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Research Article

Selection of stable and high-yielding hybrids of maize based on various stability parameters

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Abstract
Selecting a stable and high-yielding hybrid of maize requires an efficient method of evaluation. Evaluating hybrids in multi environments is crucial in breeding process to identify the optimal genotype adapted to different kind of environments. Two promising white grain three way crosses *i.e.* TWC-SK-330 and TWC-SK-331 and two promising yellow grain three way crosses TWC-Nub 8 and TWC-Nub 10 plus four commercial three way cross hybrids were assessed during Summer, 2021 in five different environments in Egypt, *i.e.* Sakha, Gemmiza, Nubaria, Sids and Mallawy laid out in a randomized complete block design. The data showed that environments (E), hybrids (H) and their interaction (HEI) mean squares were significant or highly significant for all the studied traits except (HEI) for 50% silking. E, H, HEI explained 86.41, 5.46 and 8.13 % of the total grain yield variations, respectively. The two promising white grained three way crosses, TWC-SK-330 and TWC-SK-331 recorded 9.03 and 9.07 t ha^{-1} of grain yield, respectively which exceeded insignificantly the two white checks TWC-321 and TWC-324 and showed stable by 7, 8 stability statistics, respectively. Therefore, these hybrids are considered as stable genotypes and high yielding.

Keywords: Maize, GxE, Grain Yield, Stability, Genotype, Environment

INTRODUCTION

One of the most important annual cereal crops is maize, which covers more than 188 million hectares of crop land globally and accounts for approximately 50% (1.171 Mt) of the world's food production [FAOSTAT]. Maize is crucial for both human and animal consumption in Egypt. Additionally, it is employed in industries like manufacturing starch and cooking oils. The country's expanding population will require more food than the current production capability can provide. Development of hybrid varieties with specific adaptation and best-fitting target conditions is crucial for maximising production. Evaluation of maize hybrids in diverse conditions is one of the pivotal duties in the maize breeding programme. The genotypes should be evaluated in numerous environments spanning distinct ecological domains in order to identify and select the stable and adaptable genotypes across a variety of habitats (Shrestha *et al.,* 2021)

The genotype sustainability traits are a result of genotype x environment interaction (GEI). (Alwala *et al.,* 2010 ; Mousavi *et al.,* 2019). Multilocation and multi-year trials could assist to pick up the superior and sustainable cultivar (Rakshit *et al.,* 2012). Plant breeders test genotypes in multi environment trials (MET), including both favourable and unfavourable ones to determine how the genotype and environment interact (GEI). The interaction between genotype and environment (GEI) for quantitative traits like grain yield could constrain the selection of ideal genotypes to develop modified cultivars (Farshadfar *et al.,* 2001). To estimate GEI, breeders assess varieties in diverse environments to select a stable and high yielding variety. Grain yield is impacted by genetics, environment, and management techniques, as well as their interaction (Messina *et al.,* 2009). The environment has a significant impact in overall variation (Blanche *et al.,* 2009). The genotypes yield in diverse environments is directly influenced by the genotype x environment interaction (Malosetti *et al*., 2013; Meng *et al*., 2016; Brankovic-Radojcic *et al*., 2022). Therefore, information on genotype x environment interactions is crucial to the breeders to develop improved varieties (Lata *et al.,* 2010).

Several statistical models were suggested to study GEI. Each of the methods employed so far has its own benefits and drawbacks and breeders usually use them combined. This led to the development of numerous parametric and non-parametric statistical analyses for the study of GEI (Mohammadi *et al.,* 2014; Abd-Elaziz *et al.,* 2020, Shojaei *et al.,* 2021, Ruswandi *et al.,* 2022; Matongera *et al.,* 2023). Although they are based on different conceptions of stability, all methods of stability are valid (Flores *et al.,* 1998). In view of this, an ideal strategy in plant breeding is developing cultivars that perform reasonably uniformly (low G x E) over a wide range of environments with the ability to utilize the resources in high yielding environment. METs stability analysis is often carried out for one trait, such as grain yield (GY). However, by considering the mean performance and the stability of several traits the credibility of recommended genotypes can be increased. So, the present study was undertaken (i) to study the effect of genotype, environment, and genotype × environment interactions (GEIs) on maize hybrid yields, days to 50% silking and plant height and (ii) to select and compare hybrids of maize for high yield and stability in diverse environments in Egypt based on coefficient of variation (CV%), coefficient of determination (R^2), ecovalence (W_i^2), stability variance (σ_i^2), the genotype absolute rank difference mean as tested across n environments ($S_i^{(1)}$) and the variance between the ranks across "n" environments ($S_i^{(2)}$).

