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Genotype by environment interaction of some faba bean genotypes under diverse broomrape environments of Tigray, Ethiopia

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Advanced breeding lines with acceptable resistance and tolerance levels to broomrape is an important way of decreasing yield loss. The objective of this research was to assess the yield stability of faba bean genotypes under diverse broomrape (*Orobanche crenata*) prone production environments. Six faba bean genotypes were tested across six environments. The AMMI analysis showed significant (P<0.01) genotype, environment and genotype by environment interaction and the environment explained higher sum of square for the response variable grain yield. The AMMI one gives the best model fitness for the grain yield and broomrape number. Using the AMMI 1 biplot, polygon view of the GGE biplot and comparison of genotypes based on ideal genotype, the genotype ILB4358 was higher yielder and stable with lower Orobanche number followed by the genotype Sel.F5/3382/2003-4. Using the AMMI biplot analysis E3 (Adigolo, 2011) and E4 (Adigolo, 2012) were unfavorable environments, while, E1 (Awliegara, 2011), E2 (Awliegara,), E5 (Kolatsihidi, 2011) and E6 (Kolatsihidi, 2012) were favorable testing environments.

Key words: AMMI, broomrape, environments, genotypes, GGE, faba bean.

INTRODUCTION

Legume crops represent an important component of agricultural food crops consumed in developing countries and are considered a vital crop for achieving food and nutritional security for both poor producers and consumers. Faba bean (*Vicia faba* L.) is one of the earliest domesticated food legumes in the world (Singh et al., 2013). Faba bean occupies around 2.44 million ha with annual production of 4.4 million tons (FAOSTAT, 2008). The main faba bean producers are China (1.65 Mt), Ethiopia (0.61 Mt), France (0.44 Mt), Egypt (0.29 Mt) and Australia (0.19 Mt) (FAOSTAT, 2009). Faba bean is used as a source of protein (20-41%) in human diets, as forage crop for animals, and for available nitrogen in the biosphere (Crépona et al., 2010; Rubiales, 2010). Faba bean takes the largest share of the area and production of pulses grown in Ethiopia including Tigray region. It occupies close to 574,060 ha^{-1} of land with annual production about 943, 964 tones (CSA, 2013). However, in spite of these advantages faba bean acreage has declined due to low and unstable yields as well as

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Table 1. List of faba bean International *Orobanche* Nurseries (FBION-08) in Tigray.

Name	Pedigree	Origin	FAO status
ILB 4358	ILB 4358	Morocco	Designated
Sel.F5/3053/2003-3	HBP/DS0/2000	ICARDA	Undesignated
Sel.F5/3085/2003-4	HBP/DS0/2000	ICARDA	Undesignated
Sel.F5/3382/2003-4	HBP/DS0/2000	ICARDA	Undesignated
ILB 1814(Susc. check)	Syrian local large	Syria	Undesignated
Local check	-	Ethiopia	-

incidence of diseases worldwide (Stoddard et al., 2010) including Ethiopia (Nigussie et al., 2008). Meanwhile, the major constraint for faba bean cultivation in the Mediterranean area and west Asia (Pérez-de-Luque et al., 2010; Maalouf et al., 2011) and Ethiopia (Besufikad et al., 1999; Rezene and Gerba, 2003; Abebe et al., 2013) is broomrape infection. Broomrapes are root parasitic weeds which are completely dependent on the host due to the lack of chlorophyll and functional roots. Several broomrape species can infect faba bean, crenate broomrape (*Orobanche crenata* Forsk.) being the most damaging and widespread (Fernández-Aparicio et al., 2012; Rubiales et al., 2014). The damage caused by the parasite is significant and estimated yield losses were 7 to 80% depending on the level of infestation (Maalouf et al., 2011). In Ethiopia, the yield losses due to *O. crenata* reached 75 to 100% depending on host susceptibility, level of infestation and environmental conditions. Consequently, farmers in highly infested areas generally avoid growing food legume crops, resulting in substantial reductions to both the extent of cultivated areas and to food legume production (Besufikad et al., 1999; Rezene and Gerba, 2003; Abebe et al., 2013).

