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AMMI, Parametric and Non-parametric Stability Analysis of Multi-Environment Yield Trials in Maize.

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Cross Mark

ABSTRACT

An ideal hybrid of the plant breeder should have both high yield and stable. Thirteen white promising maize hybrids and two commercial hybrids were examined in trial B (first stage evaluation of new maize hybrid registration for grain yield in Egypt) in 2022 season at five Agricultural Research Stations (ARS). A randomized complete block design (RCBD) with four replicates was utilized. This study aimed to identify high yield, and stable hybrids based on different stability parameters. AMMI analysis exhibited that highly significant mean squares were obtained for; locations (L) and attributed by (49.96%) from total sum of squares, genotypes (G) had (13.28%) of the total sum of squares, and G×L interaction had (21.02%) of the total sum of squares. IPCA1 and IPCA2 were highly significant and recorded 58.91% and 27.29% of (G×L) sum of squares, representing 86.2% of the interaction variation for grain yield. Also, AMMI analysis showed that the promising hybrid G-6 had high grain yield and low values of ASV, IPCA1 and IPCA2, so this hybrid is better yield stability than rest hybrids. Meanwhile, according to six parameters (CV% b_i, S^2d_i, R^2, W^2_i, P_i) and two non-parametric ($S_i^{(1)}$ and $S_i^{(2)}$) as stability parameters, the promising hybrids; G-2, G-4 and G-6 had high yield and stable of most of studied stability parameters. This study recommends moving these hybrids to the following level of evaluation in Egypt hybrid registration program

Keywords; *IPCA1, IPCA2, ASV, Stability parameters, Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) is a corer cereal whose planting has a fundamental turn in the nourishing of the world's excess inhabitant, (Katsenios *et al*. 2021). Universal predictions refer that by 2025, maize production will be the largest all over the world, and that belongings for this crop in developing countries will be multiplied by 2050 (Rosegrant *et al.* 2008). Average productivity of maize grain yield in last years is near to 5 t/ha on universal scales, while most of the developed countries achieve the mean of 8 – 9 t/ha of dry grain (Radojcic *et al*. 2018). The selection of hybrids with high yield potential coinciding with vast stability is very important objective of maize breeding program in Egypt. (Mosa *et al.* 2023). Stability and adaptability of genotypes occur by examined them in various locations and ecological areas. Different conditions in locations affect not only crop growth but also grain yield because of the regarded interactions between genotypes and environments (GEI) (Xu *et al.* 2013 and Oyekunle *et al.* 2017). Therefore, this interaction should be studied and determined before producing new hybrids for wide commercial use and adapted to new environmental conditions (Katsenios *et al*. 2021). The considered interaction between genotypes and environment complicates the explanation of the obtained results and detracts the proficiency of selecting the best genotypes (Solonechnyi *et al.* 2015 and Smith and Cullis 2018). Many stability statistics were used to divide GEI include additive main effect and multiplicative interaction (AMMI) (Gauch 1992), parametric and non-parametric approaches. All manners of stability are proper though they are depended on different precepts (Flores *et al.* 1998). There is not a standardized method can sufficiency explain genotype performance across environments. Consequently, both AMM, parametric and non-parametric approaches were utilized in this study. AMMI analysis can detect GEI in a multi-dimensional space and introduces the interaction ocularly using a biplot. Many researchers had used AMMI to analyze GEI in maize (Badu-Apraku *et al.* 2011, Oyekunle *et al.* 2017, Radojcic *et al.* 2018, Shojaei *et al.* 2021 and Katsenios *et al.* 2021). The parametric models necessitate three assumptions, i.e., normality, homogeneity of variances and additivity or linearity of effects. Example for parametric models are Wricke's (1962) Eco valance, (W_i^2) Eberhart and Russell's (1966) the regression coefficient (b_i) and deviation from regression (S^2d_i), Francis and Kannenberg's (1978) coefficient of variability (CV_i%), Pinthus's (1973) coefficients of determination (R^2), Lin and Binn's (1988) superiority index (P_i). Non-parametric models use rank interaction and not linked to specific distribution or assumptions. The interaction is used in specific environment depending upon the preference of breeder, providing useful alternative to parametric estimates. Example for such models include Nassar and Huehn (1987) ($Si^{(1)}$, $Si^{(2)}$), these parameters in analyses of stability supposed to indicate the response pattern of a genotype to a changing environment, so that, facilitate selecting a genotype suitable for specific environment. Zivanovic *et al.* (2004) an Mosa *et al.* (2021) found that the strategy that furnishes a maximal genetic amelioration in maize yield should involve instantaneous breeding for yield and stability, commencing from primary segregating generations. Delic *et al.* (2009) cleared that high

