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RESEARCH ARTICLE

GGE Biplot Analysis of Genotype by Environment Interaction in Field Pea (*Pisum sativum* L.) Genotypes in Northwestern Ethiopia

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Abstract

Ten field pea genotypes were evaluated in randomized complete block design with four replications for three consecutive years (2010-2012) main cropping seasons at four locations in each year. The objectives were to determine magnitude of genotype by environment interaction and to identify stable field pea genotype with high grain yield to be released as a cultivar to producer for Northwestern Ethiopia. The GGE [genotype main effect (G) and genotype by environment interaction (GE)] biplot graphical tool was used to analyze yield data. The combined analysis of variance revealed a significant difference ($P<0.01$) among genotypes, environments and genotype-by-environment interaction for grain yield. The average environment coordinate biplot revealed that EH99005-7 (G2) was the most stable and the highest yielding genotype. Polygon view of GGE-biplot showed the presence of three mega-environments. The first section includes the test environments E1 (Adet 2010), E3 (Debretabor 2010), E5 (Adet 2011), E6 (Motta 2011), E7 (Debretabor 2011), E8 (Dabat 2011), E9 (Adet 2012) and E12 (Dabat 2012) which had the variety G1 (EH99009-1) as the winner; the second section contains the environments E4 (Dabat 2010), E10 (Motta 2012) and E11 (Debretabor 2012) with G2 as the best grain yielder and the third section contains the E2 (Motta 2010) with G4 (Tegegnech X EH90026-1-3-1) as the best grain yielder. The comparison GGE- biplot of field pea genotypes with the ideal genotype showed that G2 was the closest genotype for the ideal cultivar. Among the twelve environments, E2, E6 and E10 were more discriminating and E3, E9 and E12 were less discriminating. Genotype EH99005-7 was the most stable and the highest yielding genotype. As a result it is released officially for Northwestern Ethiopia. Therefore, it is recommended to use genotype EH99005-7 for wider cultivation in Northwestern Ethiopia and similar areas.

Key words : Field pea, genotype-by-environment interaction, genotype, genotype main effect and genotype by environment interaction biplot, stability

Introduction

Field pea (*Pisum sativum* L.) is one of the most important cool-season food legumes grown in Ethiopia. It is the second most important cool-season food legume, after faba bean, in terms of both area and total annual production and usually grown at an altitude range of 2300-3000 m above sea level in the high and mid-altitude areas (1800-2300 m above sea level) having annual rainfalls between 800-1100 and 700-900 mm, respectively (Mulusew et al. 2009; Mussa et al. 2006). According to Central Statistical Agency (2015), on average 255,968.83 hectares of land has been allotted to field pea providing a total average production of 327,377,514 kg, in 2015. This constitutes about 13.74% of the total area and 11.9% of the total annual national production of pulse crops.

Field pea grain is an important source of protein supplement for the majority of the Ethiopian population and used as a source of foreign earning (Asfaw et al. 1994). It plays a significant role in soil fertility restoration as a suitable rotational crop that fixes atmospheric Nitrogen and also serves as

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rotational crop which play a great role in controlling disease epidemics in areas where cereal mono-cropping is abundant.

Numerous methods have been used to analyze multi-environment trials (MET) data to reveal patterns of genotype-by-environment interaction (GEI). Yan et al. (2000) proposed the methodology known as genotype plus genotype-by-environment interaction biplot (GGE-biplot) for graphical display of GEI pattern of MET data with many advantages. The GGE-biplot analysis utilizes both genotype (G) and GEI effects and graphically displays GEI in a two way table (Yan et al. 2000). It helps visual evaluation of the relationships among the test environments, genotypes and the GEI. It has been recommended by several scholars that GGE-biplot analysis was the best method for the analysis of GEI (Butron et al. 2004; Fan et al. 2007; Samonte et al. 2005; Yan and Kang 2003) and had been widely used by plant breeders in the variety evaluation of wheat (Yan and Hunt 2001; Yan et al. 2000), Maize (Fan et al. 2007) and soybean (Yan and Rajcan 2002).

