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GENOTYPE × ENVIRONMENT INTERACTION AND STABILITY ANALYSIS FOR GRIAN YIELD IN SOME WHITE MAIZE (*ZEA MAYS* L.) HYBRIDS.

BY

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ABSTRACT

Genotypes showing stable grain yield under varying environments may be useful in a breeding programme for direct release as a commercial variety or for evolving high yielding maize genotypes well adapted to a wide range of macro-environments. Twelve white maize single crosses (denoted here as G1, G2, G3, G4, G5, G6, G7, G8, G9, G10, G11, and G12) developed at Giza Research Station, Agriculture Research Center, along with two commercial white check hybrids, *i.e.* SC10 and SC129 were field evaluated in replicated mega-environment trials (METs) at nine locations *i.e.*, Behaira (Env1), Kafr El Seikh (Env2), Dakahlia (Env3), Monofia (Env4), Sharkia (Env5), Beni Suief (Env6), Minia (Env7), Assuit (Env8), and Sohag (Env9) to test genotype × environment interaction (GEI) for some newly developed white maize hybrids and to estimate their yield stability under different METs conditions. Randomized complete block design (RCBD) with six replications was the design used. Each of these nine environments was considered as an independent environment in the statistical analysis. Significant differences among genotypes, environments, and GEI were detected. Partitioning of G x E interaction into G x E (linear) and pooled deviations (non-linear) revealed significance of both types when tested against pooled error, indicating that both components contributed for G × E interaction. Genotype × environment (linear) component was not significant when tested against pooled deviation from regression indicating equal importance of both predictable and unpredictable interactions in these materials. Regression coefficients of all the genotypes were not significantly different from unity. Coefficient of determination (R^2) values ranged from 0.65 to 0.96 for grain yield, suggesting a large portion of variation was existed. Single cross SC10 (check) had the highest value of regression coefficient and average grain yield more than the general mean, indicating its response to favorable conditions and improved environments. In contrary, G10 would be especially good for unfavorable environments. Single cross (G2) had the highest yield (32.00 ardabs feddan^{-1}), a regression coefficient similar to unity (b_i = 1.11), and small insignificant deviation from regression (S^2d_i = 10.13). In addition, its R^2 value was 0.94, confirming its stability. Single cross (G2) should be released as a commercial hybrid.

Key words: *Zea mays*, Maize, corn, Grain Yield, Stability Analysis, Genotype × Environment.

INTRODUCTION

Gene expression is subjected to modification by the environment; therefore, genotypic expression of the phenotype is environmentally dependent (Kang, 1998). Genotypes showing stable grain yield under varying environments may be useful in a breeding program for direct release as a commercial variety or for evolving high yielding maize genotypes well adapted to a wide range of macro-environments. Yield trial is one of the most common experiments in agricultural research, typically testing a number of genotypes in a number of environments. The improved maize genotypes are evaluated in mega-environment trials (METs) to test their performance across different environments and to select the best genotypes in specific environments. Multi environment trials are important in agronomy and plant breeding studies because they aim (i) to estimate and predict yield with high precision, (ii) to determine yield stability and patterns of response in the environment, and (iii) to select the best genotype to be sown in future years and new localities (Crossa, 1990).

In most cases, genotype × environment interaction (GEI) is observed, complicating selection for improved yield. Some genotypes may perform well in certain environments, but fail in several others. The most widely used method to evaluate the phenoltypic stability is the regression method, based on regressing the mean value of each genotype on the environmental index or marginal means of environments (Romagosa and Fox, 1993; Tesemma *et al.*, 1998). Eberhart & Russel (1966) investigated a model to test the stability of varieties under different environments. They defined a stable variety as having a unit regression over the environments (b_i= 1) and minimum deviation from the regression (S^2d_i= 0). Therefore, a variety with a high mean yield over the environments, unit regression coefficient (b_i=1), and deviation from regression as small as possible (S^2d_i= 0), will be a better choice as a stable variety.