Ever since crenate broomrape is a menace in Ethiopia, efforts are being made to manage by different methods including hand weeding, crop rotation, fallowing, late sowing and chemical control. Nevertheless, none of these disease controls have been proved satisfactory. Therefore, breeding for resistance was considered to be the best form of control against broomrape (Rubiales et al., 2006). Producing varieties with high yielding ability have always been the first and the foremost among plant breeding objectives but, such high yielding varieties have to be characterized by relative resistance to biotic stresses in general and broomrape specifically. Many programs in the regions viz. Spain, Egypt, Syria, Morocco and Ethiopia have set up faba bean breeding programs to select broomrape-resistant varieties despite the complexity of resistance breeding for broomrape. As a result, only cultivars with moderate levels of resistance to *O. crenata* are available (Pérez-de-Luque et al., 2010; Maalouf et al., 2011; Gutiérrez et al., 2013). According to Maalouf et al. (2011), selection of genotypes with adequate broomrape resistance is also strongly affected by the genotype – environment interaction (GEI). This makes it difficult to predict the behavior of the accessions in different situations reinforcing the need for multi-environmental testing of stability of disease resistance for faba bean crop. Genotype by environment interaction are important sources of variation in any crop and the term stability used to characterizes a genotype, which shows a relatively constant yield, independent of changing environment conditions (Sabaghnia et al., 2006). GGE biplot analysis has been previously proven useful to identify and characterize disease resistance and yield stability of breeding material in field trials (Fernández-Aparicio et al., 2012; Rubiales et al., 2012; Flores et al., 2013; Sánchez-Martín et al., 2014) taking advantage of the discrimination power versus representativeness view of the GGE biplot effective in evaluating test environments. In Ethiopia, sufficient information regarding stability parameters is not available in Orobanche resistance faba bean genotypes which could be used in further breeding programme. Hence, this investigation aimed at study genotype stability of some faba bean genotypes and select resistant and/or tolerant with high seed yield potentiality under different *Orobanche* infestation levels and environments.

MATERIALS AND METHODS

The present research was carried out in Ofla district, Tigray, Ethiopia, located at 12°31'N latitude and 39°33'E longitude. Five genotypes were introduced from International Center for Agricultural Research in Dry Areas (ICARDA) and local check were evaluated for *Orobanche* resistance in highly infested soils with *O. crenata* and tested at six environments and three locations. The pedigree and origin of genotypes were presented in Table 1. These genotypes and one local check were evaluated in complete randomized block design with three replications in each environment. Sowing was done during the first week of July each year. The plot size for each genotype consists of 6 rows of 3 m length, with 0.1 m intra-row and 0.5 m inter-row spacing. At planting, 100 kg DAP ha^{-1} (46 kg P_2O_5 and 18 kg N) was applied. All the culture practices were applied during the whole growing environments to ensure good crop stand. Hand weeding of other than broomrape was carried out; herbicides were not applied to avoid interference with broomrape development. The valuable examined were yield and number of emerged broomrape shoots per plot was determined at crop maturity.

Combined analysis of variance was conducted to determine genotypic differences and the significant genotype x environment interactions for broomrape was studied by using the AMMI model

Table 2. Mean value of seed yield and *Orobanche* number under diverse locations and seasons.

Genotype	Yield Qt/ha						Orobanche number per ha ('000)					
	Adigolo		Awliegara		Kolatsihidi		Adigolo		Awliegara		Kolatsihidi	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
ILB 1814 (Susc. check)	14.54	4.36	15.81	12.2	19.07	22.16	214.2	534.2	402.2	408.9	30.8	538.3
Sel.F5/3053/2003-3	6.79	14.9	15.2	19.97	47.91	23.35	339.2	520	376.7	175	0	619.2
ILB 4358	21.24	21.54	39.00	38.57	50.46	41.42	404.2	383.3	145	90	0	188.3
Sel.F5/3382/2003-4	14.82	14.11	29.15	21.33	44.98	25.99	330.8	409.2	146.7	135	0	411.7
local check	6.53	0	19.05	12.9	18.11	11.85	351.7	435	276.7	171.7	1.7	774.2
Sel.F5/3085/2003-4	12.6	11.48	26.30	20.97	45.03	20.58	311.7	500.8	368.3	153.3	1.7	521.7

Table 3. Additive main effects and multiplication interaction (AMMI) for yield and Orobanche count over six environments.

