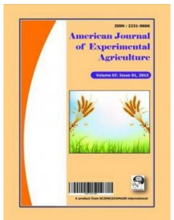

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GGE Biplot Analysis of Multi-environment Yield Trials of Durum Wheat (*Triticum turgidum* Desf.) Genotypes in North Western Ethiopia

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Authors' contributions

This work was carried out in collaboration between all authors. Author FA designed the study, wrote the first draft of the proposal and managed the literature searches, wrote the protocol and conducted the experiment, performed the statistical analysis and wrote this manuscript. Author FM serve as major adviser, edit the first draft of the proposal, participate on supervision of the experiment at field condition and edit the first draft of this manuscript. Author YD serve as Co-adviser, edit the first draft of both the proposal and this manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This experiment was done to identify the most stable durum wheat genotype(s) as well as desirable environment(s) for durum wheat (*Triticum turgidum var. durum* Desf.) research in north western Ethiopia. Grain yield performance of the tested genotypes were evaluated at four locations (Adet, Debretabor, Gaint and Simada) using randomized complete block design with three replication for two consecutive years (2010 and 2011). Combined analysis of variance showed that grain yield was significantly affected by environments (E), genotypes (G) and GE interactions. The first two principal components (PC1 and PC2) were used to create a two-dimensional GGE biplot and explained 45.67% and 32.71% of the total sums of squares of GE interaction, respectively. The 'which-won-where' feature of the GGE biplot suggested that the existence of three durum wheat mega-

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environments in north western Ethiopia. Among the testing environments, six environments such as E1, E2, E4, E5, E6 and E8 were included inside mega-environment one (ME1) while the remaining two testing environments, E3 and E7 were included inside mega–environment two (ME2) and mega-environment three (ME3), respectively. The GGE biplot also identified G7, G5 and G10 as winning genotypes at ME1 whereas G11 was identified as a high yielding genotype in both ME2 and ME3. According to the average environment coordination (AEC) views of the GGE-biplot, genotype G10 was identified as the most stable and high yielding genotype. In addition, G1 and G6 also showed better stability performance among the high yielding genotypes whereas genotype G12 was identified as the least stable and low yielding genotype. Therefore, genotypes G10, G1 and G6 were recommended for commercial production in most wheat growing areas of north western Ethiopia.

Keywords: Durum wheat; GE interaction; grain yield; GGE; stability.

1. INTRODUCTION

Durum wheat (*Triticum turgidum var. durum* Desf.) is one of the most important cereal crops which is grown in the high lands of Central, South Eastern and North Western part of Ethiopia. In Amhara region, particularly in west Gojam and South Gondar zones of North Western Ethiopia, Small scale farmers had traditionally grown the crop mainly on heavy black clay soils (Vertisols) under rain fed conditions. While following the introduction of improved bread wheat varieties in the two zones, bread wheat is being a dominant crop and replaces almost all the durum wheat landraces which had been grown before [1]. This is because durum wheat landraces lack stability in performance and showed inconsistent behavior (GEI) when grown in areas which have variable environmental conditions as in north western Ethiopia. Therefore, Plant breeders should perform multi-environment trials (MET) to evaluate improved genotypes across test environments (several locations and over years), before a specific genotype is recommended to growers for commercial production. Improving the prediction of genotype performance requires a thorough understanding of the interaction between genotype and environment since genetic effects are not independent of environmental effects, most genotypes do not perform satisfactorily in all environments, one genotype may have the highest yield in some environments and second genotype may be excellent in other environments [2-6]. [7] pointed out that it is often difficult to determine the pattern of genotypic responses across environments without the use of appropriate analytical tools such as GGE biplot for graphical display of data. GGE biplot analysis allows visual examination of the relationships among the test environments, genotypes and the GE interactions. Therefore, even though several multivariate statistical methods have been developed to measure the response of genotypes in various environmental conditions, GGE biplot analysis had been used for this study. GGE is an effective tool used for: (i) mega-environment analysis (e.g. “which-Won-where” pattern), where by specific genotypes can be recommended to specific mega-environments [8,7], (ii) genotype evaluation (the mean performance and stability), and (iii) environmental evaluation (the power to discriminate among genotypes in target environments) [9]. Hence, the objectives of this investigation were (1) to evaluate the yielding performance of thirteen durum wheat genotypes across four locations over two consecutive years; (2) to examine the possible existence of different mega environments in the durum wheat growing areas of north west Ethiopia; (3) to identify the winning genotype for each mega environment and determine the discriminating ability and representativeness of the environments.

