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Evaluation of Food Barley (*Hordeum vulgare* L.) Varieties at Highlands of Southwestern Part of Ethiopia Using AMMI and GGE Biplot Stability Models

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Abstract: A multi location trial was conducted across the highlands of Southwestern (SW) Ethiopia from 2020 to 2022 during main cropping seasons to evaluate grain yield and yield related traits of food barley varieties across the different locations to identify and recommend high yielding and stable food barley varieties to farmers for large scale planting using AMMI and GGE biplot models. A total of eight food barley varieties were obtained from the Sinana Agricultural Research Center (SARC) for use in this study. Varieties were evaluated in three environments, over three growing seasons. The experiments were conducted at Dedo, Yem and Gechi districts of SW part of Ethiopia during the main cropping seasons. The experiment was laid out in RCBD with three replications. The experimental plot for each variety consisted of six rows of 2.5m length and rows were spaced 20cm apart. Spacing between rows, plots and replications 25cm, 30cm and 1m respectively. Data for all relevant agronomic traits were collected, but only plot yield data converted to t/ha was subjected to statistical analysis. The combined ANOVA showed highly significant differences (P<0.001) among E, G and GEI for grain yield. The environmental variance was more accountable (68.2%) to the total variance as compared to the genetic variance (3.16%) and the interaction variance (19.13%) for grain yield. Dedo 2022 was the highest yielding (4.1 t/ha) while Gechi 2022 was the lowest yielding (1.5 t/ha) environment. The mean grain yield of the varieties across eight environments was 3 t/ha. The GGE biplot identified two barley growing mega-environments. The first mega environment consisted of environments E5, E8, E1 with a vertex genotype T4. E6, E4, E3, E2 and E7 were found in the second mega environment with the winning genotype of T8. It was also noted that no mega-environments fell into sectors where genotype T2 and T7 were the vertex genotypes, did not fit in any of the mega-environments. According to both AMMI and GGE biplot analysis, food barley varieties T3, T7 and T5 were found to be benchmarks/ideal genotypes and could be used as checks to evaluate the performance of other genotypes and also can be recommended for wider cultivation in the highland environments of Southwestern Ethiopia.

Keywords: AMMI, Food Barley Varieties, GGE Biplot, Southwestern, Stability

1. Introduction

Barley is the fourth most important cereal crop in the world after wheat, maize, and rice, and is among the top ten crop plants in the world [1]. Globally, European Union, Russian Federation, Ukraine, Turkey and Canada are the top five largest world barley producers where, European union's produce the greatest quantities of barley with an estimated production of nearly 60 million tons followed by Russian federations with a production of about 20 million tons according to Untied state of Agricultural institute estimate in 2014. On the African continent, Morocco, Ethiopia, Algeria, Tunisia and South Africa were the top five largest barley producers for the year 2014 with estimated production of approximately 2.1 million tones, 1.7 million tones, 1.3 million tones, 0.9 million tones and 0.307 million tons respectively.

Barley is an important grain crop in Ethiopia and has diverse ecologies being grown from 1800 to 3400 m altitude in different seasons and production systems [2] and makes

Ethiopia being the second largest producer in Africa, next to Morocco, accounting for about 25% of the total barley production in the continent [3] and recognized as one of the world's most ancient food crop, which is believed to have first domesticated about 10,000 years ago from its wild relatives in the fertile crescent of the Near East and center of diversity in Ethiopia. In Ethiopia, out of the total area under cereals, barley covered 926,106.9ha with the production and productivity of 23,391,098ha and 25.26qt respectively. At the same time, in terms of the area coverage and production, Oromia regional State contributes 440,702.06ha and 12,319,947.09qt respectively, to the nation with average productivity of 27.96qt [4].

In Oromia regional state, the highlands of Southwestern (SW) Ethiopia, Jimma, Buno bedele and Yem special districts with the area coverage and productivity of barley were 18,203.56, 4659.53 and 1148.2ha and 24.57, 24.72 and 23.6qt respectively [4]. The average productivity (24.3qt) was lower than that of the national average (25.25qt) and potential yield of the crop (6t/ha) [5]. This is due to constraints including lack of high yielding and stable varieties, poor soil fertility, limited supply of production inputs (fertilizer and improved seed) and biotic and abiotic factors.

