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Genotype x Environment Interaction and Stability Analysis of Some Selected Field Pea (*Pisum sativum* L.) Varieties in Northern Part of South Regional State, Ethiopia

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Abstract: Field pea (*Pisum sativum* L.) is one of the major legumes grown in Ethiopia as well as in Southern Ethiopia. Field experiment was conducted with eight field pea genotypes for two consecutive years (2017 - 2018) comprising six environments in order to determine the effect of genotype x environment (GxE) interaction and to identify specific and wider adaptability. The objective of this study was to identify and select high performing varieties with better adaptability. The experiment was laid out in a randomized complete block design with four replications in each environment. Grain yield data was analyzed using analysis of variance and AMMI models. The combined analysis of variance of grain yield showed a highly significant differences ($P<0.001$) for environments, varieties and GxE interactions. The significant differences for the GxE interaction indicated the necessity of analyzing the stability of the varieties across the environments in order to select stable ones. The lowest mean grain yield of all varieties was obtained in E2 (Yem 2018) whereas the highest was obtained in E3 (Geta 2018). The average grain yield of the varieties ranged from 4571.0 kg/ha for G6 (Bukitu) to 4143.6 kg/ha for G4 (Gume). The AMMI analysis revealed that differences between the environments accounted for about 80.61% of the treatment sum of squares while the varieties and the GxE interaction accounted for 3.99% and 15.40%, respectively. The mean squares were significant at $P \leq 0.001$ for PCA 1 and at $P \leq 0.05$ for PCA2 cumulatively contributing for 79.39% of the total GxE interaction sum of squares, indicating that most the information could be generated from the two axes. The AMMI analysis, AMMI stability value (ASV) and yield stability index (YSI) identified G5 (Bilalo), G7 (Adi) and G6 (Burkitu) as the most stable varieties with higher yields. AMMI biplots indicated that E2 (Yem2) with its lowest grain yield was identified as stable environment and E6 (Azernet2) as relatively stable with its yield higher than the grand mean. Therefore, the three stable and high yielding varieties (Bilalo, Adi and Burkit) can be recommended for the study areas and similar agro-eologies of the Southern Region. Varieties with grain yield higher than the grand mean such as G2 (Bursa) with an environment E1 (Yem1) as well as G6 (Burkitu) with environments E3 (Geta2) and E6 (Azernet2) showed specific adaptation.

Keywords: Field Pea, Additive Main Effect and Multiplicative Interaction (AMMI), Yield Stability Index, Interaction Principal Component Axes (IPCA)

1. Introduction

Field pea is one of the major legumes grown in Ethiopia as well as in South Nations, Nationalities and Peoples Region (SNNPR). It is used as a protein source for home consumption as well as for income generation of the poor farmers. It is widely used for food because of its highest protein contents. Since it is a legume crop, its residues increase soil fertility so that it used as a rotation crop with cereals. The crop is grown in highlands and semi-highland areas of the country with altitude ranging from 1800-3000 masl.

The Central Statistical Agency indicated that in South Region, during 2017/18 *Meher* cropping season, about

426,500 private peasant holdings covered 49662.53ha of land with field pea from which 7624.6 tones were produced showing that the productivity of 1535 kg/ha [1]. Hence, in addition to developing new varieties, evaluating the adaptability of released field pea varieties and selecting high yielding varieties with better tolerance/resistance to biotic and abiotic stresses is very crucial.

According to Romagosa and Fox [2], Kaya *et al.,* [3], Nassir and Ariyo [4] and Ersullo [5]; AMMI model provides a hybrid analysis that incorporates both the additive and multiplicative components of the two-way data structure and is powerful in revealing a scale for principal component analysis (PCA) scores which allows estimation of specific GxE interaction terms. AMMI clarifies the G ×E interaction and it summarizes patterns and relationships of genotypes and environments [6, 7]. However, the AMMI model has a good chance of being able to predict for new sites and new years. Gauch and Zobel [8] showed that AMMI1 with IPCA1 and AMMI2 with IPCA1 and IPCA2 are usually selected and the graphical representation of axes, either as IPCA1 or IPCA2 against main effects or IPCA1 against IPCA2 is generally informative. The AMMI analysis for the IPCA1 captured 46.1% and the IPCA2 explained 28.6%. When it goes beyond IPCA2 the degree of prediction percentage decreases.

