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YIELD STABILITY AND RELATIONSHIPS AMONG PARAMETERS IN MAIZE

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ABSTRACT

Producing high yielding maize (*Zea mays* L.) hybrids well-adapted to many environments is the most important goal of the National Maize Research Program in Egypt. Genotype x environment interaction (GEI) continues to be a major challenging issue to plant breeders and production agronomists. The objective of this study was to identify maize hybrids with stable and high yield performance across different location under Egyptian conditions. Five yellow single crosses (SC Sk-149, SC Sk-150, SC Sk-151, SC Gm-111 and SC Gz-312); three red single crosses (SC Sk-1 Red, SC Sk-2 Red and SC Sk-3 Red); and two yellow commercial hybrids (SC 162 and SC 168) were evaluated at five sites in Egypt. Stability parameters for grain yield were performed to estimate both regression coefficient (b_i), deviation from regression (S^2d_i) and coefficient of determination (R^2). Results showed that mean squares due to environments (E), hybrids (H) and their interaction (H × E) were significant, or highly significant for all traits. The best hybrids were SC Sk-3 Red for earliness, SC Gm-111 for highest plant; and SC Sk-149 and SC Sk-2 Red for resistance to late wilt disease. Superiority percentage for grain yield of two yellow promising crosses SC Gm-111 (22.78 and 19.69%) and SC Sk-150 (11.00 and 8.21%) were significantly out yielded the two checks SC 162 and SC 168, respectively. Four hybrids can be considered stable for grain yield based on the regression coefficient; as well as five hybrids based on deviation from regression and eight hybrids depending on coefficient of determination. Hybrids SC Sk-150 and SC Gm-111 had high grain yield and stable for R^2. Mean grain yield was significant and positively correlated with S^2d_i; but not significant with b_i and R^2. Also, R^2 was significant and negatively correlated with S^2d_i, but not significant with b_i also b_i or with S^2d_i.

Key Words: Adaptation, single cross, *Zea mays*

RÉSUMÉ

La production d'hybrides de maïs à haut rendement (*Zea mays* L.) bien adaptés à de nombreux environnements est l'objectif le plus important du programme national de recherche sur le maïs en Égypte. L'interaction génotype x environnement (GEI) continue d'être un défi majeur pour les sélectionneurs de plantes et les agronomes de production. L'objectif de cette étude était d'identifier des hybrides de maïs avec des performances stables et à haut rendement à différents endroits dans les conditions égyptiennes. Cinq croix simples jaunes (SC Sk-149, SC Sk-150, SC Sk-151, SC Gm-111 et SC Gz-312); trois croix simples rouges (SC Sk-1 Red, SC Sk-2 Red et SC Sk-3 Red); et deux hybrides commerciaux jaunes (SC 162 et SC 168) ont été évalués sur cinq sites en Égypte. Les paramètres de stabilité du rendement en grain ont été calculés pour estimer à la fois le coefficient de régression (bi), l'écart par rapport à la régression (S^2d_i) et le coefficient de détermination (R^2). Les résultats ont montré que les carrés moyens dus aux environnements (E), aux hybrides (H) et à leur interaction (H × E) étaient significatifs ou hautement significatifs pour tous les caractères. Les meilleurs hybrides étaient SC Sk-3 Red pour la précocité, SC Gm-111 pour la plante la plus haute ; et SC Sk-149 et SC Sk-2 Red pour la résistance au flétrissement tardif. Le pourcentage de supériorité pour le rendement en grains de deux croisements jaunes prometteurs SC Gm-111 (22,78 et 19,69 %) et SC Sk-150 (11,00 et 8,21 %) a été significativement supérieur aux deux témoins SC 162 et SC 168, respectivement. Quatre hybrides peuvent être considérés comme stables pour le rendement en grain sur la base du coefficient de régression ; ainsi que cinq hybrides basés sur l'écart par rapport à la régression et huit hybrides en fonction du coefficient de détermination. Les hybrides SC Sk-150 et SC Gm-111 avaient un rendement en grain élevé et stable pour R^2. Le rendement moyen en grain était significatif et positivement corrélé avec S2di ; mais non significatif avec bi et R^2. De plus, R^2 était significatif et corrélé négativement avec S2di, mais non significatif avec b_i aussi b_i ou avec S^2d_i.

