
Genotype by Environment Interaction and Stability Analysis in Ethiopian Mustard (*Brassica Carinata* A Braun) Using AMMI Biplot and Stability Parameters

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Abstract: The objective of this study was to evaluate genotype by environment interaction and yield stability in multi environmental locations in Ethiopia. Ten Ethiopian mustard genotypes along with one local check and one standard check were evaluated for seed yield at four locations namely, Holeta, Debrezeit, Asasa and Arsi Negelle during the growing season of 2020/2021. The experimental design was randomized complete block design with four replication. Analysis of variance, Ammi biplot and stability parameters were applied for evaluation of genotype by environment interaction and stability. The analysis of variance showed significant differences ($P < 0.05$) among genotypes, locations and GXE interaction for yield. One of the most widely used models to analyses genotype-by-environment data is the additive main effects and multiplicative interaction (AMMI) model. The AMMI1 biplot showed that genotypes G7, G5, and G8 are less affected by the interaction of genotypes and environmental changes and genotypes G1, G7, G8 and G11 are stable genotypes across locations. The AMMI2 biplot indicates that environments E4 and E3 do not exerted strong interaction forces, while strong interactions forces was observed for E1 and E2. AMMI2 also revealed that genotypes G6, G10, G7, G2, G1 and G5 are less affected by the environmental change whereas the remains are more responsive to environmental change.

Keywords: AMMI Biplot, Gollob's Test, Genotypes, Stability Parameters, Ethiopian Mustard

1. Introduction

Brassica carinata ($n=17$) is an amphidiploids species derived from interspecific crosses between *Brassica nigra* ($n = 8$) and *Brassica oleracea* ($n = 9$). No wild forms of *Brassica carinata* have been reported. It is the most neglected *Brassica* species of in terms of crop improvement. The species is an excellent source of genes for tolerance to various biotic and a biotic stresses [1]. Ethiopian mustard (*Brassica carinata* A Braun) is a potential oil crop for the rain-fed areas. Its cultivation is restricted to the Ethiopian plateau, where it might have originated from hybrids between kale, which has been grown in the plateau since ancient times, and wild or cultivated *Brassica nigra*. *Brassica carinata* grows slowly, a trait which it might have inherited from its *Brassica oleracea* parent, and its seed contains mustard oil comparable to *Brassica nigra*. Farmers in Ethiopia grow *Brassica carinata* as a leafy

vegetable in their gardens and also harvest seed for oil.

The rising in global population, pressure on the resource base and climate change are challenging global food security. To solve the problem of food security, development of improved varieties is found to be important and the development of high yielding and stable genotypes is the main purpose of the most breeding program [2]. Agricultural production is strongly influenced by environmental conditions that generally lead to wide variations in yield, both between years in one location and among locations in a single year or, even further, among locations and years [1, 3]. The study of genotype by environment interaction is particularly important to identify stable genotypes and in the improvement and evaluation of plant improvement programs in crop plants [4]. In order to identify stable genotype, actual testing over a wide

range of environments including poor and good ones would be advantageous as mean seed yield of each genotype depends on the particular set of environmental conditions. Genotype-Environment interaction is an extremely commonly used, fundamentally when evaluating stability, specific and general adaptations of cultivars in a given location, in which it is intended to be introduced, as well as the productive potentials and limitations of these in the localities [5]. Yield components in crops are closely influenced by the genotype x environment (GxE) interaction [6].

GxE interaction can cause genotypes with high yields in one location not to perform well in other localities as different factors impact yield and cause variations between locations or environments [7]. The most commonly used models of the biplot analysis are AMMI1 (the AMMI model with one PC), GGE2 (the GGE model with two PCs) and AMMI2 (the AMMI model with two PCs) [8]. AMMI biplots and AMMI stability parameters helps to evaluate yield stability after reduction of the noise from the GxE interaction effects [9]. Gauch, H. G. and R. W. Zobel [10] Implemented the first use of AMMI1 biplot to identify which-won where pattern. The maximum productive potential of crop varieties and genotypes are achieved through proper trial management and conducting trials at multi locations. Evaluation of response of different genotypes to changing environments and identification of stable and widely adopted and unstable but

specifically adapted genotypes needs clear understanding of the magnitude and pattern of genotype by environment interaction. The effect of genotype by environment interaction can be reduced by identifying the most stable genotypes [2, 17]. Characterization of crop production environments and evaluation of genotypic performances in multi-location experiments provides valuable information about the adaptation and stability of the varieties to be released.

