Original Research Article||

Adaptability evaluation and stability analysis of faba bean (*Vicia faba L.*) varieties in high altitude areas of southern Ethiopia

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Abstract

The production and productivity of faba bean in Southern Ethiopia are low due to a shortage of improved varieties, agronomic practices, and diseases. An experiment was conducted in eight environments during the 2019 and 2020 main cropping seasons to investigate grain yield performance and identify stable, high-yielding varieties. Fourteen faba bean varieties including a control were grown in a randomized complete block design with four replications. Additive main effects and multiplicative interaction (AMMI) analysis was used to estimate genotype by environment interaction and found to be significant ($p<0.05$) for the environment, varieties and variety by environment interaction. The two principal components (IPCA1 and IPCA2) explained 43.66% and 36.29% of the interaction, respectively. The varieties Tumsa, Dosha and Gora had good performance in mean grain yield over the tested environments with 2876.78, 2801.28 and 2775.48 kg ha^{-1}. Ranking genotypes relative to the ideal genotype is done using the GGE biplot. The Dosha variety was found to be at the center of a concentric circle, with the average environment representing the ideal genotype (stable and high-yielding). Tumsa and Gora were the next most ideal genotypes, located near the ideal environments, indicating wider adaptation. Consequently, these varieties were identified and approved for large-scale production to improve production and productivity.

Key words: AMMI, grain yield, stability, faba bean varieties

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INTRODUCTION

Faba bean (*Vicia faba* L.) is the dominant pulse crop in Ethiopia in terms of area coverage and amount of production (Goa and Kambata, 2017). Even though it is an important crop in Ethiopia, the production and productivity in the Southern region are low, at 2030 kg ha^{-1} (CSA, 2020), due to a shortage of improved varieties, inconsistent agronomic practices, and diseases.

This study involved faba bean varieties to provide valuable information on their adaptation and stability.. Several statistical methods may be used to analyze and interpret the grain yield performance of different genotypes by environment interaction. However, the Additive Main effects and Multiplicative Interaction (AMMI) model is accurate in estimating the yield of genotypes within locations than the unadjusted mean. Besides, AMMI can address both the additive main effects and multiplicative interaction components by employing analysis of variance and Interaction Principal Components (Tadesse et al., 2016).

There are two possible strategies for developing genotypes with low genotype-environment interactions (GEI). The first step is partitioning a heterogeneous area into more homogeneous subregions. However, even with this refinement, the level of interaction remains high due to unpredictable variations (Abo-Hegazy et al., 2013). The second strategy for reducing GEI involves selecting genotypes with better stability across a wider range of environments (Eberhart and Russell, 1966). The stability of yields across environments is critical because growers rely on each year's crop harvest to survive. In countries like Ethiopia where resources allocation to agricultural research activities are limited, it is not feasible to develop specifically adapted varieties for each pocket area. In such case, there is no doubt that the stability of a variety to release is more important than high yield in specific areas.

If there is no interaction, then the best genotype in one environment will be the best in all (Falconer, 1983). The most frequently utilized methods for detecting the stability are partitioning of GEI of evaluated genotypes (Wricke, 1962) and the regression model (Eberhart, 1966). Eberhart (1966) considered regression coefficient (βi) parameter for measuring the varietal phenotypic stability. The variety with a (βi) value not significantly different from unity would be described as a stable variety. The mean CV analysis introduced by Francis and Kannenberg (1978) was designed to aid in studies on the physiological basis of yield stability. They introduced a simple graphical approach to assess both performance and stability simultaneously. It measures the performance and variability of each genotype across all environments.

The yield potential under ideal growing conditions varies among genotypes. The maximum yield potential of a given genotype is influenced by climatic and environmental conditions. The genotype with the highest yield potential under ideal conditions may not yield the same when affected by yield-limiting factors. The best way to account for this variability is to look at yield data from as many different environments as possible. Evaluating genotype performance over a wider range of locations helps to select the best adapted genotype (Staton and Thelen, 2009).

Farmers in the study areas are highly demanding for better yielding varieties to maximize their production, which increases income and improve the livelihood of their families. Therefore, this activity was specifically initiated to investigate the grain yield performance of faba bean varieties in the highlands, determine the stability of the varieties, and identify those that are specifically and widely adapted.