Recommending a cultivar over wide agro-ecological zones is difficult due to the apparent genotype by environment interaction (GEI). GEI commonly refers to yield variation that cannot be explained by the genotype and the environmental main effects. For cultivar evaluation, however, both G and GEI must be considered simultaneously [6]. Yield stability usually refers to a genotype's ability to perform consistently at high or low yield levels, across a wide range of environments [7]. Several methods have been proposed to estimate the relative stability of performance of genotypes across environments. Multivariate methods include the AMMI (Additive Main Effects and Multiplicative Interaction) model reported by [8] and Genotypic Main Effect plus Genotype by environment (GGE) biplot analysis [9].

GGE biplot was the most effective and commonly used multivariate model for the analysis of stability, adaptability and ranking of genotypes and for selecting suitable mega environments [10]. It is used for mega environment analysis ("Which-Won-Where" pattern), evaluation of genotype (ranking biplot) and environment (comparison biplot), which provides discriminating power and representation of the environments [11]. The additive main effects and multiplicative interaction (AMMI) model is a powerful multivariate method to multi-environmental trial. This technique incorporates both additive and multiplicative components into an integrated, powerful least square analysis [12].

Using more than one stability estimation method helps to obtain most reliable stability parameter(s) because a single method may not adequately explain performance across different environments [13]. Therefore, the objective of the study was to evaluate performance and stability of food barley varieties at the highlands of southwestern part of Ethiopia using GGE biplot and AMMI stability models.

2. Materials and Methods

2.1. Experimental Materials

Eight nationally released food barley varieties were obtained from Sinana Agricultural Research Center (SARC) used for the study (Table 1). The varieties were evaluated in three environments, over three growing seasons, in the highlands of SW Ethiopia. The experiments were conducted at Dedo, Yem and Gechi districts of SW part of Ethiopia during the main cropping seasons (Table 2).

Table 1. *Descriptions of experimental materials used in the study.*

#SN	Variety name	Year of Release	Breeder / Maintainer
1.	Dafo	2005	SARC/OARI
2.	Guta	2007	SARC/OARI
3.	Biftu	2005	SARC/OARI
4.	Abdane	2011	SARC/OARI
5.	HB1307	2006	HARC/EIAR
6.	Harbu	2004	SARC/OARI
7.	Robera	2016	SARC/OARI
8.	Adoshe	2018	SARC/OARI

NB: OARI; Oromia Agricultural Research Institute; SARC: Sinana Agricultural Research Center, HARC: Holetta Agricultural research

2.2. Testing Environments

Table 2. *Description of the Study Sites.*

Stations	Zones / Region	Altitude (m.a.s.l.)	Temp (°C)	Rainfall (mm)	Soil type
Dedo	Jimma	2284	22	1850	Nitosol
Yem special dist.	SNNPR	2470	22.5	1550	Nitosol
Gechi	Buno bedele	2087	20.7	1800	Nitosol

NB: SNNPR=Southern Nation, Nationalities and peoples region

2.3. Experimental Design, Management and Data Collection

The experiment was laid out in randomized complete block design (RCBD) with three replications. The experimental plot for each variety consisted of six rows of 2.5m length and rows were spaced 20cm apart. Spacing between rows, plots and replications 25cm, 30cm and 1m respectively. The seed rate was 125kg/ha. Fertilizer was applied at rate of 100kg NPS and 150kg of urea was applied in spilt: half at the time of planting and the remaining half at the tillering stage. In addition, other relevant field trial management practices were carried out uniformly for all experimental units. Data were taken for days to 50% heading, effective tillers, plant height, disease, days to 90% maturity and grain yield, according to barley descriptors [14] but, only plot yield data converted to t/ha was subjected to statistical analysis.

