analysis two.

Genotype Selection Index (GSI)

[26] developed this new approach as a measure of genotype stability. GSI incorporates both mean yield and stability in a single criterion. Low value of this parameters shows desirable genotypes with high mean yield and stability. GSI was calculated as: GSI = RASV + RY; Where: RASV is the rank of AMMI stability value, RY is the rank of mean yield of genotypes across environments.

3. RESULT AND DISCUSSION

Mean Performance of wheat varieties across locations

The analysis of variance (ANOVA) revealed that there was a highly significant difference ($p<0.001$) among grain yield across testing environments indicating that there is a possibility to select good performing bread wheat variety/ies (Table 3).The mean grain yield of wheat varieties ranged from 3.5t/ha (Ogolocho) to 4.6t/ha (Danda'a) with mean grain yield of 3.8t/ha (Table 3).The performance of wheat varieties at highlands of Southwestern part of Ethiopia was higher than that of national average (3.1t/ha) even in the presence of different biotic and abiotic factors. This show the highlands of Southwestern part of Ethiopia was appropriate site to conduct different trials and to identify stress tolerant genotypes.

Wheat varieties showed different performance across different locations. For example, the popular variety Danda'a, was ranked first at Dedo2021 location but, fifth at Gechi2021 and fourth at Yem2021 (Table 3).This rank change of the same genotype over different environments for the same trait is the consequence of the highly significant GEI. Bread wheat varieties showed yield variation across different locations and years. This indicates that two years data showed the different response at the same location and the presence of high seasonal variation within the same location and the need to consider both seasons and locations for multi-environment trial (MET) analysis of wheat varieties for different traits.

Table 3: Mean performance of twelve bread wheat varieties across tested locations

Bread wheat varieties	**Locations and Years**						**Overall mean**	**Rank**
	Dedo 2021	**Gechi 2021**	**Yem 2021**	**Dedo 2022**	**Gechi 2022**	**Yem 2022**		
ETBW9089	4.6	2	4.1	6.4	4.3	4.7	**4.4**	**3**
Jajabo	4.8	1.2	4.6	6.5	3.7	4.8	**4.3**	**5**
Liben	4.8	1.5	3.4	6.3	4.4	5	**4.2**	**7**
Lemu	4	1.7	4	6.1	4.8	4.9	**4.3**	**6**
Wane	5.1	1.9	3.7	6.4	3.2	4.8	**4.2**	**8**
Huluka	4.5	2	4	7.1	4.2	5.1	**4.5**	**2**
Alidoro	4.1	2.8	3.3	6.9	3.6	5.2	**4.3**	**4**
Hidasse	4.3	1.3	3.3	5.4	3.1	4.6	**3.7**	**11**
Ogolcho	1.5	1.7	3.4	5.1	4.4	4.9	**3.5**	**12**
Daka	3.4	2.5	4.4	7.1	3.2	4.5	**4.2**	**9**
Danda'a	5.3	2	4	6.4	3.8	5.8	**4.6**	**1**
Boru	4.6	1.3	3.9	5.6	3.9	5.1	**4.1**	**10**
Mean	**3.5**	**2**	**3.9**	**5.8**	**3.2**	**4.6**	**3.8**	
F test	*******	*****	*******	*******	*****	*******		
CV (%)	**4.2**	**1.8**	**3.9**	**6.3**	**3.8**	**4.9**		
LSD at 5%	**15.6**	**29.3**	**9**	**9.6**	**15.5**	**6.7**		

CV =coefficient of variation, LSD =least significant difference*,** significant ($p < 0.05$) and highly significant ($p < 0.01$) respectively

Combined Analysis of Variance (ANOVA) for grain yield and related traits

ANOVA showed significant differences ($p<0.05$) among the tested varieties. Except FT and KPS which were non-significant, all other traits showed significant differences between varieties (Table 4).From the combined ANOVA,high grain yield was harvested from wheat variety T11

(4.5), T6 (4.5) and T1 (4.4) and the lowest grain yield was harvested from the genotype T9 (3.5) (Table 4).