MATERIALS AND METHODS

Description of the Study Areas

This experiment was conducted at Alicho Wuriro 1 (AL1), Alicho Wuriro 2 (AL2), Worabe Agricultural Research Center (WARC) main station, located in Worabe town administration, Alibazer 1 (Alib1), Alibazer 2 (Alib2), Gumer 1 (Gum1), Gumer 2 (Gum2), Lemo 1 (Lem1), and Lemo 2 (Lem2) districts. The experiment took place during the 2019 and 2020 main cropping seasons. List of the testing locations with their characteristics are summarized in Table 1.

Soil Characteristics

The dominant soil types at all locations are loam and clay loam, which are naturally well-drained and suitable for faba bean production. Food barley, enset, and faba bean are the predominant staple food crops grown in the study areas.

Experimental Design and Data Analysis

The field experiment was carried out with 14 faba bean varieties; Gebelcho, Alloshe, Bule-04, Ashebeka, Mossisa, Shallo, Tumsa, Gora, Hachalu, Walki, Dosha, Deggaga and Numan together were compared with eachother and with Motti as a local check because of its acceptance by most farmers in the study areas. These varieties were selected based on year of release, performance in previous trials and the agro-ecologies they were released for (Table 1). The experiment was conducted under rain fed conditions in eight environments, representing different faba bean growing agro-ecologies. At each site, the varieties were planted in a randomized block design in three replicates. Sowing was done by hand in plots of 6.4 m^2 with 4 rows measuring 1.6 m and 0.4 m within a row and 0.10 m between plant spacing with 4 m length. The seed rate was 200 kg ha^{-1} and the fertilizers rate was with the ratio of 19%N, 38% P_2O_5 and 7% S at planting for all environments. The two middle rows with an area of 3.2 m^2 were harvested. Grain yield obtained was computed per hectare.

Table 1. Agro-ecological characteristics of test sites

Locations/Year	Administrative zone	Altitude (masl)	Mean annual rain fall (mm)	Average temperature (°C)	Soil texture	Global position	
						Latitude	Longitude
Lemo 1/2019 Lemo 2/2020	Hadiya	2383	1210.32	19.45	Loam	7°60'27"	37°89'
Alibazer 1/2019 Alibazer 2/2020	Siltie	2311	1312	21.15	Loam	7°87'23"	38°15'
Alicho 1/2019 Alicho 2/2020	Siltie	2453	825	13.26	Clay loam	7°58'	37°29'
Gumer 1/2019 Gumer 2/2020	Gurage	2450	1015.10	14.45	Clay loam	8°00'62"	38°09'

The model by Eberhart (1966), $Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij,}$ defines stability parameters that may be used to describe the performance of a variety over a series of environments. Y_{ij} is the varieties mean of the i^{th} variety at the j^{th} environment, μ_i is the i^{th} variety means overall environments, β_i is the regression coefficient that measures the response of the i^{th} variety to varying environments, δ_{ij} is the deviation from regression of the i^{th} variety at the j^{th} environment, I_j is the environmental index. Stability was also measured by combining the mean yield and coefficient of variation (CV_i) (Francis and Kannenberg‘s, 1978). Ecovalence (W_i^2) suggested by Wricke (1962) and cultivar superiority measure (P_i) were computed to further describe stability. R windows version R-3.3.1 was used for statistical AMMI model‘s IPCA1 and IPCA2 scores and GGE biplot for each variety of grain yield computed.

RESULTS AND DISCUSSION

Genotype by Environment on Yield

A significant variation ($p<0.05$) was found among the varieties in mean grain yield performance at Alibazer 1 (main station), Gumer 1, Lemo 1 and Lemo 2 environments (Table 2). Higher mean grain yield of the varieties was obtained in the Gumer 1 (2901.49 kg ha^{-1}), and Lemo 2 (2879.37 $kgha^{-1}$) environments followed by Gumer 2 (2758.83 kg ha^{-1}). Comparing varieties across environments, Tumsa (3593.30 kg ha^{-1}), Gora (3434.80 kg ha^{-1}), Dosha (3257.80 kg ha^{-1}) at Lemo 2 and Tumsa (3214.90 kg ha^{-1}) Dosha (3212.20 kg ha^{-1}) and Bule-04 (2940.90 kg ha^{-1}) at Lemo 1 gave higher mean grain yield. Variety Dosha and Ashebeka (3047.90 and 3060 kg ha^{-1}) at Gumer 1 and Numan (3104.00 kg ha^{-1} at Gumer 2 scored higher mean grain yield and above grand mean yield, which were in agreement with the reports of Tadesse *et al*. (2016) on faba bean mean grain yield.