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grain yield and yield stability are not bandied aggregative. Sabaghnia *et al.* (2006) revealed that usually the low mean yielding genotypes are the most stable. Nonparametric statistical manners are standalone of any supposition about the circulation of remarks and thus can be beneficial alternatives to boilerplate conventional statistical approaches. (Sabaghnia, 2016) stated that the nonparametric approaches are simple and easy for stability analysis. Abd-Elaziz *et al*. (2020) and Mosa *et al*. (2021) used both parametric and non-parametric manners to study GEI in Egyptian hybrids of maize. This study aimed to determine grain yield stability for 15 hybrids using AMMI, parametric and non-parametric stability analysis and identify the hybrids with the high yield and stable.

MATERIALS AND METHODS

Code and name of thirteen promising white maize single crosses produced by maize breeding program at Sakha, Sids and Gemmiza Agricultural Research Stations along with two check hybrids; (SC 128 and SC 10) are presented in Table 1. These 15 hybrids were evaluated in five locations: Sakha (SAK), Gemmiza (GEM), Nubaria (NUB), Sids (SDS) and Mallawi (MALL) Research Stations in trial B in 2022 season. Trial B was the first stage evaluation of new maize hybrid registration for grain yield in Egypt. A randomized complete block design (RCBD) with 4 replications was used at each location. Plot size consisted of 4 rows, 6 m long and 0.8 m apart between rows and 0.25 cm between hills. Planting was done in hills (2-3 grains/hill), thinning to one plant/hill after twenty-one days from planting. All recommended practices were carried out at proper time. At harvest, weight of ears/plot, shelling percentage, and grain moisture were recorded. These data were utilized for calculating grain yield in tons/hectare (t/ha) adjusted at 15.5 % grain moisture.

Statistical Analysis: Additive main effects and multiplicative interaction (AMMI) analysis and stability parameters were conducted using GenStat version 19.

Table 1. Code, name and geographic origin of 15 hybrids.

Code	Name	Geographic origin
G-1	SC-Sk-155	Sakha
G-2	SC-Sk-156	Sakha
G-3	SC-Gm-1001	Gemmiza
G-4	SC-Sd-8	Sids
G-5	SC-Sd-20	Sids
G-6	SC-Sd-21	Sids
G-7	SC-Sd-22	Sids
G-8	SC-Sd-1D	Sids
G-9	SC-Sd-2D	Sids
G-10	SC-Sd-4D	Sids
G-11	SC-Sd-5D	Sids
G-12	SC-Sd-6D	Sids
G-13	SC-Sd-7D	Sids
G-14	Check SC128	Sakha
G-15	Check SC10	Sids

RESULTS AND DISCUSSION

Combined analysis of variance of AMMI for grain yield (t/ha) of 15 hybrids is presented in Table 2. Results exhibited that highly significant mean squares were obtained for locations (L) and attributed by (49.96%) from total sum of squares, meaning that locations were different in their climatic and soil conditions causing most of the variation in grain yield. The differences between genotypes (G) were highly significant and act (13.28%) of the total sum of squares, referring that genotypes were different in their performance for grain yield. The mean squares of interaction between genotypes × locations (G×L) which act (21.02%) of the total sum of squares was highly significant, meaning that mean performance of genotypes was affected by change locations. Abd-Elaziz *et al.* (2020) and Mosa *et al.* (2023) found that G, L, and (G×L) were significant for grain yield. Mosa *et al.* (2019) stated that, L, G and G×L accounted for 56.7%, 20.47% and 22.78% from total variation, respectively.