Table 4: Combined analysis of variance (ANOVA) for different traits

Varieties	DH	DM	GFP	PH(cm)	PL(cm)	FT	TSW(g)	KPS	BY (t)	GY(t)	SY(t)
T1	67.2	133.0	65.8	80.9	8.1	4.3	39.3	42.2	9.9	4.4	5.9
T2	69.5	131.2	61.8	83.3	8.6	4.9	38.6	45.2	10.8	4.3	6.5
T3	70.3	132.7	62.4	80.5	8.1	5.0	34.0	40.3	9.7	4.2	5.5
T4	72.2	134.1	61.9	82.6	8.1	4.6	35.7	39.9	10.1	4.2	5.8
T5	69.7	132.6	62.9	77.9	7.5	4.6	37.6	43.4	10.3	4.2	6.1
T6	66.9	133.2	66.3	79.1	8.1	4.5	36.9	43.7	10.3	4.5	5.8
T7	69.1	131.1	61.9	87.1	8.8	4.5	37.4	44.7	11.0	4.3	6.6
T8	65.2	130.8	65.7	78.6	7.9	4.8	37.6	42.8	9.0	3.7	5.3
T9	65.6	130.1	64.5	80.9	8.2	4.2	35.7	43.3	8.3	3.5	4.8
T10	67.4	133.7	66.2	83.5	8.1	4.8	36.8	44.6	10.6	4.2	6.4
T11	70.3	134.2	63.9	83.3	8.3	4.3	37.4	42.4	10.4	4.5	5.9
T12	66.8	132.9	66.2	76.5	8.0	4.3	40.0	42.7	9.5	4.1	5.4
Mean	**68.2**	**132.7**	**64.4**	**81.7**	**8.2**	**4.5**	**37.1**	**43.1**	**10.0**	**4.1**	**5.9**
F test	***	***	***	***	**	Ns	**	ns	***	***	***
LSD at 5%	**2.1**	**1.7**	**2.7**	**4.2**	**0.6**	**0.6**	**2.6**	**3.6**	**0.9**	**0.3**	**0.8**
CV (%)	**4.8**	**2.0**	**6.4**	**7.8**	**10.3**	**19.5**	**10.7**	**12.7**	**12.9**	**12.7**	**20.0**

Where;T1=ETBW9089, T2=Jajabo, T3=Liben, T4=Lemu, T5=Wane, T6=Huluka, T7=Alidoro, T8=Hidasse, T9=Ogolcho, T10=Daka, T11=Danda'a and T12=Boru, *,** significant ($p < 0.05$) and highly significant ($p < 0.01$) respectively,ns =non significant ;DH=days to heading,DM=days to maturity,GFP=Grain filling period,PH=plant height,PL=panicle length,FT=fertile tillers,TSW=thousand seed weight,KPS=number of kernel per spike,BY=above ground biomass,GY=grain yield,SY=Straw yield

According to the results, the combined ANOVA over environments for grain yield was highly significant ($p<0.001$) for genotypes, environments and interaction effects (Table 5). The effect of environment, genotypes and GEI accounted for 77.6%, 3.87% and 10.57% of the total sum squares (Table 5), respectively. A large sum of squares for environments indicated that the test environments were diverse with large differences among environmental means which causing most of the variation in grain yield. Therefore; this result designated the reliability of the multi-environment experiments. The variation in temperature, rainfall, soil type, soil fertility and moisture availability might be the main reasons for the presence of variation.

Table 5: Combined ANOVA for yield and the percentage sum of squares of the twelve bread wheat varieties tested at three environments over a period of two years (2021 and 2022)

Source of variation	df	SS	MS	%SS
Environment (E)	5	412.46	82.492***	77.6
Genotype (G)	12	20.56	1.72**	3.87
Interaction (GEI)	60	56.14	0.94**	10.57
R/E	12	2.08	0.174^{ns}	0.39
Error	144	39.82	0.27	
Total	**233**	**531.07**		
Mean= 4.2	**CV=**12.7	**R^2=92.5**		