The mean grain yield of the varieties across the environments generally ranged from 2,247.30 kg ha^{-1} (Motti) to 2,876.80 kg ha^{-1} (Tumsa variety). Of all the varieties, Motti (the local check) was the lowest-yielding genotype among the 14 tested.

Yield Components (pods per plant, seeds per pod, hundred seed weight, plant height)

The highest grain yield was obtained by Tumsa followed by Dosha and have yield advantage of variety 21.88% and 19.77% over the control (Motti). The plant height (cm) of the varieties ranged from 100.68 (Gebelcho) to 107.98(Tumsa) whereas the hundred seed weight (g) also ranged from 53.66 (Deggaga) to 88.31 (Numan). Pod per plant ranged from 11.67 (Motti) to 15.55 gm (Shallo) whereas seed per pod also ranged from 2.79 (Walki) to 3.15 (Numan) in number. Generally, Gumer 1, Gumer 2, Lemo 1 and Lemo 2 had above grand mean performance in grain yield and can be considered as optimum environments for faba bean production despite the need for testing across seasons (Goa and Kambata, 2017). Combined analysis of variance (ANOVA) over eight environments revealed that there was highly significant ($p<0.05$) variation among location and location by varieties effects. The difference among the varieties was highly significant for pod per plant, seeds per pod, hundred seed weight and grain yield, except plant height (Table 3).

Partitioning of the Sum of Squares

The partitioning of the sum of squares of the treatment accounted for by the environment, genotype, and GxE is given in Table 4. In the case of grain yield, the result showed that the variation explained by the environment was high 47.18 %, GxE 34.16 % and varieties took only 18.66 % of the total sum of squares. The largest portion of the total sum of squares was captured by the environment, which implies a significant influence of the environment on the evaluation of genotypes for grain yield performance and caused most of the variation in grain yield. A similar result for a large contribution of the environment was reported by Mirosavljević *et al.* (2014) where environment accounted for the largest proportion followed by GEI and genotypes in food barley grain yield.

Additive Main Effects and Multiplicative Interaction (AMMI)

The AMMI model demonstrated the presence of GEI and this partitions the total sum squares into IPCA components. The result from AMMI analysis (Table 4) showed that the first principal component axis (IPCA1) of the interaction captured 43.66% of the interaction sum of square and the second principal component axis (IPCA2) explained 36.29% of the GEI sum of squares, and cumulatively both axes contributed 79.95% of the total GEI. This result is in agreement with that reported by Gauch and Zobel (1997) who recommended that the most accurate model for AMMI can be predicted using the first two IPCAs. The results of the present study showed that the influence of the environment on faba bean grain yield were significant at ($p<0.05$). The mean squares for IPCA1 and IPCA2 ($p<0.05$) were also significant.

Stability and Superiority Parameters

Using Wricke's (W_i^2) stability parameter, varieties Hachalu, Walki and Ashebeka with lowest Wricke's ecovalence were considered to be stable as they contribute 37138.22, 74010.93 and 155945.50 to the interaction sum of squares, showed wider adaptation; whereas Mossisa, Tumsa and Motti with higher Wricke's ecovalence value were unstable and made the higher contributions 887803, 816009.20 and 516251.10 to GEI and shows specific adaptation. However, cultivar superiority measure (P_i) depicted Gora, Tumsa and Dosha as stable and high yielder, indicating wider adaptation across the environments, and hence recommended for tested areas; whereas Motti, Mossisa and Gebelcho were the most unstable varieties with limited adaptation. With respect to parameter CVi, Deggaga, Shallo and Gora varieties were stable with lower CVi and high grain yield than grand mean whereas Gebelcho, Mossisa and Ashebeka varieties having higher CVi values, indicating instability.

