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Research paper

Genotype x environment interaction and stability of drought tolerant durum wheat

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Genotype x environment interaction is of great interest for selecting cultivars for variable environment. The objectives were to evaluate presence of genotype by environment interactions and identify stable genotypes using different stability parameters. Twenty five selected durum wheat genotypes grown in randomized complete block design with three replications over six environments in main rainy season. The combined analysis of variance indicated that highly significant variations among genotypes, environments and their interactions on grain yield. The largest variation was accounted by environments, followed by GEI and then genotypes. The stability analysis using parametric measures identified G-24 as the most stable genotype followed by G-23 with above average grain yield. Stability parameters showed similar rankings of genotypes with different magnitudes and identified Genotypes 1, 24, 4, 10 and 17 as the most stable genotypes. As per the AMMI analysis the first two IPCAs showed significant variations and explained about 61% of GEI. GGE biplot categorized the environments in to two mega environments where Akaki and Gimbichu grouped together and that of Debre-Zeit light and black soil and Alemtena in the second mega environment and Minjar remained alone.

Key words: AMMI, ASV, durum wheat, biplot, stability

INTRODUCTION

Plant breeders have commonly faced the problem of genotype x environment (G x E) interaction in the development of plant cultivars. In multi-environments field experiment, a significant G x E interaction (GEI) reduces the correlation between phenotypic and genotypic values as well as the progress from selection (Rajesh et al., 2016). G x E interaction is studied therefore, in order to answer a number of questions related to varietal adaptation and stability. Understanding G x E is useful, amongst others for developing different cultivars in different agro-ecologies, effective environments of resources and for the characterization of genotypes to variable productivity levels (Yau, 1995). The methods of partitioning G x E interaction into components assignable to each genotype would be useful to breeders. Several parameters are now available for estimating stability of genotypes tested over a range of environments. AMMI analysis combines ANOVA and Principle Component Analysis (PCA) into a single analysis with both additive and multiplicative parameters (Zobel et al., 1988). The data of each trial are analyzed using this model because this model partitions the genotype x environment interaction sum of squares into interaction principal component (IPCA) axes. The AMMI analysis of variance summarizes most of the magnitude of genotype x environment interaction into one or few interaction principal component analysis (IPCA). AMMI analysis lacks effectiveness to evaluate test environments and indicate the contribution of genotypes and environment to GEI. On the contrary, the GGE bilplot is superior to AMMI 1 graph in mega environment analysis and genotype evaluation since it explains more on genotypes plus genotypes by environment interaction and has the inter-product property of the biplot (Weikai et al., 2007). Furthermore, other stability parameters proposed by Finlay and Wilkinson (1963) and Eberhart and Russell (1966) use the regression of average genotype yield on an environmental index and deviation from the regression as secondary estimate of stability to evaluate stability of genotypes across environments. The ecovalence stability index of Wricke (1962) and stability variance developed by Shukla (1972) have also been used to measure the contribution of each genotype to G x E interaction. Several researchers used and reported the importance and contribution of G X E study and AMMI for identification of stable genotypes in Ethiopia Tesfaye (2007) and Shitaye (2012) on durum wheat; Sisay and Sharma (2015); Melkamu et al. (2015); Temesgen (2017), Alemu et al. (2018) and Gadisa et al. (2019). The objectives of this study were to examine the genotype, environment and G x E effect and estimate stability of drought tolerant durum wheat genotypes in Ethiopia.

MATERIALS AND METHODS

Experimental management

Twenty five durum wheat genotypes including two standard checks (Tesfaye and Alemtena) were used in this study (Table 1). The experiments were conducted in six sites namely; Alemtena, Minjar, Debre-Zeit sandy soil, Debre-Zeit clay soil, Akaki and Gimbichu (Table 2). These environments are the main multi-environments variety testing sites for the national durum wheat improvement program and representative of different durum wheat agro-ecologies of Ethiopia. The experiments were arranged in lattice square design in three replications. The plot size of 2.0 m^2 with four rows of 2.5m length and 0.20 cm spacing between rows were kept at 5 cm. Plant density, planting time and other management practices were used according to specific recommendations made for each environments. 100 Kg of Urea was used half after emergence and the remaining half at tillering and all 100 kg of DAP was applied at planting across environments.

