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Application of AMMI and Tai's Stability Statistics for Yield Stability Analysis in Faba bean *(Vicia faba* L.*)* Cultivars Grown in Central Highlands of Ethiopia

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Abstract: Seventeen faba bean cultivars released over three decades including four promising genotypes in the pipeline were evaluated at five locations in 2007 and two locations in 2009 main cropping seasons in central highlands of Ethiopia. The objective of the study was to determine the magnitude and pattern of G × E interaction and yield stability. The study was conducted using a randomized complete block design with four replications. G × E interaction and yield stability were estimated using AMMI and Tai's stability methods. Pooled analysis of variance for grain yield showed significant differences at ($p \leq 0.001$) among the main effects of genotypes and environments and at ($p \leq 0.01$) for G × E interaction effects. This indicated that either the genotypes differentially responded to the changes in the test environments or the test environments differentially discriminated the genotypes or both. Environment main effect accounted for 73.6% of the total yield variation; whereas, genotype and G × E interaction effects accounted for 5.0% and 8.5%, respectively, indicating the necessity for the need of spatial and temporal replication of variety trial. The first two multiplicative component terms sum of squares of the AMMI explained 66.6% of the interaction effect. No single cultivar showed superior performance across all environments but cultivars TUMSA and DOSHA, followed by CS20DK were top ranked at 71.4% and 57.1% of the environments, respectively and found the most stable across environments. Based on Tai's stability analysis, eight of the tested cultivars exhibited average stability; whereas, none of them was able to demonstrate a static performance stability. Generally, the application of AMMI and Tai's methods were facilitated the visual comparison and identification of superior cultivars, thereby supporting decisions on faba bean cultivar recommendation for different environments.

Keywords: Cultivars, Faba Bean, G x E Interaction, Grain Yield, Stability

1. Introduction

Faba bean (*Vicia faba* L., 2n=12) is one of the major pulses grown in the highlands of Ethiopia ranging from 1800-3000 meters above sea level where the need for chilling temperature is satisfied, and receiving an annual rainfall of 700-1100mm [1, 2]. It is the first most important staple food legume produced in the country occupying 31% of the total area cultivated for pulses and 34% of the total annual pulses production [3]. Ethiopia is the second largest faba bean producing country in the world next to Peoples Republic of China [4, 2] and now considered as one of the secondary centers of genetic diversity for faba bean [1].

Faba bean is widely considered as a good source of protein, starch, cellulose and minerals for humans in developing countries [4, 2], and is a crop of great economic merits in Ethiopia [5]. The crop serves as a source of food and feed with valuable cheap sources of protein as a complement to cereals for the majority of the poor mainly for those who cannot afford to use proteins from animal sources [2]. It is also a good source of cash to the farmers and generates foreign currency to the country [5]. Faba bean is one of the most efficient fixers of the atmospheric nitrogen in an endo-symbiotic relationship with root nodule bacteria known as *Rhizobia* [2], hence, significantly contribute to sustain or enhance total soil nitrogen fertility through biological N2-fixation. In Ethiopia, it is considered as a suitable rotation crop with cereals [6].

Despite its importance, however, the productivity of faba bean has been very low compared to a number of cereals and always variable from year to year. In Ethiopia, the low productivity is mainly attributed to a number of yield limiting factors including the inherent biologically low yielding limitations [7] and biotic and abiotic constraints such as fungal diseases, insect pests, weeds, waterlogging problems, frost damage and low soil pH [8, 9, 10, 11, 2].

Consequently, most of the hitherto breeding thrusts on faba bean were focused on improving grain yield and seed quality with resistance to important diseases, including chocolate spot, rust and fusarium root-rot [5]. As a result, a number of improved faba bean varieties have been developed and released for general production under different recommendation domains, including mid altitude (1800-to-2300 m.a.s.l.), and high (2300-to-3000 m.a.s.l.) agro-ecologies and waterlogged vertisol condition [12]. In addition to high yielding potential, a successfully developed new cultivar should have stable performance and broad adaptation over a wide range of environments.

However, crop genotypes grown in different environments would frequently encounter significant fluctuations in yield performance, particularly when the growing environments are distinctly different, the test genotypes differentially respond to changes in the growing environments or both. The fluctuation of crop performance with changing environments, technically termed as genotype × environment (G × E) interaction, potentially presents limitations on selection and recommendation of varieties for target set of environments, particularly when it is a "crossover" type or when rank order changes among the genotypes are involved [13].

Better understanding of the level of G × E interaction and performance stability in crops serves as a decision tool, particularly at the final stage of variety development process, to generate essential information on pattern of adaptation in breeding lines, new varieties for release, and to determine the recommendation domains for released varieties [14]. G × E interaction is of major importance in faba bean because phenotypic response to a change in the environment is different among genotypes [15]. This differential phenotypic response of genotypes to environmental changes cannot be explained by the genotype and the environment main effect, unless and otherwise it is considered along with G × E interaction effects [16]. G × E interaction can be quantified using several procedures, all of which are based on evaluation of genotypes under multiple environments.