Where=CV=coeffiencient of variation, *, ** significant ($p < 0.05$) and highly significant ($p < 0.01$) respectively, ns =non significant R/E=replication in the environment; SS: sum square, MS: mean square;df-degrees of freedom ;CV coefficient of variation

The proportions of sum of squares of different components were determined for the agronomic traits of twelve bread wheat varieties (Table 6). Genotype contributed less than 15% for all traits except DH and TSW to the total treatment sum square. The genotype, environment and GEI contributed total treatment sum square greater than 70% in the traits of SY, GY, BY, FT, PH and DM (Table 6). These traits were determined mainly by the environment. The genotype contribution was high for the traits of DH and TSW and least for the traits of SY (1%), GY (4.2%), BY (5.7%) and FT (1.4%). The genotype, environment and GEI contributed total treatment sum square 22%, 23% and 55% in TSW and 10.5, 34.5 and 54.9% respectively.GEI was more important in the determination of most agronomic traits, that is, its contribution was mostly higher than the contribution of the genetic variability of genotypes.

Table 6: Proportion of total treatments (G+E+GEI) contributed by G, E and GEI and IPCA in agronomic traits

Traits	Genotype (%)	Environment (%)	GEI (%)	IPCA1 (%)	IPCA2 (%)
DH	21.1	38.6	40.3	65.5	14.4
DM	7.8	81.2	10.9	43	29.6
GFP	12.6	58.7	28.7	52.3	26.8
PH	9.3	71.6	19.2	67.3	16.6
PL	11.9	42.4	45.7	59.9	18.3
FT	1.4	88.4	10.1	53.3	18.4
TKW	22	23	55	56.7	21.2
KPS	10.5	34.6	54.9	42	27.1
BY	5.7	79.2	15.2	54.1	22.9
SY	1	94.3	4.7	60.8	24.3

Where HD=days to heading,DM=days to maturity,GFP=grain filling period,PH=plant height,PL=panicle length,FT=fertile tillers,TKW=thousand kernel weight,KPS=kernel per spike, *BY=above ground biomass,GY=grain yield and SY= straw yield GEI=genotype by environment interaction,IPCA=interaction principal component*

Stability Analysis

Univariate Stability Analysis

[14] defined the concept of ecovalence, is the stability of the genotype in its interaction with environments, squared and summed across environments. The genotypes with the lowest ecovalence have fewer fluctuations across the environments and therefore it is considered to be more stable than others. According to the wricke ecovalence stability parameter, wheat varieties ETBW9089, Huluka and Hidasse were the three most stable genotypes. The unstable varieties are Ogolocho,Daka and Alidoro had the highest stability ecovalence value and ranks 12th, 9th and 4th respectively (Table 7). This result shows that the unstable genotypes contribute the highest amount of variation to the total GEI variance and this leads the genotype unstable. According to [15], a genotype is described as stable if the stability variance (σi^2) is the environmental variance (σe^2) which means that $\sigma i^2 = 0$. The relatively large value of σi^2 indicates greater instability of genotype i. wheat variety ETBW9089, Huluka and Hidasse were stable, while Ogolcho, Daka and Alidoro were unstable.

The cultivar superiority measure (Pi) varied from 0.1961 to 1.8082 (Table 7). Genotypes with the lowest values are considered as the most stable. From the result of the cultivar superiority measure indicated that the most stable genotypes were genotype Huluka followed by Danda'a and ETBW9089. However, the most unstable genotypes according to this measure were Ogolcho, Hidassie and Daka (Table 7).Coefficient of determination (r^2) represents the predictability of estimated response of the genotypes. The values of coefficient of determination ranged between 0.5242 for Ogolocho and 0.9879 for Huluka, suggesting that linear regression accounted from 66% to 94%. This result showed that the variation in wheat mean grain yield was explained by genotype response across the testing environments. Bread wheat varieties Huluka, ETBW9089 and Hidasse with highest value of coefficient of determination were considered as stable and Ogolcho and Daka with low values were unstable [17].According to [16], genotypes exhibiting low coefficient of variation (CVi) ETBW9089, Lemu and Alidoro cultivars had smaller coefficient of variation (CVi) than those of the rest for grain yield confirming their high stability (Table 7).