Field pea breeding in Ethiopia started in 1960` with the objective of improving productivity through generation of high yielding varieties tolerance/resistance to different production constraints and suitable to different agro-ecologies of the country (Mussa et al. 2006). Currently demand of field pea is high but the productivity of field pea is very low and unstable. This is due to lack of improved varieties, susceptibility of the old varieties for different biotic and abiotic stress. By far, genotype by environment interactions is the most difficult factor to increase yield of field pea in Ethiopia because of diverse agro-climatic zones and high sensitivity of field pea to various environmental factors (Girma et al. 2000; Mulusew et al. 2009, 2010; Tezera 2000; Tolossa et al. 2013). Hence it is important to develop and release best performing varieties suitable to different agro-ecology of Ethiopia. Therefore, the objective of this study was to determine magnitude of genotype by environment interaction and to identify stable field pea genotype with high grain yield to be released as a cultivar to producer for Northwestern Ethiopia using GGE biplot analysis.

Materials and Methods

Description of the study area

The experiment was conducted at four locations per year namely, Adet, Motta, Debretabor, and Dabat for three consecutive years (2010-2012) under the main cropping seasons. These four locations represent various agro-ecology of Northwestern Ethiopia where field pea is widely grown (Table 1).

Experimental design, planting materials and field management

Ten field pea genotypes including one standard check were used in this experiment (Table 2). These genotypes were selected based on their good performance on preliminary yield trials, among 54 genotypes, which was conducted at Adet Agricultural Research Centre in 2009. The experiment was laid out on Randomized Complete Block Design with four replications. Each experimental plot had four rows of 4 m long. The gross and harvestable plot sizes was 0.8 m X 4 m (3.2 m^2) with 4 rows and a 1.5 m distance was maintained

Table 1. Geographic location, rainfall and soil condition of the study areas.

Location	Altitude (m.a.s.l)	Total annual rainfall (mm)	Soil type	Global position	
				Latitude	Longitude
Adet	2240	1331.8	Nitosol	11°16`N	37°29`E
Dabat	2620	740.4	Cambisol	13°39`N	37°85`E
Debretabor	2630	1378.6	Luvisol	11°89`N	38°9`E
Motta	2470	1012.6	Nitosol	11°20`N	37°88`N

Table 2. List of Genotypes/Varieties and their Origin/Source.

Genotype/Variety name	Origin/Source
EH99009-1	Holeta Agricultural Research Center
EH99005-7	Holeta Agricultural Research Center
Adet-I X PGRC/E32239-1-3	Holeta Agricultural Research Center
Tegegnech X EH90026-1-3-1	Holeta Agricultural Research Center
Tegegnech XEH90026-1-1	Holeta Agricultural Research Center
IFPI3422	International Center for Agricultural Research in the Dry Areas
Adet-I X EH90026-1-3-1	Holeta Agricultural Research Center
Adet-I X EH90026-1-1	Holeta Agricultural Research Center
PGRC/E32239 X 88P022-6-3	Holeta Agricultural Research Center
Sefinesh	Adet Agricultural Research Center

Table 3. Combined analysis of variance for grain yield of field pea genotypes grown across twelve environments.

Source of variation	DF	SS	MS	F pr	Explained (%)
G	10	69371707	6937171	<0.001	30.68
E	11	151237590	13748872	<0.001	60.79
ER	36	48549976	1348610	<0.001	5.98
GEI	110	63725577	579323	<0.001	2.56
Residual	360	81509472	226415		
Total	527	414394323			

DF: degree of freedom; SS: sum of squares; MS: mean square; F pr; F probability; ER: environment by replication interaction

between replications at all locations. The spacing between plots, rows, and plant was 1, 0.2, and 0.1 m, respectively. A seed rate of 75 kg ha^{-1} (160 seeds per plot and 40 seeds per row) was used. The fertilizer rate used was 18/46 N/P_2O_5 kg ha^{-1} and applied fully at time of planting. Planting was carried out from mid to the end of June following the farmers' practice. Weeding was done three times starting from 30 days after planting depending on weed infestation. Other management practices were done as required.