	Yield			Orobanche count	
Source	df	MS	% Explained	MS	% Explained
Treatments	35	484**	86.59	132873**	89.02
Genotypes	5	1347.5**	39.77	22811*	2.45
Environments	5	1627.2**	48.03	788527**	84.78
Rep (environment)	12	44.4	3.15	4674	1.21
Interactions	25	82.7**	12.20	23755**	12.77
IPCA1	9	175.8**	76.54	55952**	84.79
IPCA2	7	46.3ns	15.67	11485ns	13.54
IPCA3	5	26^{ns}	6.29	1924^{ns}	1.62
IPCA4	3	10.3^{ns}	1.50	96^{ns}	0.05
IPCA5	1	0	0.00	0	0
Error	60	34.8		8625	

which proposed by Zobel et al. (1988). A bipolt on the first main effect of the interaction ICPA-1 of both genotypes and environments simultaneously (Kempton, 1994).The analysis were done using the CropStat *7.2 software* to compare the genotypes under different environments by GGE biplot analysis proposed by Yan et al. (2000) and the analysis was done using the software Genestat13.

RESULTS

Combined analysis variance

The combined analysis of variance for grain yield across different growing environment showed that the genotype ILB 4358 was consistently higher yielder. The genotype ILB 4358 was also recorded the lowest number of broomrape population than the remaining genotypes (Table 2). However, the genotype ILB 1814 (susceptible check) and local check had the lowest yield across locations and years.

AMMMI analysis grain yield

The AMMI analysis of variance for the additive main effect showed a significant difference (P≤ 0.01) for the genotype, environment and genotype by environment interaction (Table 3). The result showed that the environment captured the maximum sum of square 48.03% followed by the genotype 39.77% and the genotype by environment interaction sum of square was lowest 12.2%. The magnitude of the environment was 3.9 times greater than the genotype by environment interaction (Table 3). The significant genotype by environment interaction were decomposed in to principal component analysis and the first interaction principal component explained 76.54% and the second interaction principal component additionally explained 15.67% the two interaction principal component totally captured 92.21% of the genotype by environment interaction variation. The first (IPCA1) interaction principal component was significant (Table 3).

AMMI 1 biplot grain yield

Genotype or environment located to the right side of the perpendicular line had the high yielding with favorable environment and when the genotype and environment are located to the left of the perpendicular line (grand