2.4. Data Analysis

All data were subjected to analysis of variance (ANOVA) using SAS software 9.0. Bartlett's test for homogeneity of variances was carried out to determine the validity of the individual experiment and thereafter, combined analysis of variance was performed using PROC GLM. GGE biplot analysis was conducted on the mean best linear unbiased estimate (BLUE) values of eight food barley varieties in the respective locations using GenStat 18 [15]. Statistical analysis was performed by statistical packages of Genstat 18th version using VSN [2015] and GEA-R [16] Genotype by environment interaction with R-software). The GGE biplot model was formulated as [17] $Y_{hij} = \mu + E_h + G_i + GE_{hi} + B_{j(h)} + e_{hij}$, where μ is the population mean, E_h is the environmental effect, G_i is the genotypic effect, GE_{hi} is the genotype × environment effect, $B_{j(h)}$ is the block effect, and e_{hij} is the random error. AMMI analysis was done by using Genstat version 16th software, according to the model suggested by [18]. AMMI statistical model equation is: $\bar{Y}_{ijk} = \mu + G_i + E_j + \Sigma m\ k=1\ \lambda k\alpha ik\gamma jk + Y_{ij}$ Where: $\bar{Y}_{ijk}$. = The yield of the ith genotype in the jth environment, $_I$ = The mean of the ith genotype minus the grand mean, E_j = The mean of the jth environment minus the grand mean, λ_k = The square root of the eigen value of the kth IPCA axis, αik and γjk = The principal component scores for IPCA axis k of the ith genotypes and the jth environment.

3. Result and Discussion

The analysis of variance (ANOVA) revealed that there was a highly significant difference ($p<0.001$) among grain yield across testing environments indicating that there is a possibility to select good performing food barley variety/ies (Table 3). The mean grain yield of food barley varieties ranged from 3.21t/ha (HB1307) to 2.8t/ha (Dafo) with mean grain yield of 3t/ha (Table 3). The performance of food barley varieties at Southwestern part of Ethiopia was higher than that of national average (2.55t/ha) even in the presence of different biotic and abiotic factors. This show the highlands of Southwestern part of Ethiopia was appropriate site to conduct different trials and to identify stress tolerant genotypes.

Table 3. *Mean grain yield (t/ha) of tested food barley varieties across different locations during 2020 to 22 main cropping seasons.*

Food barley varieties	Locations and Years								Mean	Rank
	Dedo 2020	Gechi 2020	Dedo 2021	Gechi 2021	Yem 2021	Dedo 2022	Gechi 2022	Yem 2022		
Dafo	3.7	1.9	3.5	2.4	2.2	3.7	1.8	3.0	2.8	8
Guta	4.6	2.3	3.1	2.8	2.3	3.0	1.5	2.8	2.81	7
Biftu	3.9	2.1	3.3	2.9	3.6	4.6	1.6	3.5	3.19	2
Abdane	4.7	1.9	4.1	2.4	4.1	3.2	1.3	3.3	3.13	4
HB1307	3.7	2.3	3.7	3.1	3.1	4.8	1.5	3.5	3.21	1
Harbu	3.6	2.2	3.4	3.2	2.2	4.0	1.8	3.3	2.96	5
Robera	3.7	2.1	3.4	3.1	4.1	4.5	1.3	3.2	3.18	3
Adoshe	3.4	2.0	4.1	3.0	2.2	5.3	1.3	2.4	2.96	6
Mean	3.9	2.1	3.6	2.9	3.0	4.1	1.5	3.1	3	
F test	**	*	***	***	***	***	**	***		
LSD at (5%)	0.62	0.3	0.3212	0.3	0.65	0.5	0.3	0.30		
CV (%)	9.02	7.4	5.1	5.9	12.5	7.5	11.3	5.38		

NB: Significant at * = 0.05, ** =0.01 and *** = 0.001 probability level, CV =coefficient of variation