Despite their importance, the production and productivity of highland pulses including field pea is far below the potentials due to several factors [9]. A number of improved varieties of highland pulses have been released for the last two to three decades, totally 224 pulse crops varieties and 40 varieties of field pea released [10]. However, these varieties were not evaluated and selected for adaptability especially in the northern part of the South Region.

Therefore, evaluation of different varieties to select best performing variety/ies with their wider as well as specific adaptability using AMMI method was proposed to fill the gap.

Objective: To identify and select high performing varieties with better adaptability and other agronomic characters.

2. Materials and Methods

2.1. Description of Test Varieties and Environments

Seven field pea varieties viz. G1 (Megeri), G2 (Bursa), G3 (Tegegnech), G4 (Gume), G5 (Bilalo), G6 Burkitu) and G7 (Adi) that were received from Holeta Agricultural Research Center and one farmers' cultivar G8 (Fc) were evaluated at six environments of northern part of SNNPRS (Table 1). The environments were E1 (Yem 2017), E2 (Yem 2018), E3 (Geta 2018), E4 (Endegagn 2018), E5 (Azernet 2017) and E6 (Azernet 2018).

The trial was conducted under rain-fed condition for two consecutive years (2017 - 2018) at two districts (Azernet and Yem Special Woreda) and for one year at two districts (Geta and Endegagn) totally six environments (Table 2). Fetien and Bjornstad [11], Sabaghnia *et al* [12], Fiseha Baraki *et al* [13] and Ersullo [5]; also studied GE interaction of food barley, durum wheat, sesame and field pea varieties respectively, using additional locations after the first season. In each environment, a Randomized Complete Block Design (RCBD) with three replications was used. A plot consisted of 4 rows of a genotype and each row was 4m long comprising a plot size of 3.2 m^2 (0.8 x 4m). The rows were 0.2 m apart whereas from plant-to-plant distance in each row was 0.05 m. All data including grain yield were collected from the whole plot due to overlapping nature of the crop. Fertilizer was applied as basal application during planting in the form of NPS grade 19N-38P_2O_5-0K_2O+7S. The gangways left between plots and blocks were 1.5 and 2m, respectively. Weeds were controlled manually.

Table 1. *Description of the test varieties.*

Varieties	Source	year of release	Breeder/Maintainer
(G1) Megeri	HARC	2006	HARC/EIAR
(G2) Bursa	"	2015	KARC/EIAR
(G3) Tegegnech	"	1993/4	HARC/ EIAR
(G4) Gume	"	2006	HARC/EIAR
(G5) Bilalo	"	2012	KARC/EIAR
(G6) Burkitu	"	2009	HARC/EIAR
(G7) Adi	"	1995/6	HARC/EIAR
(G8) Fc	Farmers' cultivar		

*KARC=Kulumsa Agricultural Research Center, HARC= Holeta Agricultural Research Center and EIAR= Ethiopian Institute of Agricultural Research.

Table 2. *Description of the experimental sites.*

No	Location/environment	Administrative Zone	Altitude (masl)	Average annual RF (mm)	Coordinates	
					Latitude	Longitude
1 2	E1 (Yem 2017) E2 (Yem 2018)	YemSp/District	2300	NA	NA	NA
3 4	E5 (Azernetr 2017) E6 (Azernet 2018)	Siltie zone	2630	NA	7°44'N	37°54'E
5	E3 (Geta 2018)	Guraghe zone	2873	NA	7° 52'N	38°0'E
6	E4 (Endegagn 2018)	Guraghe zone	2550	NA	7°46'N	37°51'E

* masl = meter above sea level, RF = Rainfall, mm = millimeter, NA = Data not available.