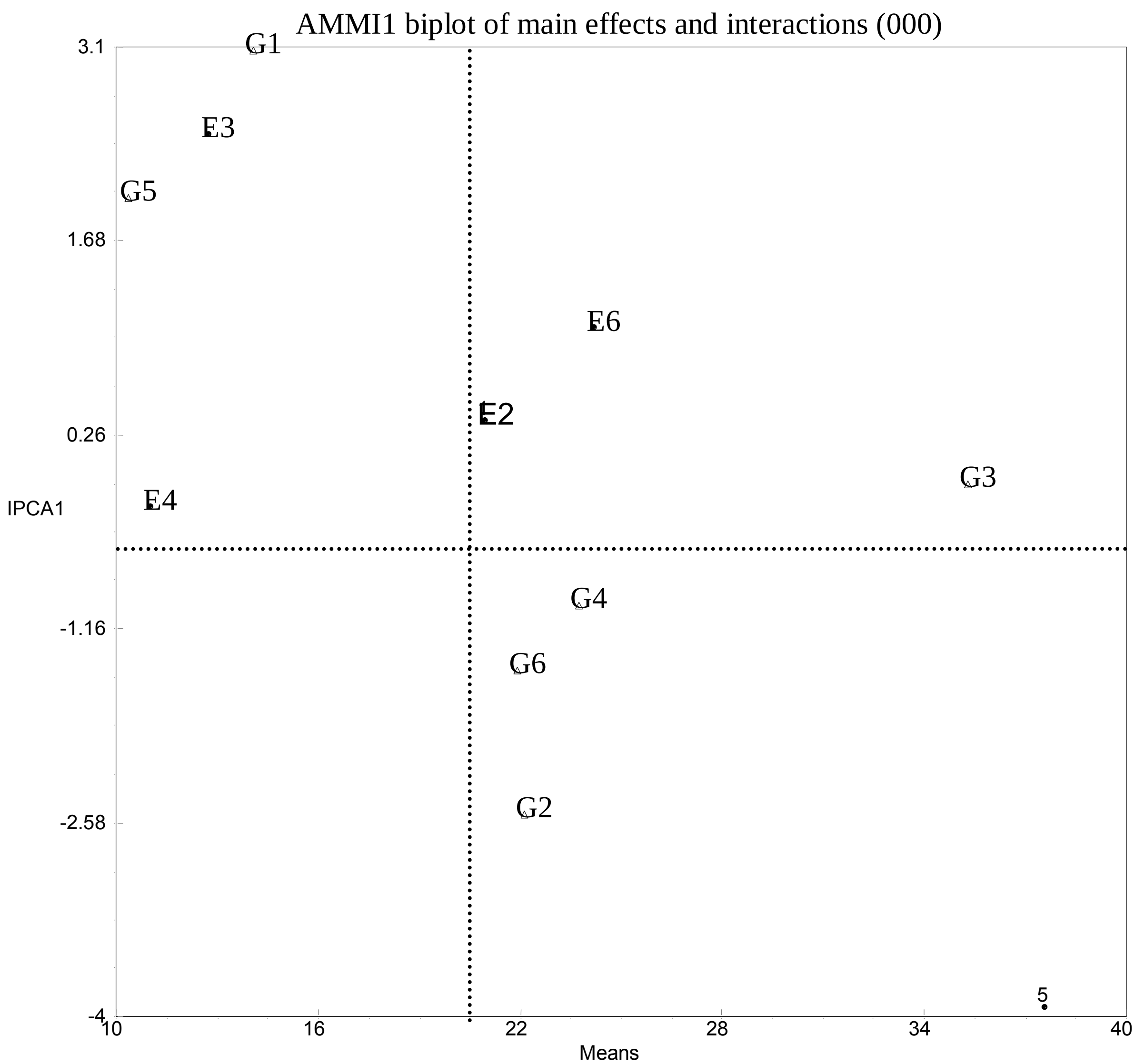

Figure 1. AMMI biplot for grain yield of six faba bean genotypes in six environments of Tigray.The genotypes abbreviated as G1, G2… and environment abbreviated as E1, E2,…G1 (ILB 1814), G2 (Sel.F5/3053/2003-3), G3 (ILB 4358), G4 (Sel.F5/3382/2003-4), G5 (local check) and G6 (Sel.F5/3085/2003-4). E1 = Awliegara, 2011, E2 = Awliegara, 2012, E3= Adigolo, 2011, E4= Adigolo, 2012, E5 = Kolatsihidi, 2011 and E6 = Kolatsihidi, 2012.

mean) the reverse is true. Genotype or environment nearly placed to the origin (horizontal line) is stable genotype while**,** the genotype or environment disparaged from the origin the reverse is true.

The two genotypes; G1 (ILB 1814 or susceptible check) and G5 (local check) were lower in yield than the other genotypes and located to the left of the grand mean. The three genotypes; G2 (Sel.F5/3053/2003-3), G3 (ILB 4358), G4 (Sel.F5/3382/2003-4) and G6 (Sel.F5/3085/2003-4) were higher in yield (Figure 1). The two genotypes; G3 (ILB 4358) and G4 (Sel.F5/3382/2003-4) were stable nearly placed to the origin. G1 (susceptible check) was interactive genotype with unstable performance across testing environment. The E3 (Adigolo, 2011) and E4 (Adigolo, 2012) were unfavorable environments while, E1 (Awliegara, 2011), E2 (Awliegara, 2012), E5 (Kolatsihidi, 2011) and E6 (Kolatsihidi, 2012) were favorable testing environments (Figure 1).