The practical use of different statistical methods to explain G × E interaction, thereby facilitate variety recommendation decision, have been extensively reviewed by different authorities [17, 18, 19, 20]. However, not all methods are equally effective enough in analyzing the multi-environment data structure in breeding programs [17, 13]. Additive main effects and multiplicative interaction (AMMI) and Tai's stability are among the most widely used methods of statistical analyses [21, 17, 22, 23]. AMMI combine the additive main effect and the multiplicative interaction principal components (IPC) of two-way data structure [16] that clearly distinguishes between the main and the interaction effects. In Tai stability analysis, there is a possibility to partition the interaction term into two components: α, which is the linear response to environmental effects, and λ, which is the deviation from the linear response.

Though different authors [24, 25, 26] have reported the existence of high G × E interaction effect in faba bean genotypes grown in Ethiopia and few have been reported on the use of AMMI [27] in Bale highlands. Application of linear-bilinear statistical models as a tool for the determination of the extent and pattern of G × E interaction effects in the context of central highlands of Ethiopia where faba bean is cultivated as the most important rotation crop is limited or nil. Thus, the objective of this study was attempted to apply AMMI biplot and Tai's stability statistical models for determination of the magnitude and pattern of G × E interaction effects and performance stability of grain yield in 17 faba bean cultivars released over three decades.

2. Materials and Methods

2.1. Planting Materials and Testing Locations

Seventeen faba bean cultivars released over three decades of breeding program including two promising lines from the last stage of variety trial were grown at five locations in 2007 and two locations in 2009 during the main cropping seasons (June-November). The locations are representatives of the central highland of the country were faba bean is widely cultivated as major rotation crop with cereals. Each year at each location was considered as a separate environment, making seven test environments for this study. The descriptions of the five test locations and the seventeen test cultivars are given in Tables 1 and 2, respectively.

Table 1. *Description of the test environments.*

Environments	Geographical Position		Altitude (masl)	Average rainfall (mm)	Temperature (0C)		Agro-ecologies
	Latitude	Longitude			Min	Max	
Asassa	$07^0 06'12''$N	$39^0 11'32''$E	2300	620	5.8	23.6	THMH
Kulumsa	$08^0 01'00''$N	$39^0 09'32''$E	2200	820	10.5	22.8	TSmMH
Bekoji	$07^0 31'22''$N	$39^0 14'46''$E	2780	1010	7.9	16.6	CHMH
Holetta	$09^0 04'12''$N	$38^0 29'45''$E	2400	975.5	6.05	22.41	TMMH
Koffale	$07^0 04'27''$N	$38^0 46'45''$E	2660	1211	7.1	18	CHMH

THMH = tepid humid mid highland, TSmMH = tepid sub-moist mid highland, CHMH = cool humid mid highland, TMMH = tepid moist mid highland

Table 2. Description of the 17 faba bean cultivars used in the experiment.

No.	Name of Varieties	Pedigree	Source	Year of release	Seed Size	Recommendation domain
1	CS20DK	CS20DK	Collection	1977	Small	2300-3000m.a.s.l
2	NC58	NC58	Collection	1978	Small	1800-2300m.a.s.l
3	Kuse-2-27-33	Kuse 2-27-33	Introduction	1979	Small	2300-3000m.a.s.l
4	Bulga-70	Coll 111/77	Collection	1994	Small	2300-3000m.a.s.l
5	Massay	74TA12050 x 74TA236	Hybridization	1995	Small	1800-2300m.a.s.l
6	Tesfa	74TA26026-1-2	Hybridization	1995	Small	2300-3000m.a.s.l
7	Holetta-2	BPL 1802-2	Introduction	2000	Small	2300-3000m.a.s.l
8	Wayu	Wayu 89-5	Collection	2002	Small	1800-3000m.a.s.l
9	Selale	Selale Kasim 91-13	Collection	2002	Small	1800-3000m.a.s.l
10	Degaga	R878-3	Introduction	2002	Small	1800-3000m.a.s.l
11	Moti	ILB4432 x Kuse 2-27-33	Hybridization	2006	Large	1900-2800m.a.s.l
12	Gebelcho	ILB4726 x Tesfa	Hybridization	2006	Large	1900-3000m.a.s.l
13	Obsie	CS20DK x ILB 4427	Hybridization	2007	Large	1900-2800m.a.s.l
14	Dosha	Coll 155/00-3	Collection	2009	Medium	1900-2800m.a.s.l
15	Tumsa	Tesfa x ILB 4726	Hybridization	2010	Large	1800-2800m.a.s.l
16	EH9086-2	Tesfa x EH95156-1	Hybridization	Pipeline	Medium	1900-2800m.a.s.l
17	EH91016-5-1-1	Kassa x L82104-3-1-1	Hybridization	Pipeline	Medium	1900-2800m.a.s.l

2.2. Experimental Layout and Design

The treatments were laid out in a randomized complete block design with four replications. Each plot was four rows and 4 m long with spacing of 40 cm between rows. Fertilizer was applied to each plot at the rate of 18 kg N and 46 kg P_2O_5 ha^{-1} in the form of diammonium phosphate at planting. Other agronomic practices were kept as none experimental variables and applied uniformly to the entire experimental area. For data analysis, grain yield measured from a net plot size of 3.2 m^2 was converted into kg ha^{-1} at 10 % standard grain moisture content.