2.2. Statistical Analysis

2.2.1. ANOVA

The mean grain yield performances of the genotypes and environments, the significance of mean squares, and mean separation of the grain yield was done using SAS software version 9.0. With the ANOVA model $Y_{ijk}= \mu+ E_j+ B(E)_{k(j)}+ G_i+ GE_{(ij)}+ e_{ijk}$. If ANOVA showed significant differences for environments, genotypes and GxE interactions we can further analysis for AMMI [14]. AMMI uses ANOVA to test the main effects of genotypes and environments and PCA to analyze the residual multiplicative interaction between genotypes and environments. Mean separation was done using the Duncan's Multiple Range Test (DMRT).

2.2.2. Additive Main Effects and Multiplicative Interaction (AMMI) Analysis

AMMI analysis was conducted using GenStat 18th edition. AMMI combines additive components in a single model for the main effects of genotypes and environments, as well as multiplicative components for the interaction effect [6, 8]. Analysis of variance was used to partition variance into three components: genotypic, environmental and GxE interaction deviations from the grand mean. Multiplication effect analysis was used to partition GxE interaction deviations into different interaction principal component axes (IPCA), which can be tested for statistical significance through ANOVA [15]. The AMMI model was employed to investigate the grain yield response of the genotypes to different environments.

The AMMI model equation following Zobel *et al* [6] is:

$$Yij = \mu + Gi + Ej + n \Sigma \lambda k\ \alpha ik\gamma jk + \epsilon ij$$

Where, Yij is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; Gi and Ej are the genotype and the environment deviations respectively, from the grand mean; λk is the eigenvalue of the PCA axis k; αik and γjk are the genotype and environment principal component scores for axis k; n is the number of PCA axes considered and Єij is the residual term which includes the experimental error.

2.2.3. AMMI Stability Value (ASV)

The AMMI model does not make provision for a quantitative stability measure, such a measure is essential in order to quantify and rank genotypes according to their yield stability, the ASV measure was proposed by Purchase *et al* [16] to cope with this problem.

The AMMI stability value (ASV) as described by Purchase [16] was calculated as follows:

$$\text{ASV} = \sqrt{\left[\frac{IPCA1sum\ of squares}{IPCA2sum\ of squares}(IPCA1\text{score})\right]^2 + (IPCA2\text{score})^2}$$

Where; IPCA1sum of square /IPCA2 sum of square was the weight given to the interaction principal component axes (IPCA) value by dividing the IPCA1 sum of square by the IPCA2 sum of squares.

The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments, whereas smaller ASV scores indicate a more stable genotype across environments [14].

2.2.4. Yield Stability Index (YSI) and Rank of Yield (RY)

Stability by itself can't be the only parameter for selection, because the most stable genotypes would not necessarily give the best yield performance Mohammadi *et al* [17]; hence there is a need for approaches that incorporate both mean yield and stability in a single index. Therefore, Farshadfar *et al* [14] calculated YSI and RY by the following formula:

$$YSI = RASV + RY$$

where RASV is the rank of AMMI stability value and RY is the rank of mean grain yield of varieties across environments. YSI incorporate both mean yield and stability in a single criterion. Low value of this parameter shows desirable varieties with high mean grain yield and stability.

3. Results and Discussion

3.1. ANOVA and Mean Performance of the Varieties

When comparing the mean of grain yield from environments, overall mean grain yield of the genotypes across environments ranged from the lowest mean yield (3077.09 kg/ha) that obtained in E2 (Yem 2018) to the highest (6136.63kg/ha) was obtained in E3 (Geta 2018); 4143.6 kg/ha for G4 (Gume) and 4571.0 kg/ha for G6 (Bukitu) (Table 3).

AMMI analysis of variance of grain yield Table 4 showed highly significant differences ($P<0.001$) for environments, genotypes and GxE interactions indicating the effect of environments in the GxE interaction, genetic variability among the genotypes and possibility of selection for stable genotypes [14]. The significant GxE interactions suggest that grain yield of genotypes varied across the test environments.

As GxE interaction was significant, we can further proceed and estimate phenotypic stability of the yield of the test genotypes [5, 14, 18].

3.2. AMMI Analysis

In this study, mean grain yield, IPCA 1 and IPCA 2 scores, AMMI stability values (ASV) and YSI with their ranking orders of the eight field pea varieties tested at six environments are presented in Table 5. The mean squares were highly significant for varieties, environments and GxE interaction for grain yield at the significance level of ($P\leq 0.001$) with the contribution of 3.99% (genotypes), 80.61% (environments) and 15.40% (GxE interaction) of the treatment sum of squares.