When G×L interaction was significant, further calculation of hybrids stability is possible. According to AMMI analysis, genotype × location interaction (G×L) was pointed to two interactions principal component axes (IPCA) for grain yield. Data indicated that IPCA1 and IPCA2 were highly significant and recorded 58.91% and 27.29% of (G×L) sum of squares, representing 86.2% of the interaction variation, explaining the magnitude of the interaction effect on grain yield. Gasura *et al*. (2015) found that IPCA1 and IPCA2 explained 36.8% and 29.5 % respectively.

Table 2. Combined analysis of variance of AMMI model for grain yield (t/ha) across five locations.

SOV	df	SS	%SS	MS
Locations (L)	4	479.9	49.96	119.98**
Blocks (Rep/L)	15	11.2	1.17	0.74
Genotypes (G)	14	127.6	13.28	9.11**
G×L (Interaction)	56	201.9	21.02	3.61**
IPCA 1	17	119	58.91	7.0**
IPCA 2	15	55.1	27.29	3.67**
Residuals	24	27.9	13.80	1.16
Error	210	139.9	14.56	0.67

**** indicates significance at 0.01 level of probability.**

IPCA scores, AMMI stability values (ASV) and the rank of 15 genotypes are presented in Table 3. A genotype is considered as stable if its PCA1 and PCA2 scores are near to zero (Kang, 2002).

Table 3. Mean, interaction principal component analysis scores and AMMI stability values of 15 genotypes for grain yield (t/ha) across five locations.

Genotype	Mean	IPCA 1	IPCA 2	ASV	Rank
G-1	9.7	-0.888	-0.042	1.919	13
G-2	9.441	-0.685	0.477	1.555	10
G-3	9.663	-1.195	0.032	2.581	15
G-4	10.149	0.474	0.548	1.162	8
G-5	8.651	0.074	0.005	0.16	1
G-6	9.30	0.175	0.279	0.471	4
G-7	8.986	0.388	-0.777	1.144	7
G-8	8.394	-0.065	0.411	0.434	3
G-9	8.937	0.810	-0.019	1.75	12
G-10	8.131	0.958	-0.270	2.088	14
G-11	7.803	-0.090	-1.228	1.244	9
G-12	9.215	0.670	0.632	1.58	11
G-13	9.189	0.141	0.081	0.316	2
Check SC128	9.81	-0.353	0.340	0.835	5
Check SC10	9.82	-0.415	-0.471	1.013	6
Grand mean	9.15	-	-	-	-
LSD	0.52	-	-	-	-

(IPCA) interaction principal component analysis and (ASV) AMMI stability value.

ASV is the distance from zero in a two-dimensional scatterplot of IPCA1 score against IPCA2, and the hybrid with the least ASV value is the most stable (Purchase *et al.* 2000). Consequently, G-5, G-13, G-8 and G-6 showed the least values of ASV, and their IPCA1 and IPCA2 scores. So, these genotypes were the most stable respectively. The perfected genotype should have the highest grain yield and the lowest values for both ASV and IPCA's. These results showed that the genotype G-6 had grain yield > grand mean and not significant than two checks SC10 and SC 128 and showed low values of ASV and IPCA's, so this genotype is better yield stability than the rest of genotypes. Genotypic stability is conclusive in addition to grain yield (Naroui *et al.* 2013). Stability should be marked in combination with yield (Farshadfar 2012).

As per the biplot of mean grain yield (t/ha) and the first interaction principal component (Figure 1), G-4 gave the highest mean yield (10.15 t/ha), followed by SC10 (9.82 t/ha), SC128 (9.81 t/ha), G-1 (9.70 t/ha), and G-3 (9.66 t/ha). H-5 was the most stable genotype with an IPC1 score near to zero compared to the other genotypes. The IPC1 values of G-13, G-6 and G-8 were not very far away from the zero axis, while G-10, G-9, G-3 and G-1 had maximum values of IPC1 and were marked as not stable. On environments, MAL had IPC1 value near to zero and near to the mean yield (9.64 t/ha). Sakha location had the highest mean yield (11.36 t/ha) and its IPCA1 value was very far from zero axis, while, NUB location had the lowest (7.96 t/ha).