Data collection

Data on the following phenology and yield and yield related traits were collected:

1. Days to heading (DH): The number of days from date of sowing to 50% of the stand in a plot is headed and 75% of the spikes have fully emerged.
2. Days to maturity (DM): The number of days from sowing to the stage when 90 % of the stand in a plot have reached physiologically maturity and ripe, i. e., when the peduncles were turned yellow.
3. Spike length (SL): The average spike length in cm measured at physiological maturity on five (5) random samples taken from each genotype.
4. Number of spikelet per spike (NSS): The average number of spikelet per spike counted from main tiller of each of the spike of five (5) randomly selected plants
5. Number of kernels per spike (NKS): The average number of kernels per spike counted from main tiller of each of the spike of five (5) randomly selected plants
6. Thousand Kernel Weight (TKW): The grain weight (g) of 1000 seeds sampled at random from total grain harvest of the experimental plot was recorded, when 12.5% of moisture content and measured by using sensitive balance.
7. Grain yield (YLD): The grain yield per plot was measured in grams using sensitive balance after moisture of the seed is adjusted to 12.5%. Total dry weight of grain was harvested from the middle four rows out of six rows and were converted to tones per hectare

Table 1. List of genotypes used in the study

No	Genotypes	Code
1.	Accession-214485	G1
2.	ICARDA#382	G2
3.	2015/16DW/PVLMA-Set-I#17	G3
4	2015/16DW/LRPL#3	G4
5	ICARDA#30	G5
6	Accession-203882	G6
7	MCD-I-21	G7
8	2015/16DW/LRPL#31	G8
9	2015/16DW/IDYT#7	G9
10	ICARDA#360	G10
11	2015/16DW/IDON#22	G11
12	2015/16DW/IDYT#13	G12
13	ICARDA#46	G13
14	2015/16DW/PVTLMA-Set-I-#20	G14
15	Accession-203762	G15
16	ICARDA#58	G16
17	ICARDA#354	G17
18	2015/16DW/IDYT#20	G18
19	2015/16DW/IDYT#11	G19
20	ICARDA#346	G20
21	2015/16DW/IDYT#2	G21
22	ICARAD#381	G22
23	2015/16IDON#87	G23
24	Alemtena (standard check)	G24
25	Tesfaye (standard check)	G25

Table 2. Descriptions of test environments

	Environments	Code	Altitude (masl) meter	Annual rain fall(mm)	Soil texture	Annual temperature(°c)	
						Min.	Max.
1	AlemTena	AT	1200	500	Sandy	10.2	30.1
2	Minjar	MN	1800	800	Vertisol	NA	NA
3	Debre-Zeit	DZ	1900	800	Sandy	10.1	27
4	Debre-Zeit	DB	1900	800	Pellicvertisol	10.1	27
5	Gimbichu	GM	2450	1200	Pellicvertisol	9.8	24
6	Akaki	AK	2200	1100	Pellicvertisol	10.0	25

NA=Not available

8. Normalized Differences Vegetative Index (NDVI): was taken about 50 cm above leaf canopy at heading using hand held green seeker equipment.

Data analysis

Data analysis was carried out using SAS statistical software version 9.0 and was used for analysis of variances of the individual environments and the combined data over environments. Homogeneity of variances was checked following Leven's test of the SAS statistical procedures before combined analysis of variance over environments. AMMI analysis The Additive Main effect and Multiplicative Interaction (AMMI) model analysis was performed for grain yield. The AMMI stability value (ASV) was computed as described by Purchase et al. (1997).The linear regression (bi) of genotype mean yield on environmental index, the deviation mean square from the regression of Eberhart and Russell (1966), and coefficient of determination (r^2) between average yield of each genotype and environmental index. The variance of genotype (S^2i) across environments (Lin et al., 1986) and the coefficient of variability (CV) of each genotype (Francis and Kannenberg, 1978) were used. The ecovalence stability index (W^2i) developed by Wricke (1962) and stability variance developed by Shukla (1972) were carried out using R statistical software. GGE biplot analysis was done by to graphically evaluate the relationship between environments and genotypes.

