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Grain Yield Stability of Ethiopian Mustard (*Brassica carinata* A. Braun) Genotypes Using AMMI Analysis in the Highlands of Bale, Southeastern Ethiopia

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Abstract: The presence of significant G*E for quantitative traits such as yield can seriously limit the feasibility of selecting superior genotypes. Thus, the purpose of this study was to investigate grain yield stability and genotype X environment interaction for fifteen Ethiopian Mustard genotypes (Brassica carinata A. Braun) conducted in the highlands of Bale, Southeastern Ethiopia for three consecutive years (2018 to 2020) at two locations, Sinana and Agarfa. Randomized Complete Block Design with four replications was used. The combined analysis of variance for grain yield indicated highly significant interaction (P<0.01%) for genotypes, genotype X environment interaction, and environment. The analysis of variance for AMMI for grain yield revealed highly significant interaction for genotypes, genotypes X environment interaction, and environment. It was observed that 44.84% of the variation in grain yield was accounted by environment, 37.54% for genotypes by environments, and, 17.62% was for genotypes. The first and the second IPCA components with degree freedom of 34 was accounted for 67.64% of the interaction effect and revealed the two models were fit. Genotype G12, G11, G8, and G1 showed the lowest AMMI Stability Value (ASV) indicating stability. Furthermore, Genotypes G11, G12, G5, and G8 have the lowest GSI value indicating high stability. However, out of these genotypes, G11 showed a high mean grain yield with a yield advantage of 25.8% and showed the lowest GSI value compared to overall genotypes and the checks used in the study. Therefore, G11 was identified as a candidate genotype to be verified in the coming main season of 2022/23 for possible release for the highlands of bale zone, Southeastern Ethiopia, and similar agro-ecologies.

Keywords: AMMI, Genotypes, Genotype by Environment Interaction, Grain Yield, Stability

1. Introduction

Ethiopian mustard (Brassica carinata A. Braun) is mainly originated in the highlands of Ethiopia. It is locally known as “Gomenzer”. This crop is well adapted in the Mediterranean areas and it is a heat and drought-tolerant oilseed crop [4]. It is believed to have originated from the Ethiopian highlands and its cultivation is thought to have started about 4000 years B. C. [1, 23]. It is cultivated as an oil and leafy vegetable crop in the Ethiopian highlands at altitudes between 1500 and 2600 m.

Genotype and environment interaction plays a key role in phenotypic expression and must be estimated and considered when indicating cultivars for the breeding program [21]. G×E is defined as a phenomenon in that phenotypes respond to genotypes differently according to different environmental factors [18]. The presence of significant G*E for quantitative traits such as yield can seriously limit the feasibility of selecting superior genotypes [11]. However, the G*E can be properly exploited to advantage through various approaches [13, 16]. Therefore, identification of yield contributing traits and knowledge of the G*E interactions and yield stability is important for breeding new cultivars with improved adaptation to the environmental constraints prevailing in the targeted environments.

Gene-environment interactions are situations in which environmental factors affect different individuals differently, depending upon genotype, and in which genetic factors have a differential effect, depending upon attributes of the environment [17].

Understanding the implications of GEl structure/nature is important in crop improvement programs because a significant GEl can seriously impair the selection of superior genotypes in new crop introduction and cultivar development programs. The stability of varieties over environments is closely linked with G x E interaction. When the interaction is present, it indicates that the genotype is statistically non-additive, indicating that the genotypic performance is largely depending on the environment [5]. Genotype by environment interaction may occur in both the short and long terms (several years and several locations) for crop performance trials. Therefore, analysis of genotype by environment interaction is very necessary in any variety performance evaluation to interpret the genotypic or environmental main effects [15, 27] so that one can make an informed decision when making variety selections [7]. Several statistical approaches are available to understand G x E interactions, but the most powerful of these is additive main effects and multiplicative interaction (AMMI) analysis [14]. AMMI uses analysis of variance (ANOVA) and principal component analysis to study G x E interactions. Therefore, this study was conducted to identify high-yielding stable genotypes with other desirable traits with tolerant and/or resistant to major Ethiopian mustard diseases in the highlands of Bale, Southeastern Ethiopia.