Statistical analysis

The analysis of variance for each location and the combined analysis of variance over locations were done to evaluate the performance of yield among varieties following the standard procedure given by Gomez and Gomez (1984) GenStat software (version 15) (www.genstat.co.uk). The grain yield data graphically analyzed for interpreting GEI using GenStat software (version 15). GGE biplot methodology, which is composed of two concepts, the biplot concept (Gabriel 1971) and the GGE concept (Yan et al. 2000), was used to visually analyze the field pea genotypes for grain yield MET data. This methodology uses a biplot to show the factors (G and GEI) that are important in genotype evaluation and that are also the sources of variation in GEI analysis of MET data (Yan 2001). The graphs generated based on (i) ranking of genotypes on the basis of yield and stability, (ii) “which-won-where” pattern, (iii) comparison of genotypes to an ideal genotype, (iv) ranking of test environment relative to the highest yielding genotype, (v) ranking of genotypes relative to the test environment with highest yielding performance, (vi) relationships between testing environments based on the angles between the vectors of the environments and (vii) evaluation of environments relative to an ideal environment.

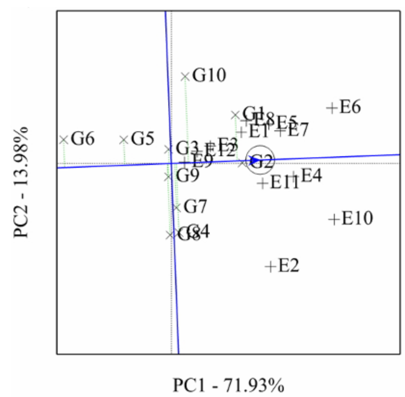

Fig. 1. GGE biplot showing the ranking of varieties for both yield and stability performance over environments.
The varieties are plotted as G and environments as E (G1: EH99009-1, G2: EH99005-7 , G3: Adet-I X PGRC/E32239-1-3, G4: Tegegnech X EH90026-1-3-1, G5: Tegegnech XEH90026-1-1-1, G6: IFPI3422, G7= Adet-I X EH90026-1-3-1, G8: Adet-I X EH90026-1-1, G9: PGRC/E32239 X 88P022-6-3 and G10: Sefinesh, E1: Adet 2010, E2: Motta 2010, E3: Debretabor 2010, E4: Dabat 2010, E5: Adet 2011, E6: Motta 2011, E7: Debretabor 2011, E8: Dabat 2011, E9: Adet 2012, E10: Motta 2012, E11: Debretabor 2012 and E12: Dabat 2012); X: Genotpe scores; +: Environment scores; o: AEC.

Results and Discussion

Combined analysis of variance

According to the combined analysis of variance for grain yield highly significant difference ($P < 0.01$) observed among all sources of variation ($P < 0.01$) (Table 3). The largest grain yield variation was occurred due to environment main effect (E) that explained 60.79% of total grain yield variation and followed by genotype main effect (G) (30.68%) and the genotype-by- environment interaction (GEI) (2.56%). The result implies that the grain yield performance of field pea genotypes significantly affected by environment two times than the genotype. The contribution of genotype was relatively high as compared to the genotype-by-environment interaction. The presence of genotype-by-environment interaction showed a significant difference in grain yield performance among the genotypes evaluated. This indicates the nature of interaction was crossover genotype-by-environment interaction. Similar results were obtained in previous studies also (Ceyhan et al. 2012; Mulusew et al. 2009, 2010; Tezera 2000; Tolossa et al. 2013).