2. MATERIALS AND METHODS

2.1 Experimental Design and Methods

Thirteen durum wheat genotypes were evaluated across four wheat growing areas of north western Ethiopia: namely Adet, Debretabor, Gaint and Simada (As shown Table 2). Among these thirteen genotypes, twelve are released varieties by regional and federal agricultural research centers of Ethiopia such as Adet, Debrezeit, Sinana, and Sirinka Agricultural Research Centers and one local variety commonly grown by farmers. The experiment was conducted using randomized complete block design with three replications in the two main cropping seasons in the years of 2010 and 2011. The size of experimental plot is 1.2 m x 2.5 m (3 m^2), with six rows which are 20cm apart each other, the spacing between the two adjacent blocks is 1 meter. Recommended seed rate (150 kg/ha) and fertilizer rate (92/46 kg/ha N and P_2O_5) were used in the experiment. The whole amount of DAP was applied at planting while Urea was split in to half at planting and the remaining half at tillering stage. All agronomic managements were applied equally as per the recommendation. Finally, in order to avoid border effect grain yield data was taken from the central four rows and was considered for statistical analysis.

2.2 Statistical Analysis

Before doing combined analysis variance, both Bartlett's homogeneity test and normality test were conducted in order to know the homogeneity of the data and to check whether the date was normally distributed or not, respectively. Then a homogeneous and normally distributed data was obtained, which allowed pooling the grain yield data of the testing environments for further combined analysis variance. Combined analysis variance across the testing environments and the GGE biplot pattern explorer performed using Gen Stat 12th statistical software [10]. The most recent method, the GGE (genotype main effect (G) plus G x E interaction) biplot model, provides breeders a more complete and visual evaluation of all aspects of the data by creating a biplot that simultaneously represents mean performance and stability, as well as identifying mega-environments [9,8]. The GGE biplot can be useful to display the which-won-where pattern of the data that may lead to identify high-yielding and stable genotypes and discriminating and representative test environments [11].

3. RESULTS AND DISCUSSION

Combined analysis of variance indicated the presence of highly significant differences ($p<0.001$) on G, GEI and E (Location, Year and location x Year interaction) in the grain yield performance of the tested durum wheat genotypes. The relative contribution of G, E and GEI were 8.38%, 71.24% and 20.38% of the total variation, respectively (Table 3). From the total environmental variation (71.24), a larger portion (64.39) was explained by L, whereas a smaller portion was explained by YxL (0.33) and Y (3.46). Whereas in the case of GE interaction, it's effect is 2.4 times more than that of the genotypes effect, this high value of GE interaction showed that a particular genotype does not necessarily exhibit the same phenotypic performance in different environmental conditions or different genotypes may respond differently to a specific environment since GE interaction is confounding the performance of genotypes. This result is similar to the previous findings of various authors on wheat genotypes [15-19]. From the total GEI, only very small portion of the interaction variance, 1.40% and 1.43% were contributed by G×Y and G×L×Y respectively. These values were collectively less than the contribution of GXL (12.44%).

3.1 Which-Won-Where Pattern of Genotypes and Environments

GGE biplot analysis is a multivariate analytical technique that graphically displays a two way table and allows visualizing the relation among genotypes, environments and their interactions [11]. In the present investigation, the GGE biplot graphic analysis of thirteen durum wheat genotypes revealed that the first two principal components explained 78.38% of the total GEI variance (Fig. 1). The polygon view of a GGE-biplot clearly displays the which-won-where pattern, and hence it arranged the genotypes in such a way that some of them were on the vertexes while the rest were inside the polygon.

The vertex genotypes such as G3, G4, G7, G8, G10, G11 and G12 were the most responsive genotypes since they are located far away from the biplot origin as compared to the other genotypes that are located on similar sectors of the polygon. There is not any environment which fell inside the sectors of the vertex genotypes G3, G4 and G12 which indicated those vertex genotypes were not the best in any of the test environments.