2. Materials and Methods

Twelve Ethiopian mustard genotypes were evaluated along with two standard checks, Yellow zone Southeastern Ethiopia for three consecutive years, 2018 to 2020. The experiment was laid out in RCBD with four replications having a plot size of 4.8m^2 (4rows at 0.3m spacing with 4m long) was used. Recommended fertilizer rate was also used at all locations. A list of genotypes along with their sources is presented in (Table 1). Crop stat program was used to compute the combined ANOVA and LSD for mean separation. AMMI analysis was also analyzed using the model suggested by Crossa *et al.,* 1991 [6].

The AMMI Stability Value (ASV): 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. It is calculated using the model suggested by [22]. This weight is calculated for each genotype and environment according to the relative contribution of IPCA1:

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

Where, $\frac{SSIPCA1}{SSIPCA2}$ the weight given to the IPCA1 value by dividing the IPCA1 sum squares by the IPCA2 sum of squares. The larger the IPCA score, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller IPCA score indicates a more stable genotype across environments.

Stability per se does not give much information about the level of yield so [10, 26] used yield stability index (YSI) and genotype stability index (GSI) which combined high yield performance with stability. Both the YSI and the GSI are based on the sum of the ranking due to ASV scores and yield or performance ranking. Lower YSI and GSI values indicate genotypes that combine high yield or performance with stability [2], and it is calculated as follows:

GSIi= RYi +RASVi, where GSI = genotype selection index, RYi = 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 for the study.*

Genotypes	Source of the genotypes
ACC 241902	Brought from Holetta, Ethiopia
ACC 241895	Brought from Holetta, Ethiopia
ACC 243738	Brought from Holetta, Ethiopia
ACC 242852	Brought from Holetta, Ethiopia
ACC 242854	Brought from Holetta, Ethiopia
ACC 241906	Brought from Holetta, Ethiopia
ACC 242855	Brought from Holetta, Ethiopia
ACC 241916	Brought from Holetta, Ethiopia
ACC 241909	Brought from Holetta, Ethiopia
ACC 20133	Brought from Holetta, Ethiopia
ACC 20131	Brought from Holetta, Ethiopia
ACC 241904	Brought from Holetta, Ethiopia
Yellow dodola	Released from Holetta
Shaya	Released From Sinana
Local check	Local cultiva

3. Result and Discussion

The combined analysis over location and years for mean grain yield revealed that highly significant variation at ($P<0.01$) was observed among genotypes, environments, genotypes x environment interaction (Table 2). The same result was reported by [20, 24]. This significant variation happened due to the change in the magnitudes of difference between genotypes from one environment to another. Furthermore, the significant variation of the GEI revealed that as there are factors that are of economic relevance that can be related to complex or polygenic characteristics, and show a high influence on the environment. Because of this, in breeding programs, various experiments are conducted in several locations to evaluate grain yield. [8], indicated that genotype x environment interaction is important for plant breeding because it affects the genetic gain and recommendation and selection of cultivars with wide adaptability.

Table 2. *Combined ANOVA for grain yield of 15 Ethiopian Mustard genotypes combined over two locations and three years.*

Source of Variation	Degree freedom	Sum Squares	Mean Squares
YEAR (Y)	2	24.39	12.19**
Location (L)	1	28.77	28.77**
Genotype (G)	14	1.11	0.37**
Replication	3	3.43	0.24
Y X L	2	19.11	9.55**
G X L	14	4.9	0.35**
Y X L X G	56	13.75	0.25**
RESIDUAL	267	83.5	0.31
TOTAL	359	178.96	0.5

The highest mean grain yield obtained from genotypes G11 (1.94t/ha) followed by G12 (1.56t/ha), G10 (1.55t/ha) and G14 standard check, (1.54t/ha) whereas the mean grain yield across locations was ranged from 1.82t/ha for Sinana 2018 to 0.96t/ha for Agarfa 2018 (Table 3). The grand mean for grain yield across locations and years was 1.45t/ha (Table 3).