RESULTS AND DISCUSSION

Combined analysis of variance

The combined analysis of variance (Table 3) revealed that the main effect of genotypes (G), for all measured traits of the genotypes varied across the tested environments. These results were in agreement with the works of Veselinka *et al*. (2009) and Karimizadeha *et al*. (2012) who reported for TKW, SL, DH, DM. Sonia *et al*. (2013) also reported similar results for all of these traits. Environment and GEI were also showed highly significant effect on all traits except spike length. Spike length was not affected by both environment and G x E interactions. This results indicated that selections of genotypes based on spike length is for wide environment may be preferable than other traits. The total sum of squares was partitioned into components to estimate the magnitude of GEI. For all measured traits, the explained percentage sum of square for genotypes varied from 8.85 for NDVI to 84.04 % spike length of the total variance. The partitioning of total sum of squares indicated that the genotypes effect was a predominant source of variation for three of the seven traits SL, NKPS, and DF variations (84,04, 52.9, 49.9) respectively. It is clearly seen that the contribution of genotypes variation to the sum of squares is considerable on SL, NKPS and DF and this means that the environment in which the experiment was undertaken did not affect these traits and it is preferable to identify and select stable durum wheat genotypes. Knezevic et al. (2013) reported genetic factor was higher than environmental and GEI factors on spike length. Similarly environment which showed largest variations on TKW (76.9%) followed by NDVI (70.9) and days to maturity (46.6%). Shitaye et al. (2012) on durum wheat and Gadisa et al. (2019) on bread wheat also indicated that environment and interaction effects are higher than the effect of genotypes in most crop variety trial in Ethiopia.

AMMI analysis

The combined and AMMI analysis of variance on grain yield of 25 durum wheat genotypes tested at six environments are given in Table 4. The additive component of analysis showed significant effect of genotypes, environments and their interaction on grain yield. Environments accounted the largest variations on grain yield (60.6 %) followed by genotypes by environments interaction (20.6%) and genotypes (18.2%). This result clearly indicated that there is a large variation exhibited in durum wheat yields in multi-environment experiments. This could be due to high influence of local environment associated to climate components and soil variations on crop yield and explained the need to classify the testing environments in to different mega environments for crop variety evaluations. In line with this result, the phenomena of genotype by environment interactions and the maximum share of environment from the total variations are commonly reported in different crops by various authors in Ethiopia: Shitaye (2017) and Tefaye (2007) on durum wheat; Asrta et al. (2011) on common bean; Kebebew et al. (2010) on tef; Taddele et al. (2017) on Linseed. Several researchers also reported that an environment was the major sources of variations than genotypes and genotypes by environment interactions on wheat Taddeses et al. (2009); Sisay and Sharma (2015); Melkamu et al. (2015) ; Alemu, (2018) and Alemu et al. (2018) on bread wheat. The average environments grain yield across genotypes ranged 2290.26kg/ha at Debre-Zeit clay soil to 6126.02 kg/ha at Gimbichu, while genotypes grain yield across environments ranged from 2000.12 kg/ha for G13 to 5590.74 from G8 (Table 5). The magnitude of variation between genotypes and genotypes by environment interaction sum of squares were comparable and three times less than from sum of squares of environments. In contrast environments showed quite tremendous effect on genotypes performance and classification of environments to screen genotypes at different test environments are need to be considered in future multi-location trials of the national durum wheat improvement program.

The AMMI analysis showed that five interactions of principal components (IPCA1, IPCA2, IPCA3, IPCA4, IPCA5, and IPCA6) and the first two were highly significant ($p \leq 0.01$) and significant ($p < 0.05$) effect was observed on IPCA-3 and IPCA-4. The variations explained by IPCA1, IPCA2, IPCA3 and IPCA4 and IPCA5were 39.2%, 22.2 %, 16.4%, 13.7%

Table 3. ANOVA of phenology, NDVI and yield related traits between genotypes (G), Environment, and GE interactions for 25 durum wheat genotypes.

Traits	Df	DH		DM		NDVI		TKW	
		MS	%	MS	%	MS	%	MS	%
Environment (E)	5	417.4**	24.3	700.04**	46.6	2802.9**	70.9	6924.8**	76.9
Genotypes(G)	24	178.8**	49.8	56.6**	18.1	72.9**	8.9	190.5**	10.2
GxE interactions	120	18.4**	25.7	22.1**	35.3	33.4**	20.3	48.5**	12.9

Traits	Df	SL		SPNPS		NKPS	
		MS	%	MS	%	MS	%
Environment (E)	4	1.26^{NS}	1.02	23.9**	21.4	2585.8**	24.2
Genotypes(G)	24	26.4**	84.04	7.05**	37.9	941.7**	52.9
GxE interactions	96	1.17^{NS}	14.9	1.88^{NS}	40.6	101.7**	22.9