AMMMI analysis *Orobanche* count

The additive main effect of the AMMI analysis of variance revealed that genotype by environment interaction and environment were significant at level ($P \leq 0.01$) where as the genotype was significant at level ($P \leq 0.05$). The significance effect of the genotypes indicated that the

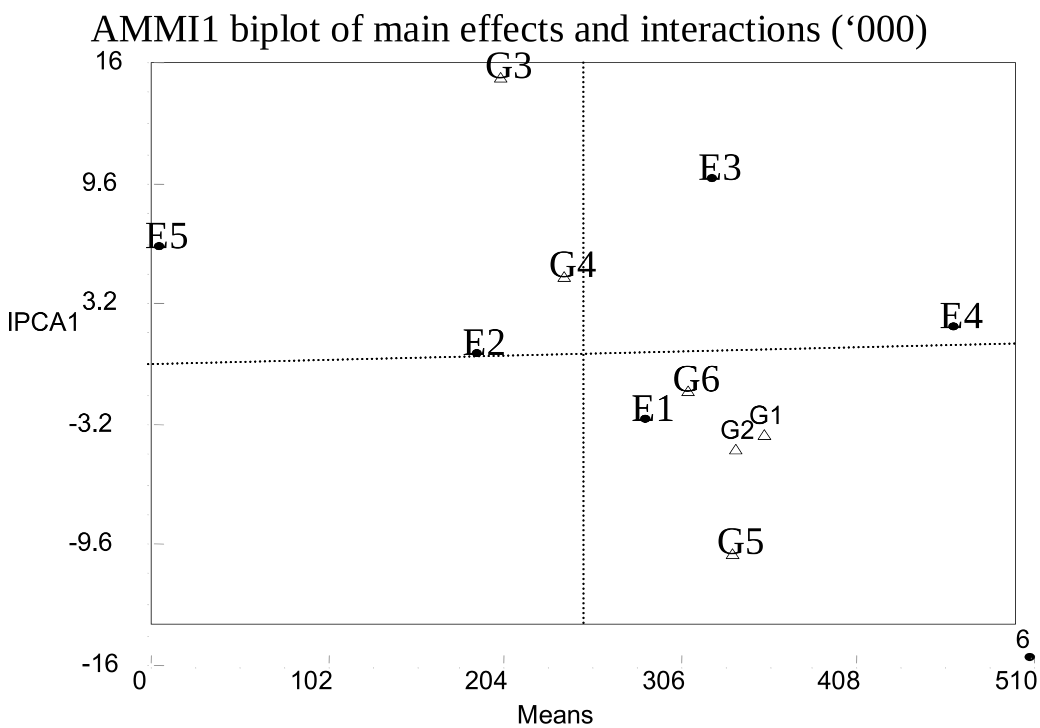

Figure 2. AMMI biplot for Orobanche count of six faba bean genotypes in six environments. The genotypes abbreviated as G1, G2… and environment abbreviated as E1, E2,…G1 (ILB 1814 or susceptible check), G2 (Sel.F5/3053/2003-3), G3 (ILB 4358), G4 (Sel.F5/3382/2003-4), G5 (local check) and G6 (Sel.F5/3085/2003-4) E1 = Awliegara, 2011, E2 = Awliegara, 2012, E3 = Adigolo, 2011, E4 = Adigolo, 2012, E5 = Kolatsihidi, 2011 and E6 = Kolatsihidi, 2012.

differential of the genotypes in tolerating the Orobanche infestation (Table 3). The multiplicative effect of the AMMI analysis was further classified into interaction principal components and the first interaction principal component (IPCA1) explained 84.79% and the second interaction principal component (IPCA2) was 13.54%. Grossly they explained 98.33 of the genotype by environment data. The F-test showed that only the first interaction principal component (IPCA1) was significant (Table 3).

AMMI 1 biplot Orobanche count

The two genotypes; G3 (ILB 4358) and G4 (Sel.F5/3382/2003-4) had lower number of Orobanche count located to the left of the perpendicular line. The two environments; E2 (Awliegara, 2012) and E5 (Kolatsihidi, 2011) were with lower *Orobanche* count (Figure 2).

Polygon view of the GGE biplot analysis

The four genotypes; G1 (susceptible check), G3 (ILB 4358), G5 (local check) and G2 ((Sel.F5/3053/2003-3),) were located on the vertices of the polygon performed either the best or the poorest in one or more environments (Figure 3). The genotype G3 (ILB 4358) was the best adapted in all testing environments. The remaining vertex genotypes were not adapted to specific environment.

Evaluation of genotypes based on ideal environment

The genotype G3 (ILB 4358) was located in the first concentric circle and with short vector length as a result it was an ideal genotype with the highest yield and stable in performance in all environments. The two genotype; G1 (susceptible check) and G5 (local check) were undesirable genotypes according to distant from the first concentric circle and the lowest yield located under the grand mean level (Figure 4).