Table 2. Means of grain yield (kg ha^{-1}) performances of eight environments for the fourteen faba bean varieties

Varieties	AL1	AL2	Alib1	Alib2	Gum1	Gum2	Lem1	Lem2
Gebelcho	1911	2414	1778^{e}	2456	2914^{ab}	2507	2512^{bcdef}	2925^{bcdef}
Alloshe	1968	2407	2136^{bcde}	2439	2988^{a}	2755	2583^{abcde}	2392^{f}
Bule-04	2016	2405	1936de	2405	2915^{ab}	2760	2941^{ab}	2737^{cdef}
Ashebeka	2058	2436	1950^{cde}	2432	3060^{a}	2825	2517^{bcdef}	2944^{bcde}
Mossisa	1749	2420	2778^{ab}	2382	2650^{bc}	2789	1851^{f}	2635^{def}
Shallo	2040	2413	2669^{abc}	2384	2932^{ab}	2507	2232^{def}	2421.30^{def}
Tumsa	2702	2410	2954^{a}	2406	2895^{ab}	2839	3215^{a}	3593^{a}
Gora	2667	2402	2737^{ab}	2383	2934^{ab}	2725	2922^{abc}	3435^{ab}
Hachalu	2134	2435	2182^{bcde}	2446	2974^{a}	2772	2452^{bcdef}	2961^{bcd}
Motti	1766	2446	1725^{e}	2444	2389^{c}	2770	2037^{ef}	2401^{ef}
Walki	2033	2457	2220^{bcde}	2427	2954^{ab}	2710	2780^{abcd}	2934^{bcdef}
Dosha	2747	2408	2516^{abcd}	2424	3048^{a}	2797	3212^{a}	3258^{abc}
Deggaga	2290	2493	2626^{abcd}	2390	2988^{a}	2762	2249^{cdef}	2712^{cdef}
Numan	2167	2380	1785^{e}	2458	2982^{a}	3104	2411^{bcdef}	2963^{bcd}
Mean	2161	2416	2285	2420	2902	2759	2565	2879
CV %	22.19	2.10	18.83	1.50	6.49	11.19	15.97	11.36
LSD (5%)	804.72	85.23	722.10	61.49	316.02	518.22	687.37	548.98
Significance of MSRep	73950^{Ns}	6065^{Ns}	50094^{Ns}	847^{Ns}	121469**	2533745**	310844^{Ns}	1380444**
Significance of MSTrt	322363^{Ns}	1313.32^{Ns}	531565.73**	2312^{Ns}	93190**	60453.47^{Ns}	507246**	408237**

AL1 = Alicho Wuriro; AL2 = Alicho Wuriro 2; Alib1 = Alibazer 1; Alib2 = Alibazer 2; Gum1 = Gumer 1; Gum2 = Gumer 2; Lem1 = Lemo 1; Lem2 = Lemo 2; Means with similar letters in the same columns are not significantly different; Ns = not significant and ** = highly significant at 0.05 probability levels; PH = Plant height (cm), PPP = Pod per plant (number), SPP = Seed per pod (number), HSW = Hundred seed weight (gm) and GY = Grain yield (kg/ha); MSRep = mean square of replication and MSTrt = mean square of treatments

Table 3. Combined mean values of five traits of fourteen faba bean varieties across eight environments

Varieties	PH	PPP	HSW	SPP	GY
Gebelcho	100.7	12.05^{f}	72.17^{def}	2.89^{b-e}	2427^{bc}
Alloshe	102.6	13.26^{c-f}	68.33^{fgh}	2.82^{de}	2458^{b}
Bule-04	107.0	11.74^{f}	77.99^{bc}	2.99^{a-d}	2514^{b}
Ashebeka	105.1	12.68^{ef}	73.05^{de}	2.98^{a-e}	2528^{b}
Mossisa	102.8	14.77^{abc}	57.89^{i}	2.91^{b-e}	2407^{bc}
Shallo	103.0	15.55^{a}	57.42^{i}	2.85^{cde}	2450^{b}
Tumsa	108.0	13.68^{b-e}	74.31^{cd}	2.88^{b-e}	2877^{a}
Gora	106.4	12.33^{ef}	81.12^{b}	2.95^{a-e}	2775.^{a}
Hachalu	103.9	12.96^{def}	67.34^{gh}	2.91^{b-e}	2544.^{b}
Motti	106.2	11.67^{f}	69.89^{efg}	3.06^{ab}	2247.^{c}
Walki	103.1	15.18^{ab}	57.65^{i}	2.79^{e}	2564.^{b}
Dosha	102.4	14.37^{a-d}	65.37^{h}	3.02^{abc}	2801.^{a}
Deggaga	106.8	14.54^{a-d}	53.66^{i}	2.99^{a-d}	2551.^{b}
Numan	103.0	12.27^{ef}	88.31^{a}	3.15^{a}	2531.^{b}
Mean	104.4	13.36	68.89	2.94	2548
CV%	8.21	21.11	11.18	11.31	13.93
LSD (5%)	4.92^{Ns}	1.60	4.38	0.19	201.9
Trt	0.97^{Ns}	4200**	2388**	0.23*	680739**
Loc	17253**	118.9**	1692**	0.76*	3453342**
Loc* Trt	0.36^{Ns}	0.25^{Ns}	70.86*	0.09^{Ns}	177991**