** Highly significant at 1% level of probability, NS: Non significant, DH: days to heading, DM: days to maturity, SL: spike length: SPNPS: spikelet number per spike NKPS: number of kernels per spike, TKW: thousand kernel weight, NDVI: Normalized Difference Vegetative Index.

and 6.9%. In the current study except IPCA-5, all IPCAs showed significant variations but the magnitude of the first two IPCAs were relatively higher than the remaining IPCAs to explain the GEI and GGL biplot. The first principal component sum of square was greater than the second suggesting that the existence of variations on grain yield of genotypes due to G x E interactions. Similar results were reported by Shitaye (2017) in G x E study using 20 durum wheat genotypes tested at seven environments of Ethiopia. Several other authors: Tesfaye (2007) on durum wheat; Melkamu et al. (2015) and Taddese et al. (2009) on bread wheat suggested that the first two IPCAs as the most commonly used predictive model for explaining variation on G x E interactions and for further analysis of GGE biplot interpretations.

Stability analysis

The stability parameters are useful in characterizing and indicating genotypes performance across various environments. Based on Eberhart and Russel (1966), a genotype whose regression coefficient value is

Table 4.AMMI Analysis on Grain Yield of 25 durum wheat genotypes tested at six environments

Sources of Variations	Degree of freedom	Sum of squares	Mean Squares	Proportion of Explained variances
Environments	5	32170905	6434181**	60.6 %
Genotypes(G)	24	9993835	416409.8**	18.2%).
Env. X Gen.	120	10926312	91052.6**	20.6%)
IPCA1	28	4286365	153084.5**	39.2%,
IPCA2	26	2425674	93295.17**	22.2 %,
IPCA3	24	1795749	74822.88*	16.4%,
IPCA4	22	1502319	68287.23*	13.7%
IPCA5	20	754335.4	37716.77	6.9%.
Residuals	300	15666023		

** and * significant at 0.01 and 0.05 probability level respectively

Table 5.Mean grain yield (Kg/ha) of durum wheat genotypes tested across environments, 1918 season.

Genotypes	DZSLS	DZCVS	Alemtena	Minjar	Akaki	Gimbichu	Mean
G1	1434.23	1059.39	2123.94	3852.86	4297.48	5082.17	2975.01
G2	4607.65	1519.30	4126.03	2999.00	5897.91	6672.39	4303.72
G3	3192.36	1750.89	4873.07	3846.54	4854.90	6881.94	4233.28
G4	3288.48	1506.56	3720.85	3499.94	4767.11	6476.55	3876.58
G5	1428.39	833.26	1827.15	5259.96	5225.84	6261.37	3472.66
G6	1407.87	895.95	2048.65	4307.99	5389.37	4504.08	3092.32
G7	3909.83	1468.58	2564.85	3653.00	5450.80	6182.37	3871.57
G8	6154.47	4479.83	6007.09	5062.82	5807.75	6032.46	5590.74
G9	2607.53	1659.07	3924.36	5227.31	6073.99	5353.68	4140.99
G10	3149.30	1707.19	3437.61	3168.33	4280.12	5174.68	3486.21
G11	1503.59	733.10	1684.87	3788.72	5609.85	7472.44	3465.43
G12	2052.32	825.06	2185.70	4579.60	5151.20	6622.86	3569.46
G13	1544.20	897.78	1410.85	2026.53	2375.65	3745.70	2000.12
G14	2239.45	4654.73	3916.87	4844.42	5645.91	6916.67	4703.01
G15	3685.07	3716.19	4548.88	5128.28	5031.15	6028.76	4689.72
G16	3422.17	1337.34	3076.45	4180.07	4589.80	4894.01	3583.31
G17	3664.71	2337.33	2860.35	3975.26	6376.65	6837.84	4342.02
G18	2894.22	3966.32	3795.34	4555.71	6001.42	4892.09	4350.85
G19	3209.97	4499.94	4501.20	3628.46	4439.99	7683.54	4660.52
G20	3019.56	2318.05	4068.66	2692.40	7211.54	6079.47	4231.61
G21	2670.59	1373.98	2725.87	4705.20	5842.69	5856.87	3862.53
G22	1444.78	1551.14	3852.40	4153.53	5805.53	6553.73	3893.52
G23	3280.23	3739.28	3629.51	3592.51	5459.32	6607.32	4384.69
G24	3051.62	3420.53	3339.95	4096.83	6353.43	6512.83	4462.53
G25	5099.44	5005.82	4296.66	4553.63	5739.38	7824.69	5419.94
Mean	2958.48	2290.26	3381.89	4055.16	5347.15	6126.02	4026.49