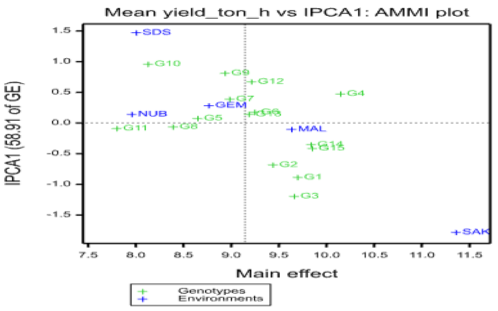

Figure 1. The relationship between mean grain yield (t/ha) and IPCA1 for 15 genotypes of maize assessed under 5 environments.

Data in Table 4. Shows environmental index for grain yield which calculated by subtracting mean over locations from the location mean. SAK and MAL were the most favorable locations which gave the highest mean grain yield. While, GEM, SDS and NUB were the lowest yielding locations. This informs those hybrids behaved differently from one location to another. This result is agreement with Abd-Elaziz *et al.* (2020).

Table 4. Environmental index for grain yield (t/ha) at five locations

Location	Mean (t/ha)	Environmental index
SAK	11.36	2.22
GEM	8.76	-0.38
SDS	8.00	-1.14
MAL	9.63	0.49
NUB	7.96	-1.18
Grand mean	9.15	-

SAK= Sakha, GEM= Gemmiza, NUB= Nubaria, SDS= Sids, MAL= Mallawy.

Stability parameters of the 15 genotypes for grain yield are presented in Table 5. Stable genotypes which have low CV% (<20%) according to Francis and Kannenberg (1978). So, the genotypes: G-4, G-5, G-6, G-7, G-8, G-9, G-10, G-12 and G-13 were stable. While, G-1, G-2, G-3, G-11, SC 128 and SC10 were unstable. Abd-Elaziz *et al.* (2020) and Mosa *et al.* (2021) indicated similar results in maize genotypes.

Based on the regression coefficient b_i and deviation from regression (S^2d_i) according to Ebrhart and Russell (1996), only five genotypes: G-5, G-8, G-11, G-13 and SC128 can be considered stable whereas they had b_i close to (1.0). Meanwhile for deviation from regression (S^2d_i), the genotypes: G-1, G-2, G-4, G-5, G-6, G-8, G-9, G-13, SC128 and SC10 had S^2d_i values lower than mean of S^2d_i, so these genotypes could be considered stable.

Depending on coefficient of determination R^2 (Pinthus 1973), the genotypes: G-1, G-2, G-3, G-5, G-8, G-13, SC128 and SC10 were stable because they had R^2 values close to 1 or (>80%).According to the eco-valence W_i^2 of Wricke (1962), the genotypes with the smallest W_i^2 values compared to W_i^2 average are considered stable. Hence, genotypes: G-4, G-5, G-6, G-8, G-13, SC128and SC10 are considered stable.

Table 5. Estimates of parametric and nonparametric stability statistics of 15 hybrids for grain yield(t/ha) across five environments.

Genotype	Mean	CV(%)	b_i	S^2d_i	R^2	W_i	P_i	$S_i^{(1)}$	$S_i^{(2)}$
G-1	9.70	24.62	1.64	2.22	0.95	40.87	10.23	2.00	16.50
G-2	9.44	23.73	1.52	3.21	0.92	33.71	11.89	0.70	7.00
G-3	9.66	29.43	1.95	4.19	0.94	82.28	13.65	2.90	34.75
G-4	10.15	11.04	0.65	3.28	0.68	22.95	6.42	1.50	8.00
G-5	8.65	17.03	1.02	-0.59	0.97	2.78	24.48	0.80	2.75
G-6	9.30	12.19	0.71	1.51	0.80	14.93	16.94	2.10	15.75
G-7	8.98	13.69	0.65	6.48	0.56	32.69	24.61	1.40	18.50
G-8	8.39	17.08	0.96	0.98	0.90	7.54	31.17	0.90	4.00
G-9	8.94	7.49	0.35	0.92	0.55	37.67	25.77	1.50	16.25
G-10	8.13	14.35	0.45	9.99	0.30	56.25	43.45	2.30	24.75
G-11	7.80	25.68	1.15	15.19	0.65	51.60	52.14	2.30	23.50
G-12	9.21	10.23	0.47	3.77	0.51	35.70	18.81	2.80	22.75
G-13	9.19	14.10	0.91	-1.19	0.98	1.53	15.16	0.60	2.50
Check SC128	9.81	17.91	1.18	2.13	0.90	13.35	7.51	1.20	6.00
Check SC10	9.82	20.41	1.37	2.22	0.92	20.85	7.63	1.40	7.25
Mean	9.15	17.26	1.00	3.62	0.77	30.31	20.66	1.63	14.02