Means with similar letters in the same columns are not significantly different; Ns = not significant at 0.05 probability levels; PH = Plant height (cm), PPP = Pod per plant (number), SPP = Seed per pod (number), HSW = Hundred seed weight (gm) and GY = Grain yield (kg/ha)

Table 4. AMMI analysis of variance for grain yield of fourteen faba bean varieties across eight environments

Source	DF	MS	Variance explained (%)
Environment	7	3196533**	47.18
Variety	13	680739**	18.66
Variety x Environment	91	177991**	34.16
Principal Component 1	19	372150 **	43.66
Principal Component 2	17	345801 **	36.29
Principal Component 3	15	107353 ^{ns}	9.76
Principal Component 4	13	54459 ^{ns}	4.37

**Significant at $p<0.01$, Ns = non-significant at $p<0.05$, grand mean = 2548.25 kg ha^{-1}, CV% = 13.93

Table 5. Mean grain yield and popular stability parameters for fourteen faba bean varieties at eight environments

Varieties	Mean kg ha^{-1}	W_i^2	Pi	CV_i (%)	βi
Gebelcho	2427	270923	212374	16.97	1.36
Alloshe	2458	240168	202950	13.19	0.96
Bule-04	2514	296124	157845	15.48	1.22
Ashebeka	2528	155946	154377	15.81	1.40
Mossisa	2407	887803	254958	16.74	0.73
Shallo	2450	469720	206302	10.96	0.53
Tumsa	2877	816009	6507	13.82	0.97
Gora	2776	487179	20799	12.11	0.88
Hachalu	2544	37138	129454	12.78	1.15
Motti	2247	516251	365127	16.33	0.79
Walki	2564	74011	115032	13.07	1.17
Dosha	2801	470574	25157	12.22	0.83
Deggaga	2551	270235	134838	10.24	0.69
Numan	2531	406994	172400	17.98	1.48

W_i = Wricke's ecovalence, (Pi) Lin and Binns's cultivar performance measure, regression coefficient (bi), CV = Coefficient variability

It is important that not only the IPCA scores be used for stability analysis, but also other factors to judge whether a given variety is stable across environments. Accordingly, Tumsa, Gora and Dosha as higher yielding varieties across all environments with linear regression coefficients of 0.97, 0.88 and 0.83, respectively were adapted to ideal environments (Table 5).

Purchase (1997) explained that IPCA1 is plotted against IPCA2, the closer the genotypes score to the center of the biplot, the more stable they are. The biplot interaction graph also revealed that Hachalu and Walki varieties were the most stable genotypes as they are coordinated to the origin (Figure 1) with regression coefficient values of 1.15 and 1.17, indicating that they are sensitive to changing environments.

AMMI biplot indicates that Tumsa, Mossisa, Motti, Numan and Dosha varieties were the most unstable, since they were further from the biplot origin and were sensitive to the environment and had large interaction, indicating that these varieties had specific adaptations (Fig 1).

