Middle East Journal of Agriculture Research
Volume: 12 | Issue: 04| Oct. – Dec.| 2023

EISSN: 2706-7955 ISSN: 2077-4605
DOI: 10.36632/mejar/2023.12.4.65
Journal homepage: www.curresweb.com
Pages: 977-984

Estimation of Heterosis in Some Maize Hybrids Using Line X Tester Analysis in two Locations

Youssef M.F., M. F. Ahmed [2], Yasser A. El-Gabry[2] and T.A.E. Abdallah[3]

[1]Nile for Agriculture Development, El -Ahram gardens, Cairo, Egypt.
[2]Agronomy Department, Faculty of Agriculture, Ain Shams University, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt.
[3]Deputy Director for Field Crops Research Institute, Agriculture Research Center (ARC), Egypt.

Received: 10 Sept. 2023 **Accepted:** 25 Dec. 2023 **Published:** 30 Dec. 2023

ABSTRACT

This study employed a line × tester mating design to evaluate maize inbred lines. We obtained nine imported white maize inbred lines from CIMMYT and IITA and used three testers with diverse genetic backgrounds. Our analysis using ANOVA revealed highly significant genetic variability among the tested genotypes and significant differences among check varieties for various traits at two different locations, Menya and Ismailia. The mean square due to lines (L) was found to be significant or highly significant for all traits, except for the no. of kernels per row at the Ismailia location. This indicates the presence of a wide range of variability among the lines, providing an opportunity for selection to improve yield and yield-related traits.The mean squares due to testers were found to be significant or highly significant for all traits, except for 100 kernel weight, at both locations. The line x tester interaction showed significance for most traits, highlighting the influence of specific testers on inbred line performance. The grain yield per plant exhibited significant variation, with certain single crosses, particularly (L2 × T2) at the Menya location, outperforming the check variety SC 128. Furthermore, we calculated superiority percentages of 27 hybrids for grain yield per plant, relative to SC 128 for nine single crosses, and relative to TWC 324 for nine three-way crosses and nine topcrosses. At the Ismailia location, four single crosses (L1, L4, L6, and L9) in combination with T1 and the double cross L4 × T3 demonstrated significant or highly significant useful heterosis for grain per plant yield, highlighting their desirability. This research offers valuable insights into the performance and potential of various maize hybrids, aiding in informed selection and breeding strategies to enhance yield and related traits.

Keywords: White maize, Line × tester, useful heterosis, Means of performance

Introduction

Maize (*Zea mays* L.) is the third most important crop among the cereal crops grown in Egypt. Maize grain is rapidly gaining popularity in our country, primarily due to the high demand in the poultry feed industry. Additionally, maize has diverse uses as both food and industrial raw materials. The cultivation of maize, as well as its production, has been increasing with the introduction of hybrid varieties, which have shown high yield potentials. Therefore, maize can play a crucial role in increasing Egypt's food production.

Currently, farmers in Egypt are cultivating some imported hybrid maize varieties, which are quite expensive. As a result, there is a need to develop our own hybrid maize varieties. By developing maize crops with desirable attributes, such as high yield potential and improved average yield per hectare, we can certainly make significant progress. The identification of such desirable genotypes within a mixed or base population is one of the main objectives of plant breeders (Khan *et al.,* 2014).

The performance of experimental lines using the line × tester approach is one of the key selection

Corresponding Author: M. F. Ahmed, Agronomy Department, Faculty of Agriculture, Ain Shams University, P.O. Box 68, Hadayek Shoubra 11241, Cairo, Egypt
E-mail: Mohamed_5541@agr.asu.edu.eg

criteria in maize hybrid breeding programs. It aims to improve the vigor and yield potential of inbred lines and develop better cultural practices. The production of hybrid seed involves the development and preservation of inbred lines, followed by controlled crosses to produce commercial seed. In maize breeding programs, early testing of lines is considered an efficient approach by maize breeders to identify high-performing lines, which are then evaluated for grain yield and yield-related traits.

The objective of this study is to evaluate 27 hybrids developed from crossing nine inbred lines with three testers at two different locations.

2. Materials and Methods

2.1 Materials and experimental layout

The objective of the current study was to evaluate some maize inbred lines using a line x tester mating design under two different locations. Nine imported white maize inbred lines were obtained from CIMMYT (International Maize and Wheat Improvement Center) and IITA (International Institute of Tropical Agriculture) for this investigation. Three testers with diverse genetic backgrounds were used, including one single cross from the Maize Research Department and two testers from a private seed company in Egypt (one inbred line and one double cross). The genetic backgrounds of these lines and testers are presented in Table 1.

Table 1: The code number, name, and sources of nine inbreed lines and three testers.

Code	Line	Source
L1	CML332	CIMMYT
L2	TZSTRI 126	IITA
L3	CML 484	CIMMYT
L4	TZSTRI 125	IITA
L5	CML 331	CIMMYT
L6	CML 482	CIMMYT
L7	CML 518	CIMMYT
L8	CML 379	CIMMYT
L9	TZMI 715	IITA
T1	Inbred Line Nile 1	ARC
T2	Single Cross 128	Nile For Agriculture Development
T3	Double Double White Nile 1002	Nile For Agriculture Development

In the 2021 season, a line x-tester mating design, following the procedure outlined by Kempthorne (1957), was employed to cross nine inbred lines as female parents with three testers as male parent. This resulted in the production of 27 F_1 crosses at the Ismailia location. Subsequently, in the 2022 season, the 27 F_1 crosses, along with two commercial checks (SC128 and TWC324), were evaluated at two different locations: Ismailia and Menya. The trials were conducted using a randomized complete blocks design (RCBD) with three replications.

