Stability Analysis in Bread Wheat (*Triticum aestivum* L.) Genotypes in North-western Ethiopia

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Abstract: Northwestern Ethiopian is one of the areas that has been experiencing weather variability both from season to season as well as from place to place in the same season over relatively small areas. In such weather conditions, the magnitude of genotype x environment interaction is more important than the average performance of crop genotypes. Therefore, experiments were conducted at Adet, Simada and Debretabor in 2014 and 2015 cropping seasons under rain-fed condition with the objectives of evaluating the stability of bread wheat genotypes for grain yield, and estimate the magnitude of genotype x environment interaction on grain yield. The treatment consisted of twelve bread wheat genotypes, namely, Bolo (G8), Dand'a (G5), Gambo (G4), Gassay (G6), Hidase (G1), Huluka (G3), Kubsa (G12), Menze (G10), Ogolcho (G2), Shorima (G11), Tay (G7), and Tsehay (G9). The experiments were laid out as a randomized complete block design with three replications per treatment at each site. The analysis of variance revealed the significant ($P \leq 0.01$) effect of genotype, growing season, location and all possible interactions of the three main factors. The results of AMMI analysis depicted significant ($P \leq 0.01$) differences among genotypes across the environments. According to the study, the performances of genotypes grain yield were highly affected by environment and the genotype. The highest variation was accounted for location (29 %) followed by genotype (18%) and location by year (18 %) and genotype by year (12%) effects. Based on Additive Main effects and Multiplicative Interaction (AMMI), genotype and genotype by environment (GGE) biplot and stability coefficient analyses Ogolcho (G2), Gambo (G4), Shorima (G11) and Tsehay (G9) were relatively stable genotypes across the test environments than the checks, TAY (G7) and Kubsa (G12). Therefore, based on the stability and overall mean grain yield of genotypes, recently released genotypes Gambo (G4), Ogolcho (G2) and Tsehay (G9) and relatively older genotypes Shorima (G11) and TAY (G7) could be recommended for production at the test environments in the Western Amhara Region.

Keywords: Additive Main effects and Multiplicative Interaction (AMMI*)*; Genotype and Genotype by environment (GGE); Grain Yield and Stability coefficient

1. Introduction

Ethiopia is frequently exposed to food shortages due to environmental variability, degradation of soil fertility, and ever increasing population (Ashenafi, 2008) and inappropriate use of improved technologies (Zerihun, 2016). However, the production and productivity of wheat in Ethiopia has increased in the last decades. The national average yield is 2.54 ton/ha (CSA, 2014). It is lower than the world's average yield/ha, which is about 3.3 ton/ha (FAO, 2014). This is due to factors such as use of low yielding cultivars; uneven distribution of rainfall, poor agronomic practices and serious wheat diseases like rusts (Dereje *et al*., 2000).

Therefore, Ethiopia's wheat production covers only 75% of the national demand; the remaining 25% of the wheat is obtained through imports (Eyob *et al*., 2014). So to overcome wheat yield imports and to cut down wheat national demand deficiency conducting considerable research works that contribute positive impact on wheat productivity and production are mandatory.

The process of variety development in the country is continuing year after year through various research institutes and universities. However, once released for production, the varieties are used for a long period of time continuously without considering their adaptation domain, grain yield stability and testing whether they are losing their yield potential or not. High yielding and rust disease resistant bread wheat varieties have recently been released in Ethiopia. However, farmers in Western Amhara Region commonly use relatively older bread wheat varieties such as Kubsa and Tay which were released in 1995 and 2005, respectively (MoA, 2013). Therefore, there is a need to evaluate the recently released bread wheat varieties across the environment and years. Hence, it is vital to evaluate grain yield stability of bread wheat genotypes used in the region with the objectives of evaluating the extent of grain yield stability of bread wheat varieties and cultivars, and estimate the magnitude of genotype x environment interaction on grain yield.

2. Materials and Methods

2.1. Description of the Experimental Sites and Materials

The experiment was conducted during the 2014 and 2015 cropping season under rain-fed conditions at Adet Agricultural Research Center, namely Adet, Simada and Debretabor. Twelve improved bread wheat genotypes were used for the study. The detail agro-ecological data of environments and the description of genotypes are listed in Tables 1 and 2, respectively.

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Table 1. Altitude, geographical location, and climate data of the research sites.