Mots Clés : Adaptation, croisement simple, *Zea mays*

INTRODUCTION

Producing high yielding maize hybrids and well-adapted to many environments is the most important goal of the National Maize Research Program in Egypt. Genotype x environment interaction (GEI) continues to be a major challenging issue to plant breeders and production agronomists. When genotypes are evaluated over a series of environments, and whenever interaction is significant, the use of overall genotype means across environments becomes questionable. Karimizadeh *et al.* (2012) stated that genotype x environment interactions (GEI) have assumed importance in plant breeding programmes because the yield performance of a genotype is the result of genotype, environment and their interaction. Khalil *et al.* (2010) and Maqbool *et al.* (2019) stated that selecting appropriate and productively stable maize hybrids for cultivation is an effective solution for increasing the grain yield of maize. Moreover, we can select ideal maize hybrids in diverse sites by evaluating genotype and environment interaction (GEI) and their stability.

Several parameters have been proposed to characterise yield stability when genotypes are tested across multiple environments, with each parameter giving different results (Temesgen *et al.*, 2015). Becker and Leon (1988) distinguished between two different concepts of stability; static stability and dynamic stability. A genotype is said to exhibit static stability when its performance is unchanged with respect to varying environments, thus implying that the variance of yield or other relevant traits over environments is low. Dynamic stability, has on the other hand, to do with a genotype showing predictable response to environments, and thus showing small deviations from its expected response in the testing environments. The stability statistics *per se* are not informative and useful in selection unless they are integration with yielding capacity.

Thus, efforts have been made to combine yield and stability parameters (Kang and Pham, 1991; Kang, 1993). Zivanovic *et al.* (2004) reported that a strategy that provides a maximal genetic improvement in maize yield must include simultaneous breeding for yield and stability, starting from initial segregating generations. Several other researchers (Tollenaar and Lee 2002; Delic *et al.,* 2009; Mosa *et al.,* 2019; Sedhom *et al.,* 2021) reported that the high grain yield and yield stability are not mutually exclusive in determining selected genotypes. Mosa *et al.* (2021) found that simultaneously identifying for high grain yield and stability can be helpful in selecting good hybrids in a plant breeding programme.

The objective of this study was to identify maize hybrids with stable and high yield performance across different location under Egyptian condition and to study the relationships among stability parameters.

MATERIALS AND METHODS

Eight promising hybrids, *i.e.* five yellow single crosses (SC Sk-149, SC Sk-150, SC Sk-151, SC Gm-111 and SC Gz-312); and three red single crosses (SC Sk-1, SC Sk-2 and SC Sk-3) produced by the maize breeding programme at Sakha (Sk), Gemmiza (Gm) and Giza (Gz) Agriculture Research Stations in Egypt, plus two checks, *i.e.* yellow SC 162 and SC 168, were considered for this study. These hybrids and two yellow commercial hybrids were evaluated at five locations in Egypt; i.e., Sakha, Gemmiza, Sids, Mallawy and Nubaria Agriculture Research Stations in 2021 season.

A randomised complete block design (RCBD), with four replications was used. Each plot consisted of four rows; 80 cm apart, with row length of 6 m. Hand-sowing was done in hills spaced 25 cm along the row. All recommended agricultural practices for maize were done throughout the growing season.

Data were recorded for number of days to 50% silking, plant height, measured on 50 guarded plants from ground to the point of flag leaf insertion after flowering period, resistance to late wilt (data were recorded for percentage of resistant plants to late wilt disease at the age 35 days after 50% silking) and grain yield in per hectare (t ha^{-1}) estimated from 50 guarded plants. Yield was adjusted at 15.5% grain moisture on the internal two rows of each plot.

At each location, the statistical analysis by RCBD was done and the combined analysis across 5 locations or environments (E) was done after the homogeneity test, according to Snedecor and Cochran (1967). Calculation of analysis of variances and Fisher's protected LSD test were carried out using the statistical analysis system (SAS-institute Inc. 1999).