Yan et al. [20] reported that responsive genotypes were those having either best or the poorest performance in one or all environments. Accordingly, among the vertex genotypes G10 and G7 were identified as the high yielding genotypes while G3 and G12 were considered as the low yielding genotypes across the testing environments (as shown Table 1). Another interesting feature of the GGE biplot is the identification of mega-environments as well as their winning genotypes. The present investigation suggested that the existence of three durum wheat growing mega-environments (ME1, ME2 and ME3) in the north western Ethiopia as shown in the Fig. 1. Among the testing environments, E1, E2, E4, E5, E6 and E8 fell inside mega-environment one (ME1) while E3 and E7 fell inside mega–environment two (ME2) and mega-environment three (ME3) respectively. On the other hand, genotypes G7,G5 and G10 were suggested as high yielding genotypes in the mega environment one (ME1) while G11 was also identified as a high yielding genotype in both mega environment two (ME2) and mega-environment three (ME3).

3.2 Average Yield and Stability of Durum Wheat Genotypes

In the present study the stability and yielding performance of thirteen durum wheat genotypes were evaluated using average environment coordination (AEC) method as shown in the Fig. 2. This method stated that the abscissa of the average environment coordination (AEC) is a line that passes through the average environment which represented by a small circle (mean PC1 and PC2 scores) and the biplot origin while the ordinate of the AEC is a line that passes through the origin and perpendicular to the abscissa of AEC. [21] reported that AEC abscissa has a one directional arrow which is important for approximating the mean yield performance of the genotypes. Therefore, in this investigation, genotype G10, G7 and G5 had showed highest average yielding performance, which were followed by genotypes G6, G1 and G11 respectively (Fig. 2). On the other hand, besides to the genotypic grain yield performance (as shown in the Table 1), stability of genotypes 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 G10 was identified as the most stable and high yielding genotypes across the eight environments which are listed in table 2. Whereas genotypes G4, G8 and G12 was identified as the least stable low yielding genotypes.

Table 1. Code, pedigree, origin, area of adaptation and mean yield of genotypes

Code	Genotypes	Pedigree	Origin	Area of adaptation (masl)	Mean yield (t/ha)
G1	Bakalcha	98-OFN-Gedilfa/Guerou/15patho	SARC/ORARI	2300-2600	3.49
G2	Ejersa	LABUD/NIGRIS-3//Gan-CD98206	SARC/ORARI	2300-2600	3.44
G3	Flakit	EN-25	SARC/ARARI	2400-3000	2.61
G4	Leliso	Cit-71/3/Gerado//61-130/G//˝S"/4/Boohai//Hora//Gerado/3/Bohai	SARC/ORARI	2300-2800	3.30
G5	Megenagna	DZ-2023	ADARC/ARARI	1900-2800	3.60
G6	Metaya	DZ-2212	ADARC/ARARI	2000-2800	3.50
G7	Mosobo	DZ-2178	ADARC/ARARI	1900-2800	3.63
G8	Obsa	ALTAR84//ALTAR84/SERI/3/6*ALTAR84	SARC/ORARI	2300-2600	3.23
G9	Oda	DZ046881/imlo/cit71/3/RCHI/LD357//imlo/4/Yemen/cit'5'/plc'5'/3/Taganroy	SARC/ORARI	2300-2600	3.32
G10	Selam	DZ-1666-2	ADARC/ARARI	1900-2800	3.57
G11	Ude	CHEN/ALTAR84//JO69	DZARC/EARO	1800-2700	3.45
G12	Yegibrsinde	–	FARMERS	-	2.55
G13	Yerer	CHEN/TEZ/GVIL//C11	DZARC/EARO	1800-2700	3.14

Note that: ADARC = Adet Agricultural Research Center, DZARC = DebreZeit Agricultural Research Center, SRARC = Sirinka; Agricultural Research Center, SARC = Sinana Agricultural Research Center, ARARI=Amhara Region Agricultural Research Institute, EARO= Ethiopian Agricultural Research Organization, ORARI= Oromiya Region Agricultural Research Institute, masl = meter above sea; Level

Table 2. Environmental code, locations, cropping season, altitude, soil type, latitude and longitude of the experimental sites