Table 7: Univariate stability models for used for GEI and Stability Analysis of grain yield (t/ha) of twelve bread wheat varieties tested in Southwestern Ethiopia

Bread wheat varieties	Mean	σi^2	Wi	Pi	CV	R^2
ETBW9089	4.3667	0.0359	0.2732	0.2566	32.1409	0.9747
Jajabo	4.2561	0.2913	1.3538	0.449	41.5759	0.9345
Liben	4.2372	0.1993	0.9642	0.3934	38.7918	0.9354
Lemu	4.2367	0.1942	0.9429	0.4281	34.4388	0.9131
Wane	4.1811	0.27	1.2635	0.4638	37.8474	0.9
Huluka	4.4906	0.0617	0.382	0.1961	37.2073	0.9879
Alidoro	4.3289	0.351	1.6063	0.3935	35.0504	0.8614

Hidasse	3.6733	0.094	0.5188	0.9904	39.2169	0.9512
Ogolcho	3.5083	1.4984	6.4606	1.8082	45.2504	0.5242
Daka	4.2033	0.5936	2.6325	0.6259	38.2826	0.7968
Danda'a	4.5461	0.217	1.0394	0.2036	35.4115	0.9231
Boru	4.0822	0.1803	0.8838	0.5466	36.7247	0.9215

Where;Wi=Wrieck ecovalence, pi=cultivar superiority index,r^2=Coefficient of determination, (σ^2)= stability variance

Additive Main Effects and Multiplicative Interaction (AMMI) Bi-plot Analysis

AMMI analysis of twelve bread wheat in three environment for two years in the highlands of southwestern part of Ethiopia showed that 84.2% of the sum of squares was explained by the environment and 4% and 11.9% were attributable to the genotype effects and the GEI, respectively (Table 8).The large environmental percentage for the sum of squares indicates the significant differences between the averages of some environments, which caused most of the variation in the bread wheat grain yield. In line with this result, [27] reported large yield variation of bread wheat genotypes due to environments. This also indicates the existence of a considerable amount of differential response among the evaluated bread wheat varieties to changes in growing environments and the differential discriminating ability of the test environments. The higher percentage of GEI was explained by IPCA-1 (53.3%); followed by IPCA-2 (26.5%).[28] and [29] suggested the most accurate model for AMMI could be predicted by using the first two IPCA (Table, 8).

Table 8: Pooled analysis of variance for grain yield (t/ha) per plot of twelve bread wheat varieties across different environments using AMMI model