2.3. Data Analysis

The grain yield data was subjected to analysis of variance using the SAS Statistical Package [28]. Variance homogeneity was tested and combined analysis of variance was done using the General Linear Model (PROC GLM) procedure to partition the total variation into components due to genotype (G), environment (E) and G × E interaction effects. The following model was used for combined ANOVA:

$$Y_{ijk} = \mu + G_i + E_j + GE_{ij} + B_{k(j)} + \epsilon_{ijk}$$

where Y_{ijk} is an observed value of genotype i in block k of environment j; μ is a grand mean; G_i is effect of genotype i; E_j is an environmental effect; GE_{ij} is the interaction effect of genotype i with environment j; $B_{k(j)}$ is the effect of block k in environment j; ϵ_{ijk} is an error effect of genotype i in block k of environment j. Genotype was regarded as a fixed effect while environment was regarded as a random effect. The main effect of E was tested against the replication within environment (R/E) as Error 1, the main effect of G was tested against the G × E interaction, and the G × E interaction was tested against pooled error as Error 2. Separation of the main effect was done using Duncan's Multiple Range Test at 5% probability level.

AMMI analysis and AMMI2 GE biplot was done using the SAS program following the procedures of [29] as modified by [30]. AMMI1 graph was done using the scatter plot program of Excel spreadsheet. The following AMMI linear-bilinear model was used for analyses of G × E interaction and performance stability:

$$\bar{y}_{ij.} = \mu + \tau_i + \delta_j + \sum_{k=1}^{t} \lambda_k \alpha_{ik} \gamma_{jk} + \bar{\varepsilon}_{ij.}$$

where $\bar{y}_{ij.}$ is the mean of the i^{th} cultivar in the j^{th} environments; μ is the overall mean; τ_i is the genotypic effect; δ_j is the environment effect; λ_k ($\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_t$) are scaling constants (singular values) that allow the imposition of orthonormality constraints on the singular vectors for genotypes, $\alpha_{ik} = (\alpha_{1k}, \ldots, \alpha_{gk})$ and sites, $\gamma_{jk} = (\gamma_{1k}, \ldots, \gamma_{ek})$, such that $\sum_i \alpha_{ik}^2 = \sum_j \gamma_{jk}^2 = 1$ and $\sum_i \alpha_{ik} \alpha_{ik'} = \sum_j \gamma_{jk} \gamma_{jk'} = 0$ for $k \neq k'$; α_{ik} and γ_{jk} for k=1,2,3,… are called "primary," "secondary," "tertiary,". . . etc. effects of genotypes and environments, respectively; $\bar{\varepsilon}_{ij.}$ is the residual error assumed to be NID (0, α_{ik} and γ_{jk}) (where σ^2 is the pooled error variance and r is the number of replicates). Least square estimates of the multiplicative (bilinear) parameters in the k^{th} bilinear term were obtained as the k^{th} component of the deviations from the additive (linear) part of the model.

Partitioning the G × E interaction effect of i^{th} genotype into two Tai's statistics, namely α and λ, which measures linear response to environmental effects and the deviation from linear response, respectively, was done using the G × E interaction component of SAS program developed by [19].

A stratified ranking for grain yield based on the technique suggested by [31] was done using the SAS program developed by [19] to determine the "top, middle and lower" third genotypes across the environments.

3. Result and Discussion

3.1. Genotypic Performance

Pooled analysis of variance for gain yield (kg ha^{-1}) of the 17 faba bean cultivars tested across seven environments was shown in (Table 3). The main effect differences among genotypes, environments, and the interaction effects were highly significant ($p \leq 0.01$). The environmental effect is accounted for 73.6% of the total yield variation, whereas, genotype and G × E interaction effects were only accounted for 5.0% and 8.5% of the total variation, respectively (Table 3). This shows that grain yield of faba bean cultivars was found to be significantly affected by changes in the environment, followed by G × E interaction and genotypic effects (Table 3). Previous reports in faba bean in Ethiopia also indicated that the environmental effect accounted for the largest part of the total variation [24, 25, 26, 27]. The G × E interaction effect was almost two times higher than the genotypic effect. This may indicate the existence of a considerable amount of deferential response among the genotypes to changes in growing environments and the differential discriminating ability of the test environments. Such circumstances are believed to minimize the usefulness of cultivars [32] by confounding their yield performances. Thus, it is very important to study in depth the yield levels, adaptation patterns and stability of faba bean cultivars in multiple environments.

The average environmental grain yield across genotypes ranged from the lowest of 1691 kg ha^{-1} at Holetta 2007 to the highest of 4474 kg ha^{-1} at Asassa 2007, with a grand mean of 3180 kg ha^{-1} (Table 4). The genotypes grain yield across environments ranged from the lowest of 2694 kg ha^{-1} for SELALE-KASIM to 3581 kg ha^{-1} for TUMSA (Table 4). The result of stratified ranking showed that cultivars, TUMSA and DOSHA, were ranked the first in 71.4% of the test environments followed by the oldest variety CS20DK, which was ranked in the top third of the genotypes in 57.1% of the test environments. Similarly, other two better performing cultivars, namely MESSAY and HOLETTA-2 were yielded in the top third of the cultivars in 42.9% of the test environments. Those widely cultivated cultivars such as DEGAGA, MOTI and GEBELCHO, and the promising genotype EH91016-5-1-1 were ranked in the middle third of the cultivars in 57.1% of the test environments (Figure 1).