Environmental code	Location	Cropping season	Altitude (meter)	Soil type	Global Position Latitude	Longitude
E1	Adet	2010	2216	Nitosol	$11^0$16N	$37^0$29E
E2	Debretabor	2010	2706	Luvisol	$11^0$51N	$38^0$01E
E3	Gaint	2010	3120	Luvisol	$11^0$44N	$38^0$28E
E4	Simada	2010	2460	Luvisol	$11^0$03N	$37^0$03E
E5	Adet	2011	2216	Nitosol	$11^0$16N	$37^0$29E
E6	Debretabor	2011	2706	Luvisol	$11^0$51N	$38^0$01E
E7	Gaint	2011	3120	Luvisol	$11^0$44N	$38^0$28E
E8	Simada	2011	2460	Luvisol	$11^0$03N	$37^0$03E

Sources: [12-14]

Table 3. Combined analysis of variance for grain yield data (t/ha) of durum wheat genotypes at four Locations during 2010 and 2011 cropping seasons

Source	df	Total sum of squares	Mean sum of squares	% of total sum of squares
Environments(E)	-	-		71.24
Locations(L)	3	271.20	90.40**	64.39
Years(Y)	1	14.56	14.56**	3.46
Location*Year	3	1.39	0.46*	0.33
Reps within E	16	12.90	0.81**	3.06
Genotypes(G)	12	35.28	2.94**	8.38
G*E	-	-	-	20.38
Genotype*Year	12	5.90	0.49**	1.40
Genotype *Location	36	52.40	1.46**	12.44
Genotype*Year*Location	36	6.02	0.17*	1.43
Error	192	21.51	o.11	5.11

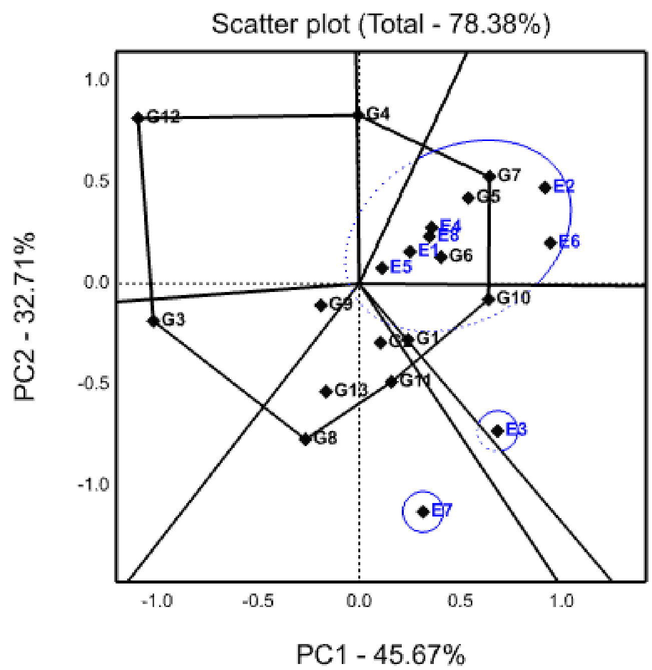

Fig. 1. Polygon view of the GGE biplot based on yield data of 13 durum wheat genotypes tested at four locations of north western Ethiopia in 2010 and 2011 cropping seasons

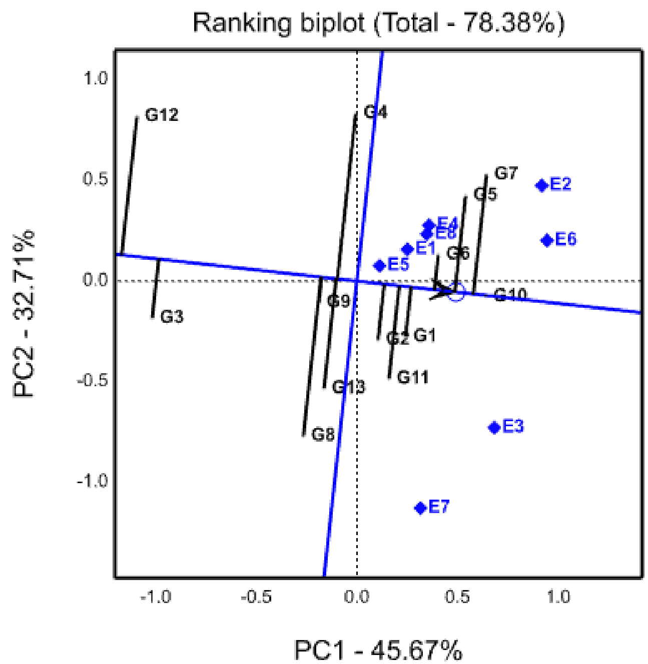

Fig. 2. Average environment coordination (AEC) views of the GGE-biplot based on genotype-focused scaling which shows the mean yield performance and stability of genotypes. PC stands for principal component