In these considerations this study was conducted to estimate the influence of genotype by environment interaction in the Ethiopia mustard genotypes.

2. Materials and Methods

2.1. Experimental Materials and Procedures

This study was carried out to determine the yield performance of eleven Ethiopian mustard genotypes along with one standard check at 4 locations namely Holeta (E1), Debrezeit (E2), Asasa (E3) and Arsi Negelle (E4) during the growing season of 2020-2021. The experimental design used was randomized complete block design with four replications. The trial was planted by drilling and all agronomic practices were done as per national recommendation.

Table 1. Ethiopian mustard genotypes used for the study tested over four locations in 2020-2021.

Genotype code	Pedigree	Status	Source
G1	S-67xY.D.3/1/5/1/9/4-G1/20	NVT	HARC
G2	S-67xHoletta-1-9/2/18/2/41/1-G2/20	NVT	HARC
G3	S-67xHoletta-1-7/1/13/2/26/2-G-3/20	NVT	HARC
G4	S-67xY.D.2/2/4/1/7/3-G4/20	NVT	HARC
G5	Y.D.xBAR-1030/79-436/2001/6/1/10/1/15/3-G5/20	NVT	HARC
G6	S-67xHoletta-1-5/2/10/2/20/4-G6/20	NVT	HARC
G7	S-67xHoletta-1-9/2/18/2/37/3-G7/20	NVT	HARC
G8	S 67xBAR-1030/79-436/2001/2/1/2/1/3/1-G8/20	NVT	HARC
G9	S 67xBAR-1030/79-328/2002/3/2/5/1/7/2-G9/20	NVT	HARC
G10	Y.D.xBAR-1029/79-328/2002/9/2/15/1/26/2-G10/20	NVT	HARC
G11	Tesfa	Breeder S.	HARC
G12	Local check	Local variety	HARC

2.2. Data Collected

Yield data was recorded on plot bases from the central rows and adjusted at 7% using the following formula and then converted to yield (kg) per hectare.

$$\text{Yield in gram (Adjusted)} = \frac{100 - \text{moisture content at 7\%}}{93 - \text{Fresh weight}}$$

2.3. Data Analysis

Data was subjected to analysis variance, AMMI biplot and stability parameters analysis using excel and R-software's.

3. Results and Discussions

3.1. Analysis of Variance

Analysis of variances showed the significant difference ($P < 0.05$) for genotypes and genotypes by environment interaction (Table 2).

Table 2. Analysis of variance for seed yield in Ethiopian mustard studied at four locations.

SOURCE	DF	Type III SS	Mean Square	F Value	Pr > F
REP	3	12910080.92	4303360.31	7.81	<.0001
REP (ENV)	9	21454222.64	2383802.52	4.32	<.0001
GEN	11	14732312.20	1339301.11	2.43	0.0087
ENV*GEN	33	14059491.48	426045.20	0.77	0.02032

3.2. Gollob F-Test for the AMMI Terms

The Gollob's F-test [11] for the significance of each AMMI term are Presented in Table 3. The first column shows the sum of squares corrected by the number of replicates (SS), the second column shows the percent of the genotype by environment interaction sum of squares explained by each

AMMI term (PORCENT), the third column shows the cumulative percent of the genotype by environment interaction sum of squares explained until nth AMMI term (PORCENAC) and the remaining columns shows degree of freedom of each AMMI term (DF), their mean squares (MS), their F-value (F) and the probability level associated to each F-test for each AMMI term (PROBF) respectively.

Table 3. Gollob F-test for the AMMI terms.