Superiority percentage relative to check for grain yield was estimated following the method of Mather and Jinks (1982). Once ANOVA revealed that hybrids (H) and environments (E) and H×E interaction (HEI) were significant, stability parameters; regression coefficient (b_i) and deviation from regression (S^2d_i), by Eberhart and Russell (1966); and coefficient of determination (R^2) by Pinthus (1973) were performed for grain yield. Estimation of Stability parameters were performed using GEA-R (2017).

RESULTS AND DISCUSSION

The results of the combined analysis of variance for number of days to 50% silking, plant height, resistance to late wilt, and grain yield for the ten hybrids are presented in Table 1. The differences among locations were significant or highly significant. Also, similarly highly significant differences were observed among hybrids for all traits, indicating that these locations differed significantly in their environmental conditions. Also, these hybrids differed from one to the other.

The highly significant differences of the interaction between hybrids x environments were detected for all traits, indicating that these hybrids tended to score differently for all traits at different environments; and also valid of stability analysis. These results are agreement with those of Sowmya *et al.* (2018), Mosa *et al.* (2019, 2021) and El-Hosary (2020).

Mean performance of eight promising hybrids and two checks under five locations for number of days to 50% silking, plant height, resistance to late wilt and grain yield (t ha^{-1})

are shown in Table 2. For number of days to 50% silking, the earliest promising cross was SC Sk-3 Red (60.10 days), while the latest yellow promising cross was SC Sk-149 (64.50 days). All crosses, except SC Sk-149, were significantly earlier than the best check hybrid, SC-168. Plant height ranged from 214.45 cm for the cross SC Sk-3 Red to 272.70 cm for the cross SC Gm-111. The cross SC Gm-111 plants was significantly taller than the check hybrid SC-162.

For resistance to late wilt, the best value (99.95%) was recorded for the crosses SC Sk-149, SC Sk-2 Red. For grain yield, two yellow promising crosses SC Gm-111 (10.94 t ha^{-1}) and SC Sk-150 (9.89 t ha^{-1}) significantly

TABLE 1. Mean squares for number of days to 50% silking, plant height, resistance to late wilt % and grain yield across environments

SOV	df	Number of days to 50% silking	Plant height (cm)	Resistance to late wilt (%)	Grain yield (t ha^{-1})
Environments (E)	4	407.51**	17021.97**	3.64*	149.37**
Rep/E	15	2.10	300.37	1.19	0.90
Hybrids (H)	9	41.71**	6721.42**	1.91**	30.52**
H x E	36	5.25**	263.14**	1.53**	3.99**
Error	135	1.55	118.95	0.43	0.90

*,** significant at 0.05 and 0.01 levels of probability, respectively

TABLE 2. Mean performance of number of days to 50% silking, plant height, resistance to late wilt and grain yield for eight promising yellow and red hybrids; and the two check hybrids across five environments

Hybrid	Number of days to 50% silking	Plant height (cm)	Resistance to late wilt (%)	Grain yield (t ha^{-1})
SC Sk-149	64.50	261.75	99.95	8.88
SC Sk-150	63.10	247.10	99.50	9.89
SC Sk-151	61.85	249.50	99.75	8.83
SC Gm-111	62.75	272.75	98.95	10.94
SC Gz-312	61.50	243.60	99.75	8.49
SC Sk-1 Red	62.55	237.05	99.80	7.82
SC Sk-2 Red	62.90	222.60	99.95	6.89
SC Sk-3 Red	60.10	214.45	99.75	6.98
SC 162	64.95	263.65	99.95	8.91
SC 168	63.90	234.90	99.95	9.14
Mean	62.81	244.74	99.73	8.68
LSD 0.05	0.78	6.82	0.41	0.59

out yielded the best check hybrid SC-168. These two hybrids need to be evaluate in advanced maize trial breeding programme.

The results showed that superiority percentage for grain yield of the two yellow promising single crosses SC Gm-111 (22.78 and, 19.69%) and SC Sk-150 (11.00 and 8.21%) were significantly out yielded by the two yellow checks SC 162 and SC 168, respectively (Table 3). So, these two hybrids need to be evaluate in advanced trial maize breeding programme.