close to one regarded as the most stable genotypes and the vice versa. Accordingly, Genotype 24, genotype 9, genotype 3 and genotype 2 found to be the most stable in their respective order whereas Genotype 8 followed by genotype 18 showed regression value close to zero (Table 6) were most sensitive to environmental variations. Coefficient of determination (r^2) between average grain yield of each genotype and location index were in the range of 0.21-0.98 suggesting large stability differences among genotypes. Accordingly to r^2, G8 which showed the highest grain yield was the least stable genotype. R^2 is the better index than stability variance for measuring the validity of the linear regression because its value always ranges between zero and one (Metin Kara, 1997). According to cultivar superiority measures, a small value indicates high stability of genotype and better genotypes performance (Martin, 2004). Based on the current result, G8 followed by G25 had small Pi values and identified as the most stable genotypes (Table 6). On the contrary, the highest cultivar superiority measures were observed by G13 followed by G1 and thus found to be the most unstable genotypes. The most stable genotypes had the maximum yielding records. Cultivar superiority measures identified the highest yielding ones as the most stable genotypes and the lowest yielding genotypes as the most unstable genotypes and hence, cultivar superiority measures simultaneously identified both stable and high yielding genotypes and the vice versa and could be used for identification of both superior and stable genotypes in crop performance evaluations. The stability of genotypes is inversely proportional to Wricke' ecovalence, Shukula stability parameters, variance of genotypes across environment and coefficient of variations, stable genotypes should have low values for these stability parameters. Accordingly, the most stable genotypes would be identified as G1 for Wricke' ecovalence and Shukula stability and G13 and G8 for variance of genotypes across environment and coefficient of variations. Similarly, Shitaye (2012) reported that genotypes that showed relatively stable performance gave below average yield on the evaluation of 20 durum wheat genotypes across environments using Wricke' ecovalence stability parameters.

AMMI stability value (ASV)

The interaction principal component one (IPCA 1) scores and the interaction principal component two (IPCA 2) scores in the AMMI model are indicators of stability. The genotypes with lower ASV value are considered more stable and genotypes with higher ASV are unstable. According to ASV (Table 6), G-8 was the most stable with ASV value of

Table 6.Mean grain yield (Kg/ha), AMMI stability value (ASV) , stability parameters and their rank for 25 durum wheat genotypes tested at six environments in2017/18.