				Climate data for two cropping seasons			
		Geographical		2014		2015	
Testing site	Altitude (m.a.s.l)	Latitude	Longitude	RF (mm)	Average temp (^{0}C)	RF (mm)	Average temp (^{0}C)
Adet	2240	$11^0$16'N	$37^0$29'E	789.2	17.53	948.9	19.4
Simada	2460	$11^0$03N	$37^0$30'E	736.1	13.27	770.6	15.07
Debretabor	2591	$11^0$51'N	$38^0$01'E	1102.7	15.48	958.1	15.94

Note: RF (mm) = total amount of rain fall in the cropping season, and Average tem (^{0}C) = average temperature in the cropping season.
Source: AARC (2014) and ANRSMA (2014 and 2015).

Table 2. Description of bread wheat genotypes evaluated at three locations during 2014 and 2015 cropping seasons in Northwestern Ethiopia.

Genotype	Code	Breeder center	Year of release	Grain yield (t/ha) at time of release at		Recommended agroecology Zone	
				On station	On farm	Altitude(masl)	RF(mm)
Hidase (ETBW 5795)	G1	KARC	2012	4.4-7	3.5-6	2200-2600	>500
Huluka (Flag 5)	G3	KARC	2012	4.4-7	3.8-6	2200-2600	500-800
Ogolcho (ETBW 5520)	G2	KARC	2012	2.8-4	2.2-3.5	1600-2100	400-500
Shorima (ETBW 5483)	G11	KARC	2011	2.9-7	2.3-4.4	2100-2700	700-1100
Gambo (QUIAU#2)	G4	KARC	2011	3.5-5.7	4.5	750	NA
Tsehay (HAR 3837)	G9	DBARC	2011	3.8	2.8-3.5	2600-3100	>900
Danda'a (DANPHE#1)	G5	KARC	2010	3.5-5.5	2.5-5	2000-2600	>600
Bolo (HAR 3816)	G8	DBARC	2009	2.8-3.5	2.3-3.3	2580-3100	>904
Menze (HAR 3008)	G10	DBARC	2007	1.9-3.3	1.5-2.7	2800-3100	>904
Gassay(HAR 3730)	G6	ADARC	2007	4.4-5	3.5-4.7	1890-2800	>700
Tay (ET-12 D4/ HAR-604(1) (C)	G7	ADARC	2005	2.5-6.1	3.4-5.8	1900-2800	>700
Kubsa (HAR 1685)(C)	G12	KARC	1995	5.8-6.3	4-4.5	1850-2800	500-800

Note: ADARC = Adet Agricultural Research Center, DBARC = Debrebirhan Agricultural Research Center, KARC = Kulumsa Agricultural Research Center, C = Check and NA = Not available
Source: MoA, Crop Variety Register (1995-2012)

2.2. Experimental Procedures and Data Analysis

The land was ploughed three times and labeled manually at time of planting. The treatments were laid out as randomized complete block design with three replications per treatment at each site and six rows per plot. Planting was done in the first up to the second week of July with seeding rate of 150 kg/ha on the plot area of 1.2 x 2.5 m with a net plot area of 0.8 x 2.5 m. Urea and DAP fertilizers as a source of nitrogen and phosphorous were applied with at the rate of 74 kg N/ha and 46 kg P_2O_5/ha for Adet and 120 kg N/ha and 46 kg P_2O_5/ha for both Simada and Debretabor. Total amount of DAP and 1/3 of urea were applied at planting and the remaining 2/3rd of urea was applied at tillering after the first weeding. Weeding was done manually two times at tillering stage (three weeks - a month) and booting stage (50-60 days before heading) depending on the weed infestation of the trial site.

The grain yield data were analyzed using GenStat (17th Edn) software to compute genotype and environment main and interaction effects, seasonal variation effects and grain yield stability of genotypes. Whenever the results were found to be significant, Fisher's LSD test at 1% and 5% probability level was used, respectively, to separate the means of genotypes, environments and genotypes by environments interaction.

The AMMI analysis of variance summarizes most of the magnitude of genotype by environment interactions into one or a few interaction principal component axes (IPCA) (Zobel *et al.,* 1988; Crossa, 1990). The following AMMI model equation was used:

$$Y_{ger} - u - \alpha_g - \beta_e = \Sigma_n \lambda_n \tau_{gn} \delta_{en} + p_{ge} + \varepsilon_{ger} \qquad (1)$$

Where: Y_{ger} is the grain yield of genotype (g) in environment (e) for replicate (r), *u* is the grand mean, α_g are genotype mean, β_e are the environment mean deviations, λ_n is the singular value for IPCA axis n, τ_{gn} are genotype eigenvector values for IPCA axis n, δ_{en} are the environment eigenvector values for (PCA) axisn, p_{ge} are the residuals and ε_{ger} is the error term.