Food barley varieties showed different performance across different locations. For example, the popular variety Abdane, was ranked first at Dedo 2020 location but, eighth at Gechi 2020 (Table 3). This rank change of the same genotype over different environments for the same trait is the consequence of the highly significant GEI. Food barley variety, Abdane, ranked first at high yielding environment Dedo 2020 with mean grain yield of 3.7t/ha, and second at Dedo 2021 with mean grain yield of 4.1t/ha and seventh at Dedo 2022 with mean grain yield 3.2t/ha. This indicates that three years data showed the different response at the same location and the presence of high seasonal variation within the same location and the need to consider both seasons and locations for multi-environment trial (MET) analysis of barley varieties for different traits. The observed mean grain yield ranged from 1.5t/ha (Gechi2022) to 4.1 t/ha (Dedo2022). Barley varieties were performed best at Dedo location and low at Gechi hence, location Dedo was potential and Gechi was stressful environment for barley production.

3.1. Combined Analysis of Variance (ANOVA) of Grain Yield

According to the results, the combined ANOVA over environments for grain yield was highly significant ($p<0.001$) for genotypes, environments and interaction effects (Table 4). The effect of environment, genotypes and GEI accounted for 68.26%, 3.162% and 19.13% of the total sum squares (Table 4), respectively. A large sum of squares for environments indicated that the test environments were diverse with large differences among environmental means which causing most of the variation in grain yield. Therefore; this result designated the reliability of the multi-environment experiments. The variation in temperature, rainfall, soil type, soil fertility and moisture availability might be the main reasons for the presence of variation.

Table 4. *Sum squares, mean squares and percent of variance explained by different sources of variation from the ANOVA of grain yield of eight food barley varieties tested at eight locations.*

Source of variation	Df	Sum squares	Mean squares	Explained Variance (%)
Genotypes	7	6.2064161	0.8866309***	3.162
Locations	7	133.9886078	19.1412297**	68.28
Rep/location	16	4.4908667	0.2806792^{ns}	2.28
GEI	49	37.5440797	0.7662057**	19.13
Error	112	13.9948667	0.1249542	7.12

Significant at * =0.05, **=0.01 and *** = 0.001 probability level, ns = not significant; GEI=genotype by environment interaction

3.2. Additive Main Effects and Multiplicative Interaction (AMMI) Bi-plot Analysis

AMMI model analysis of variance for grain yield is presented in Table 5. This analysis revealed presence of highly significant ($P< 0.001$) differences among food barley varieties for grain yield performance. From the total treatment sum of squares, the largest portion was due to environments main effect (75.4%) followed by GEI was 21.12% and genotype main effect was 3.49%. A large yield variation explained by environments indicated that the existence of both spatial and temporal diversity in test-environments, with large differences among environmental means causing most of variation in grain yield (Table 5). In line with this result, [19] reported large yield variation of bread wheat genotypes due to environments. This also indicates the existence of a considerable amount of deferential response among the evaluated food barley varieties to changes in growing environments and the differential discriminating ability of the test environments. The higher percentage of GEI was explained by IPCA-1 (52.1%); followed by IPCA-2 (30.7%). [20, 21] suggested the most accurate model for AMMI could be predicted by using the first two PCA (Table 5).

Table 5. *Pooled analysis of variance for grain yield (t/ha) per plot of eight food barley varieties across different environments using AMMI model.*

Source of variation	df	Mean squares variation	% Explained
Genotype	7	0.88663***	3.5
Environment	7	19.14*	75.4
GE interaction	49	0.77**	21.1
IPCA1	13	1.50	52.1
IPCA2	11	1.05	30.7
IPCA3	9	0.43	10.2
Pooled error	128	0.14	-

NB: Significant at * = 0.05, ** =0.01 and *** = 0.001 probability level

AMMI biplot graph with X-axis plotting IPCA1 and Y-axis plotting IPCA2 scores illustrate stability and adaptability of food barley varieties to tested environments (Figure 1). The more the IPCA scores approaches to zero, the more stable or adapted the genotypes is overall the test environments. (Figure 1). Considering the IPCA1 score, food barley varieties Guta, Adoshe and Abdane were the most unstable varieties and Biftu, HB1307 and Dafo were more stable in comparison to other varieties.