Genotype x environment interaction was studied by different researchers in various crops (Singh *et al.*, 1987; Jain and Pandya 1988; Rao and Suryawanshi 1988; Ashraf *et al.*, 2001; Zubair and Ghafoor, 2001). Also, stability parameters have also been studied in maize for measuring phenotypic stability (Scapim *et al.*, 2000; Worku *et al.*, 2001; Rasul *et al.*, 2005 and Soliman, 2006), but these parameters are still very important informations that should be available for the forth-coming maize hybrids. Therefore, the present investigation aimed at evaluating the GEI for some newly developed white maize hybrids and to estimate their yield stability under different METs conditions.

MATERIALS AND METHODS

Twelve white maize single crosses developed at Giza Research Station, Agriculture Research Center, which have been denoted as G1 to G12, along with two comercial white check hybrids, *i.e.* SC10 and SC129 were field evaluated in replicated METs at nine locations *i.e.* Behaira (Env1), Kafr El Seikh (Env2), Dakahlia (Env3), Monofia (Env4), Sharkia (Env5), Beni Suief (Env6), Minia (Env7), Assuit (Env8), and Sohag (Env9), during the summer season of 2008. Each location was considered as a macro-environment. Randomized complete block design (RCBD) with six replications was used. Each cross was planted in a 4-row plot, 6 m long and 0.8 m apart. Planting was done in hills spaced 0.25 m along the row. Two kernels were planted per hill and then thinned to one plant per hill prior to the first irrigation, giving a plant density of approximately 22000 plants $feddan^{-1}$ (Feddan = 4200 m^2). All cultural practices were applied as recommended at the proper time. At maturity, ears of the two central rows of each plot was harvested, weighed and a sample of 5 kg $plot^{-1}$ were taken for measuring moisture percentage. Grain yield was adjusted to 15.5% moisture content and recorded in ardabs/feddan, where one ardab = 140 kg. Each of these nine environments was considered as an independent environment in the statistical analysis.

Analysis of variance (ANOVA) for each environment and combined analysis of variance across environments were computed for grain yield. Bartlett's test according to Gomez and Gomez (1984) was also computed to test the homogeneity of variances prior to combined analysis. Stability of yield performance of each genotype was calculated by regressing the mean yield if individual genotype on environmental index and calculating the deviation from regression as suggested by Eberhart and Russell (1966). However, regression coefficient (bi) was considered as an indication of the response of the genotype to varying environments while mean square for deviation from regression (s^2di) was used as the criterion of stability as suggested by Becker and Leon (1988). According to this model, an ideal genotype should have high mean (μ > X), a unit regression coefficient (b_i=1) and no deviation from linearity (S^2d_i = 0). The basic model for the Eberhart and Russel (1966) model is shown as follows:

$Yij = \mu i + bii + Ij + \delta ij$, where

Yij= genotypic mean of the ith genotype at the jth environment.

μi= mean of the ith genotype over all environments.

bi= regression coefficient which measures the response of ith genotype to environments

Ij= environmental index as mean of all genotypes at jth environment minus the overall mean, and

δij= deviation from regression coefficient of ith genotype at jth environment.

The regression coefficients (b_i) were tested for significant difference from unity using "t test", while the significance of the deviations from regression (S^2di) from zero was tested by the "F test". Coefficient of determination (R^2) was computed for each genotype by individual linear regression analysis (Pinthus, 1973). All statistical analyses were performed using the SAS (Statistical Analyses Systems) program (SAS Institute, 1999).