The large environmental sum of squares (80.61%) indicated that environments were diverse, with large differences among environmental means causing most of the variation in grain yield. The GxE interaction sum of squares was almost four times higher than that of the genotypic effect, suggesting the possible existence of different environment groups [19] and the importance of the GxE interaction. Consequently, the results of AMMI analysis indicated that IPCA1 score was found to be highly significant at P≤ 0.001 explaining 60.97 and IPCA2 was also at P≤ 0.05 significant level explaining 18.42% GxE interaction sum of squares (Table 4). Therefore, since the magnitudes of the first two PCAs are high, which accounted for a total of 79.39% of the interaction variation, the first two PCAs can be suffice to predict the GxE interaction effects. Zobel *et al* [6], Gauch and Zobel [8], Yan and Rajcan [20] and Sabaghnia *et al* [12]; were suggested that the most accurate model for AMMI can be predicted by using the first two PCAs, if the magnitude of the first two IPCAs is high. Thus the interaction of this study was best predicted by the first two principal components of GE interaction.

3.2.1. AMMI 1 Biplots Analysis

The AMMI model I biplot of the grain yield of the eight field pea varieties evaluated in six environments is demonstrated in Figure 1. The AMMI model 1 is generated from main effects of varieties and environments as well as the IPCA1 scores. The abscissa shows the main effects and the ordinate shows the IPCA 1 scores that captures interaction effects. Genotypes and environments with IPCA 1 scores tending towards zero, have small interaction effects and considered stable, while genotypes with large IPCA 1 scores, either positive or negative direction were highly interactive [7, 15]. When a genotype and environment have the same sign on the IPCA axis, their interaction is positive and if different, their interaction is negative [5, 21, 22]. In the present study, the first AMMI biplot (Figure 1) accounted for 60.97% of the GE interaction sum of squares. The remaining multiplicative interaction principal component which is included in this biplot analysis i.e., IPCA2 and the residuals accounted only for 39.03% of the GxE interaction sum of squares (Table 4). The top 4 high yielding varieties that recorded above the grand mean were G6, G7, G2 and G5 among which the first two with positive IPCA-I scores 21.56 and 4.31, respectively were located in quadrant I whereas the latter two with negative scores -23.99 and -0.54 in their respective orders were located in quadrant IV.

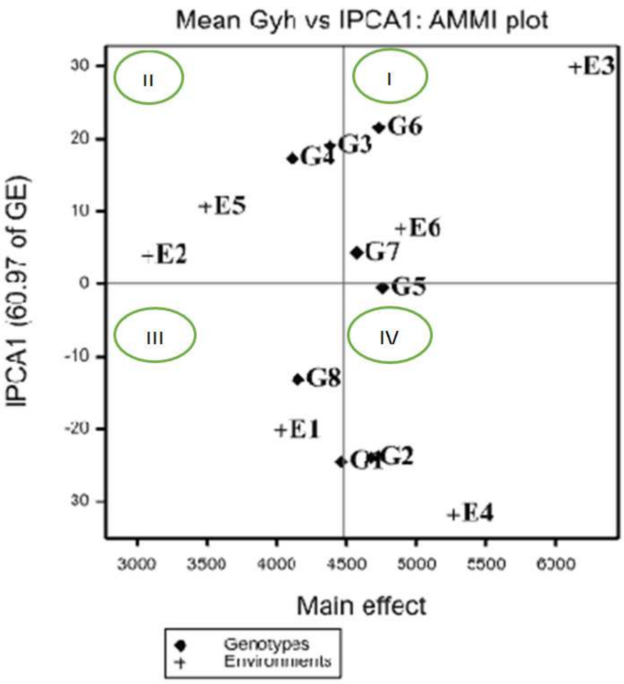

Figure 1. *AMMI model I biplot of the grain yield of eight field pea varieties evaluated in six environments.*