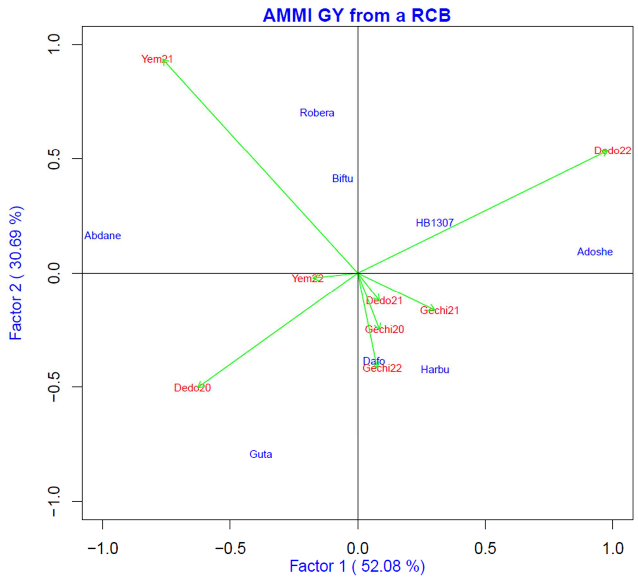

Figure 1. *Biplot of interaction principal component axis (IPCA1) against interaction principal component axis (IPCA2) food barley varieties evaluated across eight environments of southwestern Ethiopia.*

3.3. Genotype Main Effect and Genotype by Environment (GGE) Bi-plot Analysis

3.3.1. Which-Won-Where/What Polygon View of GGE Bi-plot

GGE biplot is visualized on the basis of results explained for the first two principal components [22]. In the present study, the first two principal components of GGE biplot explained 83.06% (PC1=44.91% and PC2=38.15%) of the total variations (Figure 2). The polygon view of GGE biplot showed the interaction patterns between genotypes and environments and visualized the best performing genotypes. In this GGE biplot, a polygon was drawn by joining the vertex genotypes, which were placed far from the origin and hence, all the other genotypes were enclosed within the polygon. Vertex genotypes were T2, T4, T7 and T8. The term mega environment analysis defines the partitioning of a crop growing region into different target zones [6]. The GGE biplot identified two barley growing mega-environments. The first mega environment consisted of environments E5, E8, E1 with a vertex genotype T4. E6, E4, E3, E2 and E7 were found in the second mega environment with the winning genotype of T8. It was also noted that no mega-environments fell into sectors where genotypes T2 and T7 were the vertex genotypes, did not fit in any of the mega-environments.

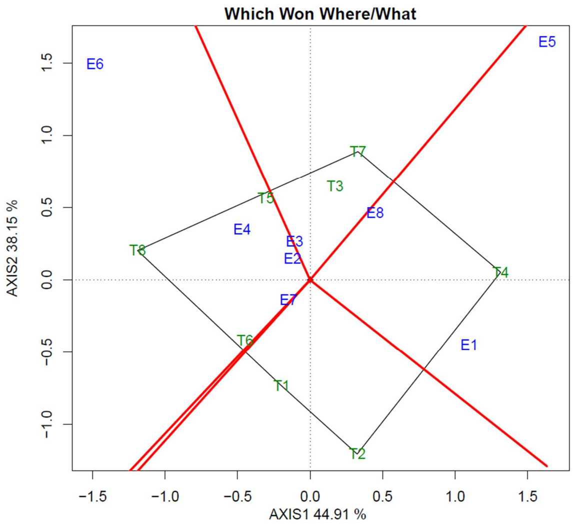

Figure 2. The polygon view of GGE biplot to the identification of winning genotypes and their related Mega environments: Where, E1=Dedo 2020, E2= Gechi 2020, E3= Dedo 2021, E4= Gechi 2021, E5= Yem 2021, E6= Dedo 2022, E7= Gechi 2022 and E8= Yem 2022 and T1= Dafo, T2= Guta, T3= Biftu, T4= Abdane, T5= HB1307, T6= Harbu, T7= Robera and T8= Adoshe.