Table 3. *Mean grain yield (t/ha) of for 15 Ethiopian Mustard (Brassica carinata) genotypes tested across locations.*

Entry	Treat code	Sinana 2018	Agarfa 2018	Sinana 2019	Agarfa 2019	Sinana 2020	Agarfa 2020	TRT MEANS
ACC 241902	G1	1.71	0.8	1.63	1.12	1.7	1.63	1.43
ACC 241895	G2	1.62	0.95	1.24	1.7	1.04	1.42	1.33
ACC 243738	G3	1.71	0.68	1.58	1.31	1.02	1.85	1.36
ACC 242852	G4	1.89	1.04	1.42	1.06	1.74	1.58	1.45
ACC 242854	G5	1.8	0.98	1.38	1.2	1.79	1.96	1.52
ACC 241906	G6	1.76	0.87	1.11	1.39	1.35	1.75	1.37
ACC 242855	G7	1.77	0.78	1.11	1.85	1.34	1.72	1.43
ACC 241916	G8	1.93	1.08	1.25	1.03	1.49	1.89	1.45
ACC 241909	G9	2.01	0.69	1.19	1.54	1.11	1.8	1.39
ACC 20133	G10	1.74	1.27	1.31	1.57	2.33	1.09	1.55
ACC 20131	G11	2.77	1.69	1.8	1.41	2.28	1.65	1.94
ACC 241904	G12	2.22	0.65	1.37	1.38	1.93	1.79	1.56
Yellow Dodola	G13	1.66	0.7	1.59	0.8	1.82	1.42	1.33
Shaya	G14	1.69	1.32	1.65	1.23	1.87	1.46	1.54
Local check	G15	1.01	0.97	1.12	0.84	1.04	1.55	1.09
Mean		1.82	0.96	1.38	1.3	1.59	1.64	1.45
LSD 5%		0.76	0.51	0.5	0.62	0.96	0.99	0.34
CV%		21.9	21.3	21.4	23.2	21.5	22.7	21.2

3.1. AMMI Analysis

The AMMI method combines the traditional ANOVA and PCA into a single analysis with both additive and multiplicative parameters [12]. The first part of AMMI uses the normal ANOVA procedures to estimate the genotype and environment main effects. The second part involves the PCA of the interaction residuals (residuals after the main effects are removed). In this study, the combined analysis of variance and AMMI analysis is shown in Table 4. It was observed that there are highly significant differences in the environment, genotype, and their interactions. The combined ANOVA showed that grain yield was significantly affected by the environment because of significant variance at 1% level (Table 4), which explained 44.84% of the total variation whereas the GEI accounted for 37.54%, and the genotypes captured 17.62% of the total sum square. Similar significant variation for the genotypes, genotypes by environment interaction, and the environments were reported by [3, 9].

Table 4. *ANOVA for the Additive Main effect and Multiplicative Interaction (AMMI) for grain yield of 15 Ethiopian Mustard genotypes over environment.*

Sources	DF.	SS	MS	TSS explained %
Genotypes	14	2.681	0.191	17.62**
Environment	5	6.821	1.364	44.84**
G X E	70	5.71	0.082	37.54**
AMMI COMPONENT 1	18	2.659	0.148	46.56
AMMI COMPONENT 2	16	1.204	0.075	21.08
AMMI COMPONENT 3	14	0.978	0.07	6.43
AMMI COMPONENT 4	12	0.512	0.043	3.36
GXE RESIDUAL	10	0.359		
TOTAL	89	15.21		

The two principal components of GE interaction accounted jointly for 67.64% of the whole G × E interaction effect variation of grain yield and were significant. The first principal interaction component (IPCA 1) accounted for 46.56% of the variation caused by the interaction, while IPCA 2 accounted for 21.08% of this variation. The first two bilinear terms jointly accounted for 67.64% of the G x E sum of squares and used 34 of the total 70 degree freedom available in the interaction indicating the model is fit to describe stability.