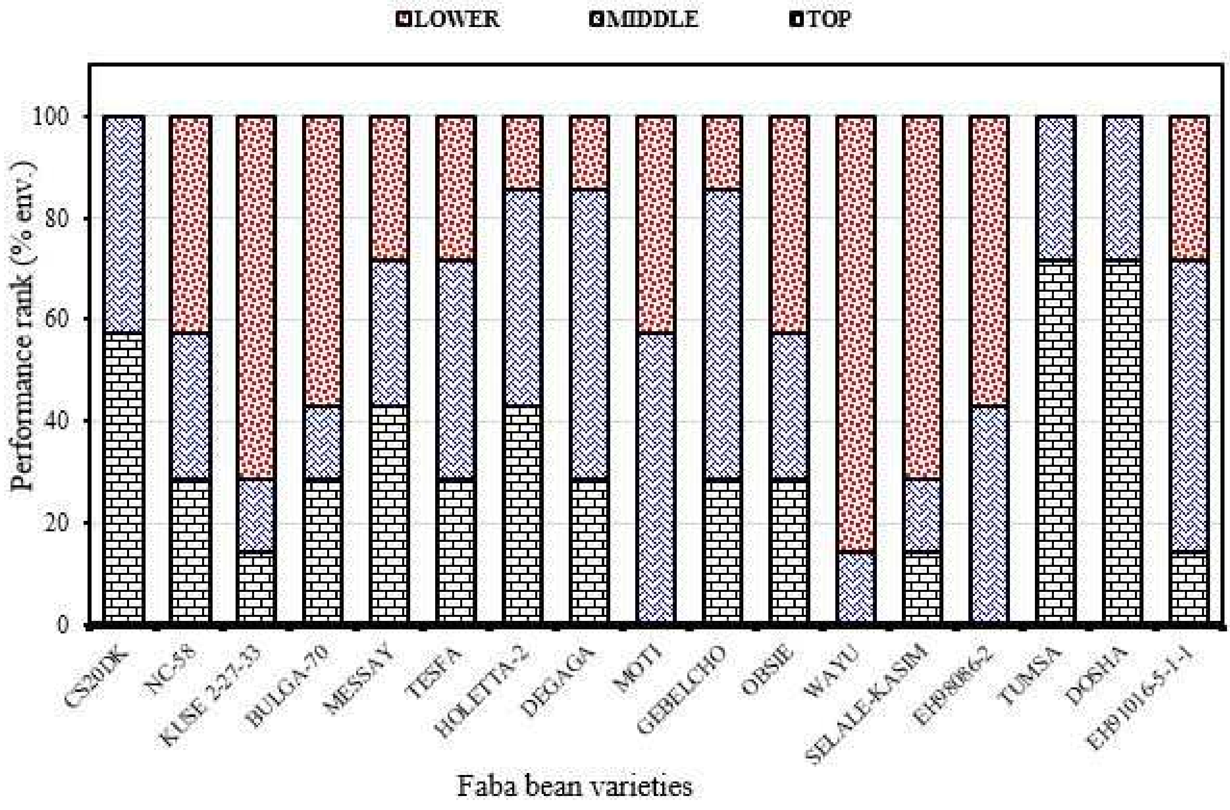

Figure 1. *Genotypic performance rank (%) in the Top, Middle & Bottom third of the test environments according to (Fox et al., 1990).*

3.2. AMMI Analysis

The application of AMMI model for partitioning the G × E interaction effect revealed that only the first two terms of AMMI were significant based on Gollob's F-test [33]. These two multiplicative component sum of squares, with their cumulative degrees of freedom of 40, were captured 66.6% of the G × E interaction sum of squares. In this study, the proportion of the first interaction principal component axis sum of squares (IPC1 = 45.50%) to the interaction sum of squares was far greater than that of the second interaction principal component (IPC2 = 21.10%) (Table 3). This indicated that the existence of differential yield responses among the current released faba bean cultivars across the testing environments due to the presence of significant G × E interaction effect. Therefore, in order to identify a faba bean cultivar with specific or relatively broader adaptation, studies on the magnitude and patterns of G × E interaction effect is of paramount importance in central highland environments of Ethiopia.

Prediction assessments were indicated that AMMI with only the first two multiplicative component axes was adequate for cross-validation of the variation explained by the G × E interaction [17, 34]. The present investigation also revealed that the first two multiplicative components of the interaction term were significant at $p \leq 0.001$ and $p \leq 0.05$, respectively (Table 3). Thus, the interaction pattern of the 17 faba bean genotypes with the 7 environments scattered over the first two AMMI multiplicative components of genotypes and environments visualized the pattern of affinity between the genotypes and the environments.