DISCUSSION

The AMMI analysis for grain yield indicated that the percentage explained by the genotypes was similar with that of the environment and this implying that the faba bean genotypes had differences in tolerance to Orobanche.

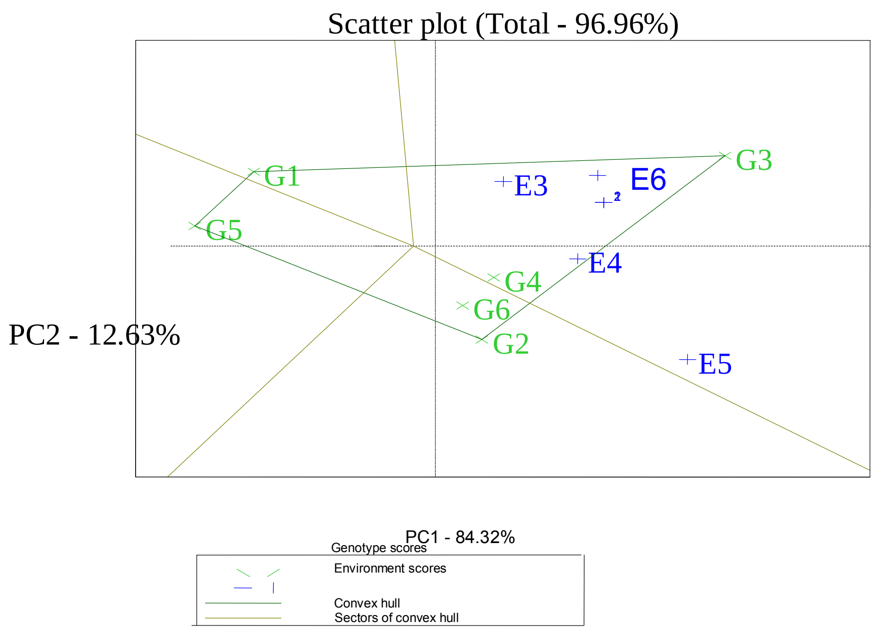

Figure 3. Polygon view of the GGE biplot of six faba bean genotypes across six environments. G = Genotypes and E = environment G1 (ILB 1814 or susceptible check), G2 (Sel.F5/3053/2003-3), G3 (ILB 4358), G4 (Sel.F5/3382/2003-4), G5 (local check) and G6 (Sel.F5/3085/2003-4) E1= Awliegara, 2011, E2 = Awliegara, 2012, E3 = Adigolo, 2011, E4 = Adigolo, 2012, E5 = Kolatsihidi, 2011 and E6 = Kolatsihidi, 2012.