Mean yield and stability performance of varieties

Identification and selection of high yielder and more stable field pea variety were done as shown in Figure 1. The result of GGE biplot analysis showed that the first principal components (PC 1) and the second principal components (PC 2) explained 71.93 and 13.98% of the total variation in the data matrix of GGE, respectively. Therefore, the first two principal components contributed 85.91% of the total GGE sum of squares. The average tester coordinate (ATC) is the line passing through the biplot origin and it is explained by the average PC1 and PC2 scores of all environments (Yan and Kang 2003). This line is used to indicate the mean yield performance of the varieties. The varieties which are found more close to concentric circle have higher mean yield. Thus, variety G2 had the highest mean yield, followed by variety G1 and variety G10. Varieties G3, G4, G7, G8, and G9 had mean yield similar to grand mean while variety G5 and G6 had mean yield less than overall mean yield across all locations. The stability of varieties is explained by the double arrows line which passes through the origin and perpendicular to the ATC. The GEI increases and the stability of varieties decrease as we go from the biplot origin to the end of this axis. Thus, genotype G2 was the most stable genotype across environments, followed by genotypes G3 and G9. Genotypes G5 and G6 were relatively stable genotypes, whereas genotypes G10, G8, G1, G7, and G4 were unstable for grain yield. The superior varieties to be released for commercial production in plant breeding should have both high mean grain yield and stability performance. In the biplot, they are located more close to the origin and have the shortest vector from the ATC. Therefore, based on the biplot, genotype G2 is considered as genotypes with both high grain yield and stability performance. The other varieties which are located on the right side of the line with double arrows have greater grain yield performance than the mean grain yield. However, the varieties on the left side of this line had less grain yield than the mean grain yield. The variety with high grain-yielding performance but low stability was G10, whereas the variety with low grain yield and relatively stable was variety G6. The distribution of environments fails into two groups. The first group contains E6, E7, E5, E8, E1, E3, E12, and E9. The second group contains E10, E4, E2, and E11. For the first group environment, the mean yield of the variety is in the following order: the highest is G1, then G10 and so on. The least yielding variety is G6. For the second group, the mean yield of the variety is in the following order: the highest is G4, then G7 and so on. The least yielding variety is G9.

Polygon view of GGE-biplot analysis of MET data

The patterns of interaction between varieties and environments can be identified using polygon view of a GGE biplot (Yan and Kang 2003). This graph helps to demonstrate the nature of the GEI and to show the mega environments present in the target environment (Gauch and Zobel 1997; Yan and Rajcan 2002; Yan and Tinker 2006). Figure 2 represents a polygon view of field pea varieties MET data in this investigation. In this biplot, a polygon was formed by connecting the vertex varieties with straight lines and the other varieties located within the polygon. The perpendicular lines are equality lines between adjacent varieties on the polygon, which facilitate visual comparison of them (Yan and Kang 2003). In Fig. 2,

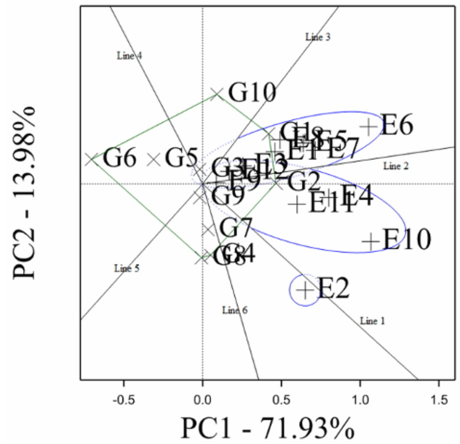

Fig. 2. Polygon view of genotype- environment interaction for field pea genotypes over twelve test environments.
The varieties are plotted as G and environments as E (G1: EH99009-1, G2: EH99005-7 , G3: Adet-I X PGRC/E32239-1-3, G4: Tegegnech X EH90026-1-3-1, G5: Tegegnech XEH90026-1-1, G6: IFPI3422, G7= Adet-I X EH90026-1-3-1, G8: Adet-I X EH90026-1-1, G9: PGRC/E32239 X 88P022-6-3 and G10: Sefinesh, E1: Adet 2010, E2: Motta 2010, E3: Debretabor 2010, E4: Dabat 2010, E5: Adet 2011, E6: Motta 2011, E7: Debretabor 2011, E8: Dabat 2011, E9: Adet 2012, E10: Motta 2012, E11: Debretabor 2012 and E12: Dabat 2012); X: Genotpe scores; +: Environment scores; Line 1 is perpendicular to the side that connects variety 4 with 2, Line 2 is perpendicular to the side that connects variety 2 with 1, Line 3 is perpendicular to the side that connects variety 1 and 10, Line 4 is perpendicular to the side that connects variety 10 with 6, Line 5 is perpendicular to the side that connects variety 6 with 8, Line 6 is perpendicular to the side that connects variety 8 and 2.