The pattern of interaction of fourteen faba bean varieties is presented on Figure 1. In AMMI biplot, the performance of varieties in each sectors is independent of their performance in the other sectors. Each sector had a variety at the vertex of its polygon indicating that the variety had the largest positive interaction with that specific environment. Environments AL1 and Lem2 with Tumsa and Dosha, Environment Alib1 with Mossisa, Environments Gum1, Gum2, AL2 and Alib2 with Motti and environment Lem1 with Dosha were the interaction pattern of varieties was independent. These varieties made the largest contribution to the GEI and were unstable. Varieties near the center of the biplot (Alloshe, Hachalu and Walki) contributed very little to the GEI and were stable based on AMMI. The result from the present study is in agreement with that reported in literature (Gauch and Zobel, 1988) where AMMI sectors on barley genotypes were investigated.

Gumer 1 and Lemo 2 environments were considered the most favorable environments where maximum mean grain yield (kg ha^{-1}. 2902 and 2879) were recorded for Motti and Dosha having higher positive interactions due mostly to optimum temperature and annual rain received. The least favorable environment for the performance of the varieties were Alicho Wuriro 1, Alibazer 1, Alicho Wuriro 2 and Alibazer 2, where lower grain yields (kg ha^{-1}), had 2161, 2285, 2416 and 242, respectively likely due to scarcity of rain during planting time, vegetative stage and poor soil fertility. Varieties and environments that fall into the same sector interact positively or negatively if they fall into opposite sectors (Purchase, et al., 2000).

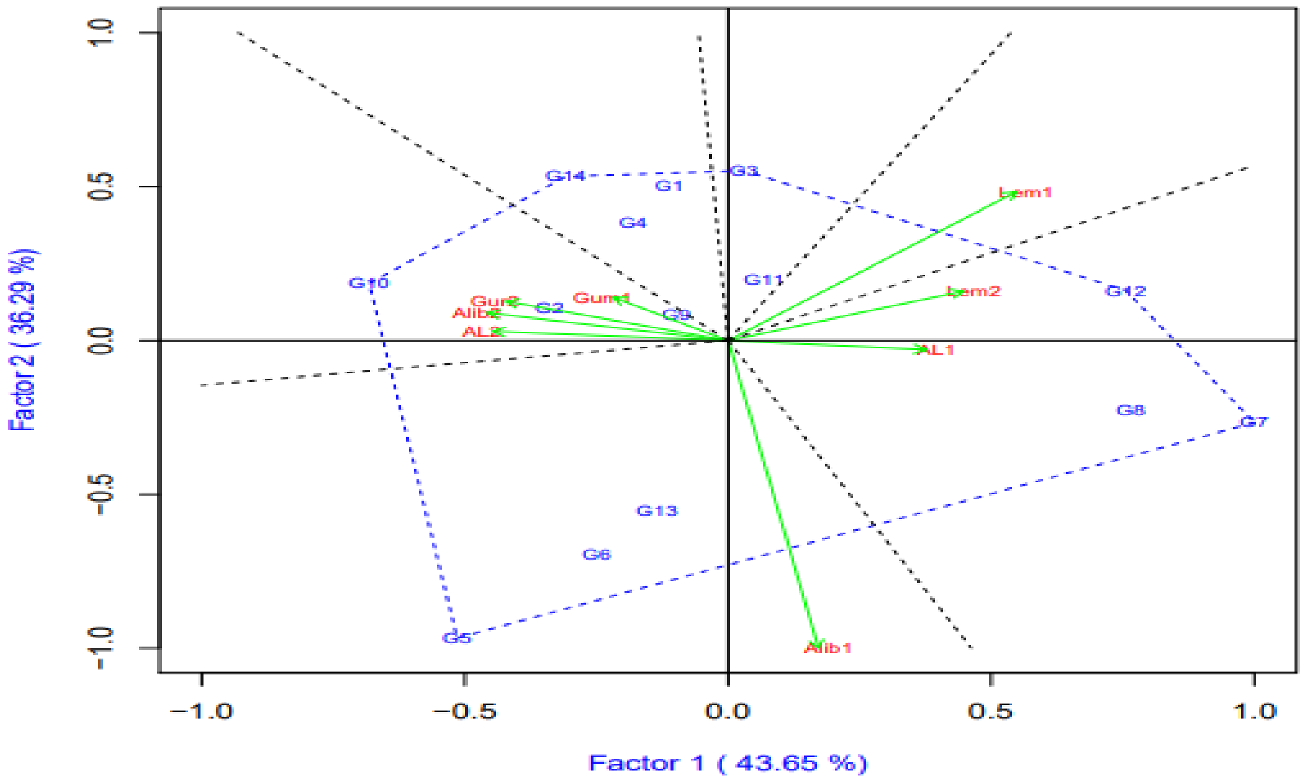

Figure 1. AMMI biplot of (IPCA1) vs (IPCA2) for grain yield (kg ha-1) of faba bean at eight environments plotted as G1 - G14 and environments plotted as AL1, AL2, Alib1, Alib2, Lem1, Lem2, Gum1 and Gum2 in the biplot.