Stability analysis of variance of the 10 hybrids for grain yield across five environments is presented in Table 4. Mean squares due to hybrids (H) were highly significant, indicating that they differed in yielding ability; therefore, it is possible to choose between them. Mean squares due to the environments (linear) was highly significant, indicating a wide range of environmental effects in soil and climate conditions; therefore, the selection for hybrids is difficult.

Hybrids x environments interaction further partitioned into H x Env. (Linear) and non-linear or pooled deviation components were tested against pooled error mean squares. The results showed that H x Env. (Linear) variance was significant, meaning that the tested hybrids did not similarly respond to varied environments. Therefore, a hybrid can be assigned to the appropriate environment. The pooled deviations were highly significant, indicating that the deviation of all hybrids for linearity was significant. H x L (linear) was not significant when tested against pooled deviation or nonlinear, indicating equal importance of both H x L (linear) and nonlinear interaction for grain yield in these hybrids. These results support the findings of Worku *et al.* (2001), Lee *et al.* (2003) and Mosa *et al.* (2015).

Four hybrids, SC Sk-150, SC Gz-312, SC Sk-1 Red and SC-162, can be considered stable for grain yield, based on the regression coefficient (b_i) (Table 5). The distribution of ten hybrids in the different section of Figure 1

TABLE 3. Superiority percentage relative to the two check hybrids of the eight promising yellow and red hybrids for grain yield across environments

Hybrid	Superiority relative to check (%)	
	SC 162	SC 168
SC Sk-149	-0.34	-2.84
SC Sk-150	11.00*	8.21*
SC Sk-151	-0.90	-3.39
SC Gm-111	22.78*	19.69*
SC Gz-312	-4.71	-7.11*
SC Sk-1 Red	-12.23*	-14.44*
SC Sk-2 Red	-22.67*	-24.62*
SC Sk-3 Red	-21.66*	-23.63*
LSD 0.05	0.59	

* significant at 0.05 levels of probability

TABLE 4. Stability analysis of variance of 10 hybrids across five environments

SOV	d.f.	Grain yield (t ha^{-1})	
		SS	MS
Hybrid (H)	9	68.64	7.63**
Env. + (H×Env.)	40	40.19	4.63**
Env. (Linear)	1	149.36	149.36**
H × Env. (Linear)	9	15.44	1.72*
Poold deviation	30	20.42	0.68**
SC Sk-149	3	2.09	0.70*
SC Sk-150	3	3.41	1.14**
SC Sk-151	3	0.38	0.13
SC Gm-111	3	5.32	1.77**
SC Gz-312	3	1.35	0.45
SC Sk-1 Red	3	0.67	0.22
SC Sk-2 Red	3	0.17	0.06
SC Sk-3 Red	3	1.77	0.59*
SC 162	3	0.39	0.13
SC 168	3	4.87	1.62**
Pooled error	150	33.88	0.23

*,** significant at 0.05 and 0.01 levels of probability, respectively

TABLE 5. Estimates of the three stability parameters of eight promising yellow hybrids and the two check hybrids for grain yield across five environments

Hybrid	b_i	S^2d_i	R^2
SC Sk-149	0.76*	0.47*	0.81
SC Sk-150	1.21	0.91**	0.88
SC Sk-151	0.66*	-0.10	0.94
SC Gm-111	1.71*	1.55**	0.89
SC Gz-312	1.02	0.22	0.92
SC Sk-1 Red	1.32*	0.01	0.97
SC Sk-2 Red	0.64*	-0.17	0.97
SC Sk-3 Red	0.99	0.37*	0.89
SC 162	0.94	-0.10	0.97
SC 168	0.73*	1.40**	0.62
Mean	1.00	0.45	0.88