GGE biplot analysis was carried out to identify high yielding and stable varieties as well as representative and discriminating environments as per Yan (2001).

$$Y_{ger} - \beta_e = \Sigma_n \lambda_n \tau_{gn} \delta_{en} + p_{ge} + \varepsilon_{ger} \quad (2)$$

Where: Y_{ger} is the grain yield of genotype (g) in environment (e) for replicate (r), β_e are the environment mean deviations, λ_n is the singular value for IPCA axis n, τ_{gn} are genotype eigenvector values for IPCA axis n, δ_{en} are the environment eigenvector values for (PCA) axis n, p_{ge} are the residuals and ε_{ger} is the error term.

AMMI Stability Value (ASV) is the distance from the coordinate point to the origin in a two-dimensional plot of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase, 2000). ASV was calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction sum of squares as follows:

$$ASV = \sqrt{\left[\left(\frac{SS_{IPCA1}}{SS_{IPCA2}}\right)(IPCA1score)\right]^2 + (IPCA2score)^2} \quad (3)$$

Lin and Binns (1988) defined the superiority measure (Pi) of the i^{th} test cultivar as the MS of distance between the i^{th} test cultivar and the maximum response as,

$$P_i = \left[n(\overline{X}_i - \overline{M})^2 + \left(\sum_{j=1}^{n}(X_{ij} - \overline{X}_i - M_j + \overline{M})^2\right)\right]/2n \quad (4)$$

Where: Xij=is the average response of the i^{th} genotype in the j^{th} environment, Xi=is the mean deviation of genotype i, Mj=is the genotype with maximum response among all genotypes in the j^{th} location, and n is the number of locations. The first term of the equation represents the genotype sum of squares and the second part represents the GE sum of squares.

According to Lin *et al.* (1986) the variance of genotype yields recorded across the test environments can be used as a measure of stability. For the genotype greatest stability is $S_i^2=0$.

The formula is:

$$S_i^2 = \Sigma R_{ij} - m_{i.})^2 / (e-1) \quad (5)$$

Where: S_i^2= environmental variance, R_{ij} = observed genotype yield across environments, $m_{i.}$ = marginal means of genotypes, e=number of environments

3. Results and Discussion

3.1. Impact of Genotype, Location and Year on Grain Yield of Bread Wheat

The analyses of variances revealed highly significant ($P \leq 0.01$) differences among genotypes, locations, year and their interactions for grain yield (Table 3). The highest variation was accounted for by location (29%) followed by genotype (18%) and location by year (18 %) and genotype by year (12%) effects (Table 3). The grain yield of genotypes was highest at Adet in 2014 cropping season, and at Debretabor in 2015 cropping season. Similarly, grain yield of genotypes was lowest at Simada in 2015 (Table 4). Genotypes G4 (Gambo), G2 (Ogolcho), G11 (Shorima) and G9 (Tsehay) showed 31.4%, 25.8%, 10% and 8.9 % t/ha grain yield advantage over standard check (G7 = Tay) and 49.6%, 41.8%, 25.4% and 23.6% t/ha grain yield advantage over standard check (G12 = Kubsa), respectively (Table 4). The significant influence of genotype, location, growing season and all possible interactions of these on grain yield has been reported by Fetien Abay and Asmund Bjornstad (2009), Hintsa Gebru and Fetien Abay (2013) and Mohammed (2013). As a result, screening and development of wide adaptable and relatively stable genotypes are determinant factor to increase bread wheat productivity and production.

Table 3. Analysis of variance for grain yield of 12 bread wheat genotypes at three locations during 2014 and 2015 cropping seasons in Northwestern Ethiopia.

Source of variation	DF	SS	MS	% total sum square explained
Genotype	11	9187.87	835.26**	18
Location	2	14393.4	7196.7**	29
Year	1	2764.46	2764.46**	5.6
Genotype x Location	22	3798.1	172.64**	7.6
Genotype x Year	11	5809.92	528.17**	12
Location x Year	2	8998.73	4499.37**	18
Genotype x Location x Year	22	2591.46	117.79**	5.2
Error	142	2247.1	15.82	4.5
Total	213	49791.04		

Note: DF=Degree of freedom, SS= Sum square, and MS=Mean square

Table 4. Mean grain yield (t/ha) of twelve bread wheat genotypes at three locations during the 2014 and 2015 cropping seasons in northwestern Ethiopia.

