
Identification of Stable Lentil Genotypes Using AMMI Analysis for the Highlands of Bale, Southeastern Ethiopia

Tadele Tadesse*, Amanuel Tekalign, Belay Asmare

Oromia Agriculture Research Institute, Sinana Agriculture Research Center, Bale-Robe, Ethiopia

Email address:

tadyeko20@gmail.com (T. Tadesse), tadeleta20@yahoo.com (T. Tadesse)

*Corresponding author

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Abstract: Genotype x environment interaction was evaluated under six environments during 2017 to 2019 cropping season in the highlands of bale, Southeastern Ethiopia for grain yield of fifteen promising lentil genotypes promoted from the previous trials. Randomized Complete Block Design with four replications was used. The ANOVA revealed significant variation of grain yield for genotypes, environments, and genotypes by environment interaction. The explained percentage of grain yield by the environment, genotype, and genotype-environment interaction was 47.64, 25.47, and 26.89 respectively. In Additive Main Effect and Multiplicative Interaction (AMMI) analysis, the first two Principal components revealed more than 73% of the variability for the yield which indicates that G and GE together accounted for more than 25 percent of the total variability. The results finally indicated that AMMI stability value, GSI, and AMMI biplot are informative methods to explore stability and their by in subsequent variety recommendations. Based on AMMI Stability Value (ASV), G13, G5, G12, G1, and G15 showed the least ASV and were found to be more stable whereas G10, G7, G9, G8, and G14 have the second lower ASV and showed moderate stability. Based on Genotypes Selection Index (GSI), G5, G13, and G15 showed the lowest GSI whereas G10, G1, G4, G11, and G15 showed the second-lowest GSI. However, G4 and G10 gave grain yield higher than the checks, with moderate stability. Therefore, these two genotypes were identified as candidate genotypes to be verified for possible releases for the highlands of Bale, Southeastern Ethiopia, and similar agro-ecologies.

Keywords: AMMI, Genotypes by Environment Interaction, GSI, Lentil, Stability

1. Introduction

Lentil (*Lens culinaris* Medik.) is an annual legume better adapted to cool climates and is traditionally grown as a rain-fed crop is the fourth most important food legume crop after beans (*Phaseolus vulgaris* L.), field pea (*Pisum sativum* L.), and chickpea (*Cicer arietinum* L.) in the world [8] (FAO, 2006). Lentil is one of the most important food crops in developing countries, and its seed is a rich source of quality protein in human diets in the arid and semiarid areas in most parts of the world [19]. Cultivating legumes in a rotation with cereals has been shown to be beneficial in many arid and semi-arid areas [12]. Lentil is adapted to low rainfall and is predominantly grown in the winter in regions where the annual average rainfall is 300 to 400 mm [20]. Before any recommendation is made to a given area, new genotypes

should be evaluated at many locations and for several years. Selection based on the yield performances are the two major phases of varietal development and the latter one is highly influenced by the locations and years of testing. The main environmental effect (E) and Genotype by Environment Interaction (GEI) has been reported as the most important source of variation for the measured yield of crops [5]. To achieve this goal, multiple environmental trials (MET) are conducted annually for all major crops throughout the world with the purpose of identifying superior genotypes for the target locations. In most cases, GE interaction is observed and needs to be modeled and interpreted [17]. Evaluating genotypes of a specific crop in diverse environments for overall stability and adaptability in the presence of the

genotype \times environment ($G \times E$) interaction is essential for all stages of plant breeding [23].