	SS	PORCENT	PORCENAC	DF	MS	F	PROBF
ENV	90853843	75.77369	75.77369	3	30284614	40.64472	0.005
GEN	14789574	12.33476	88.10846	11	1344507	1.80445	0.045826
ENV*GEN	14258146	11.89154	100	33	432065	0.57987	0.03655
PC1	7758360	46.9526	46.9526	13	596796.9	0.89193	0.046311
PC2	4196058	25.394	72.3466	11	381459.8	0.5701	0.035049
PC3	2455227	14.85872	87.20532	9	272803	0.40771	0.92933
PC4	2114169	12.79468	100	7	302024.1	0.45138	0.86787
Residuals	1.07E+08	0	0	143	745105.8	NA	NA

The mean yield (YLD) of genotypes and the genotypic and environmental scores of the first three AMMI components (DM1, DM2, DM3) and the values of the variables used to generate the biplot (TYPE and NAME) are presented in Table 4.

Table 4. Final Scores YIELD From RCBD.

	TYPE	NAME	YLD	DIM1	DIM2	DIM3
1	GEN	1	2736.45	0.242209	0.530166	-0.29882
2	GEN	10	2983.767	0.093125	0.590625	0.17933
3	GEN	11	2798.856	-1	-0.69668	-0.24215
4	GEN	12	2547.494	0.833943	-0.39705	0.345035
5	GEN	2	2852.163	0.218122	-0.5491	0.337626
6	GEN	3	2339.763	-0.29583	0.49225	0.136233
7	GEN	4	2660.488	0.464268	-0.52038	-0.41798
8	GEN	5	3401.744	-0.32807	-0.00869	0.394795
9	GEN	6	2629.775	0.03898	0.653865	-0.50244
10	GEN	7	2768.5	0.134173	0.15513	0.764297
11	GEN	8	2774.7	0.573167	-0.21638	-0.61065
12	GEN	9	2302.85	-0.97409	-0.03376	-0.08527
13	ENV	1	1931.596	0.104894	-0.68937	0.389326
14	ENV	2	2467.92	1	0.138933	0.133713
15	ENV	3	3827.017	-0.13118	0.551193	0.473183
16	ENV	4	2662.663	-0.24104	-0.02358	0.466635

3.3. AMMI1 Biplot

In the AMMI1 biplot the displacements along the abscissa indicates differences in main effects, whereas, displacements along the ordinate indicate differences in interaction effects [12]. The genotypes on the right side of the perpendicular namely, G7, G5, and G10 are less affected by GXE interaction whereas, genotypes more close to the center point namely, 1, 7, 8, 11 and 4 indicates that they are stable across environments.

3.4. AMMI2 Biplot

The environments E4 and E3 had short spokes implying

that they don't exert strong interaction forces whereas environments E1 and E2 had long spokes showing that they exert strong interaction forces. Genotypes occurring close together on the plot will tend to have similar yields in all environments, while genotypes far apart may either different in mean yield or show different patterns of response over the environments. Hence genotypes near the origin are not sensitive to environmental interaction and those distant from the origin are sensitive and have large interaction. Hence, genotypes, G6, G10, G7, G2, G1 and 5 are less affected by the environmental change and would perform well across a wide range of environments. Genotypes G12, G11, G9, G8, G4 and G3 are more

responsive to environmental change.