RESULTS AND DISCUSSION

Analysis of variance for grain yield revealed significant differences ($P < 0.01$) among the genotypes (G), and environments (E). Test of homogeneity of the error mean squares across all environments indicating the possibility of conducting combined analysis. Hence, the combined analysis was performed in this study. Combined analysis also revealed that tested genotypes differed significantly from an environment to another (Table 1). Significant differences among the testing environments, and genotypes × environments interactions (GEI) were also detected (Table 1). In this regard, Eberhart and Russell (1966), and Freeman and Perkins (1971) documented that the main cause of the differences among genotypes in their yield stability trials was the wide occurrence of GEI. Thus, maize breeders should breed to develop high yielding and more uniform hybrids under varied environmental conditions. The presence of significant GEI showed the inconsistency of maize genotypes performance across the testing environments and advocating the adequacy of stability analysis. Partitioning of GEI into G x E (linear) and pooled deviations (non-linear) revealed significance of both effects when tested against pooled error, indicating that both components contributed for GEI. Similar results in maize have been reported by Scapim *et al.* (2000), Worku *et al.* (2001), Rasul *et al* (2005), and Soliman (2006). Genotype × environment (linear) component was non significant when tested against pooled deviation from regression indicating the equal importance of both predictable and unpredictable interaction in these materials. These results are in conformity with the findings of Chaudhary *et al.* (1994) in field pea and Worku *et al.* (2001) in maize.

Based on the combined data, grain yield of all crosses ranged from 28.67 ardabs feddan^{-1} (G11) to 32.00 ardabs feddan^{-1} (G2) with an average of 30.62 ardabs feddan^{-1} (Table 2). Three crosses (G2, G1, and G5) were superiors and surpassed the highest check hybrid SC10 (31.56 ardabs feddan^{-1}). These crosses did not differ significantly from the commercial check hybrid SC10. Coefficients of variation (CV %) were below 15% at all environments. In this regard, Abd El-Aziz (2000) and Soliman (2006) found that the differences in mean performance of a particular set of genotypes were considered to be mainly due to the use of those new improved varieties or hybrids, the differences among environments, and could be attributed to the farmer factor, as well as, the variation in soil fertility.

The environmental index for each environment was calculated as the difference between the environment mean and the mean over all environments. Estimates of environmental index (Table 3) showed that Kafr El Sheikh was the most favorable environment, which was linked to the highest grain yield, while Sharkia was the poorest yielding environment. This suggests that the performance of the tested genotypes varied from one environment to another. Environmental means revealed that Kafr El Sheikh (Env2) had the highest environmental average (36.79 ardabs feddan^{-1}), while Sharkia had the lowest average (23.97 ardabs feddan^{-1}) (Table 2).

Table (1): Analysis of variance (ANOVA) for stability of grain yield for the 14 maize crosses evaluated at 9 locations in 2008 season.

Source of variation	Df	Sum of squares	Mean squares
Genotype (G)	13	848.61	65.28**
Environments (E)	8	12766.01	1595.75**
G × E	104	2605.38	25.05**
Environment + (G × E)	112	15371.39	137.24**
E (linear)	1	12716.06	12716.06**
G × E (linear)	13	293.67	22.59**
Pooled deviation	98	2361.66	24.10**
G1	7	187.60	26.80**
G2	7	70.94	10.13
G3	7	144.93	20.70**
G4	7	257.69	36.81**
G5	7	115.15	16.45*
G6	7	157.84	22.55**
G7	7	68.05	9.72
G8	7	27.25	3.89
G9	7	176.98	25.28**
G10	7	225.12	32.16**
G11	7	86.27	12.32
G12	7	198.46	28.35**
SC10	7	256.50	36.64**
SC129	7	388.87	55.55**
Pooled error	585	3909.14	6.68

* Significant at the 0.05 probability level. ** Significant at the 0.01 probability level.

Table (2): Average grain yield (ardabs feddan^{-1}) of 14 maize crosses evaluated at 9 environments (Env) in 2008 season.