Where for environments E1= Yem1, E2= Yem2, E3= Geta2, E4=Endegagn2, E5= Azernet1, E6=Azernet2, and
For genotypes G1= Megeri, G2=Bursa, G3= Tegegnech, G4=Gume, G5= Bilalo, G6= Burkitu, G7= Adi, G8= Fc

Table 3. *Combined means of Grain yield kg/ha performances of eight field pea varieties at six environments.*

Gen/Env		E1 (Yem1)	E2 (Yem2)	E3 (Geta2)	E4 (End2)	E5 (Azer1)	E6 (Aze2)	Geno Mean	rk
G1 (Megeri)		4422.1ab	2954.2ab	5698.2b	6224.2a	2640.5d	4849.0a	4464.7ab	5
G2 (Bursa)		4775.2a	3071.1ab	5673.2b	6279.4a	4117.7a	4164.2a	4704.6a	3
G3 (Tegegnch)		3236.8b	3238.8a	6453.3ab	4704.6bc	3945.0ab	4711.7a	4400.7ab	6
G4 (Gume)		3801.8ab	2791.1b	6154.0b	3937.4c	3417.7bc	4578.0a	4143.6b	8
G5 (Bilalo)		4520.6a	3155.1ab	6564.7ab	5501.3ab	3337.9c	5475.5a	4759.2a	2
G6 (Burkitu)		3614.2ab	3314.8a	7272.0a	5127.6b	3774.8abc	5295.8a	4774.9a	1
G7 (Adi)		4046.3ab	3070.3ab	6498.5ab	5295.0b	3522.6bc	4993.5a	4571.0ab	4
G8 (Fc)		3824.9ab	3021.1ab	4779.2c	5082.5b	---	5054.a	4315.6ab	7
Env. Means		4030.25	3077.09	6136.63	5269.00	3490.38	4885.02	---	
Grand mean		---	---	---	---	---	---	4522.51	
Significance of MS	Env	---	---	---	---	---	---	40871509***	
	Rep	2383734*	1817696***	587214ns	1235179*	2577162***	633421ns	595129ns	
	Gen	1054907ns	107912ns	2259073***	2362573***	877467**	709568ns	1384855**	
	G*E	---	---	---	---	---	---	1174738***	
	CV	18.78	7.26	8.96	9.92	9.37	15.98	15.43	

Table 4. *AMMI analysis for grain yield of eight field pea varieties combined at six environments.*

Sources	df	SS	MS	%Trt SS	%GE SS
Treatments	47	265432709	---	---	---
Genotype (G)	7	10583380	1511911**	3.99	---
Environment (E)	5	213965198	42793040***	80.61	---
GEI	34	40884131	1202474***	15.40	---
-IPCA 1	11	24927125	2266102***	---	60.97

Sources	df	SS	MS	%Trt SS	%GE SS
IPCA 2	9	7532123	836903*	---	18.42
Residuals	14	8424884	601777ns	---	20.61
Error	123	41327139	335993	---	---

Where GEI = GxE interaction, ns = non-significant, * = significant at P ≤ 0.05, ** = highly significant at P ≤ 0.01 and *** = very highly significant at P ≤ 0.001 probability level.

The genotypes G5 and G7 had high mean value with low interaction effects. Hence, these two varieties can be considered stable. The remaining two best performing varieties; G6 and G2 with relatively larger absolute IPCA-1 scores were found to have high interaction effect and can be suited only in specific environments. i.e, varieties G6 (Burkitu) to E3 (Geta 2) and G2 (Bursa) to E1 (Yem1) are specifically adapted. Whatever the direction is, the greater the IPCA scores, the more specifically adapted these genotypes are to certain environments [7].

The genotypes G4, G8, G3 and G1 with IPCA1 scores ranging from medium to the highest were located further from zero and sparsely distributed in Quadrants II and III performing below the grand mean in their grain yield. Consequently, these varieties can be considered as unstable in addition to their low yielding performances.

High potential environments with grain yields above the grand mean; E3, E4 and E6 were sparsely distributed in quadrants I and IV among which E6 with minimum interaction effect is considered as relatively suited environment for almost all tested varieties. Environment E2 with the least IPCA1 score (3.89) showing minimum interaction effect was also the least yielding environment. The remaining environments E5 and E1 with grain yields below the grand mean were sparsely distributed in quadrants II and III, respectively.