*,** significant at 0.05 and 0.01 levels of probability, respectively

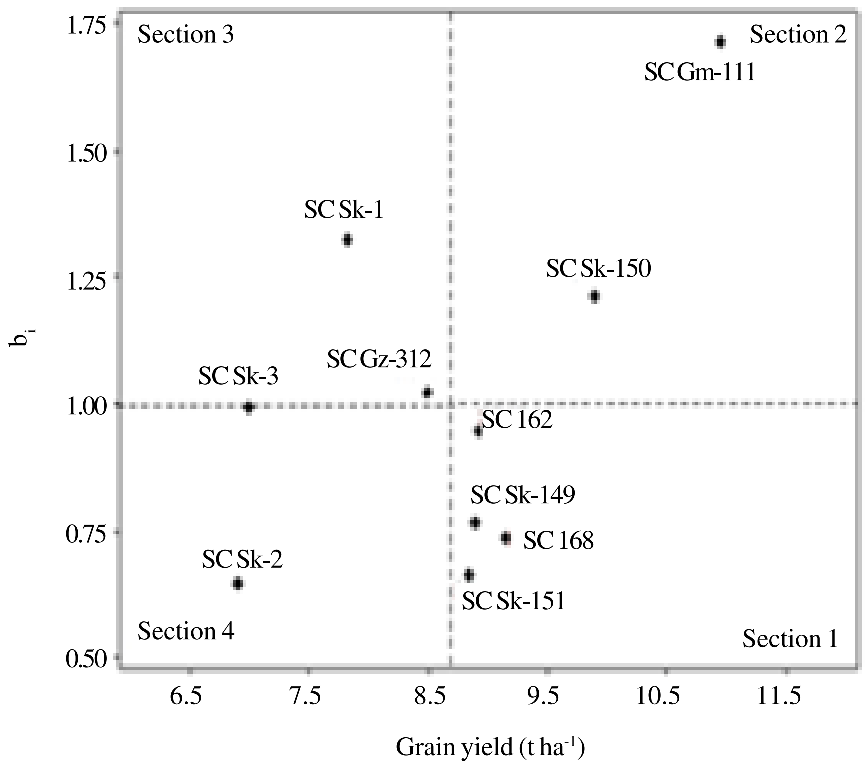

Figure 1. The coefficient of regression (b_i) against grain yield (t ha^{-1}) for 10 hybrids across five environments.

shows that the two hybrids, SC Sk-150 and SC-162, had high grain yield and will adapted to all environment. On the other hand, SC Gm-111 that had high grain yield and adapted to favourable growing conditions. The three hybrids, SC Sk-149, SC 151 and SC 168, had high grain yield and adapted to the poor environments. So these hybrids could be used under unsuitable environments.

The mean squares due to the deviation from regression values (S^2d_i) (Table 5), demonstrated that the five hybrids, SC Sk-151, SC Gz-312, SC Sk-1 Red, SC Sk-2 Red and SC 162, were not significantly different from zero; hence, they could be considered stable. Mean grain yield against S^2d_i values (Fig. 2), showed that the two hybrids (SC Sk-151and SC 162) exhibited high grain yield and general adaptation ability. Eberhart and Russell (1966) stated that cultivars that have (b_i> 1) are suitable to favourable growing conditions, those with (b_i< 1) would be adapted to unfavourable environmental conditions and those with b_i = 1 would have an average adaptation to all environments. Furthermore, the cultivars with S^2d_i equal to zero would have highly predictable behavior, whereas those with S^2d_i different from zero would have low predictability.

The coefficient of determination (R^2) according to Pinthus (1973) is the stability parameter; the genotypes with the higher