Cross	Env 1	Env 2	Env 3	Env 4	Env 5	Env 6	Env 7	Env 8	Env 9	Average
G1	35.59	40.42	34.95	34.74	26.43	26.84	29.44	31.96	27.28	31.96
G2	37.95	39.22	33.76	36.41	25.57	27.47	30.19	29.10	28.30	32.00
G3	32.14	36.25	33.38	34.56	24.90	25.86	28.94	25.44	24.14	29.51
G4	32.80	41.20	32.92	32.33	23.24	23.01	29.49	28.78	25.66	29.94
G5	33.54	37.47	34.38	37.01	24.17	28.60	29.19	26.75	32.99	31.57
G6	31.99	39.11	33.19	33.88	22.53	23.50	30.54	29.93	29.94	30.51
G7	31.98	36.30	32.44	34.11	24.83	28.02	29.02	26.07	26.67	29.94
G8	32.17	34.58	30.51	33.04	23.40	26.06	28.72	24.93	28.49	29.10
G9	33.84	35.68	33.28	33.53	22.59	28.97	30.83	25.50	25.35	29.95
G10	35.59	31.53	35.47	34.83	25.94	26.68	28.47	30.81	31.40	31.19
G11	31.37	34.06	30.45	36.43	20.40	23.17	28.10	26.55	27.53	28.67
G12	33.23	35.53	32.49	38.78	24.32	26.17	31.64	27.91	33.66	31.53
SC10	36.78	42.53	31.09	36.75	24.55	27.01	27.48	25.92	31.92	31.56
SC129	36.79	31.13	34.22	36.54	22.68	26.71	31.07	28.06	33.93	31.24
Env. Average	33.98	36.79	33.04	35.21	23.97	26.29	29.51	27.69	29.09	30.62
LSD $_{0.05}$	3.50	3.20	2.52	2.65	3.89	3.40	2.44	2.27	2.52	1.17
CV%	8.93	7.54	6.71	6.54	14.08	11.23	7.18	7.10	7.50	10.08

Table (3):Estimates of environmental index for grain yield at 9 locations.

Environment	Environmental index
Behaira (Env1)	3.36
Kafr El Sheikh (Env2)	6.17
Dakahlia (Env3)	2.42
Monofia (Env4)	4.59
Sharkia (Env5)	-6.65
Beni Suief (Env6)	-4.33
Minia (Env7)	-1.11
Assuit (Env8)	-2.93
Sohag (Env9)	-1.53
∑	0

In the present investigation, the simultaneous consideration of the three stability parameters for the individual genotype revealed that the regression coefficients of all genotypes were not significantly different from unity. Therefore, the stable performance of the genotypes in this case is predicted on the basis of the other two parameters, *i.e.*, deviation from regression and average yield over all the environments (Zubair *et al.*, 2002). Out of the 14-evaluated crosses, 10 crosses had significant deviation mean squares from linear regression, implying that these genotypes were unstable across environments (Table 4). Single cross SC129 (check) had the highest S^2d_i value, indicating its sensitivity to environmental changes and an unpredictable grain yield (Eberhart and Russel, 1966), while the lowest value was coupled to G8. The coefficient of determination (R^2) values ranged from 0.65 to 0.96 for grain yield, suggesting that a large portion of variation for this trait could be attributed to linear regression on environmental index. Similar results had been reported in maize by Worku *et al.* (2001). Single cross SC10 (check) had the highest value of regression coefficient (b_i = 1.29) and had average grain yield more than the general mean (31.56 ardabs feddan^{-1}) indicating its high performance under favorable conditions and improved environments. Single cross (G10) would be especially good for unfavorable environments. Hence, it had greater grain yield than the average grain yield of all tested genotypes, and lower value of regression coefficient (b_i = 0.68). Single cross (G2) had the highest yield (32.00 ardabs feddan^{-1}), a regression coefficient close to unity (b_i = 1.11), and small insignificant deviation from regression (S^2d_i = 10.13). In addition, its R^2 value was 0.94, confirming its stability. Thus, this cross considered the most stable cross for grain yield according to Finlay and Wilkinson, 1963; Eberhart and Russell, 1966.

Table (4): Mean grain yield (ardabs feddan^{-1}), regression coefficient (b_i), mean square deviation (S^2di) and Coefficient of determination (R^2) for 14 maize crosses evaluated at 9 environments.