3.2.2. AMMI 2 Biplot Analysis

AMMI 2 analysis evaluates stability of environments and genotypes when they are located near the origin with low scores for IPCA1 and IPCA2 axes of the interaction [23]. The genotypes and environments that are far away from the origin are more interactive and that fall into the same sector interacts positively. This model was generated using genotypic and environmental scores of the first two AMMI components [15, 24].

In the present study, Figure 2 demonstrates the AMMI-2 biplot, with the IPCA 1 and IPCA 2 for grain yields. Genotype G7 was closer to the biplot origin than any other varieties indicating minimal interaction of the genotype with tested environments and is considered as the most stable and has mean grain yield value higher than the grand mean. The genotypes G5, G4 and G8 that were a little further from the origin may be considered to have medium stability, while those falling further away with the largest interaction scores (that lack stability) were G1, G2 and G6.

As indicated in the biplot, G1 and G2 were the most divergent showing very strong interaction and remained in their most unstable positions. Genotypes those with grain yield higher than the grand mean such as G2 with an environment E1 as well as G6 with environments E3 and E6 indicated specific adaptability and positive interactions. However, genotype G2 had the most negative GxE interaction with environment E3 and E6 whereas genotype G1 had a negative interaction to an environment E5, but specific adaptation to E4.

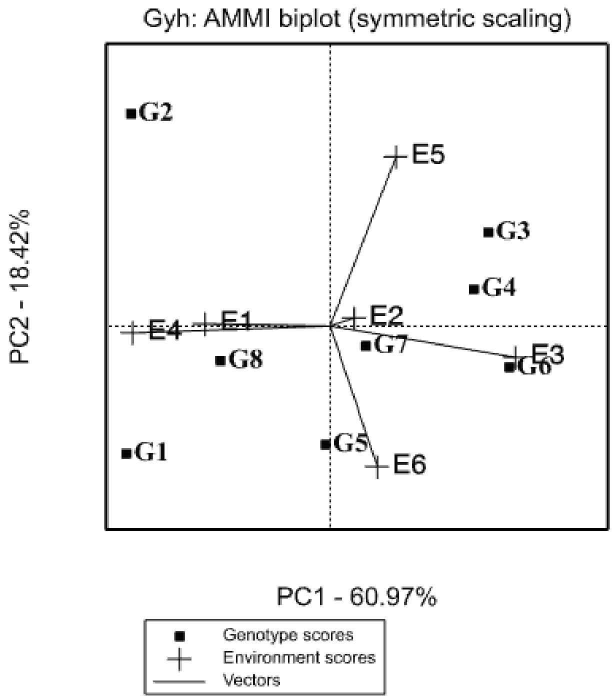

Figure 2. AMMI model 2 biplot of the grain yield of eight field pea varieties were evaluated in 6 environments.

According to this model an environment E2 is considered to have high stability, while E1 and E6 have medium stability and those falling further away from the origin with their largest interaction scores were E4, E5 and E3 and can be considered to have low stability. Consequently, these environments; E4, E5 and E3 were most discriminating as indicated by the longest distance between its marker and the origin, and they were ideal environments to identify the performance of the tested genotypes.

3.2.3. AMMI Stability Value (ASV) and Yield Stability Index (YSI)

The AMMI model does not make provision for a quantitative stability measure, such a measure is essential in order to quantify and rank varieties according to their yield stability. The ASV measure was proposed by Purchase *et al* [16] to cope with this problem. In fact, ASV is the distance from zero in a two dimensional scatter of IPCA1 scores against IPCA2 scores. Since the IPCA1 score contributes more to GE interaction sum of squares, it has to be weighted by the proportional difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 total sum of squares [15]. In ASV method, a genotype with least ASV score is the most stable. As presented in Table 5, in ASV scores G7 (Adi) was ranked first followed by G5 (Bilalo) with G8 (Farmers' cultivar) ranking third while the least ranked and the most unstable genotype was G2 (Bursa).