line 1 is perpendicular to the side that connects variety 4 with 2, line 2 is perpendicular to the side that connects variety 2 with 1, line 3 is perpendicular to the side that connects variety 1 and 10 and so on. These six lines divide the biplot into six sectors. According to the polygon view of biplot analysis of MET data in three years, the varieties fell in six sections and the test environments fell in three sections. The first section includes the test environments E1, E3, E5, E6, E7, E8, E9, and E12 which had the variety G1 as the winner; the second section contains the environments E4, E10, and E11 with G2 as the best grain yielder and the third section contains the E2 with G4 as the best grain yielder. The vertex varieties G10, G6, and G8 were not the top-yielding varieties in any environment. The varieties located on the vertex in this study were G2, G1, G10, G4, G8, and G6. These varieties were the most superior or the most inferior varieties in some or all of the environments because they were farthest from the origin of the biplot (Yan and Kang 2003).

Evaluation of varieties relative to an ideal variety

An ideal variety should have both high mean grain yield performance and high stability across environments (Yan and Kang 2003; Yan and Tinker 2006). In the GGE biplot, the ideal variety is located at the center of the concentric circles. It is defined by having the greatest vector length of the high-yielding varieties and the highest stability, as represented by the dot with an arrow pointing to it (Fig. 3).

Ideal variety projection on the ATC x-axis is designed to be equal to the longest vector of all the varieties. The ideal variety is stable because its projection on the ATC y-axis is near zero. Therefore, varieties found near to the “ideal variety” are more desirable than others. Thus, G2 and G1 were more desirable than the other varieties since they are located near to the ideal variety. G2 had both the highest mean grain yield performance and stability than the other varieties in this study. The performance of other varieties relative to the ideal variety were followed by G3, G9, G7, G10, G7, G4, G8, G5, and G6, respectively. The lowest yielding varieties (G6 and G5) were not desirable because they are located far from the ideal variety. The relative contributions of stability and grain yield to the identification of desirable variety found in this study by the ideal variety procedure of the GGE biplot are concord with those found in other crop stability studies (Fan et al. 2007; Samonte et al. 2005). Most of the environments located near to the ideal variety and some (E2, E10, and E6) are located far from the ideal variety.

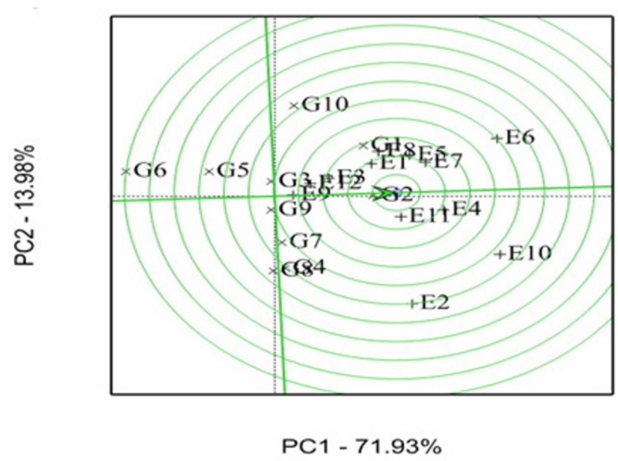

Fig. 3. GGE biplot showing the performance of varieties relative to the ideal variety.
The varieties are plotted as G and environments as E (G1: EH99009-1, G2: EH99005-7 , G3: Adet-I X PGRC/E32239-1-3, G4: Tegegnech X EH90026-1-3-1, G5: Tegegnech XEH90026-1-1, G6: IFPI3422, G7= Adet-I X EH90026-1-3-1, G8: Adet-I X EH90026-1-1, G9: PGRC/E32239 X 88P022-6-3 and G10: Sefinesh, E1: Adet 2010, E2: Motta 2010, E3: Debretabor 2010, E4: Dabat 2010, E5: Adet 2011, E6: Motta 2011, E7: Debretabor 2011, E8: Dabat 2011, E9: Adet 2012, E10: Motta 2012, E11: Debretabor 2012 and E12: Dabat 2012); X: Genotpe scores; +: Environment scores; o: AEC.