MATERIALS AND METHODS

Plant Materials: The genetic materials comprised of four promising three way crosses i.e. two white grain TWC-SK-330 and TWC-SK-331 and two yellow grain TWC-Nub 8 and TWC-Nub 10 with four commercial three way crosses (two white TWC-321 and TWC-324 and two yellow TWC-360 and TWC-368) as checks . These hybrids were developed by the Maize Research Program at Sakha (SK) and Nubaria (Nub) research stations, Agricultural Research Center, Egypt.

Field trials and Data Collection: Field experiment was conducted in five different locations across Egypt in May, 2021. Two environments i.e. Sakha and Gemmiza in north Egypt, Sids and Mallawy in middle Egypt and Nubaria represents the new reclaimed land. These locations combined represent the main environments for maize production in Egypt. The experiments were laid out in a Randomized Complete Block Designs (RCBD) with four replications. The plots consisted of four rows, 6 m long and 0.8 m apart and spacing of 0.25 m between hills was adopted. Two seeds were sown per hill and later thinned out to one plant to achieve the desired plant densities. To achieve good growth, the recommended agronomic packages of practises were implemented at the appropriate time. Data were recorded on number of days to silk emergence (DTS) i.e. the number of days from sowing date to the time when 50% of plants in the plot produced visible silks. Plant height (PH) was measured after flowering on 10 competitive plants $plot^{-1}$ in cm from ground to the point of flag leaf insertion. Additionally, grain yield [adjusted at 15.5 % grain moisture of each plot (in kg)] was measured from the inner two rows and adjusted to ton/hectare (t/ha).

Data Analysis: Combined analysis was computed after testing homogeneity of variances according to Snedecor and Cochran (1967). Once ANOVA revealed that the mean squares due to hybrids (H) and locations or environments (E) and H × E interaction (HEI) were statistically significant, calculation of variances and Fishers protected LSD test was done using SAS software (SAS-Institute Inc. 2008). In this study, eight stability parametric were used *i.e.* six parametric and two nonparametric. The parametric method namely the Eberhart and Russell mean square deviation from regression, (S^2_{di}) and the slope value (b_i) (Eberhart and Russell, 1966), the Francis coefficient of variation, CV% (Francis and Kannenberg, 1978), determination coefficient, R^2 (Pinthus, 1973), Wricke's ecovalence, Wi^2 (Wricke, 1962) and superiority index (P_i) (Lin and Binn's 1988) which the genotypes of greatest interest would be those with the lowest P_i values, while, the two nonparametric methods were the genotype absolute rank difference mean as tested across environments ($S_i^{(1)}$) and the variance between the ranks across environments ($S_i^{(2)}$) proposed by Nassar and Hühn (1987). Stability parameters were performed using GEA-R (Genotype x Environment Analysis with R for windows 2017) by CIMMYT.

RESULTS AND DISCUSSION

A combined analysis of variance for all the studied characters *i.e*. days to 50% silking, plant height and grain yield (t/ha) across five environments is presented in **Table 1**. Results revealed that, the environments (E) variance was highly significant for all the traits under study, showing that the environments differed in their climate and soil condition. Highly significant values were obtained among hybrids (H) for all the traits, showing that hybrids were diverse. The (H x E) interaction mean squares was significant or highly significant for all the traits studied except for days to 50 % silking, proving the differential response of hybrids in varying environments. Hence stability analysis is required to assess the stability of maize hybrids in terms of yield in different environments. Similar results for G x E interaction was found for grain yield (Cvarkovicet *et al*., 2009; Karadavut and Akilli, 2012; Mosa *et al.,* 2019; Raj *et al*., 2019; Boreddy *et al.,* 2020; Patil *et al.,* 2020 ; Mosa *et al.,* 2022).

Table 1. Mean squares for different traits across five environments

S.O.V	d.f	Days to 50% silking		Plant height		Grain Yield t/ha	
		MS	% TSS	MS	% TSS	MS	% TSS
Environment (E)	4	140.52**	74.97	26399.11**	84.79	145.04**	86.41
Rep./E	15	2.92	-	514.08	-	1.99	-
Hybrids (H)	7	19.60**	18.30	1251.77**	7.04	5.24**	5.46
H x E	28	1.80 ^{NS}	6.73	363.33*	8.17	1.95**	8.13
Error	105	1.38		191.07		0.80	

* and ** indicate significant at 0.05 and 0.01 probability levels, respectively.