As shown in Figure 2, ranking genotypes (with biplot total 64.80%) relative to the ideal genotype is the use of GGE biplot. Genotypes found in the center of a concentric circle on the average environments are stable. Therefore, Dosha, Tumsa and Gora are the ideal genotypes (both stable and high yielders) that were found near to the concentric circle.

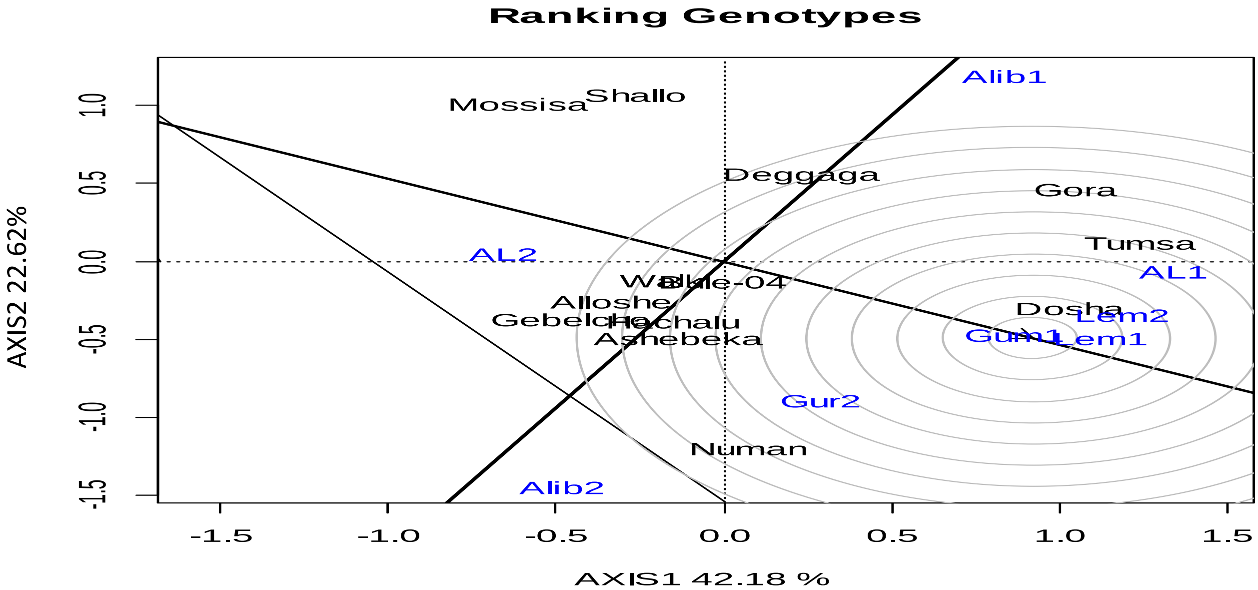

Figure 2. View of the GGE biplot for grain yield ranking Faba bean genotypes based on the G + GxE data at plotted genotypes indicated and environments plotted as AL1, AL2,Alib1, Alib2, Lem1, Lem2, Gum1 and Gum2

CONCLUSIONS

The three most stable and high-yielding varieties were Dosha, Gora, and Tumsa, and they can be recommended for the study areas and similar agro-ecological zones of the Southern region for wider scaling up and out of production to improve production and productivity under smallholder farmers. According to the GGE biplot interaction graph and cultivar superiority measures, Dosha, Gora and Tumsa varieties were the better stable and high yielders with mean grain yield levels higher than the grand mean of all tested genotypes, indicating a wider adaptation. Gumer 1 and Lemo 2 were considered as the most ideal environments to investigate the performance of faba bean varieties.

CONFLICTS OF INTEREST

Authors declare no conflicts of interest regarding the publication of this paper.

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