Geno	Mean	ASV	Pi	Rank	Wi	Rank	Bi	ri2	Rank	R2	Rank	Si(1)	Rank	CV (%)	Rank
G1	2975.01	0.31	236422.8	24	39710.1	1	1.089	7308.4	1	0.93	3	1.33	5	55.70	20
G10	3486.21	0.67	155016.3	19	59394.2	4	0.749	11587.6	4	0.88	9	1.07	2	33.61	6
G11	3465.43	0.84	211408.5	21	295442.9	24	1.787	62902.5	24	0.98	1	1.73	9	76.61	24
G12	3569.46	1.05	183539.3	20	145114.0	16	1.469	30222.3	16	0.95	2	2.73	20	62.13	22
G13	2000.12	0.61	346533.5	25	84196.2	8	0.758	16979.3	8	0.91	7	0.33	1	49.79	18
G14	4703.01	0.49	77560.2	7	198850.4	19	0.848	41904.1	19	0.62	20	2.67	17	33.62	7
G15	4689.72	0.55	59614.2	3	102395.5	11	0.570	20935.7	11	0.86	10	1.47	8	19.26	2
G16	3583.31	0.58	153801.3	18	86616.0	9	0.789	17505.3	9	0.80	15	2.07	15	36.20	10
G17	4342.02	0.19	88477.0	9	70016.5	5	1.213	13896.7	5	0.93	3	2.00	13	42.69	1
G18	4350.85	0.79	90540.4	10	185473.8	18	0.546	38996.2	18	0.58	22	2.67	17	24.41	4
G19	4660.52	0.36	71856.3	4	287303.7	23	0.742	61133.1	23	0.48	23	3.07	23	33.80	8
G2	4303.72	0.46	87507.2	8	206274.3	20	1.081	43518.0	20	0.72	19	3.73	24	43.76	14
G20	4231.61	0.42	101491.6	12	225819.1	21	1.155	47766.9	21	0.73	18	4.07	25	47.05	16
G21	3862.53	1.08	140493.0	16	76850.8	6	1.221	15382.5	6	0.92	5	1.73	9	48.45	17
G22	3893.52	0.76	145250.4	17	133080.5	14	1.376	27606.3	14	0.92	5	1.2	3	54.22	19
G23	4384.69	0.45	76170.0	5	78804.1	7	0.822	15807.1	7	0.82	13	1.87	11	30.48	5
G24	4462.53	1.13	76882.1	6	53390.3	2	1.004	10282.4	2	0.89	9	2.13	16	35.07	9
G25	5419.94	0.51	22349.5	2	177287.8	17	0.673	37216.6	17	0.60	21	1.27	4	23.59	3
G3	4233.28	1.14	96983.3	11	125815.3	12	1.057	26026.9	12	0.79	16	2.67	17	41.20	11
G4	3876.58	0.82	121920.1	14	58081.7	3	1.065	11302.2	3	0.90	8	2	13	42.67	13
G5	3472.66	0.37	212016.7	22	257562.3	22	1.492	54667.6	22	0.86	10	2.73	20	68.02	23
G6	3092.32	0.79	234478.4	23	143955.5	15	1.142	29970.4	15	0.81	14	1.93	12	60.50	21
G7	3871.57	0.66	125930.8	15	91213.1	10	1.105	18504.7	10	0.86	10	1.33	5	45.28	15
G8	5590.74	0.14	18327.4	1	341905.2	25	0.209	73003.0	25	0.21	24	1.4	7	11.99	1
G9	4140.99	0.29	118400.8	13	130335.2	13	1.040	27009.5	13	0.79	16	2.13	15	41.75	12

ASV= AMMI Stability Values Pi=Superiority measure; Wi= Wricke's E; ri2=Shukla; bi=Eberhart, R^2 coefficient of determination, Si(1) variance of genotypes across environments , CV% coefficient of variations G1-25 refers to genotypes code and R=rank

(0.14) followed by G-17 (0.19) and G-9 (0.30). The genotypes G-3 (1.14) and G-24 (1.136) were the most unstable for grain yield. The stable genotypes (G-8, G-17and G-9) showed mean grain yield above grand mean. This result was in line with Shitaye (2012) on durum wheat and Gadisa et al. (2019) on bread wheat who used ASV as one methods for evaluating grain yield stability analysis of genotypes in G x E study.

AMMI biplot

The genotypes more stable are the nearest to the origin (x and y) in consequence their yield across all environments are similar (Figure 1).The AMMIbiplot indicate that G24 gave the highest average grain yield (4462.5 kg/ha) and had an IPCA-1value relatively close to zero (0.02889) indicating that it was stable and widely adapted genotypes (Figure 1). Beyond grain yield, high stability is an important objective for selection of genotypes in any crop breeding program. Hence, genotype 20 had the lowest IPCA-1 (0.01629) and medium grain yield of 4231.6 kg/ha. This was followed by genotype G4, G16, and G7 relatively showed low average yield of 3876.6kg/ha, 3583.3kg/ha and 3871.6 kg/ha with IPCA-1 of 0.0589, 0.09448, and 0.07172 respectively. Genotypes 8 and 25 showed better yield compared to average grain yield but had relatively high IPCA-1 scores of 0.83468 and 0.57775, respectively. These genotypes would be more adapted to specific environments than the other genotypes. In contrast, Genotypes 13, 1 and 6 were among the lowest yielding ones with the highest IPCA-1 score of 0.34811, 0.214352 and 0.540224 considered as both low yielders with relatively less stable genotypes. The performance of genotypes in each location, for instance, the Genotypes 19, 8, 14 and 25 have better yield than G12, G11, G6 and G5 at Debre-Zeit clay soil. The environments categorized as similar were Gimbich with Akaki; Debre-Zeit sandy loam soil, AlemtenaandDebre-Zeitclay soil.