Table 2. Environmental index for different traits across five environments

Environment (Locations)	Days to 50% silking (day)		Plant height (cm)		Grain yield t/ha	
	Mean (d)	Env. index	Mean (cm)	Env. index	Mean (ton/ha^{-1})	Env. index
Sakha	63.97	0.48	288.21	34	11.59	2.88
Gemmiza	62.37	-1.12	263.53	9.32	10.46	1.75
Sids	66.97	3.48	223.12	-31.09	6.12	-2.59
Nubaria	62.12	-1.37	225.56	-28.65	7.07	-1.64
Mallawy	62.05	-1.44	270.62	16.41	8.29	-0.42
Average	63.49		254.21		8.71	

Environments effect had the largest portion of variation of the total (H+E+HEI) variance *i.e.* 74.97, 84.79 and 86.41% for days to 50% silking (DTS), plant height (PH) and grain yield (GY), respectively, Whereas, H and HEI sources of variation are relatively smaller. These findings are in harmony with those obtained by Badu-Apraku *et al.* 2011, Mosa *et al.* 2012 and Boreddy *et al.* 2020.

Environmental index for Days to 50% silking, plant height and grain yield (**Table 2**) was determined by subtracting the location average from the average over all locations. Results showed that Sakha and Gemmiza were the non-stress environments, which recorded the high mean values and environmental indices for grain yield and plant height, while Nubaria and Sids were the lowest in means and environmental index for grain yield and plant height, indicating that the environments at both locations could be considered as stress environments. For days to 50 % silking, Mallawy was the lowest for mean and environmental index, while the opposite was at Sids location. Frey and Maldonado (1967) identified the stress environments as the one in which mean performance for a trait is low.

Rank of hybrids changed from one location to another which represent the specific adaptation. The best hybrid was TWC-SK-330 at Sakha, Nubaria and Mallawy and the combined data. The hybrid TWC-SK-331 performed good in Gemmiza, Sids, Mallawy and at the combined. Besides, these hybrids outyielded the overall mean in each location and the combined data, reflected that hybrids *viz.*, TWC-SK-330 and TWC-SK-331 performed better for grain yield across almost all the tested locations, indicating its stability in performance.

Mean performance of the four promising hybrids for the studied traits along with the four check hybrids across five environments is shown in **Table 4**. The data revealed that the hybrid TWC-SK-331 was insignificantly out yielded, earlier and shorter in plant height compared to the best white check TWC-321. Also, the hybrid TWC-SK-330 insignificantly out yielded the best check TWC-321. Three promising hybrids *i.e.* TWC-SK-330, TWC-SK-331 and TWC-Nub-10 identified in the current study could be advanced to the next stage of evaluation in maize hybrid program in Egypt. Gama and Hallauer (1980) and Mosa *et al.* (2019) stated that the relative stability of the elite hybrids across environments should be determined after emphasizing the selection of hybrids for mean yield across environments. Hence, estimates of parametric and nonparametric stability measures of eight hybrids for grain yield are shown in **Table 5**.

According to Francis and Kannenberg (1978), CV % could be employed to classify genotypes according to their mean yield and the average of CV %. In the present study, the hybrids TWC-SK-331and TWC-321 were observed to record yield higher than the average and lesser CV than the average for grain yield. Consequently, these hybrids are considered to be stable. Eberhart and Russell (1966) stated that, the desirable genotypes are characterised by high mean of yield, b=1 or insignificant and S^2di = 0 or insignificant. Hence, the hybrids TWC-SK-331, TWC-

Table 3. The interaction between hybrids and locations for grain yield (t/ha)

Hybrid	Sakha		Gemmiza		Sids		Nubaria		Mallawy		Combined	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
TWC-SK-330	12.78	3	10.19	6	5.69	6	7.69	3	8.81	1	9.03	2
TWC-SK-331	11.37	4	10.99	3	6.93	1	7.26	5	8.80	2	9.07	1
TWC-Nub-8	9.58	8	10.19	5	5.03	8	6.50	7	8.29	6	7.92	8
TWC-Nub-10	11.11	5	9.77	7	6.64	3	7.50	4	8.48	5	8.69	6
TWC-321 (c)	10.89	7	11.40	1	6.69	2	7.15	6	8.49	4	8.92	3
TWC-324 (c)	12.94	2	11.38	2	5.55	7	5.85	8	8.78	3	8.89	4
TWC-368 (c)	12.97	1	10.35	4	6.44	4	6.76	2	7.71	7	8.84	5
TWC-360 (c)	11.08	6	9.39	8	5.97	5	7.87	1	7.00	8	8.26	7
Mean	11.59		10.46		6.12		7.07		8.29		8.71	
LSD 0.05							**1.23**					