Relationship among test environments

The environment-vector view of GGE biplot (Fig. 4) shows the summary of the interrelationships among the test environments. The vector lines that connect the test environments to the biplot origin are called environment vectors. The angle between the vectors of two adjacent testing environments is related to the correlation coefficient between them. The correlation coefficient between two testing environments is determined by the cosine of the angle between them (Kroonenberg 1995; Yan 2002; Yan and Tinker 2006). Acute angles indicate a positive correlation, obtuse angles a negative correlation and right angles no correlation (Yan and Kang 2003; Yan and Tinker 2006). A short vector may indicate that the test environment is not related to other environments. Thus, the test environment E1, E3, E4, E5, E6, E7, E8, E9, E10, E11, and E12 had positive correlation because the angle between the environment vectors is acute and environment E8 and E2 had a negative correlation because they have obtuse angle between the environment vectors. The distance between two environments measures their dissimilarity in discriminating the varieties. Therefore, the 12 environments fell into two groups: E1, E3, E5, E6, E7, E8, E9, and E12 formed one group, and E2, E4, E10, and E11 formed the other group. The length of the environment vectors is a measure of discriminating ability of the environments. Therefore, among the 12 environments, E2, E6, and E10 were more discriminating and E3, E9, and E12 were less discriminating.

The presence of close associations among test locations suggests that the same information about the genotypes could be obtained from fewer test locations, and hence the potential to reduce testing cost. If two test locations are closely correlated consistently across years, one of them can be dropped without loss of much information about the genotypes.

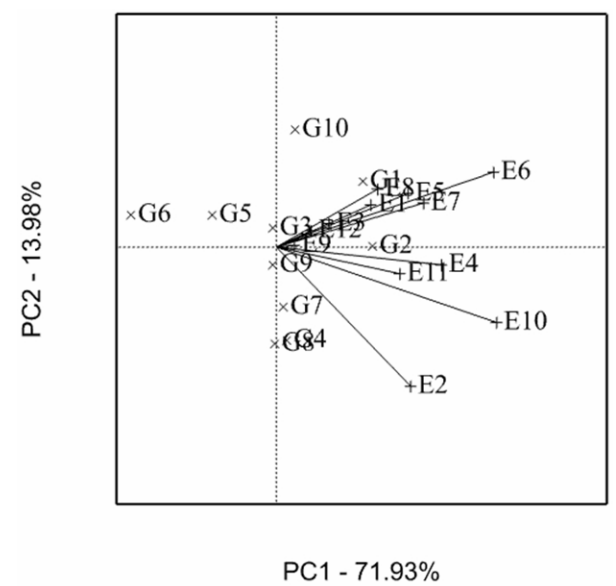

Fig. 4. GGE biplot showing the summary of the interrelationships among the test environments.
The varieties are plotted as G and environments as E (G1: EH99009-1, G2: EH99005-7 , G3: Adet-I X PGRC/E32239-1-3, G4: Tegegnech X EH90026-1-3-1, G5: Tegegnech XEH90026-1-1, G6: IFPI3422, G7= Adet-I X EH90026-1-3-1, G8: Adet-I X EH90026-1-1, G9: PGRC/E32239 X 88P022-6-3 and G10: Sefinesh, E1: Adet 2010, E2: Motta 2010, E3: Debretabor 2010, E4: Dabat 2010, E5: Adet 2011, E6: Motta 2011, E7: Debretabor 2011, E8: Dabat 2011, E9: Adet 2012, E10: Motta 2012, E11: Debretabor 2012 and E12: Dabat 2012); X: Genotpe scores; +: Environment scores.