3.2. AMMI Stability Value (ASV)

ASV, which is the distance from the coordinate point to the origin in two-dimensional scattergram of IPCA1 (Interaction Principal Component Analysis) against IPCA2 scores is used to discriminate stable genotypes. In this ASV method a stable variety is defined as one with ASV value close to zero [22]. Accordingly genotypes G12 (0.1) followed by G11 (0.22), G5 (0.22), G8 (0.27), and G1 (0.34) were the most stable whereas G10, G9, G7, G3, and G2 with the highest ASV indicate unstable (Table 5).

3.3. Genotype Selection Index (GSI)

As stability per se is not a desirable selection criterion, because the most stable genotypes would not necessarily give the best yield performance, hence, simultaneous consideration of grain yield and ASV in a single non-parametric index entitled. Accordingly in this study, Genotypes G11, G12, G5, and G8 showed lowest GSI indicating general stability however, only genotype G11 showed higher mean grain yield than the checks (Table 5).

Table 5. *Mean grain yield, Stability parameters, ASV and GSI for 15 Ethiopian mustard genotypes tested across location over years.*

Trt C0	Genotypes	Mean	Rank Yi	Slope (bi)	MS-DEV (S^2di)	IPCA1	IPCA2	ASV	Rank ASV	GSI
1	ACC 241902	1.43	8	1.15	0.27	0.12	-0.22	0.34	4	12
2	ACC 241895	1.33	13	0.48	0.45	-0.38	0.37	0.92	10	23
3	ACC 243738	1.36	12	1.09	0.5	-0.43	-0.27	0.99	11	23
4	ACC 242852	1.45	6	1.08	0.22	0.21	-0.12	0.47	6	12
5	ACC 242854	1.52	5	1.2	0.24	0.02	-0.21	0.22	2	7
6	ACC 241906	1.37	11	1.04	0.27	-0.25	0.07	0.55	7	18
7	ACC 242855	1.43	8	0.96	0.52	-0.42	0.4	1.01	12	20
8	ACC 241916	1.45	6	1.15	0.31	-0.04	-0.26	0.27	3	9
9	ACC 241909	1.39	10	1.31	0.47	-0.47	0.1	1.03	13	23
10	ACC 20133	1.55	3	0.54	0.69	0.55	0.6	1.36	15	18
11	ACC 20131	1.94	1	1.01	0.06	0.48	0.1	0.22	2	3
12	ACC 241904	1.56	2	1.8	0.15	0.04	0.02	0.1	1	3
13	Yellow Dodola	1.33	13	1.26	0.45	0.37	-0.31	0.87	9	22
14	Shaya	1.54	4	0.51	0.31	0.32	-0.01	0.7	8	12
15	Local check	1.09	15	0.32	0.38	-0.12	-0.27	0.38	5	20

3.4. AMMI Biplots

The AMMI biplot provide a visual expression of the relationship between the First Interaction Principal Component Axis (IPCA1) or AMMI component 1 and Mean of genotype and environment (Figure 1). As a result, biplots generated using genotypic and environmental scores of the AMMI 1 components can help breeders have an overall picture of the behavior of the genotypes, the environments and G x E [19, 25]. In Figure 1 the IPCA1 scores for both the genotypes and the environments were plotted against the mean yield for the genotypes and the environments, respectively. By plotting both the genotypes and the environments on the same graph, the associations between the genotypes and the environments can be seen clearly. The IPCA scores of genotypes in the AMMI analysis are an indication of the stability or adaptation over environments. The greater the IPCA scores, negative or positive (as it is a relative value), the more specific adaptation of a genotype to certain environments whereas the more the IPCA scores approximate to zero, the more stable or adaptation of the genotype in overall environments sampled.

Accordingly, in this study genotypes G5, G12, G14, G10 and G11 were the highest yielding genotypes while environment Sinana 2020, Sinana 2018 and Agarfa 2020 gave the highest mean grain yield (Figure 1).