3.3. Cultivar Stability and Environment Evaluation

Genotypes and environments additive main effects against their respective first multiplicative term (IPC1) are depicted as points on a plane in AMMI1 biplot (Figure 2). The abscissa showed the main effects and the ordinate showed the first multiplicative (IPC1) axis. The horizontal dotted line showed the interaction PC1 score of zero and the vertical dotted lines indicated the mean of the genotype main effects. A displacement along the vertical axis indicated the interaction differences between genotypes and between environments, while the displacement along horizontal axis indicated differences in genotype and environment main effects.

The relative magnitude and direction of genotypes along the horizontal and vertical axis of the graph is important to understand the response pattern of genotypes across environments. Genotypes with IPC1 scores close to zero expressed general adaptation whereas the larger scores depict more specific adaptation to environments with IPC1 scores of the same sign [35]. Accordingly, cultivars EH91016-5-1-1, CS20DK, MOTI, TUMSA, DOSHA and EH98086-2, with their relative IPC1 scores close to zero, have less response to the interaction and showed general adaptation to the test environments. Variety SELALE-KASIM demonstrated large positive IPC1 score and found better adapted to environment Bekoji 2007 with larger and same sign IPC1 score. In contrast, varieties NC-58, BULGA-70 and MESSAY, with their larger negative IPC1 scores were adapted to environments Asassa 2007 and Koffale 2009 (Figure 2). The best cultivar should hold high yield with stable performance across a range of environments. For example, recently released cultivars, TUMSA and DOSHA, and the oldest variety CS20DK in that order were combined the highest mean yield over test environments (Table 3) with demonstrated low IPC1 scores (Figure 2) are considered as the most stable cultivars with relatively less variable yield performance across environments (Figure 1). Environments, Koffale 2007 and Koffale 2009, were combined larger main effects with larger interaction effects (Figure 2). This revealed that the relative ranking of cultivars were unstable at Koffale making it less predictable location for faba bean evaluation and production compared to the remaining test environments.

Table 3. *Combined analysis of variance for grain yield (kg ha^{-1}) of 17 faba bean cultivars grown at 7 environments.*

Source of variation	DF	SS	MS	F- value	Explained % of TSS
Treatments	139	651741298	4688786		
Environments (E)	6	479395765	79899294	19.88***	73.6
Genotypes (G)	16	32376687	2023543	3.5***	5.0
G x E	96	55555601	578704	1.46**	8.5
IPC1	21	25278032	1203716	3.03**	(45.5)
IPC2	19	11722125	616954	1.60*	(21.1)
Residual	65	18555444	1213939		
Pooled error	336	133443245	397153		
CV (%) = 19.82		R^2 = 0.83			

***, ** & * are significant at 0.001, 0.01 and 0.05 probability levels respectively; ns = non-significant; DF = degree of freedom; TSS = total sum of squares; MS = mean sum of squares; IPC = interaction principal component; CV = coefficient of variation, R^2 = coefficient of determination. In the parenthesis is % proportion of interaction sum of square.