An ideal genotype is defined as genotype which having the greatest PC1 score (mean performance) and with zero GEI, as represented by an arrow pointing to it (Fig. 3). Even though such type of genotype may not exist in reality, it can be used as a reference for evaluation of genotype. If a genotype is located closer to the ideal genotype, it becomes more desirable than other genotypes which are located far away from the ideal genotype. Therefore, concentric circles were drawn around the central circle which contains the ideal genotype in order to visualize the distance between each genotype and the ideal genotype. In this study, G10 which fell closest to the ideal genotype was identified as the most desirable genotype as compared to the rest of the tested genotypes (Fig. 3).

3.3 Discriminating Ability and Representativeness of Environments

Both discriminating ability and representativeness view of the GGE biplot are the most important measures of testing environment, which provide not only valuable but also unbiased information about the tested genotypes [8]. [7] also reported that the length of environmental vector is directly proportional to the standard deviation within the respective environment and help to know the discriminating ability of this target environment. i.e. an environment with long environmental vector has high discriminating ability and vice versa. Therefore, as shown in the (Fig. 4), the test location Debretabor (E2 and E6) was identified as the most discriminating environment as compared to Adet(E1 and E5) and Simada(E4 and E8) that were identified as the least discriminating testing environments.

Another equally important measure of a test environment is its representativeness of the target environments. If a test environment is not representative of the target environments, it is not only useless but also misleading since it may provide biased information about the tested genotypes [8]. In order to know the representativeness of a test environment, understanding of some important terms such as average environment (the small circle in Fig. 5; used as a bench mark for measuring the representativeness of a test environment), the average environment coordinate axis (the line that passes through the biplot origin and the average environment) and environmental vector (the line that connects the origin of biplot and a testing environment) is very crucial task before measuring the representativeness of a test environment. Then, based on the size of the angle between the vector of an environment (in Fig. 5, but not drawn) and the AEC axis, it is possible to measure the representativeness of a testing environment. i.e a testing environment which has made acute angle with AEC axis is considered as a representative of the other testing environments while the reverse is true for a testing environment that has made obtuse angle with AEC axis.

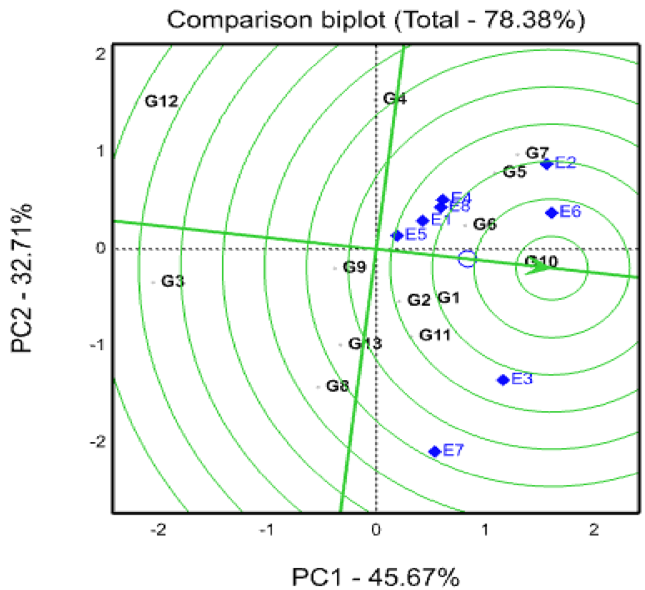

Fig. 3. GGE-biplot based on genotype-focused scaling for comparison the genotypes with the ideal genotype. PC stands for principal component