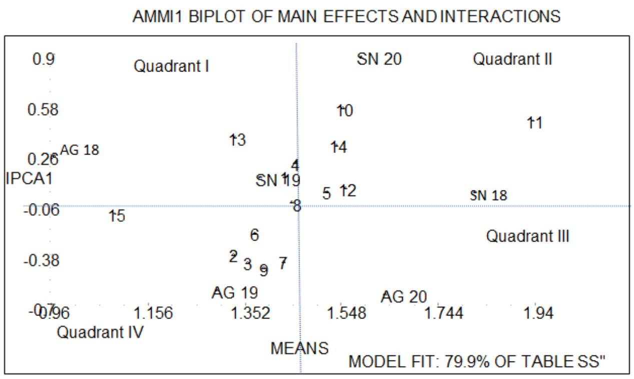

Figure 1. *Interaction biplot of AMMI1 where IPCA1 score (y-axis) plotted against mean yield (x-axis) for fifteen genotypes of Ethiopian mustard.*

AMMI Biplot II: this biplot was constructed using both the IPCA scores. i.e. Since IPCA 2 scores also play a significant role in explaining the GEI, the IPCA 1 scores were plotted against the IPCA2 scores to further explore adaptation (Figure 2). In this biplot graph, those genotypes found near the origin are considered as more stable whereas those genotypes and environments which are found far from the origin, by having the longest vertex are considered as unstable, and well adapted to the specific locations. Accordingly, G11, G12, G14, G4 G1, and G5 were found to be stable in their grain yield when tested across sites whereas the environment A B and C were less responsive to the environmental factors. However, out of those above-mentioned genotypes which showed stable performance, only G11 gave a mean grain yield higher than the checks used in the trial. The other genotypes, though they have stable performance, they gave lower mean grain yield than the checks.

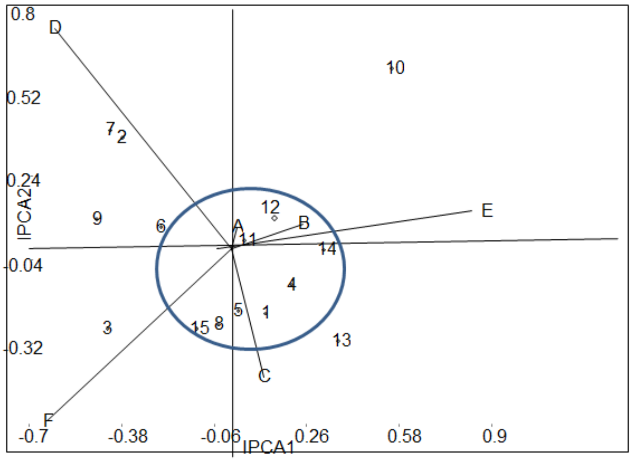

Figure 2. *Biplot analysis of GE interaction based on AMM2 model for the first two interactions principal component score.*

4. Conclusion

Plant productivity is a direct consequence of how well adapted the genotype of an individual is to the surrounding environment in order to assess the stability of the genotypes, fifteen Ethiopian mustard genotypes were evaluated over locations and years to identify and determine their grain yield stability. From the study it was concluded that genotype G11 has a mean grain yield of 1.94t/ha with a yield advantage of 25.8% over the checks, plus the AMMI model was described as this genotype had lower ASV, and lower GSI it showed stable performance. The bioplot graph also describes as G11 was yielded greater than the grand mean, and found around the origin. Therefore, we concluded that G11 was identified as a candidate variety to be verified in the highlands of Bale, Southeastern Ethiopia for possible release in the coming bona 2022 cropping season.

5. Recommendation

From this study it was observed that the yield of Ethiopian Mustard is highly affected by difference in genotypes, environments and their interaction,. Therefore, the Ethiopian Mustard growers must identified and select the potential areas, and varieties in order to get high grain yield as well as quality since these products are highly affected by environmental factors.

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