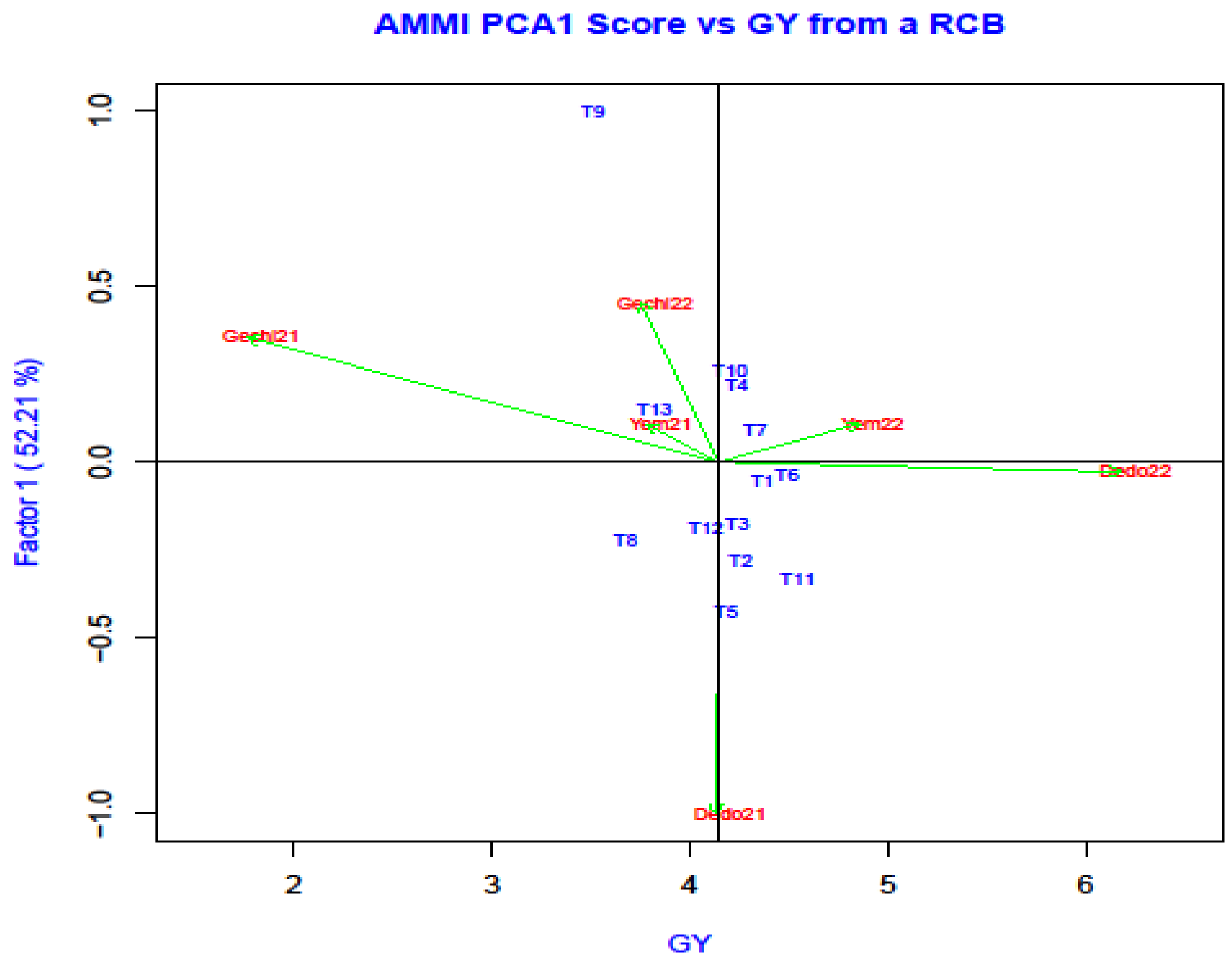
Source	df	SS	MS	F value	Total variation explained (%)	GEI (%) explained	Cumulative (%)
Environment	5	388.5	77.69***	288.3	84.2		
Genotypes	11	18.3	1.66**	6.2	4		
GEI	55	54.8	0.99**	3.7	11.9		
IPCA1	15	29.2	1.9***	7.2		53.3	53.3
IPCA2	13	14.5	1.11***	4.1		26.5	79.7
IPCA3	11	6.3	0.57**	2.1		11.5	91.2
Residual	144	38.8	0.27**				

***=very highly significant, **=highly significant, IPCA=interaction principal component, GEI=genotype by environment interactions=sum square, MS=mean square, df=degrees of freedom

Stability and Adaptability Analysis

AMMI-1 biplot for grain yield of twelve wheat varieties and three locations for two years were plotted from the main effect against IPCA-1 scores of the varieties and environment (Figure 1). The AMMI bi-plot on the relative magnitude of the position and direction of genotypes on the plane of stability parameters (i.e., interaction principal component axis) regressed on environment mean yield (main effect) is considered an important measure of not only for the pattern of adaptation (wide versus specific adaptation), but also for performance stability [30]. Accordingly, genotypes with IPCA-1 scores close to zero are considered better general adaptation, while those with IPCA-1 score far from zero are considered as genotypes with specific adaptation [31].

Varieties T1 (-0.053), T6 (0.0358) and T7 (0.088) with IPCA-1 scores closer to zero, showed less differential response to the changes in the growing environments as compared to the other genotypes. All these genotypes had high grain yield above and equal to the mean across tested locations (Table 9).On the other hand, T5 (-0.42), T11 (-0.33), T2 (-0.282) and T10 (0.259) had the highest IPCA-1 and they are considered as unstable and all these genotypes showed better grain yield performance across locations (Table 9).