	Adet		Simada		Debretabour		
Genotypes	2014	2015	2014	2015	2014	2015	Mean
G1	4.67	4.26	4.29	1.85	1.84	5.45	3.73^{cde}
G2	6.47	5.82	5.19	2.59	4.80	4.91	4.97^{a}
G3	5.70	5.32	2.46	2.12	2.80	4.34	3.79^{cd}
G4	7.09	6.01	5.69	2.64	4.94	4.70	5.18^{a}
G5	5.29	3.09	4.49	1.67	3.70	3.65	3.65^{de}
G6	4.49	3.81	4.27	2.06	3.25	3.91	3.63^{de}
G7	5.92	5.22	2.79	1.78	3.09	4.87	3.95^{c}
G8	5.06	1.39	3.49	1.47	3.59	3.37	3.01^{f}
G9	6.68	4.55	4.59	1.77	3.53	4.61	4.29^{b}
G10	5.27	1.19	3.66	1.40	2.77	3.38	2.95^{f}
G11	5.61	5.16	4.61	2.35	3.82	4.51	4.34^{b}
G12	4.97	5.57	1.28	2.20	1.71	5.09	3.47^{e}
Yr Mean	5.60	4.29	3.90	1.99	3.32	4.39	
Loc mean	4.94		2.95		3.86		3.92
LSD	0.76		0.44		0.69		0.64
CV (%)	9.4		9		11		10.2
P level	<0.001		<0.001		<0.001		

Note: G1= Hidase, G2= Ogolocho, G3= Hulluka, G4= Gambo, G5= Danad'a, G6= Gassay, G7=Tay, G8= Bolo, G9= Tsehay, G10=Menze, G11=Shorima, G12=Kubsa, Yr=Year, LOC=Location, LSD= Least significant difference and CV=Coefficient of variation

3.2. The Main and Interaction Effects of Genotypes and Environments on Grain Yield

The AMMI analysis of grain yield showed highly significant differences among genotypes, environments and their interactions (Table 5). Environment depicted the highest variation on grain yield performance of genotypes which accounted for 41.91% followed by genotype by environments interaction (19.55%) and genotype (14.72%) (Table 5). Consistent with the results of this study, Misganaw *et al.* (2015) reported higher contribution of environment followed by genotype and genotype by environment interaction to the total sum squares for grain yield of bread wheat genotypes.

The partitioning of the genotype-environment interaction in AMMI model analysis showed that four of the Interaction Principal Component Axes (IPCAs) were highly significant ($P \leq 0.01$). However, the first two IPCAs accounted for the largest proportion of 82.26% interaction sum of square while the other two IPCAs only accounted for 16.95%, indicating the first two were sufficient to explain the interactions (Table 5). Approximately as much variation in grain yield was explained by the interaction term captured by IPCA1 (66.54 %) as by the genotypic main effect. This showed that interaction is as important as genotypic main effect, implying that both specific and wide adaptations are important. In the biplot axes system, either main effects and IPCA1, or IPCA1 and IPCA2 are commonly used as abscissa and ordinates (Zobel *et al.*, 1988; Gauch, 1992).

Table 5. AMMI analysis of variance for grain yield of 12 bread wheat genotypes at six environments (three locations over two years) in the 2014 and 2015 cropping seasons.

				Sum of square explained	
Source of variation	DF	SS	MS	% total	% G x E
Genotype	11	9188	835.3**	18.3	
Environment	5	26157	5231.3**	52.1	
Block	12	718	59.8**	1.42	
G x E interaction	55	12199	221.8**	24.3	
IPCA 1	15	8117	541.1**		66.54
IPCA 2	13	1918	147.5**		15.72
IPCA 3	11	1476	134.2**		12.10
IPCA 4	9	592	65.8**		4.85
Error	132	1943	14.7	3.87	
Total	215	50205			

*Note: **=significant at P ≤ 0.01, DF = degree of freedom, SS = sum squares, MS = mean squares, G x E = genotype by environment, and IPCA = interaction principal component axes.*

The AMMI biplot showing the main and IPCA1 effects of both genotype and environment on bread wheat grain yield is depicted in Figure 1. In such a system, distances along the abscissa (horizontal line) shows main effect differences whereas the ordinate (vertical line) shows differences in interaction. Akter *et al.* (2014), genotypes that group together have similar adaptation and also environments which group together influences the genotypes in the relative way. Thus, G1 (Hidase), G3 (Hulluka), G5 (Danda'a) and G6 (Gassay) had more or less similar genotypic main effects, differing in interaction while G2 (Ogolcho) and G11 (Shorima), and G4 (Gambo) and G9 (Tsehay) had nearly similar interaction effects, only differing in genotypic main effects. In the same manner, E4 (Adet-2015) and E2 (Simada-2014) had higher interaction effect; whereas E5 (Simada-2015) and E1 (Adet-2014) had minimum interaction effect, but they had higher differences in environmental main effect.