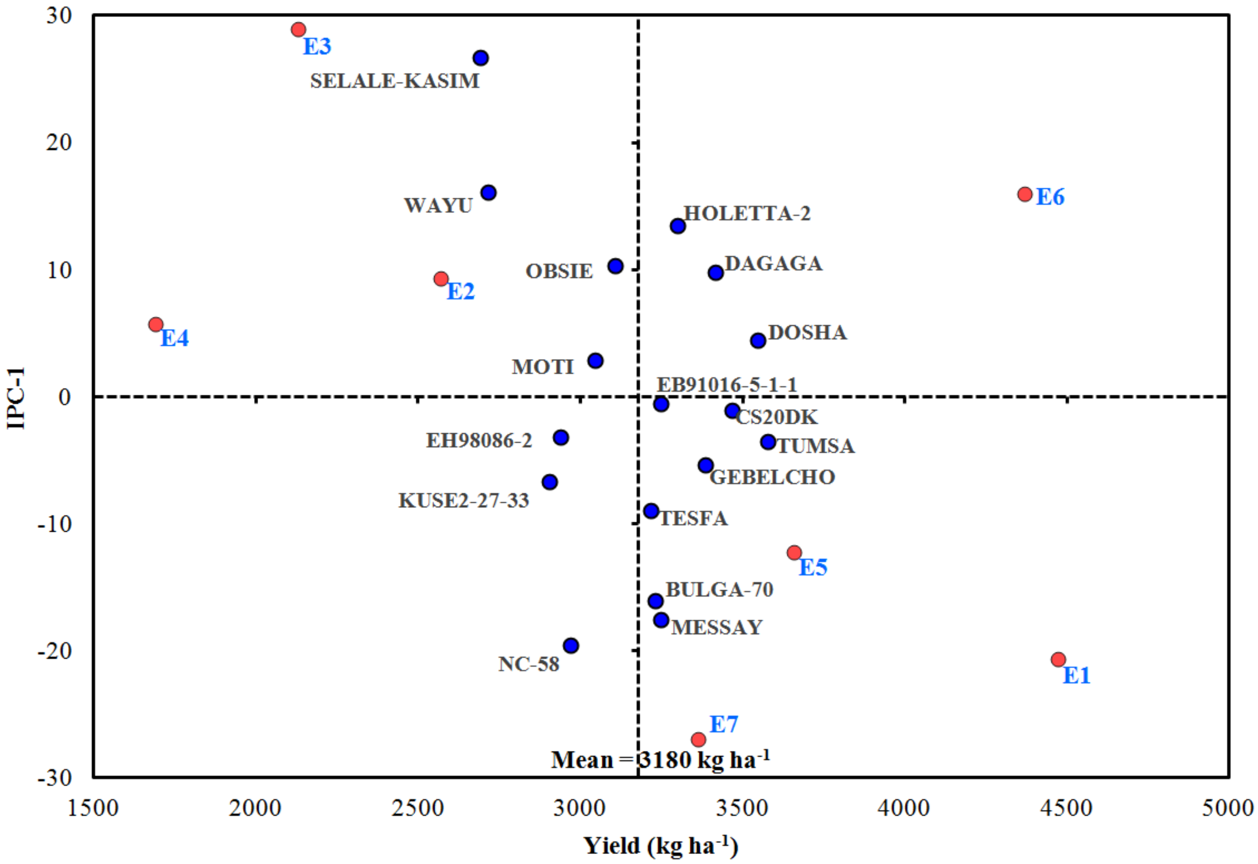

Figure 2. *AMMI1 biplot showing the mean (main effect) vs. stability (IPC1) view of both genotypes and environments on grain yield. Abbreviations of environments are as given in Table 4.*

AMMI2 biplot was generated using genotypic and environmental scores of the first two AMMI multiplicative components to cross-validate the interaction pattern of the 17 faba bean cultivars within seven environments (Figure 3). Connecting vertex cultivars markers in all direction forms a polygon, such that all genotypes are contained within the polygon and a set of straight lines that radiate from the biplot origin to intersect each of the polygon sides at right angles form sectors of genotypes and environments [29, 14]. Based on AMMI2, a biplot with seven sections were observed depending upon signs of the genotypic and environmental IPC scores; however, the test environments were grouped into four sectors (Figure 3). The vertex cultivars in each sector are considered best at environments whose markers fall into the respective sector. Environments within the same sector are assumed to share the same winner cultivars. In this case, WAYU, SELALE-KASIM, HOLETTA-2, MOTI, NC-58, MESSAY, BULGA-70 and TESFA (Figure 3) expressed either positively or negatively high interactive behavior and believed contributed more to the exhibited G × E interaction. Genotype-environment affinity depicted as orthogonal projections of the genotypes on the environmental vectors to identify the best cultivars with respect to environments. For example, the best cultivars with respect to environment Koffale 2009 were TESFA and BULGA-70. Cultivars MOTI and HOLETTA-2, and NC-58 and MESSAY were better adapted to environments Holetta 2007 and Asassa 2007, respectively. Similarly, DEGAGA, OBSE and SELALE-KASIM were better adapted to BEKOJI 2007; whereas, for the environment Kulumsa 2007, DOSHA found best adapted (Figure 3).

The distances from the biplot origin (0, 0) are indicative of the amount of interaction that was exhibited by cultivars over environments or environments over cultivars [36]. As cultivars located near the biplot origin were less responsive than the vertex cultivars [37], cultivars KUSSE2-27-33, EH91016-5-1-1 and EH98068-2 were demonstrated low interactive action over environments. This revealed that these cultivars demonstrated lower fluctuations to the changes in the growing environment. Environment Bekoji 2007 was highly associated with its higher positive IPC1 values, indicating its higher discriminative ability of the cultivars. Environments Asassa 2007, Koffale 2007, and Koffale 2009, characterized by their larger negative IPC1 values, were completely the opposite in their ability to discriminate the cultivars. Based on their proximity to the origin, Holetta 2007 relatively exhibited lesser cultivar discriminative ability and proved to be more representative of the average environment than the remaining environments. Environments Asassa 2007, Kulumsa 2007, Bekoji 2007, Koffale 2007, Bekoji 2009, and Koffale 2009, on the other hand, as indicated by the longest distance between their markers and the biplot origin, demonstrated higher cultivar discriminating ability and found to be less representative of the average environment (Figure 3).