3.3.2. Ranking of Genotype Bi-plot

An ideal genotype is expected to have the highest mean grain yield performance and stability in performance across environments [23]. Though such an ideal genotype may not exist in reality, it can be regarded as a reference for genotype evaluation [24]. The ideal genotype is located in the first concentric circle in the biplot. Genotypes found closer to the ideal genotypes are desirable genotypes and those found far from the ideal genotype are considered as undesirable genotypes. Thus, the ideal genotype can be used as a benchmark for selection. Genotypes that are far away from the ideal genotype can be rejected in early breeding cycles, while genotypes that are close to it can be considered in further tests [22]. Accordingly, genotypes placed near to the first concentric circle, T7 and T3 were found to be benchmarks for evaluation of food barley varieties (Figure 3). The food barley variety T5 which was located near to ideal genotype and considered as desirable. Undesirable genotypes were those distantly located from the first concentric circle, namely, T1, T2, T4, T6 and T8.

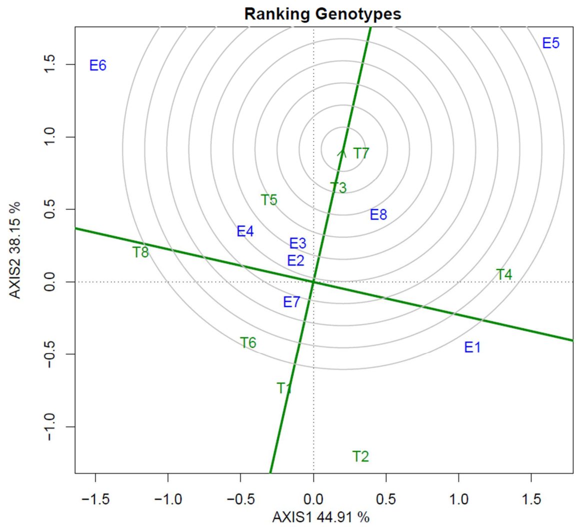

Figure 3. GGE biplot of ideal genotypes and comparison of the genotypes with respect to the ideal genotype: Where, E1=Dedo 2020, E2= Gechi 2020, E3= Dedo 2021, E4= Gechi 2021, E5= Yem 2021, E6= Dedo 2022, E7= Gechi 2022 and E8= Yem 2022 and T1= Dafo, T2= Guta, T3= Biftu, T4= Abdane, T5= HB1307, T6= Harbu, T7= Robera and T8= Adoshe.

3.3.3. Ranking of Environment Bi-plot

In figure 4, the ideal environment is located in the first concentric circle in the environment focused biplot, and desirable environments are close to the ideal environment. Nearest to the first concentric circle, environment E8, followed by E3 was close to the ideal environment. According to [25], discriminating ability and representativeness are important properties of a test location. An ideal location should be highly differentiating (discriminating) for the tested genotypes and at the same time be representative of the target locations [11]. The ideal environment is representative and has the highest discriminating power [11].

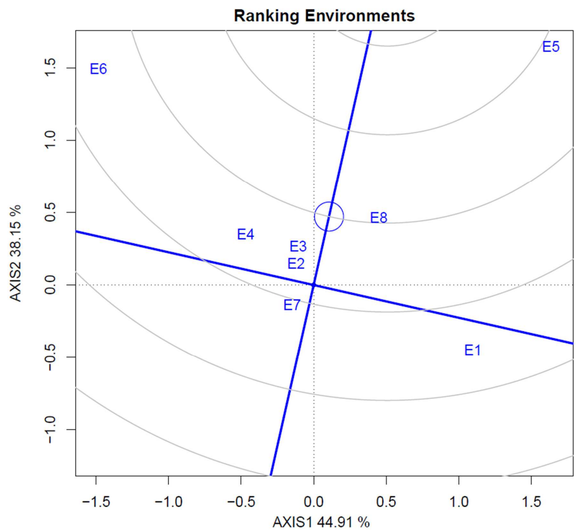

Figure 4. GGE biplot of ideal environments and comparison of the environments with respect to the ideal environment: E1=Dedo 2020, E2= Gechi 2020, E3= Dedo 2021, E4= Gechi 2021, E5= Yem 2021, E6= Dedo 2022, E7= Gechi 2022 and E8= Yem 2022.