The additive main effects and multiplicative interaction (AMMI) and site regression (SREG) models and genotype plus $G \times E$ interaction (GGE) [2, 10, 22] is the most popular parametric statistical model. These models effectively capture the additive (linear) and multiplicative (bilinear) components of $G \times E$ interaction and provide meaningful interpretation of multi-environment data to predict adaptability and genetic stability [9, 24]. The AMMI model uses ANOVA to analyze the main effects (additive part) and the principal component analysis (PCA) to analyze the non-additive residual effects of ANOVA [11] compared with the traditional ANOVA. The AMMI separates additive variance from the multiplicative variance and then applies PCA to the $G \times E$ interaction portion to a new set of coordinate axes that explain more detail of the $G \times E$ patterns [10]. The AMMI stability value (ASV) and yield stability index (YSI) generated in Core Idea AMMI are commonly used to rank and describe the stability of genotypes [18, 24]. Although several studies have focused on the genetic variation for the grain yield of lentils [14], there is limited knowledge on genetic stability, variability, and $G \times E$ interactions for lentil. Thus this study aimed to identify high yielding and stable lentil genotypes to the highlands of bale, Southeastern Ethiopia.

2. Materials and Methods

In this study twelve lentil genotypes promoted from the previous yield trial were used to be evaluated along with two standard checks, Asano and Alemaya, and local check (Table

1) at two locations, Sinana and Agarfa, in the highlands of Bale zone Southeastern Ethiopia for three consecutive years, 2017 to 2019. Randomized Complete Block Design with four replications was used with a plot size of 3.2m² (4rows at 0.2m spacing with 4m long). The combined ANOVA and LSD for mean separation were analyzed using Crop stat program.

AMMI analysis was also analyzed using the model suggested by [3]. The $G \times E$ interaction was partitioned into two principal component effects (IPCA1 and IPCA2). Stable genotypes across sites-years were identified by analyzing the contribution of the variation into total sums of squares. The ranking of genotypes was conducted using both ASV and GSI values.

The AMMI Stability Value (ASV): is the distance from zero in a two-dimensional scatter graph of IPCA1 against IPCA2 scores, was calculated for each genotype according to the relative contributions of the principal component axis scores (IPCA1 and IPCA2) to the interaction sum of squares using the model suggested by [18].

$$ASV = \sqrt{\left[\frac{SSIPCA1}{SSIPCA2} (IPCA1score) \right]^2 + [IPCA2]^2}$$

Where, $\frac{SSIPCA1}{SSIPCA2}$ the weight given to the IPCA1 value by dividing the IPCA1 sum squares by the IPCA2 sum of squares. Whereas GSI is calculated by ranking the mean grain yield of genotypes (RY) across environments and rank of AMMI stability (rASV) value $GSI_i = RY_i + rASV_i$, where GSI = genotype selection index, RY_i = rank of genotypes for mean grain yield across environment, $rASV$ = rank of the genotypes based on the AMMI stability value.

Table 1. Lists of genotypes used in the trial and their source.

Genotype code	Genotypes	Source
G1	PBA BLITZ	DZARC, Ethiopia
G2	07H212L-07HG1003-08HS2003	DZARC, Ethiopia
G3	CIPAL1304	DZARC, Ethiopia
G4	ILL 50075	DZARC, Ethiopia
G5	CIPAL 1306	DZARC, Ethiopia
G6	CIPAL 1204	DZARC, Ethiopia
G7	06H122L-07HS2003	DZARC, Ethiopia
G8	PBA BOLT	DZARC, Ethiopia
G9	07H071L-08HS2009	DZARC, Ethiopia
G10	06H13SL-07HS2001	DZARC, Ethiopia
G11	03-1 06LX1-07H4008	DZARC, Ethiopia
G12	07H029L-08HS2021	DZARC, Ethiopia
G13	Asano	Released from SARC
G14	Alemaya	Released from DZARC
G15	Local check	Local cultivar

DARC= Debrzeit Agricultural Research Center, SARC=Sinana Agricultural Research Center.

3. Result and Discussion

The analysis of variance combined over locations and years revealed that highly significant variation for mean grain

yield of lentil at ($p < 0.01$) among genotypes, environments, genotype by environment interaction (Table 2). Such a similar significant result in their study of lentil was reported by [4, 6, 21]. The highly significant effects of the environment indicate high differential genotypic responses

across the different environments. The variation in soil structure and moisture across the different environments was considered as a major underlying causal factor for the G×E

interaction. Furthermore, the significant interaction of G X E indicates the differential response of genotypes across the tested environments [15].