The genotypes: G-1, G-2, G-3, G-4, G-6, G-12, G-13, SC128 and SC10 were stable because they had the lowest values of superiority index (P_i) compared to the average. Mosa *et al.* (2019) and Shojaei *et al.* (2021) reported similar results.Based on the mean absolute rank difference of genotypes across environments $S_i^{(1)}$ the lowest $S_i^{(1)}$ values (compared to $S_i^{(1)}$ average) refers to the most stable genotype (Huehn, 1990). Consequently, genotypes: G-2, G-4, G-5, G-7, G-8, G-9, G-13, SC128 and SC10 were considered stable compared to $S_i^{(1)}$ average. In addition, the variance between the ranks across environments $S_i^{(2)}$ according to (Huehn, 1990), whereas genotypes with the smallest $S_i^{(2)}$ values compared to $S_i^{(2)}$ average were considered stable. So, G-2, G-4, G-5, G-8, G-13, SC128 and SC10 were stable. In general, breeders search about hybrids with both high yield and good static stability. Hence from previous mentioned results the promising hybrids G-2, G-4 and G-6 had high grain yield (not significant than two checks) and stable for most studied parameters so, these hybrids should be moved to next evaluation stage according to maize registration protocol in Egypt.

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تحليل الثبات باستخدام AMMI والمقاييس البارامترية واللابارامترية لتجارب البيئات المتعددة لمحصول الذرة الشامية

محمد المهدي محمد عبدالعظيم ، يسرا عبد الرحمن جلال ، رفيق حليم عبدالعزيز السباعي ، أشرف كمال مصطفى ، محمد عبد العزيز عبد النبي عبد العزيز وموسي سيد رزق

قسم بحوث الذرة الشامية – معهد بحوث المحاصيل الحقلية – مركز البحوث الزراعية – مصر

الملخص

يهتم مربي النبات بالهجين الذي يجمع بين المحصول العالي والثبات. تم تقييم 13 هجين جديد مع اثنين من هجن المقارنة في مرحلة التقييم (B) خلال موسم 2022 في خمس محطات بحثية باستخدام تصميم القطاعات الكاملة العشوائية في أربع مكررات. وكان الهدف من هذه الدراسة تحديد أفضل الهجن التي تجمع بين المحصول العالي والثبات باستخدام مقاييس ثبات مختلفة. أظهر تحليل AMMI أن التباين الراجع إلي البيئات والهجن والتفاعل بينها لصفة المحصول كان عالي المعنوية، وتمثل الإختلافات بين البيئات 49.96% والإختلافات بين الهجن 13.28% والإختلافات الراجعة للتفاعل بين الهجن والبيئات 21.02% وذلك من إجمالي الإختلافات كما كان تباين كلا من IPCA1 , IPCA2 عالي المعنوية وتمثل الإختلافات الراجعة لكل منهما 58.91% و 27.29% علي التوالي من إجمالي الإختلافات الراجعة للتفاعل بين الهجن والبيئات. بناءا علي تحليل AMMI كان الهجين G-6 هو أفضل الهجن لأنه يجمع بين المحصول العالي والثبات حيث أنه أظهر أقل قيم في IPCA1, IPCA2, ASV . وبناءا علي مقايس الثبات الأخري ($CV\%$ b_i, S^2d_i, R^2, W^2_i, P_i, $S_i^{(1)}$, $S_i^{(2)}$) كانت الهجن G-2, G-4, G-6 هي الأكثر ثباتا في معظم المقاييس المدروسة وذات محصول عالي ولذلك يتم تصعيد هذه الهجن لمراحل التقييم التالية في البرنامج المصري لتسجيل الهجن.