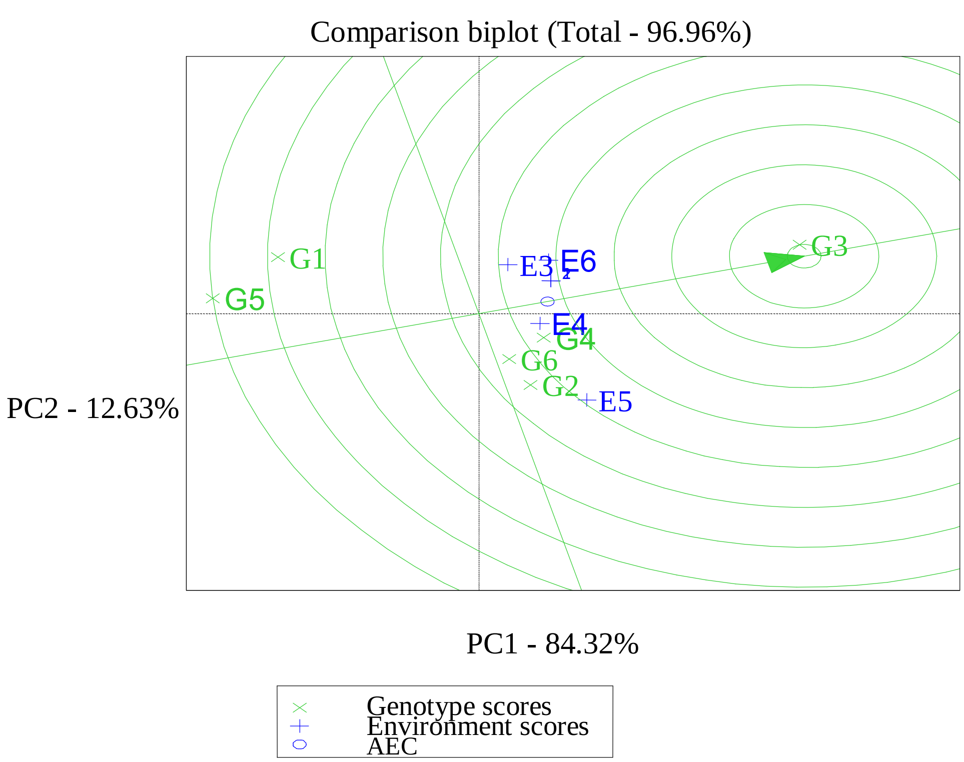

Figure 4. Evaluation based on the ideal genotypes of six genotypes over six environments. G = Genotypes and E = environment, G1 (ILB 1814 or susceptible check), G2 (Sel.F5/3053/2003-3), G3 (ILB 4358), G4 (Sel.F5/3382/2003-4), G5 (local check) and G6 (Sel.F5/3085/2003 4) E1 = Awliegara, 2011, E2 = Awliegara, 2012, E3 = Adigolo, 2011, E4 = Adigolo, 2012, E5 = Kolatsihidi, 2011 and E6 = Kolatsihidi, 2012.

According to Romagosa and Fox (1993), the variation in Orobanche number was mainly attributed to the magnitude of the environment in multi locations yield trials the variation captured by the environment is 70%, genotype 10% and genotype by environment interaction explained 20%. The resistance of these genotypes against *O. crenata* was characterized by several indexes such as low number of parasite attachments per host plant, poor performance or stand of the weed, delay of Orobanche establishment and tolerance/resistance (Rubiales et al., 2006; Maalouf et al., 2011). Orobanche number was taken in this study and be considered as simple and efficient measure of resistance or tolerance to the parasitic weed in different breeding programs in agreement with Cubero and Hernandez (1991) and Maalouf et al. (2011). The genotype ILB 4358 showed greater tolerance to Orobanche and better yield stability than the remaining genotypes followed by the genotype Sel.F5/3382/2003-4, similar results obtained by (Maalouf et al., 2011). The two genotypes (Sel.F5/3053/2003-3) and Sel.F5/3085/2003-4) recorded high infestation level of the parasitic weed but they gave acceptable levels of yield under infested soils. In contrast, the highest level of broomrape infestation was recorded/ possessed on the susceptible check (ILB 1814) and local check with non-acceptable yield (lower yield).

The multiplicative effect of the AMMI model for the response of the two variables grain yield and Orobanche count, the interaction principal components explained that one of them had the most source of variation. The most adequate model for analysis of genotype by environment interaction mainly depend on the type of crop, vegetation cover and the magnitude of genotype by environment interaction but generally the two interaction principal component analysis can identify suitable genotype by reducing systematically noise (Gauch and Zobel, 1988; Yan et al., 2000). Using the AMMI 1 biplot, polygon view of the GGE biplot and comparison of genotypes based on ideal genotype the genotype ILB 4358 was higher yielder and stable with lower Orobanche count than other genotypes. According to the results which obtained by Maalouf et al. (2011) identified that ILB 4358 had potential candidate with higher, stable yield and lower infested by Orobanche. Similarly, genotypes which had combining stability and higher mean grain yield are acceptable over wider range of environment and the most favorable (Annicchiarico, 2007).

The genotype could be used as a bench mark for screening of resistance to parasitic weeds in food legumes breeding programs. Generally using the ideal genotypes as a bench mark for selection can be made and the genotypes which are distant from the ideal genotype can be discarded in the early breeding cycle and the genotype that had great proximity with the ideal genotype can be further evaluated (Yan and Kang, 2002). Generally, the present study revealed that the level of resistance to Orobanche is not very high and stable across all environments (Table 2). Therefore, integrated broomrape management using high yielding potential lines with good levels of tolerance and/or resistance is recommended (Perez-de-Luque et al., 2010).

Conflict of Interest

The authors have not declared any conflict of interest.

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