Table 2. Combined ANOVA for mean grain yield of 15 lentil genotypes tested across locations and years.

Source of Variation	Degree freedom	Sum Squares	Mean Squares
YEAR (Y)	2	30.45	15.22**
Location (L)	1	60.4	60.40**
Replication	3	0.14	0.048
Genotype (G)	14	49.46	3.53**
Y X L	2	1.65	0.82
G X L	14	14.51	1.04**
Y X L X G	56	37.71	0.67**
RESIDUAL	267	94.55	0.35
TOTAL	359	288.87	0.8

The highest mean grain yield of genotypes (Table 3) was obtained from G4 (2.32t/ha) followed by G10 (2.08t/ha), G6 (1.98t/ha), G3 (1.81t/ha), and G5 (1.81t/ha) whereas from the

environments, the highest mean grain yield obtained from Sinana 2018 (2.26t/ha), followed by Sinana 2019 (1.92t/ha), Sinana 2017 (1.88t/ha) and Agarfa 2018 (1.68t/ha).

Table 3. Mean grain yield (t/ha) for 15 lentil genotypes tested across locations and years.

Entry	Treat code	Sinana 2017=A	Agarfa 2017=B	Sinana 2018=C	Agarfa 2018=D	Sinana 2019=E	Agarfa 2019=F	TRT MEANS
PBA BLITZ	G1	1.37	1.95	2.34	1.46	1.75	1.16	1.67
07H212L-07HG1003-08HS2003	G2	1.52	0.47	1.96	0.58	1.77	1.22	1.25
CIPAL1304	G3	2.6	1.27	2.18	1.45	2.01	1.39	1.81
EC837891	G4	2.2	1.35	3.88	2.65	2.41	1.44	2.32
CIPAL 1306	G5	2.5	0.96	1.3	2.61	2	1.49	1.81
CIPAL 1204	G6	2.38	1.05	3.47	2.02	1.8	1.25	1.99
06H122L-07HS2003	G7	1.69	0.3	2.6	1.19	1.57	0.61	1.5
PBA BOLT	G8	1.97	0.45	1.95	0.83	2.15	0.96	1.38
07H071L-08HS2009	G9	2.16	1.1	1.98	0.97	2.31	0.87	1.56
EC837840	G10	2.35	1.48	3.19	1.73	2.41	1.35	2.08
03-1 06LX1-07H4008	G11	1.71	0.57	2.49	2.2	1.81	0.8	1.6
07H029L-08HS2021	G12	1.16	0.63	1.65	1.57	1.67	0.45	1.19
Asano (st. Check)	G13	1.68	1.31	2.3	1.57	1.94	1.18	1.66
Alemaya	G14	1.6	1.43	1.17	2.82	1.81	0.73	1.59
Local check	G15	1.29	0.48	1.41	1.5	1.48	1.15	1.6
MEANS		1.88	0.99	2.26	1.68	1.92	1.07	1.67
5% LSD		0.49	0.96	0.84	1.37	0.46	0.54	0.67
C.V.		19	21.4	24	24	16	22	21.3

Table 4. Analysis of Variance for AMMI model for grain yield of 15 lentil genotypes.

Sources of variation	DF.	SS	MS	TSS explained %
Genotypes	14	12.366	0.883	25.47
Environment	5	23.124	4.625	47.64
G X E	70	13.053	0.186	26.89
AMMI COMPONENT 1	18	5.74	0.319**	43.98
AMMI COMPONENT 2	16	3.887	0.243**	29.78
AMMI COMPONENT 3	14	2.114	0.151	16.2
AMMI COMPONENT 4	12	0.785	0.065	6.01
GXE RESIDUAL	10	0.527		
TOTAL	89	48.543		