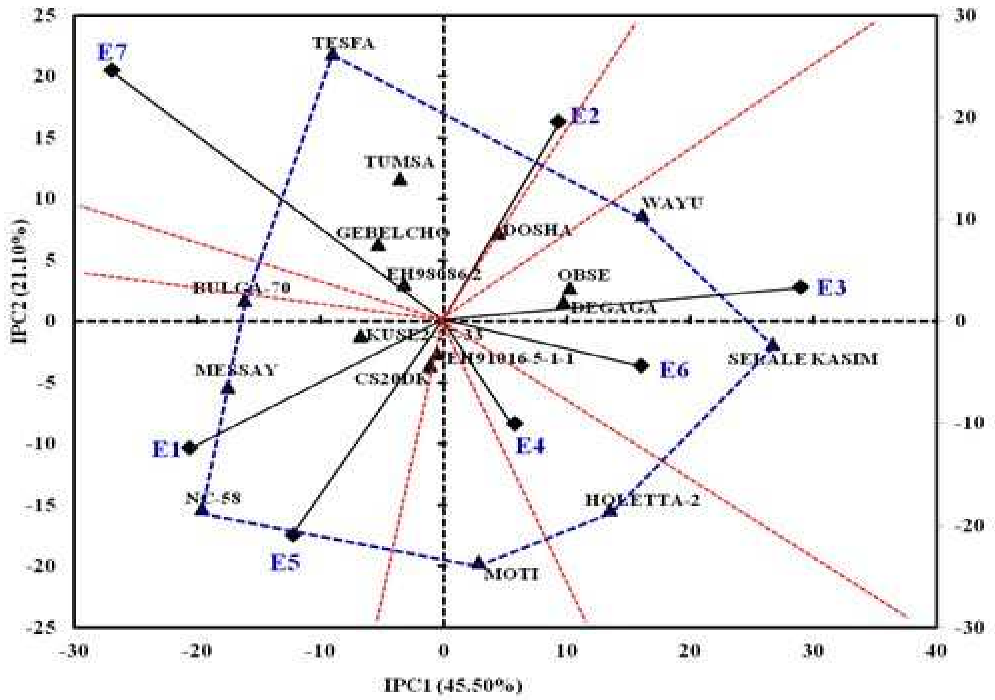

Figure 3. *AMMI biplot analysis showing the mega-environments and their respective high yielding genotypes. Abbrivetions for environments were as indicated in Table 4.*

Table 4. *Mean grain yield (kg ha^{-1}) of 17 faba bean vaireities evaluated over 7 environments.*

Cultivar	Environments†							Mean
	E1	E2	E3	E4	E5	E6	E7	
CS20DK	4899	3139	2240	1962	4133	4521	3394	3470
NC-58	4821	1926	1272	1631	4025	3831	3294	2971
KUSE 2-27-33	4180	2082	1198	1314	3401	4823	3359	2908
BULGA-70	4672	2279	1918	1534	4033	4145	4057	3234
MESSAY	5074	2403	1807	1641	4072	4024	3738	3251
TESFA	4626	2903	2084	1366	3229	4167	4167	3220
HOLETTA-2	4727	2652	2517	2010	3789	4795	2621	3302
DEGAGA	4596	3436	2404	2136	3753	4507	3093	3418
MOTI	4548	1871	2405	1787	3947	4007	2776	3049
GEBELCHO	4417	2557	2383	1624	4064	4574	4102	3389
OBSIE	4082	2504	2479	1275	3586	4658	3181	3109
WAYU	3577	2297	2238	1338	2744	4087	2749	2719
SELALE-KASIM	3214	2013	2526	1362	3019	4403	2320	2694
EH98086-2	4274	2518	1566	1834	3212	3988	3204	2942
TUMSA	4830	3271	2628	2152	3902	4193	4089	3581
DOSHA	4827	3349	2631	2047	3780	4577	3636	3550
EH91016-5-1-1	4687	2467	1907	1736	3536	5001	3423	3251
Mean	4474	2569	2130	1691	3660	4371	3365	3180
CV (%)	10.46	22.12	22.38	28.98	21.67	18.80	20.31	19.82

†Abbreviations: E1 = Asassa 2007; E2 = Kulumsa 2007; E3 = Bekoji 2007; E4 = Holetta 2007; E5 = Koffale 2007; E6 = Bekoji 2009 and E7 = Koffale 2009

3.4. TAI Stability Analysis

Tai (1971) stability model partitions the G × E interaction effect in to two components: α that measures the linear response to environmental effects and λ that measures deviation from the linear response in terms of magnitude of the error variance. The distribution of the 17 faba bean varieties on *Alpha-Lambda* space showing different stability regions was indicated in (Figure 4). The horizontal axis is λ and the vertical axis is α. The curves are prediction limits for α = 0 at levels of probability of 0.90, 0.95 and 0.99, respectively. The area between the α axis and λ = 1, inside the curve with values of α not significantly different from 0 and λ values non-significant different from 1, includes average stable cultivars and those with α < 0 and λ = 1 represents above average stable cultivars; however, cultivars contained within the area above α = 0 and λ =1, i.e., (α > 0, λ = 1) would be considered as below average performance.