Where:T1=ETBW9089, T2=Jajabo, T3=Liben, T4=Lemu, T5=Wane, T6=Huluka, T7=Alidoro, T8=Hidasse, T9=Ogolcho, T10=Daka, T11=Danda'a and T12=Boru and GY=grain yield

Figure 1: *AMMI -1 Biplot of IPCA-1 against grain yield of twelve bread wheat varieties across locations*

AMMI-2 bi-plot generated by using the first two interaction principal component axes (IPCA-1 and IPCA-2) was used to visualize and interpret the GEI patterns and identify genotypes or locations that exhibit low, medium or high levels of interaction effects [32]. AMMI-2 interaction bi-plot for grain yield of twelve bread wheat varieties tested in 2021 and 2022 is shown in figure 2. AMMI-2 analysis positioned the genotypes in different locations, indicating the interaction pattern of the genotypes. The AMMI-2 analysis for the IPCA-1 captured 53.27% and the IPCA-2 explained 26.48% and the two IPCs cumulatively captured 79.75% of the mean sum of the square of the GEI of bread wheat varieties. [25] reported that when the IPCA-1 was plotted against IPCA-2, the closer the genotypes score to the center of the bi-plot the more stable the genotype are and the further the genotypes score from the center the less stable they are. Genotypes near the origin are non-sensitive to environmental interactive forces and those distant from the origin are sensitive and have large interactions [33]. Accordingly, genotypes T1 and T6 are non-sensitive to environmental interactive forces; and hence, these genotypes are considered stable genotypes based on AMMI-2 bi-plot whereas; T9, T10 and T7 were highly influenced by the interactive force of the environment and sensitive to environmental changes, so these varieties were considered as unstable genotypes due to the long projections from the origin (figure 2).