3.1. AMMI Analysis

AMMI analysis in six environments (Table 4) shows that AMMI analysis partitioned main effects into genotypes,

environments, and G×E with all the components showing highly significant effects (P<0.001). The environment had the greatest influence and showed for 47.64% of the total sum of squares; genotype shared for 25.47% of the total sum of squares and GEI had 26.89% which is the next highest

contribution after the environment. The environment has a large sum square which indicates that the environments were dissimilar, with the large differences among environmental means causing larger variation in seed yield in lentil. [1, 4, 16] have reported the same significant variation result in grain yield of lentil. The $G \times E$ interaction was partitioned into principal component effects. Highly significant variation was observed by the first two principal components. The first principal components (IPCA1) accounted for 43.98% of the GE interaction effect whereas the second principal component (IPCA2) explained 29.78% of the interaction sum of square. The two principal components were jointly responsible for 73.76% of the total GE interaction effect variation of grain yield with 34 degrees of freedom.

3.2. Stability Analysis

AMMI stability value (ASV) was proposed by [18] quantifies and ranks genotypes according to their yield stability. In the present study, AMMI stability value discriminated genotypes G13, G5, G12, G1, G4, and G15 as the stable accessions, whereas those with the second-lowest ASV, G10, G7, G9, G3, and G4 were considered moderate stable. Since the most stable genotypes are not necessarily the high yielder, the Genotype Selection Index (GSI) which incorporates both mean grain yield and stability helped to discriminate genotypes. Accordingly, G4 and G10 were found to be the best genotypes since they gave the highest mean seed yield and showed moderate stability (Table 5).

Table 5. Mean grain yield, and Stability parameters for 15 lentil genotypes.

Code	Genotypes	Mean	Rank Yi	Slope (bi)	MS-DEV (S ² di)	IPCA1	IPCA2	ASV	Rank ASV	GSI
G1	PBA BLITZ	1.67	6	0.36	0.18	-0.11	0.4	0.43	4	10
G2	07H212L-07HG1003-08HS2003	1.25	14	0.79	0.24	0.41	0.46	0.76	14	28
G3	CIPAL1304	1.81	4	0.91	0.21	-0.43	-0.25	0.68	11	15
G4	EC837891	2.32	1	1.01	0.05	0.22	-0.62	0.7	12	13
G5	CIPAL 1306	1.81	5	1.47	0.05	0.07	-0.32	0.34	2	7
G6	CIPAL 1204	1.99	3	1.43	0.16	0.36	-0.47	0.71	13	16
G7	06H122L-07HS2003	1.5	12	1.43	0.05	0.39	-0.25	0.63	8	20
G8	PBA BOLT	1.38	13	1.05	0.23	0.35	0.41	0.66	10	23
G9	07H071L-08HS2009	1.56	8	0.88	0.24	0.22	0.57	0.65	9	17
G10	EC837840	2.08	2	0.99	0.08	0.35	0.04	0.51	7	9
G11	03-1 06LX1-07H4008	1.6	8	1.3	0.08	-0.13	-0.43	0.47	5	13
G12	07H029L-08HS2021	1.19	15	0.89	0.06	-0.27	0.04	0.41	3	18
G13	Asano (st. Check)	1.66	6	0.89	0.05	-0.02	0.13	0.13	1	7
G14	Alemaya	1.59	8	0.35	0.58	-1.11	0.08	1.64	15	23
G15	Local check	1.6	8	0.53	0.08	-0.28	0.22	0.47	5	13

3.3. AMMI Biplots

Biplots are graphs where aspects of both genotypes and environments are plotted on the same axes so that interrelationships can be visualized. There are two basic AMMI biplots, the AMMI 1 biplot, where the main effects of grain yield (genotype mean and environment mean) and IPCA1 scores for both genotypes and environments are plotted against each other. On the other hand, the second is AMMI 2 where scores for IPCA1 and IPCA2 are plotted. In the AMMI 1 biplot, the usual interpretation of biplot is that the displacements along the abscissa indicate differences in main (additive) effects, whereas displacements along the ordinate indicate differences in interaction effects [9]. Genotypes that group together have similar adaptation while environments that group together influences the genotypes in the same way [13].