AMMI PCA1 Score vs. YIELD from a RCB

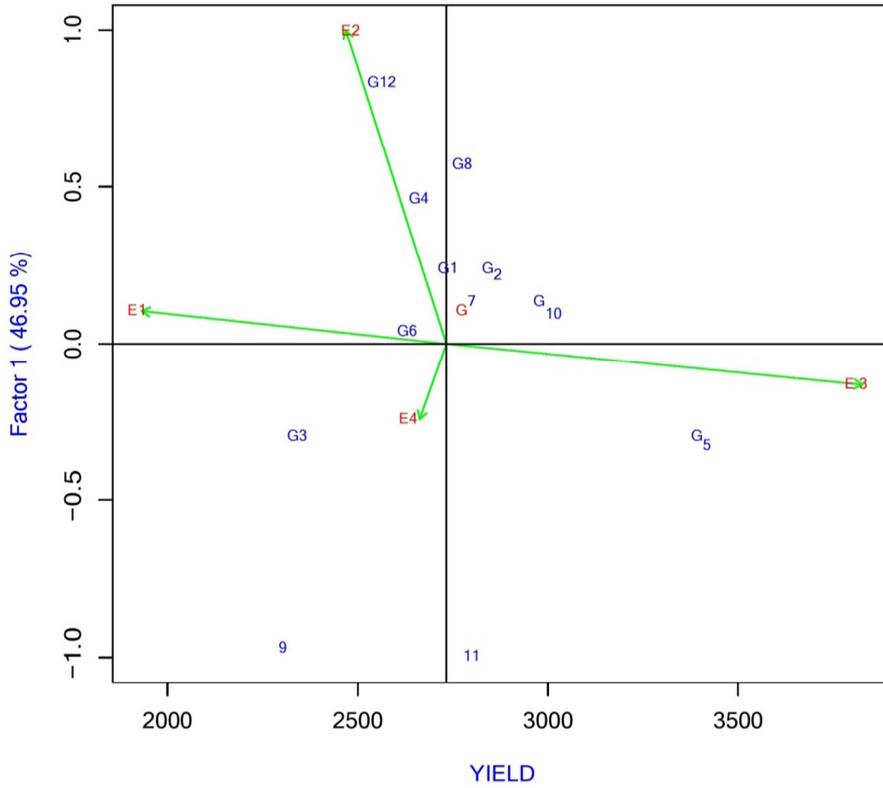


Figure 1. AMMI1 biplot for seed yield (kg/ha) using 12 Ethiopian mustard genotypes tested in four environments.

AMMI YIELD from a RCB

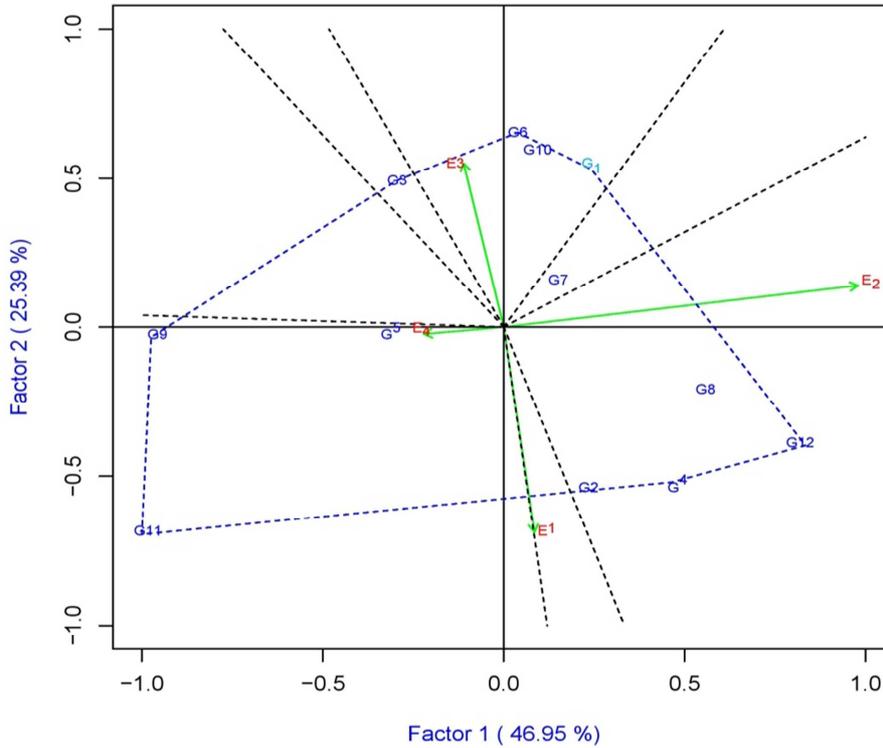


Figure 2. AMMI2 biplot for seed yield (kg/ha) using 12 Ethiopian mustard genotypes tested in four environments.