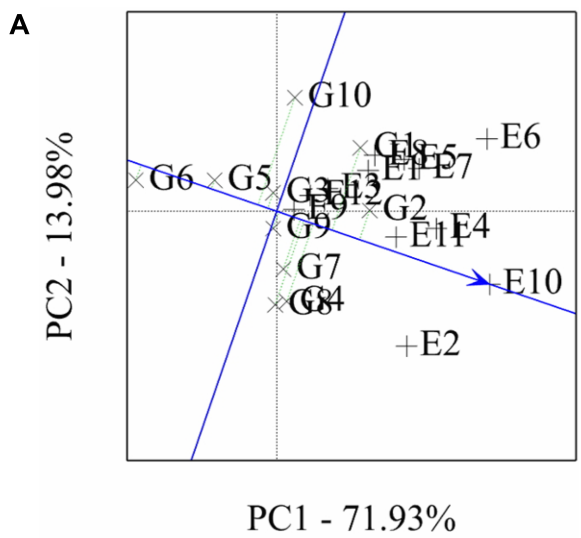

Fig. 5A. GGE biplot showing the ranking of varieties relative to highest yielding environment.
The varieties are plotted as G and environments as E (G1: EH99009-1, G2: EH99005-7 , G3: Adet-I X PGRC/E32239-1-3, G4: Tegegnech X EH90026-1-3-1, G5: Tegegnech XEH90026-1-1, G6: IFPI3422, G7= Adet-I X EH90026-1-3-1, G8: Adet-I X EH90026-1-1, G9: PGRC/E32239 X 88P022-6-3 and G10: Sefinesh, E1: Adet 2010, E2: Motta 2010, E3: Debretabor 2010, E4: Dabat 2010, E5: Adet 2011, E6: Motta 2011, E7: Debretabor 2011, E8: Dabat 2011, E9: Adet 2012, E10: Motta 2012, E11: Debretabor 2012 and E12: Dabat 2012); X: Genotpe scores; +: Environment scores.

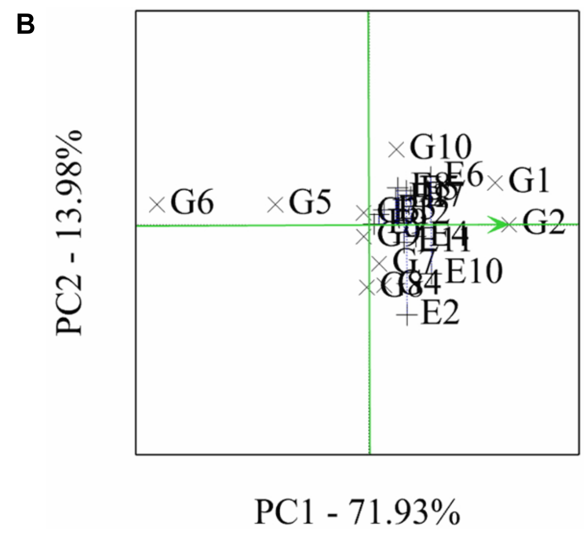

Fig. 5B. GGE biplot showing the ranking of varieties for both yield and stability performance over environments.
The varieties are plotted as G and environments as E (G1: EH99009-1, G2: EH99005-7 , G3: Adet-I X PGRC/E32239-1-3, G4: Tegegnech X EH90026-1-3-1, G5: Tegegnech XEH90026-1-1, G6: IFPI3422, G7= Adet-I X EH90026-1-3-1, G8: Adet-I X EH90026-1-1, G9: PGRC/E32239 X 88P022-6-3 and G10: Sefinesh, E1: Adet 2010, E2: Motta 2010, E3: Debretabor 2010, E4: Dabat 2010, E5: Adet 2011, E6: Motta 2011, E7: Debretabor 2011, E8: Dabat 2011, E9: Adet 2012, E10: Motta 2012, E11: Debretabor 2012 and E12: Dabat 2012); X: Genotpe scores; +: Environment scores

Ranking of varieties relative to highest yielding environment

Figure 5A illustrates the graphic comparison of the relative performance of all varieties relative to the environment E10 with the highest yielding production. A line was drawn that passed through the biplot's origin and the E10 marker to make an E10-axis, and then a line was perpendicularly drawn from each variety toward the E10-axis. This line (E10-axis) is called the axis for this environment (Yan and Tinker 2006) and along it is the ranking of varieties. The varieties were ranked on the basis of their projections onto the E10-axis, with rank increasing in the direction toward the positive end (Yan et al. 2000). Figure 5A shows ranks of varieties based on their yield performance in E10. Varieties G2, G1, G4, G7, and G8 had higher than the average yield, G9 and G3 had near average yield, and G10, G5, and G6 had lower than average yield. The highest yielder in E10 was G2 and the lowest yielder G6.