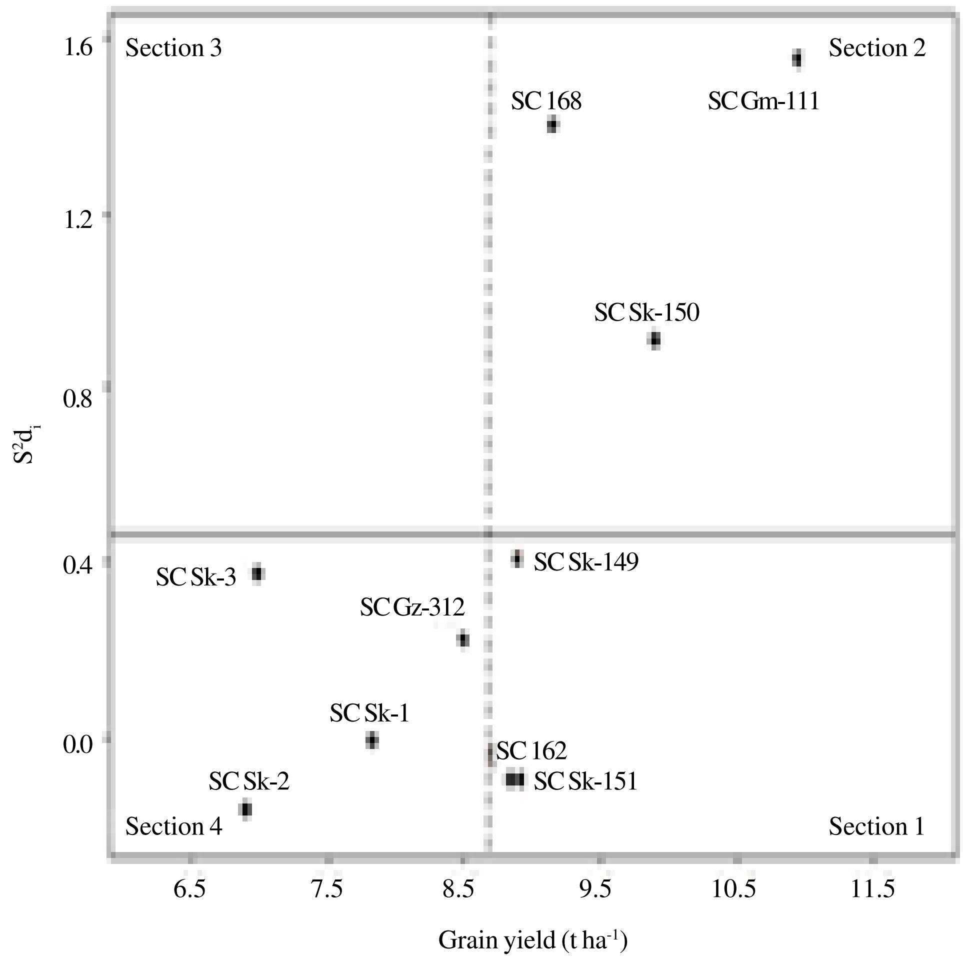

Figure 2. The deviation from regression (S^2d_i) against grain yield (t ha^{-1}) for 10 hybrids across five environments.

values (nearly to 1) are considered stable, so the eight hybrids (SC Sk-150, SC Sk-151, SC Gm-111, SC Gz-312, SC Sk-1 Red, SC Sk-2 Red, SC Sk-3 Red and SC 162) were stable because they had R^2 values nearly to 1. Carvalho *et al.* (2000) stated that the hybrids that give R^2 >80% tend to possess good production stability in all environments. However, the three hybrids (SC Sk-151, SC Gm-111 and SC 162) were stable and had high grain yield (Fig. 3). These results support the findings of Mosa *et al.* (2019) and Mosa *et al.* (2021).

In conclusion, both yield and stability of performance should be considered simultaneously to exploit the useful effect of hybrid x environment interaction (HEI) and to make hybrid selection more refined and precise. These results reflected that hybrid SC Sk-150 has both high grain yield and stability for b_i and R^2; also, SC Gm-111 has high grain yield and stable for R^2. So, from the above results, the two promising SC Sk-150 and SC Gm-111 need to be evaluate in advanced trials in a maize hybrids registration programme in Egypt.