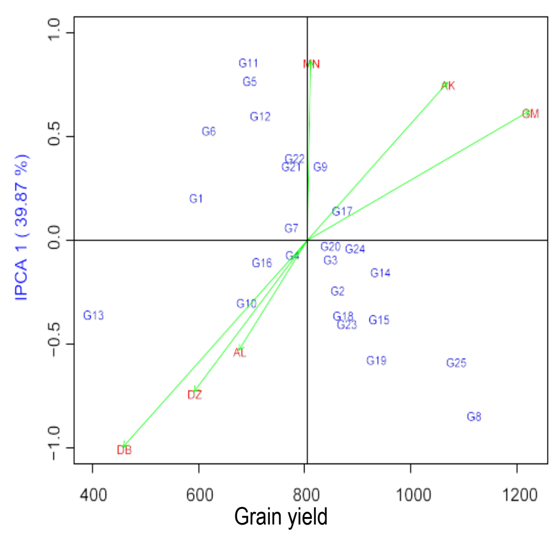

Figure 1. AMMI biplot for grain yield of durum wheat genotypes versus IPCA-1 for 25 genotypes tested across six environments.

Genotype and genotype by environment interaction (GGE) biplot

GGE biplot of 25 durum wheat genotypes evaluated at six environments are given in Figure 2. In the GGE analysis polygon view of biplot is been used to identify "which wins where" in mega environment trial data analysis. As per this study, four vertex genotypes identified as superior among the genotypes grouped together in the each environment. According to Yan (2002) vertex genotypes has higher yield than the other genotypes which are in the same environments. Stable genotypes and environments were found close to the origin with IPCA-1 and IPCA-2 values showed almost zero. Accordingly, G2 followed by G3were closer to the origin and their average grain yield was higher than the mean average yield of genotypes. In contrast, G13, G11, G8, G25 and G16 were found far from origin indicating that they perform differently across testing environments and could be categorized as unstable genotypes. The GGE biplot grouped the testing environments in to two broad category (mega environments) suggesting that testing the genotypes in limited number of environments resulted in similar findings without losing the precisions of G x E study. Akaki with Gimbichu and Alemtena, Debre-Zeit sandy soil and Debre-Zeit clay soil grouped together. Debre-Zeit clay soil environment could be used as the most discriminating testing site where as Minjar was lowest as they had long and short vector from the origin respectively.

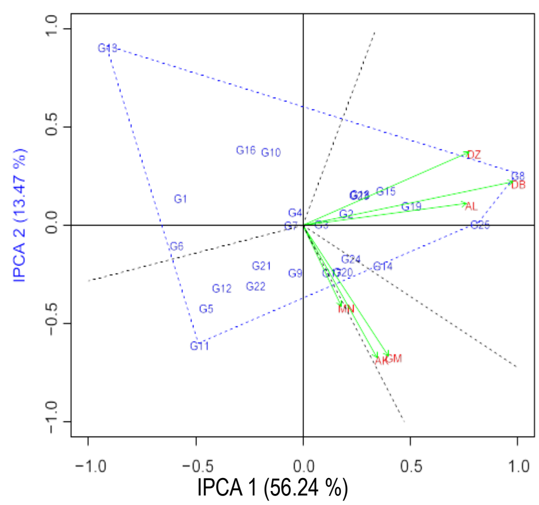

Figure 2. GGE biplot for identification of winning genotypes and their mega environments. twenty five durum wheat genotypes at six environments.

CONCLUSION

The genotype by environment study on durum wheat indicated the existence of highly significant variations on environments, genotypes and their interactions. The largest variation accounted by environments, followed by GEI and then genotypes. The stability analysis parametric measures identified G-24 as the most stable genotype followed by G-3 with above average grain yield. Some stability parameters (Wricle's and Shukla) showed similar rankings of genotypes with different magnitudes and identified Genotypes 1, 24, 4. 10 and 17 as the most stable genotypes. GGE biplot analysis categorized the environments in to two mega environments where Akaki and Gimbichu grouped together and that of Debre-Zeit light textured and black soil and Alemtena in the second mega environment and Minjar remained alone.

AUTHOR CONTRIBUTIONS

Alemayehu Zemede proposed, design, and conduct the trial. He also analyzed, drafted and finalized the manuscript. Firew Mekbib made valuable contribution to comment on final manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interest

ETHICS APPROVAL

Not applicable

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