Ranking test environments relative to the highest yielding variety

To determine the rank of testing environments relative to the highest yielding variety, a line is drawn that passes through the biplot origin and the variety. This line is called the axis for this variety, and along it is the ranking of the environments (Yan et al. 2000; Yan and Tinker 2006). Figure 5B shows the testing environments rank relative to the highest yielding variety (G2). Thus, the graph indicates

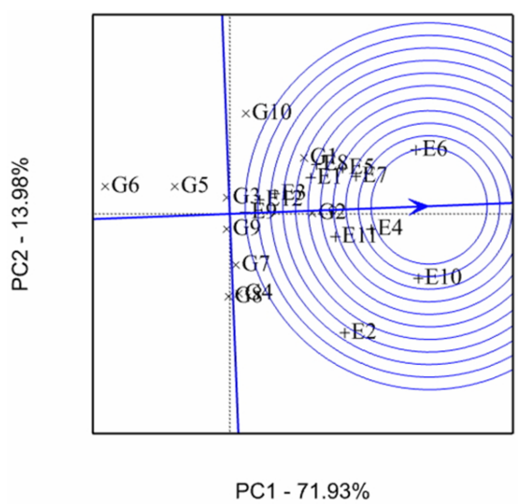

Fig. 6. GGE biplot showing the performance of environments relative to the ideal environment.
The varieties are plotted as G and environments as E (G1: EH99009-1, G2: EH99005-7 , G3: Adet-I X PGRC/E32239-1-3, G4: Tegegnech X EH90026-1-3-1, G5: Tegegnech XEH90026-1-1, G6: IFPI3422, G7= Adet-I X EH90026-1-3-1, G8: Adet-I X EH90026-1-1, G9: PGRC/E32239 X 88P022-6-3 and G10: Sefinesh, E1: Adet 2010, E2: Motta 2010, E3: Debretabor 2010, E4: Dabat 2010, E5: Adet 2011, E6: Motta 2011, E7: Debretabor 2011, E8: Dabat 2011, E9: Adet 2012, E10: Motta 2012, E11: Debretabor 2012 and E12: Dabat 2012); X: Genotpe scores; +: Environment scores; o: AEC.

that G2 had higher than the average in all test environments. G2 gave the highest yield at environment 10 and followed by

E6, E4, E7, E5, E2, E11, E8, E1, E3, E12, and E9. Among these testing environments, it performed best in E10, E6, and E4 environments than the other remaining environments.

Evaluation of environments relative to an ideal environment

An environment is more desirable if it is located closer to the ideal environment. Thus, using the ideal environment as the centre, concentric circles were drawn to help visualize the distance between each environment and the ideal environment (Yan et al. 2000; Yan and Rajcan 2002). Figure 6 shows that E4 was more desirable than the other environments since it is located near to the ideal environment. E4 was most representative of the overall environment and most discriminating of varieties. Ranking of other environments based on the ideal environment was E6 > E10 > E7 > E5 > E11 > E8 > E1> E2 > E3 > E12 > E9. Therefore E4, E6, E10, and E7 were desirable test environments, whereas E3, E12, and E9 were undesirable test environments.

Conclusion

The combined analysis of variance indicated that the main effects of environment (E), genotype (G) and GEI were significant for grain yield. The environment main effect explained most of (60.79%) of total yield variation and followed by genotype (30.68%) main effect and the GEI (2.56%). The presence of GEI indicates the differential response of genotypes across locations and years and the importance of stability analysis. According to GGE analysis the genotype EH99005-7 can be considered as genotypes with both high yield and stability performance. EH99009-1 had 24.82% yield advantage over the standard chick. Therefore, it was officially released for Northwestern Ethiopia with the name "Teshale". The use of this genotype by growers would assure them stable performance across years and increase production and productivity at Adet, Motta, D/tabor, Dabat, and areas which do have similar agro ecologies with these areas.

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