The correlations coefficients between grain yield, the regression coefficient, the deviation from regression and the coefficient of determination showed that mean yield was significant and positively correlated with (S^2d_i), meaning that the high grain yield hybrids

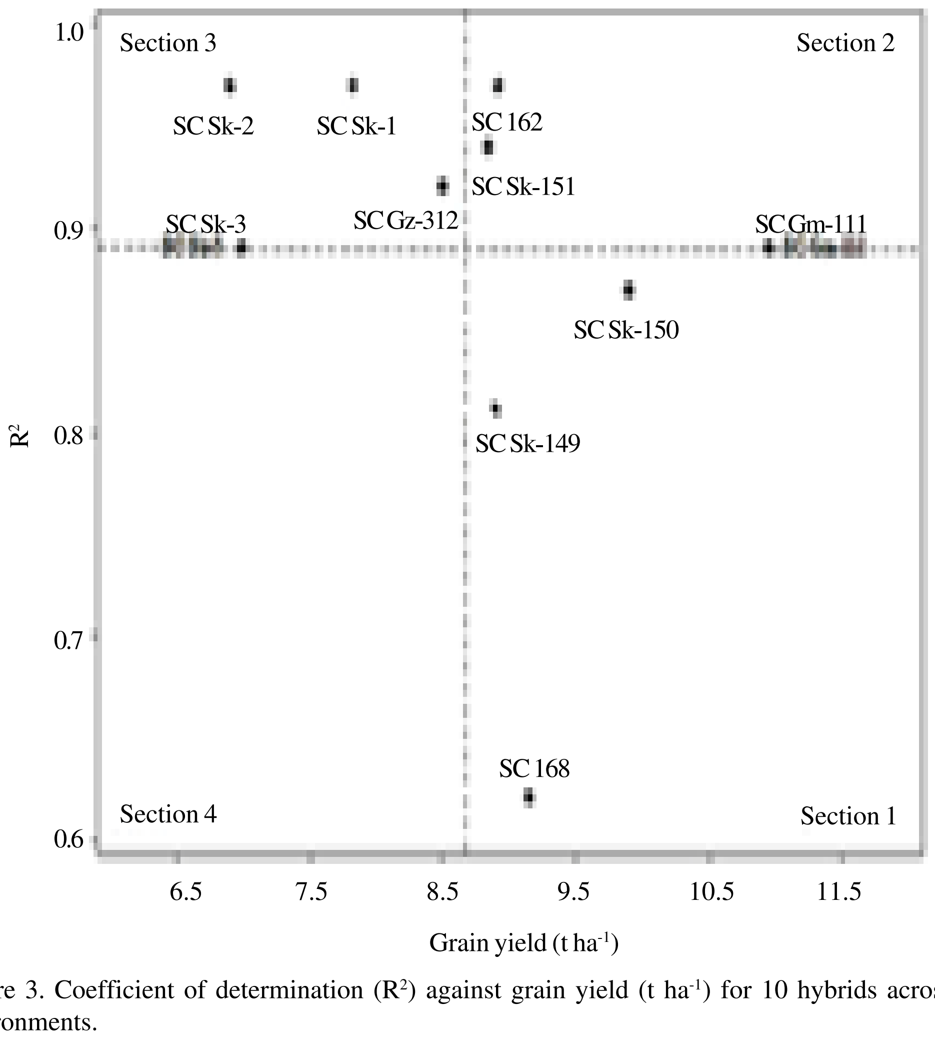

Figure 3. Coefficient of determination (R^2) against grain yield (t ha^{-1}) for 10 hybrids across five environments.

TABLE 6. The correlation coefficients between grain yield, the regression coefficient (b_i), the deviation from regression (S^2d_i) and the coefficient of determination (R^2) of 10 hybrids for grain yield

	Grain yield	b_i	S^2d_i	R^2
Grain yield	-			
b_i	0.532	-		
S^2d_i	0.704*	0.481	-	
R^2	-0.301	0.196	-0.705*	-

* significant at 0.05 levels of probability

are associated with high S^2d_i (Table 6). The non-significant correlation among grain yield and other stability statistics (b_i and R^2), meaning that stability statistics provide information that cannot be gleaned from average yield along. On the other hand, the correlation between R^2 and S^2d_i was significant and negative, meaning that R^2 showed independence with S^2d_i demonstrating that probably can be used together for the evaluation of stability. Meanwhile the correlation between (b_i and S^2d_i), (b_i and R^2) were not significant, meaning that stability statistics did not measure same aspects of stability. These results are agreement with Duarte and Zimmerman (1995), Mekbib (2003) and Mosa *et al.* (2021).

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