In Figure 2, the distances from the origin indicate the magnitude of interaction exerted by environments on genotypes, or vice versa (Voltas *et al.*, 2002; Fetien Abay and Asmund Bjornstad, 2009; Misra *et al.*, 2010; Akter *et al.*, 2014). In other words, genotypes near the origin are not sensitive to environmental interaction, whereas genotypes distant from the origin are sensitive and have large interaction effects. Hence from this study, genotypes G11 (Shorima), G9 (Tsehay), G6 (Gassay), G7 (Tay) and G3 (Hulluka) were weakly influenced by environmental factors. That is to say, the grain yield response of each genotype was relatively similar across environments while G10 (Menze), G8 (Bolo), G12 (Kubsa) and G4 (Gambo) were strongly affected by environmental factors. That means the grain yield response of each genotype varied across environments.

According to Yan *et al.* (2000) and Yan and Rajcan (2002), ideal genotypes are those having large PC1 scores (high grain yield) and small absolute PC2 scores (high stability). Accordingly, G11 (Shorima), G6 (Gassay), G2 (Ogolcho) and G9 (Tsehay) were better stable genotypes and genotypes G4 (Gambo), G2 (Ogolcho), G11 (Shorima) and G9 (Tsehay) were high yielder in that order of importance. Though G6 (Gassay) was relatively stable genotype, it is not preferable for production due its low-yielding capacity.

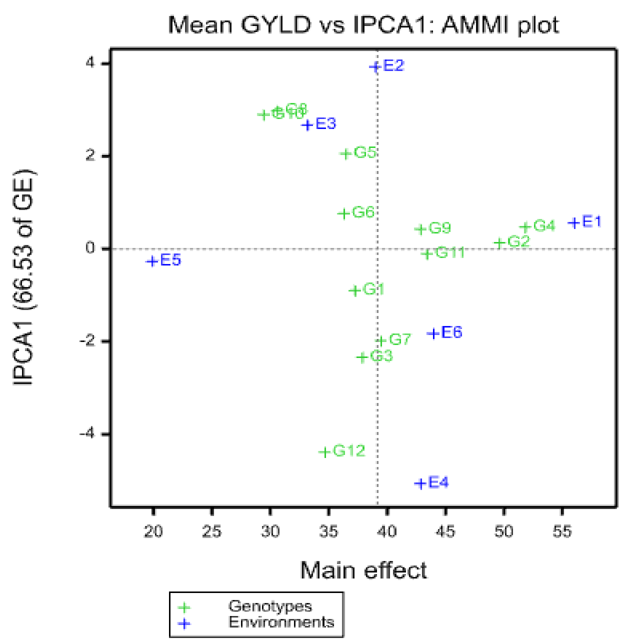

Figure 1. AMMI biplot main effects and IPCA1 of genotypes and environments using symmetrical scaling (G1 = Hidase, G2 = Ogolocho, G3 = Hulluka, G4 = Gaambo, G5 = Danda'a, G6 = Gassay, G7 = Tay, G8 = Bolo, G9 = Tsehay, G10 = Menze, G11 = Shorima, G12 = Kubsa, E1 and E4 = Adet E2 and E5 = Simada and E3 and E6 = Debretabor, IPCA = Interaction Principal Component Axes).

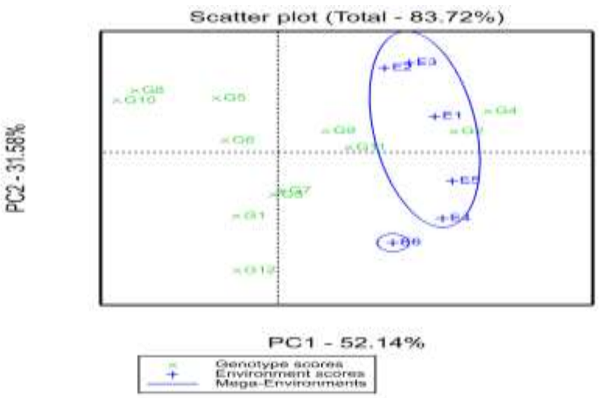

Figure 2. GGE biplot analysis of genotypes and environments using environment scaling (G1 = Hidase, G2 = Ogolocho, G3 = Hulluka, G4 = Gaambo, G5 = Danda'a, G6 = Gassay, G7 = Tay, G8 = Bolo, G9 = Tsehay, G10 = Menze, G11 = Shorima, G12 = Kubsa, E1 and E4= Adet E2 and E5 = Simada and E3 and E6= Debretabor, PC = Principal Component).