In AMMI 1 biplot genotypes and environments found at the right side of the perpendicular line gave mean grain yield higher than the grand mean. Accordingly, Genotypes, G3, G4, G5, G6, and G10 whereas environments SN 17, SN 18, AG 18, and SN 19 gave the highest mean grain yield above the grand mean (Figure 1). Genotypes and environment found in the same quadrants interact positively whereas those

that found in different quadrants interact negatively.

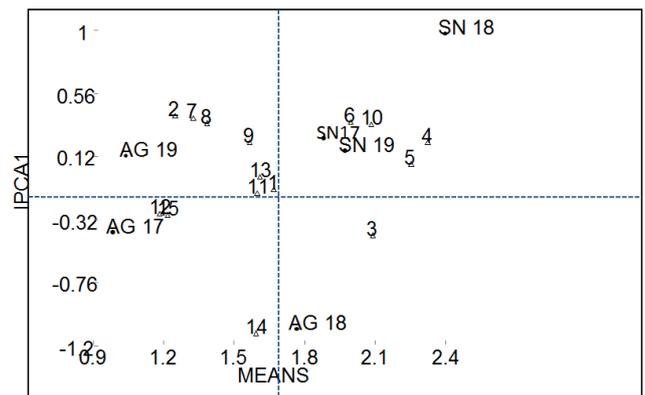


Figure 1. AMMI biplot for fifteen lentil genotypes plotted by Mean grain yield against PCA1 scores of genotypes and Environment.

AMMI 2 biplot

This biplot is constructed by plotting the IPCA1 scores against IPCA2 scores of the genotypes and environments. The environmental scores are joined to the origin by sidelines. Sites with short arrows do not exert strong interactive forces. Those with long arrows exert strong interaction. The genotypes close to ordinate expressed

general adaptation, whereas the farthest genotypes depicted more specific adaptation to environments [7, 11]. In the present study genotypes found near the center of origin were G4, G10 and G13 showed stable performance across the testing sites whereas environments that have shorter distance from the origin were Sinana 2017, Sinana 2019 and Agarfa 2019 showed little deviation or showed stability, or have less deviation to most of the genotypes and gave higher mean yield (Figure 2).

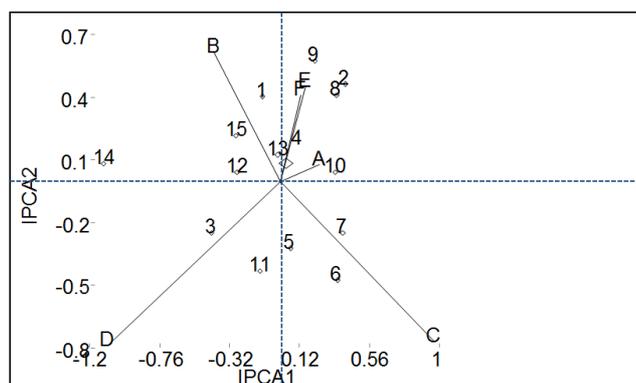


Figure 2. Interaction Biplot for the AMMI 2 constructed by plotting IPCA1 against IPCA2 for genotypes and environments.

4. Conclusion

Yield is a quantitative trait that is strongly affected by the environment. AMMI statistical model might be a great tool to select the most suitable and stable high yielding genotypes for specific as well as for diverse environments. In the present study, genotype G4, G10 showed stable performance over the testing environments. Therefore, genotypes, G4 and G10 since they gave mean grain yield higher than the checks 2.32t/ha, and 2.08t/ha, with yield advantage of 39% and 26% respectively, the ASV, and GSI also described as these two genotypes showed stable performance and further described by the AMMI biplot graphs, they were identified as candidate genotypes to be verified for possible release for the highlands of Bale, Southeastern Ethiopian and similar agro-ecologies.

5. Recommendation

Since grain yield is highly affected by several factors, due consideration upon selection of potential environments and genotypes for the maximum grain yield attainability. Accordingly, lentil growers also give attention to the environmental factors that affect the stable performance of a given genotypes.

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