Crosses	Mean	b_i	S^2di	R^2
G1	31.96	1.01	26.80**	0.83
G2	32.00	1.11	10.13	0.94
G3	29.51	0.99	20.70**	0.86
G4	29.94	1.20	36.81**	0.84
G5	31.57	1.00	16.45*	0.90
G6	30.51	1.10	22.55**	0.88
G7	29.94	0.86	9.72	0.91
G8	29.10	0.86	3.89	0.96
G9	29.95	0.96	25.28**	0.82
G10	31.19	0.68	32.16**	0.65
G11	28.67	1.12	12.32	0.93
G12	31.53	0.95	28.35**	0.81
SC10 (check)	31.56	1.29	36.64**	0.86
SC129 (check)	31.24	0.87	55.55**	0.64
Mean	30.62	1		0.85
$LSD_{0.05}$	1.17			

* Significant at the 0.05 probability level. ** Significant at the 0.01 probability level.

It could be concluded that response levels of most of genotypes differed for stability parameters. Genotype (G2) showed a stable performance under different environments, giving the highest grain yield, non-significant unit regression coefficient, and also exhibited low insignificant deviations from regression. Thus, this single cross (G2) should be released as a commercial hybrid.

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دراسة التفاعل بين التراكيب الوراثية والبيئة والثبات المظهرى لمحصول بعض هجن الذرة الشامية البيضاء

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يمكن الإستفادة من التراكيب الوراثية التى تتميز بالثبات المظهرى عبر العديد من البيئات الاختبارية بأنه يمكن استخدامها مباشرة كأصناف تجارية أو فى برامج التربية لاستنباط أصناف متميزة من الذرة الشامية تتسم بالثبات المظهرى العالى. تم زراعة ١٢ هجين فردى أبيض بالإضافة إلى هجينين اختبارين هما هجين فردى أبيض ١٠ و ١٢٩ فى تسع بيئات اختبارية بمحافظات البحيرة، كفر الشيخ، الدقهلية، المنوفية، الشرقية، بنى سويف، و المنيا، أسيوط و سوهاج باستخدام تصميم القطاعات كاملة العشوائية فى ست مكررات بكل بيئة وذلك لتقدير قيمة التفاعل بين هذه التراكيب الوراثية. و البيئات الاختبارية و تقدير الثبات المظهرى لهذه الهجن. وقد أظهرت النتائج معنوية الهجن والمواقع والتفاعل بين الهجن والمواقع المختلفة. وبتقسيم التفاعل بين الهجن والمواقع الى الهجن فى المواقع (التفاعل الخطى) والإنحراف القياسى (التفاعل غير الخطى) أظهرت النتائج معنوية كلا منهما وهذا يدل على أن كل منهما يتأثر بالتفاعل بين الهجن والبيئة. التفاعل بين الهجن والمواقع (الخطى) أظهر عدم معنوية عند إختباره على أساس الإنحراف القياسى للانحدار وهذا يدل على أن الأهمية متساوية بين التفاعل للهجن مع المواقع. أظهرت قيم معامل الانحدار لكل الهجن عدم معنوية الوحدة وكانت قيمة معامل التحديد R^2 تتراوح مابين ٦٥ر. إلى ٩٦ر. للمحصول. واظهر هجين المقارنة هجين فردى ١٠ (هجين اختبارى) قيمة عالية لمعامل الانحدار والمحصول أكثر من المتوسط العام مما يدل على ان هذا الهجين يتميز فى البيئات الجيدة والتى تتوافر فيها الظروف المثلى وعلى النقيض كان التركيب الوراثى رقم ١٠ مناسب للبيئات غير الجيدة التى تتميز بعدم توافر الظروف المثلى. أعطى الهجين رقم ٢ أعلى محصول (٣٢ اردب/فدان) ومعامل الانحدار مقارب للواحد الصحيح (b_i= ١,١١) وقيمة قليلة غير معنوية للإنحدار القياسى (S^2d_i= ١٠,١٣). وكذلك اظهر هذا الهجين قيمة R^2 وكانت ٩٤ر. مما يدل على تميز هذا الهجين محصولا و ثباتاً عبر كل البيئات الإختبارية.