3.3. Genotypes Stability Analysis for Grain Yield

AMMI biplot analyses showed adaptable and stable genotypes in graphical forms. As a matter of fact, to know the stability of genotypes in numerical terms, further stability analysis work is pertinent to explore stable genotypes using different stability analysis methods. In terms of different stability coefficient analysis methods, AMMI, Cultivar superiority and static stability values G11 (Shorima), G4 (Gambo) and G6 (Gassay) were ranked 1st and G12 (Kubsa), G10 (Menze) and G12 (Kubsa) were ranked least, respectively (Table 6). According to this study, grain yield stability of genotypes ranks varied with the methods used.

Table 6. Grain yield stability of bread wheat genotypes based on different methods of analyses.

Genotype	Mean	Stability coefficient analysis method					
		ASV	R	Cultivar Superiority	R	Static stability	R
G1	37.26	4.28	6	176.9	9	230.4	7
G2	49.65	1.99	3	8.2	2	174	4
G3	37.89	9.91	9	157.9	6	236.7	9
G4	51.84	3.34	5	4.6	1	228.3	6
G5	36.48	8.7	8	159.8	7	152.8	3
G6	36.33	3.23	4	160.9	8	77.8	1
G7	39.49	8.4	7	123.7	5	261.7	11
G8	30.61	12.7	11	318.6	11	198.3	5
G9	42.88	1.89	2	59	4	257.3	10
G10	29.47	12.4	10	346.1	12	231.5	8
G11	43.43	1.17	1	52.9	3	132.1	2
G12	34.68	18.9	12	291	10	376.2	12

Note: G1 =Hidase, G2 = Ogolocho, G3 = Hulluka, G4= Gaambo, G5 = Danda'a, G6 = Gassay, G7 = TAY, G8= Bolo, G9 = Tsehay, G10 = Menze, G11 = Shorima, G12 = Kubsa, ASV = AMMI stability value, R = *Rank*

According to Lin *et al.* (1986), Becker and Leon (1988) and Lin and Binns (1988) stability statements, Static stability analysis had a drawback which implies both higher and lower grain yielding genotypes as stable, AMMI stability value only shows consistency of genotypes contribution to genotype by environment interactions and cultivar superiority analysis only shows mean performance of genotypes across environments, nonetheless it is difficult to know consistency of genotypes yield response across environments. This shows the necessity of combined use of different stability analysis methods to properly evaluate stable genotypes both in potential and consistency of grain yield over environments. In general, G4 (Gambo), G2 (Ogolcho), G11 (Shorima) and G9 (Tsehay) were relatively high yielding and stable genotypes based on AMMI stability, cultivar superiority and static stability values. Therefore, these genotypes are preferable as a source of material for bread wheat improvement and production across the tested environments.

4. Conclusions

This study has demonstrated that the grain yields of genotypes were significantly influenced by environment and by genotype x environment interactions, which together accounted for more than 76% of the variations observed. Thus, according to the AMMI biplot, GGE biplot and stability coefficients analyses, G4 (Gambo), G2 (Ogolcho), G11 (Shorima) and G9 (Tsehay) were relatively more stable genotypes in all the test environments than the two checks G7 (Tay) and G12 (Kubsa). Therefore, in view of the mean grain yield and stability of genotypes, G4 (Gambo), G2 (Ogolcho), G11 (Shorima) and G9 (Tsehay) could be used as alternative varieties at the test environments. However, it is better to study varieties including many locations as much possible for consecutive years to identify stable genotypes and mega environments that represent the area where genotypes can be tested in the process of variety development for the region because of the northwestern Ethiopia is covering large area of the country known with wide range of variations in changing climate conditions year after year within small areas. In addition to this, In the Western Amhara Region due to evolving of epidemic rust races through weather variability and/or mutation most of the varieties break down their resistance to rust disease after few years of production. Hence Development Agents, Wheat Commercial Producers and Farmers thoroughly explore bread wheat genotypes that have high grain yielding and disease resistance potential per year for bread wheat production.

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