3.3.4. Mean and Stability

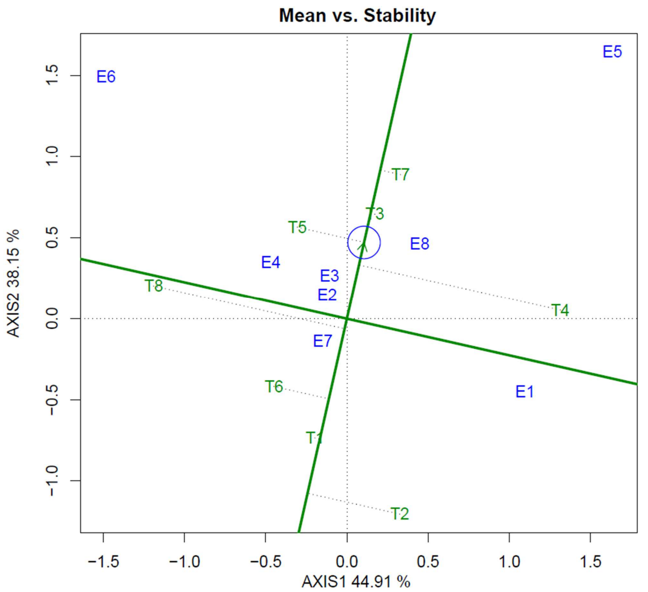

Figure 5. *GGE biplot visualization of the genotypes ranking for both yield and stability performance over environments. Where, E1=Dedo 2020, E2= Gechi 2020, E3= Dedo 2021, E4= Gechi 2021, E5= Yem 2021, E6= Dedo 2022, E7= Gechi 2022 and E8= Yem 2022 and T1= Dafo, T2= Guta, T3= Biftu, T4= Abdane, T5= HB1307, T6= Harbu, T7= Robera and T8= Adoshe.*

The mean vs. stability biplot shown in figure 5, aimed to rank the tested genotypes based on the yield mean performance and stability. As shown in figure 5, T3 ranked first as the most stable genotype, followed by T7 and T5 and had grain yield above overall mean. On the contrary, T1, T2, T6 and T8 had lower yield mean than the overall mean performance. A longer projection to the average environment coordinate (AEC), regardless of the direction, represents a greater tendency of the GEI of a genotype, which means it is more variable and less stable across environments and vice-versa. Barley varieties T1, T3 and T7 were showed less GEI and stable. The variety T8 was the least stable with low yield and had a large contribution to the GEI; it had the longest distance from the average environment. The variety T4 was high yielder but least stable because its contribution for GEI interaction as very large.

4. Conclusion and Recommendation

The study revealed highly significant differences (P<0.001) among E, G and GEI for grain yield. The environmental variance was more accountable (68.2%) to the total variance as compared to the genetic variance (3.16%) and the interaction variance (19.13%) for grain yield. Dedo 2022 was the highest yielding (4.1 t/ha) while Gechi 2022 was the lowest yielding (1.5 t/ha) environment. The mean grain yield of the varieties across eight environments was 3 t/ha. The GGE biplot identified two barley growing mega-environments. The first mega environment consisted of environments E5, E8, E1 with a vertex genotype T4. E6, E4, E3, E2 and E7 were found in the second mega environment with the winning genotype of T8. It was also noted that no mega-environments fell into sectors where genotype T2 and T7 were the vertex genotypes, did not fit in any of the mega-environments. According to both AMMI and GGE biplot analysis, food barley varieties T3, T7 and T5 were found to be benchmarks/ideal genotypes and could be used as checks to evaluate the performance of other genotypes and also can be recommended for wider cultivation in the highland environments of Southwestern Ethiopia.

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Conflicts of Interest

The author has not declared any conflict of interests.

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