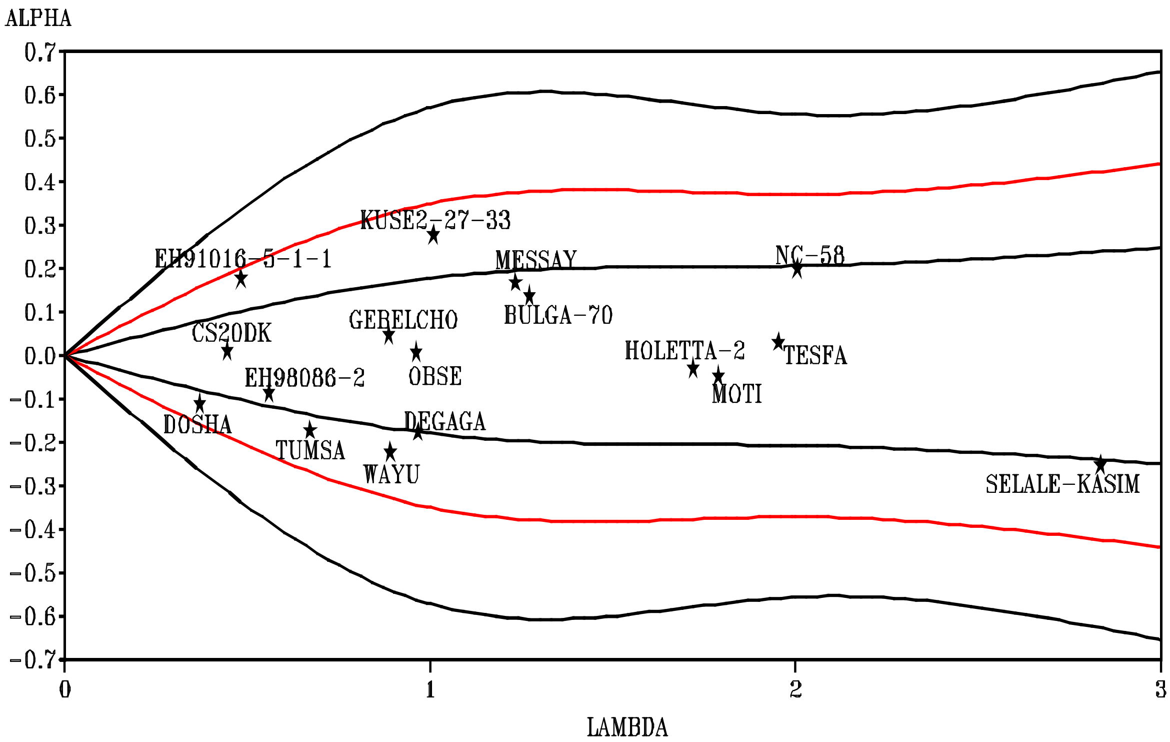

Figure 4. *Distribution of the 17 faba bean cultivars on Alpha-Lambda space showing different stability regions according to (Tai, 1971) method.*

In this case, most of the faba bean cultivars studied except SELALE-KASIM, NC-58 and TESFA showed *λ* values, which were non-significantly different from unity. Alternatively, eight of the tested cultivars namely CS20DK, OBSE, EH98086-2, DOSHA, DEGAGA, BULGA-70, HOLETTA-2 and MOTI, with their (*α, λ*) = (0, 1), were exhibited average genotypic performance stability across the environments. The distribution of *α* statistics for cultivars KUSSE 2-27-33 and EH9106-5-1-1 were positive and significantly different from zero at ($p \leq 0.05$) and believed to possess below average performance stability. Above average degree of genotypic stability was demonstrated by cultivars TUMSA and WAYU with ($\alpha < 0$ *and* $\lambda = 1$) values. The distribution of *α* statistics for cultivars TUMSA and WAYU was negative and significantly different from zero at ($p \leq 0.05$) suggesting that these cultivars were relatively responsive to poor environments.

Faba bean cultivars, SELALE-KASIM, NC-58 and TESFA were found out of range of Tai's parameters indicating that they were more responsive to the environmental changes, and in turn, they were considered unstable cultivars. On the other hand, a perfectly stable cultivar is the one, which revealed an environmental effect (*α)* of -1 and a deviation from the linear response *(λ*) of +1. However, none of the tested cultivars showed *α* value of -1. This indicated that none of them was able to demonstrate a perfect/static performance stability. Therefore, it could be assumed that genotypic performances across the environments were not consistent. Similarly, [15] reported faba bean genotypes possessing average, above, and below average genotypic performance stability, but without static stability performance.

4. Conclusion

Whenever cultivars are proposed for commercial production, information on G × E interaction and stability clearly indicating their general and/or specific adaptations needs to be available to the users. The present study revealed that faba bean yield was liable to significant fluctuations with changes in the growing environments followed by the interaction and genotypic effect contributing the least. AMMI and stratified ranking revealed that highest yielding cultivars TUMSA and DOSHA, followed by CS20DK were top ranked in most of the environments and found the most stable across environments; however, there was no single cultivar that showed superior performance across all environments. Even though none of the cultivars were able to demonstrate a static performance stability, Tai's stability analysis showed that almost half of the tested cultivars namely CS20DK, OBSE, EH98086-2, DOSHA, DEGAGA, BULGA-70, HOLETTA-2, and MOTI were exhibited average stability. Environments Bekoji 2007 and Koffale 2009 were found to have higher discriminative ability of the cultivars but Holetta 2007 relatively exhibited lesser cultivar discriminative ability and proved to be more representative of the average environment than the remaining environments. Generally, the current study clearly demonstrated that the application of AMMI and Tai's were facilitated the visual comparison and identification of superior cultivars, thereby supporting decisions on faba bean cultivar recommendation for the central highlands of Ethiopia.

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