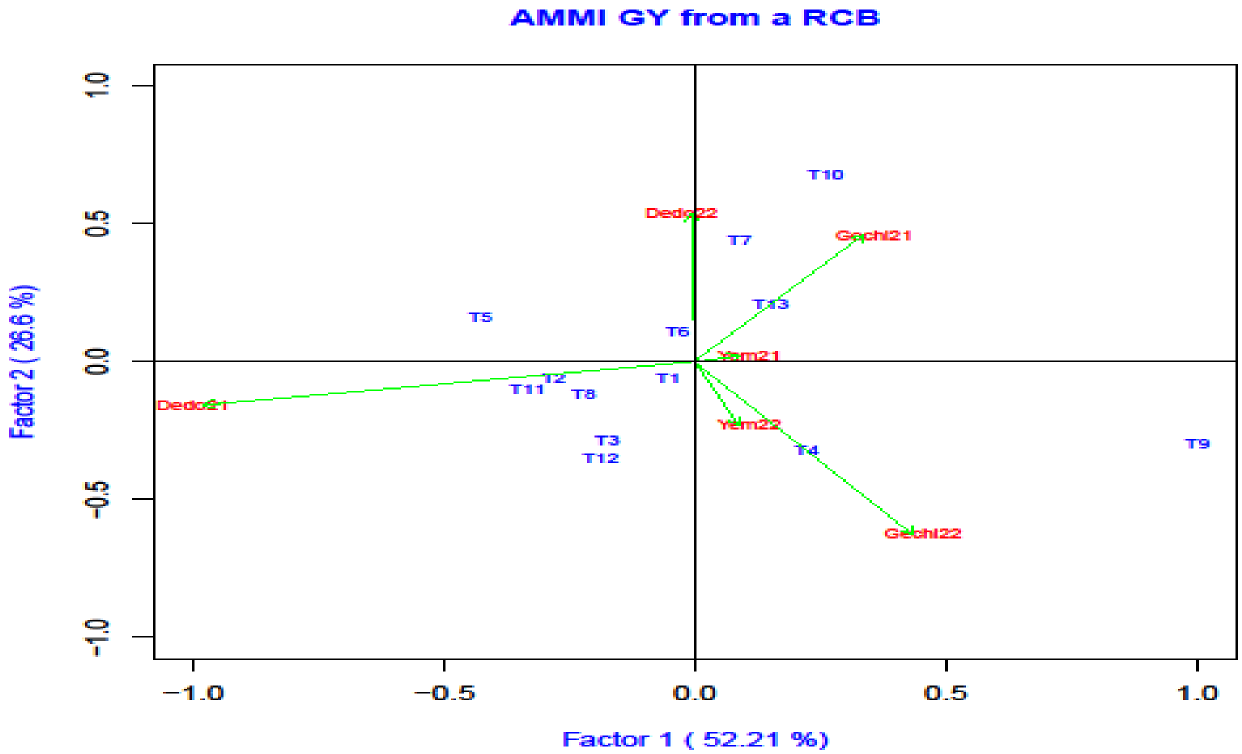


Figure 2: *Biplot of interaction principal component axis (IPCA1) against interaction principal component axis (IPCA2) bread wheat varieties evaluated across locations of southwestern Ethiopia* T1=ETBW9089, T2=Jajabo, T3=Liben, T4=Lemu, T5=Wane, T6=Huluka, T7=Alidoro, T8=Hidasse, T9=Ogolcho, T10=Daka, T11=Danda'a and T12=Boru,

AMMI Stability Value (ASV) and Genotype Selection Index (GSI)

The IPCA-1 and IPCA-2 scores for each variety and also the ASV with its ranking for twelve bread wheat varieties are presented in Table 9.A genotype/variety with least ASV score is the most stable [18]. Accordingly, ETBW9089, Huluka, Liben and Lemu the most stable bread wheat varieties. On the other hand, Ogolcho, Jajabo and Danda'a varieties were the most unstable. This measure is essential in order to quantify and rank of varieties according to their grain yield stability. Genotype with the smallest GSI value is considered as the most stable with high grain yield [19].Based on the GSI result, the most desirable variety for selection of both stability and high grain yield were ETBW9089 and Huluka.The sign of the IPCA scores indicate the pattern of interaction of the genotypes across environment and vice versa. Genotypes and environments with similar sign of their IPCA sores interact positively for that trait (Table 9).

Table 9: Ranking of twelve bread wheat varieties based on grain yield, AMMI stability value (ASV) and Genotype selection index (GSI) during 2021 to 2022 cropping seasons

Varieties	Mean	IPCA1	IPCA2	ASV	GSI	Loc	IPCA1	IPCA2
ETBW9089	4.4	-0.03855	-0.04231	0.0531	4	L1	-1	-0.15788
Jajabo	4.3	-0.2649	-0.05549	6.0364	16	L2	-0.027	0.536
Liben	4.2	-0.14738	-0.25618	0.2608	10	L3	0.356	0.46
Lemu	4.3	0.240422	-0.28653	0.3328	10	L4	0.454	-0.626
Wane	4.2	-0.41365	0.158328	2.8279	17	L5	0.108	0.019
Huluka	4.5	-0.02198	0.1405	0.1405	4	L6	0.108	-0.231
Alidoro	4.3	0.088593	0.465975	0.466	10			
Hidasse	3.7	-0.20649	-0.11877	0.6354	18			
Ogolcho	3.5	1	-0.24486	16.6807	24			
Daka	4.2	0.246777	0.692844	0.6936	17			
Danda'a	4.6	-0.31547	-0.105	2.8497	11			
Boru	4.1	-0.16738	-0.34852	0.3506	15			

Where:IPCA=interaction principal analysis,ASV=AMMI stability value,L1=Dedo 2021,L2=Gechi 2021,L3=Yem 2021,L4=Dedo2022,L5=Gechi 2022 and L6=Yem 2022;GSI=genotype selection index

4. CONCLUSION AND RECOMMENDATION

Wheat is the first most important and strategic cereal crop for the majority of the world's population. The differential ranking of genotypes showed the presence of the genotypes by environment interaction for grain yield. According to different stability models, ETBW9089, Huluka and Hidasse were stable and Ogolcho and Alidoro were unstable. Wheat variety, ETBW9089 was high yielder and stable across tested locations and recommended for large scale production

5. ACKNOWLEDGMENT

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