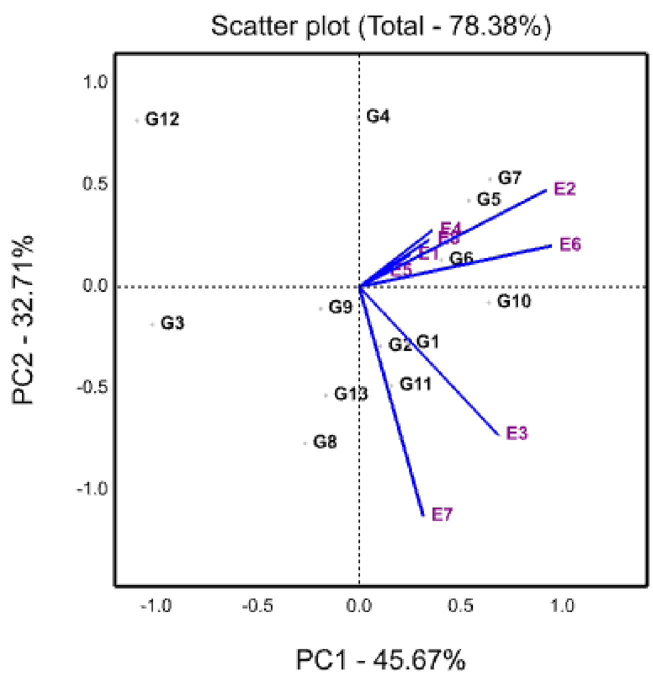

Fig. 4. The vector view of GGE biplot which shows the interrelation ships among the test environments PC stands for principal component

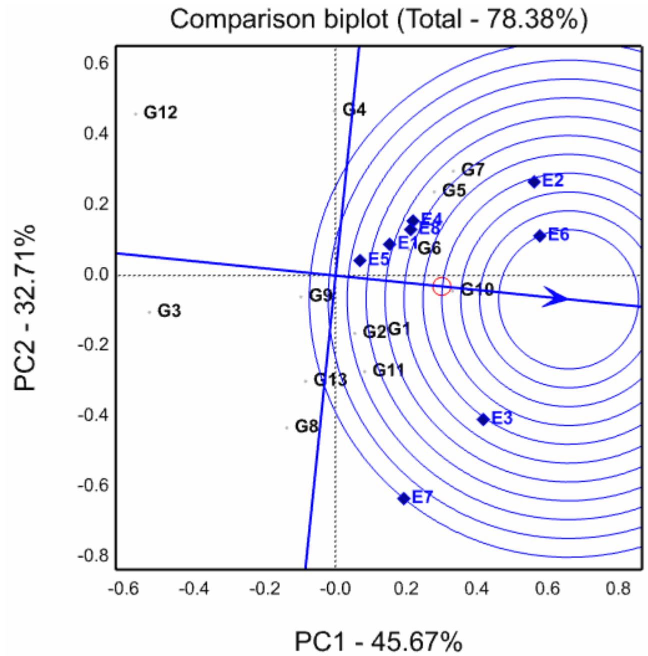

Fig. 5. GGE-biplot based on environment-focused scaling for comparison the environments with the ideal environment. PC stands for principal component

Hence Debretabor (E2 and E6) was identified as the most representative testing environment; which was able to provide unbiased information about the performance of the tested genotypes whereas Gaint (E3 and E7) was identified as the least representative testing environment.

Ideal test environment is an environment which has more power to discriminate genotypes in terms of the genotypic main effect as well as able to represent the overall environments. But such type of environment may not exist in real conditions. Therefore, by assuming a small circle which located in center of concentric circles and an arrow pointing on it as ideal environment (Fig. 5), it is possible to identify desirable environments which are found closer to the ideal environment [20]. Hence, among the testing environments, Debretabor (E2 and E7), which fell near to this ideal environment were identified as the best desirable testing environments in terms of being the most representative of the overall environments and powerful to discriminate genotypes.

4. CONCLUSION

In this investigation, combined analysis of variance indicated that grain yield performance of the tested genotypes was highly influenced by environment and GEI while the contribution of genotypic effect was very small. This indicating that a particular genotype does not necessarily exhibit the same phenotypic performance under different environmental conditions or different genotypes may respond differently to a specific environment. Furthermore, G10, G1 and G6 were identified as the most stable and high yielding genotypes, which recommended for commercial production in the wheat growing areas of north western Ethiopia. On the other hand for specific recommendation, G7 and G5 were selected for areas which belong to in ME1 whereas G11 was selected for areas which belong to in ME2 and ME3. Among the testing locations, Debrtabor was identified as the most desirable environment which able to provide unbiased information about the performance of the tested genotypes. Hence, Adet Agricultural Research Center should use this testing location for its future durum wheat research works.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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