3.5. Stability Parameters

Genotypes G8, G7 and G 5 posse's bi wich is not significantly different from 1 indicating they were adapted in all environments [13]. Genotype G 1, G10, G11, G3, G6 and G9 possess $bi > 1$ describing their sensitivity to environmental change (below average stability and greater specific adaptability to high yielding environment. Genotypes G2, G12 and G4 possess $bi < 1$ showing greater resistance to environmental change (above average stability and increasing specificity of adaptability to low yielding environments. Genotypes with β_i values not significantly different from 0.0 are judged to be stable, whereas those with significant β_i values are unstable [14].

Accordingly genotypes G5 and G7 had β_i value not

significantly different from 0.0 indicating that they were stable whereas the remaining were not significantly different from 0.0 indicating they were not stable. Genotypes G 9 and G5 had lower β_i values than others and regarded as stable. Genotype with low coefficient of variation is considered as stable [15]. Accordingly genotype G12 has lower coefficient of variation than others and is considered as stable.

Fekadu [16] used stability parameters to estimate stability of Ethiopian mustard genotypes for seed yield and yield related traits in central highland of Ethiopia using eight brassica carinata genotypes along with one local check. The loss of stability and underlying causes of the interaction may be observed due to the genetic differences between the genotypes [17].

Table 5. Mean seed yield (kg/ha), stability parameters and their rank orders for twelve Ethiopian mustard genotypes tested at four locations in 2020/2021.

GEN	*	*	Francis	Eberhart& Russell	*	*	Shukla	Perkins& Jinks	*	Wricke's Ecovalence	Superiority Measure
	Mean	Sd	CV (%)	bi	S2di	R2	ri2	Bi	DJi	Wi	Pi
G1	2736.45	1060.27	38.75	1.3095	-70426.94	0.96	115363.77	0.31	67399.59	315623.84	318473.74
G10	3019.34	893.76	29.60	1.0881	-57335.15	0.93	59364.51	0.09	80491.38	175625.67	130647.13
G11	2798.8	999.06	35.69	1.1531	104129.68	0.83	200373.17	0.15	241956.21	528147.32	272919.72
G12	2547.5	404.39	15.87	0.4757	-106171.72	0.87	222060.81	-0.52	31654.81	582366.42	479967.14
G2	2852.16	499.57	17.51	0.5875	-89339.98	0.87	156417.01	-0.41	48486.55	418256.91	255711.97
G3	2339.76	1062.41	45.40	1.3365	-131077.76	0.99	80022.51	0.34	6748.76	227270.67	642405.84
G4	2660.49	516.88	19.43	0.6388	-122294.19	0.96	100098.44	-0.36	15532.33	277460.51	362789.91
G5	3401.74	852.42	25.06	1.0443	-77480.29	0.94	38872.56	0.04	60346.24	124395.80	4885.25
G6	2629.77	1097.58	41.74	1.36	-76926.15	0.96	135700.61	0.36	60900.38	366465.93	398487.37
G7	2768.5	798.81	28.85	0.9647	-59311.02	0.92	52867.59	-0.035	78515.51	159383.37	245371.40
G8	2774.7	789.08	28.44	0.9112	12253.68	0.84	115133.08	-0.09	150080.21	315047.10	289940.04
G9	2302.85	910.04	39.52	1.1308	-102854.52	0.97	30017.12	0.13	34972.00	102257.20	662737.75

4. Conclusion

The AMMI 1 biplot showed G1, G7, and G8 are stable genotypes with consistant seed yield across the study location and thus not highly affected by the environmental fluctuation. AMMI2 indicates Asasa and Arsi Negelle donot exerted strong interaction forces; whereas strong interaction forces were observed for Holeta and Debrezeit. Genotypes G1, 2, G5, G6 AND G10 arenot highly affected by the environmental change. Finally it is recommended that to combine data across more location and years to come up with correct identification of the best genotypes and the suitable environments.

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