Table 5. *Mean grain yield, IPCA 1 and 2 scores, AMMI stability values (ASV) and YSI with their ranking orders of eight field pea varieties tested at six environments.*

Varieties		Grain Yield (Kg/ha)		IPCA1	IPCA2	ASV		YSI	
Code	**Varieties**	**Mean**	**Rank**	**score**	**score**	**Value**	**Rank**	**score**	**Rank**
G1	Megeri	4464.7	5	-24.51	15.87	82.65	7	12	7
G2	Bursa	4704.6	3	-23.99	-26.38	83.66	8	11	5
G3	Tegegnech	4400.7	6	19.04	-11.61	64.07	5	11	5
G4	Gume	4143.6	8	17.32	-4.58	57.50	4	12	7
G5	Bilalo	4759.2	2	-0.54	14.73	14.84	2	4	1
G6	Burkitu	4774.9	1	21.56	5.15	71.54	6	7	3
G7	Adi	4571.0	4	4.31	2.49	14.48	1	5	2
G8	Fc	4315.6	7	-13.19	4.33	43.87	3	10	4
Mean		4522.51	---	---	---	---	---	---	---
Environments		---	---	---	---	---	---	---	---
Code	Environment	---	---	---	---	---	---	---	
E1	Yem1	4030.25	4	-20.17	-0.34	---	---	---	---
E2	Yem2	3077.09	6	3.89	-1.29	---	---	---	---
E3	Geta2	6136.63	1	29.86	5.22	---	---	---	---
E4	Endegagn2	5269.00	2	-31.81	1.15	---	---	---	---
E5	Azernet1	3490.38	5	10.62	-28.16	---	---	---	---
E6	Azernet2	4885.02	3	7.60	23.43	---	---	---	---
	Mean	4481.40	---	---	---	---	---	---	---

NB. Fc = farmers' cultivar, IPCA1, 2 = interaction principal component axes 1 and 2, ASV = AMMI stability value, YSI = yield stability index.

Stability *per se* should however not be the only parameter for selection, because the most stable genotype would not necessarily give the best yield performance Mohammadi *et al* [17]; hence there is a need for approaches that incorporate both mean yield and stability in a single index. In this regard, as ASV takes into account both IPCA1 and IPCA2 that justify most of the variation in the GE interaction. Therefore, the rank of ASV and yield mean in such a way that the lowest ASV takes the rank one, while the highest yield mean takes the rank one and then the ranks are summed in a single simultaneous selection index of yield and yield stability named as: Yield Stability Index (YSI). The least YSI is considered as the most stable with high grain yield (Table 5). In this regard, the most stable genotype with high grain yield is G5 (Bilalo) followed by G7 (Adi) and G6 (Burkitu).

4. Recommendations

The three stable and high yielding varieties were (Bilalo, Adi and Burkitu can be recommended for the study areas and similar agro-eologies of the Southern Region. Varieties with grain yield higher than the grand mean such as G2 (Bursa) with an environment E1 (Yem1) as well as G6 (Burkitu) with environments E3 (Geta2) and E6 (Azernet2) showed specific adaptation. Environments; E4 (Endegagn2), E5 (Azernet2) and E3 (Geta2) were ideal environments to investigate the performance of field pea genotypes.

5. Conclusion

Combined analysis of variance of grain yield showed highly significant differences ($P<0.001$) for environments, genotypes and GxE interactions indicating the effect of environments in the GxE interaction, genetic variability among the genotypes and possibility of selection for stable genotypes. Genotypes exceeding the grand mean in their grain yields were G6, G5, G2 and G7 with mean values of (4774.9, 4759.2, 4704.6 and 4571.0 kg/ha), respectively. Based on YSI which incorporate ASV and mean grain yield in a single non-parametric index, G5 (Bilalo), G7 (Adi) and G6 (Burkitu) were identified to be superior.

Genotypes with grain yield higher than the grand mean such as G2 (Bursa) with an environment E1 (Yem1) as well as G6 (Burkitu) with environments E3 (Geta2) and E6 (Azernet2) showed specific adaptability and positive interactions. Environments; E4, E5 and E3 were the most discriminating as indicated by the longest distance between their marker and the origin, and they were ideal environments to investigate the performance of the tested genotypes.

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