Table 4. Mean performance of four promising hybrids and four checks for important traits as an average across five locations in 2021season

Hybrids	Days to 50% silking (day)	Plant height (cm)	Grain yield (t/ha)
TWC-SK-330	63.65	259.25	9.03
TWC-SK-331	61.50	243.75	9.07
TWC-Nub-8	62.75	251.20	7.92
TWC-Nub-10	63.20	253.85	8.70
TWC-321 (c)	63.90	252.30	8.92
TWC-324 (c)	64.45	262.60	8.90
TWC-368 (c)	64.25	265.80	8.84
TWC-360 (c)	64.25	244.95	8.26
L.S.D	**0.72**	**8.68**	**0.56**

Table 5. Estimates of parametric and nonparametric stability measures of eight hybrids for grain yield

Hybrids	Parametric measures							Non-parametric measures	
	$\bar{x}^a$	CV(%)	b_i	S^2di	R^2	W^2_i	Pi	$Si^{(1)}$	$Si^{(2)}$
TWC-SK-330	9.03	29.48	1.14	0.29	0.95	1.79	0.31	0.90	5.50
TWC-SK-331	9.07	22.68	0.89	-0.06	0.98	0.61	0.31	0.60	1.75
TWC-Nub-8	7.92	27.12	0.88	0.55*	0.88	2.50	1.87	0.90	1.75
TWC-Nub-10	8.70	20.47	0.77*	-0.14	0.99	1.20	0.64	1.00	3.00
TWC-321 (c)	8.92	23.98	0.90	0.26	0.93	1.53	0.50	1.00	5.75
TWC-324 (c)	8.90	36.89	1.42*	0.10	0.98	4.57	0.60	1.40	8.50
TWC-368 (c)	8.84	31.31	1.18	0.39	0.94	2.36	0.38	0.70	5.50
TWC-360 (c)	8.26	24.35	0.82*	0.51*	0.87	2.74	1.18	1.50	8.50
$\bar{x}$	8.7	27.03	1	0.23	0.94	2.16	0.72	1	5.03

KEY: $\bar{x}^a$ = Grain yield (t ha^{-1}); CV_i=Coefficient of variation, b_i= Regression coefficient, (S^2_{di}) mean square deviation from regression, R^2= Pinthus's coefficient of determination; W_i^2= Wrick's ecovalence; P_i=Lin and Binns superiority measure; (S_i^1) = Genotype absolute rank difference mean over environments and (S_i^2) = variance between ranks over environments.

321 and TWC-368 could be considered as stable hybrids. The results showed that the hybrids TWC-SK-330, TWC-SK-331, TWC-Nub-10, TWC-324 and TWC-368 were stable according to coefficient of determination R^2 Pinthus (1973) since they had R^2 values close to 1. Data revealed that R^2 ranged from 0.87 to 0.99, which indicated that 87% to 99% of the mean grain yield variation was explained by genotype response across environments and indicating

stability differences among genotypes. Carvalho *et al*. (2000) stated that the hybrids that give R^2 >80% had good production stability in all environments. Meanwhile, according to Wricke's ecovalence ,W^2_i , (Wricke ,1962), the hybrids TWC-SK-330, TWC-SK-331, TWC-Nub-10 and TWC-321 were stable since they had the smallest values. The hybrids TWC-SK-330, TWC-SK-331, TWC-Nub-10, TWC-321, TWC-324 and TWC-368 were considered to be stable based on P_i lowest superiority measures suggested by Lin and Binns (1988).Regarding the stability measures $S_i^{(1)}$, small values indicate stability according to Nassar and Hühn (1987). Hence, the hybrid TWC-SK-331 followed by TWC-368, TWC-SK-330 and TWC-Nub-8 were considered to be stable. The hybrids TWC-SK-331, TWC-Nub-8 and TWC-Nub-10 were found to be stable based on $S_i^{(2)}$ stability parameter (lowest values).

In view of the above results, the hybrid TWC-SK-330 was found to be promising for grain yield and stable based on seven measures of stability i.e. b_i, S^2di, R^2, W^2_i, Pi, $Si^{(1)}$ and $Si^{(2)}$. Also, the hybrid TWC-SK-331 recorded the highest grain yield and was stable based on CV(%), b_i, S^2di, R^2, W^2_i, Pi, $Si^{(1)}$ and $Si^{(2)}$. Accordingly, two hybrids TWC-SK-330 and TWC-SK-331 could be advanced for further evaluation and are recommended for using in breeding program.

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