Each plot in the trial consisted of a single row, measuring 3 meters in length, with a spacing of 0.8 meters between rows and 25 cm between hills. Initially, two grains were planted per hill, and after 21 days from the planting date, the plants were thinned to one plant per hill. The recommended agricultural practices were implemented at the appropriate times.

2.2 Recording of data

The study collected data on the following traits; Plant height (cm), Ear height (cm), Number of kernels per row, 100-Kernels weight (g), and grain yield per plant (g).

2.3 Statistical procedures

2.3.1 Analysis of variance

All the recorded data were accorded to analysis of variance (ANOVA) procedures. The analysis involved utilizing a linear model for individual analysis, and the means were compared using the least significant differences (LSD) at the 5% and 1% significance levels, as recommended by Steel and Torrie (1980). For the analysis of variance of genotypes, a separate analysis was conducted following the guidelines outlined by Snedecor and Cochran (1967).

2.3.2 Superiority (Agronomic Heterosis)

With regard to the relationship between each cross with each of the checks, this relation can be calculated similarly to calculating superiority checks, but while there is no relationship between the gene pool of the crosses and the gene pool of the check, this relationship will be designated as, superiority or useful heterosis or agronomic heterosis so; Superiority = $\frac{F1-Check}{Check}\ x\ 100$

3. Results and Discussion

3.1 Analysis of variance

The analysis of variance (ANOVA) for maize genotypes regarding the studied traits at two different locations, Menya and Ismailia, are presented in Tables 2 to 3.

The mean square values for genotypes and crosses were found to be highly significant for all the studied traits at both locations. This indicates the presence of significant genetic variability among the tested genotypes. The differences observed between the check varieties were also significant or highly significant at both locations for all the studied traits. This suggests that the tested check varieties exhibited variations from each other in terms of these traits. The contrast (C vs Ch) showed high significance for all the studied traits, except for the no. of kernels per row under the Menya location. Additionally, the mean square of crosses was highly significant for all the studied traits at both locations. The mean square due to lines (L) was found to be significant or highly significant for all traits, except for the no. of kernels per row at the Ismailia location. This indicates the presence of a wide range of variability among the lines, providing an opportunity for selection to improve yield and yield-related traits.

Table 2: Mean square for plant height, ear height and number of kernels per row, 100 Kernels weights at Menya and Ismailia locations in 2022 season.

Source of variation	D.F	Plant height		Ear height		No. of kernels/row	
		Menya	Ismailia	Menya	Ismailia	Menya	Ismailia
Reps	2	53.15**	55.85**	0.45	62.41**	26.07**	8.81**
Genotypes	28	467.26**	552.72**	256.42**	375.89**	21.12**	24.74**
Crosses (C)	26	499.33**	383.92**	266.35**	337.47**	20.15**	21.15**
Checks (Ch)	1	8.17**	3189.35**	228.17**	560.67**	66.67**	7.41**
C vs Ch	1	92.44**	2304.90**	26.52**	1189.95**	0.62	135.55**
Error	56	94.69	76.05	39.78	56.72	15.88	5.50
C.V		5.66	4.14	6.77	6.40	11.83	5.92

*and ** indicate significance at 0.05 and 0.01 levels, respectively

Table 3: Mean square for 100 Kernels weights and grin yield per plant at Menya and Ismailia locations in 2022 season.

Source of variation	D.F	100 Kernels weights		Yield / Plant	
		Menya	Ismailia	Menya	Ismailia
Reps	2	4.56*	63.25**	106.35**	1445.22**
Genotypes	28	93.73**	16.96**	1946.89**	2530.21**
Crosses (C)	26	96.78**	17.63**	1455.64**	2567.74**
Checks (Ch)	1	4.17*	6.00*	13348.17**	1472.67**
C vs Ch	1	104.00**	10.49**	3318.20**	2612.05**
Error	56	23.96	63.25	252.74	419.72
C.V		10.91	6.53	7.67	7.73

*and ** indicate significance at 0.05 and 0.01 levels, respectively

The mean squares due to testers were found to be significant or highly significant for all traits, except for 100 kernel weight, at both locations. Furthermore, the mean square due to the line x tester interaction was significant or highly significant for all traits at both locations, except for the no. of kernels per row under the Menya location and 100 kernel weight under the Ismailia location. These

results indicate that the performance of the inbred lines varied in their respective crosses depending on the specific testers used for these traits. These findings are consistent with the results reported by Kamara *et al.* (2014) and Ibrahim *et al.* (2021).

3.2. Mean values of performance indicators

The data presented in Tables 4 through 8 display the mean values of all the studied traits at the Menya and Ismailia locations. The test crosses that use inbred line as tester (T1) will compare with SC 128, While, the test crosses which use a single cross or double cross as tester will compare with TWC 324.

Regarding plant height, as shown in Table (4), the results showed that the mean performance of plant height ranged from 187.89 cm for the cross (L9 × T3) to 227.11 cm for the cross (L5 × T2) at the Menya location. Whereas, at the Ismailia location, the mean performance ranged from 148.67 cm for the cross (L2 × T1) to 201 cm for the cross (L1 × T1). For top crosses, four crosses demonstrated significant mean performance values higher than the check hybrid TWC 324 at the Ismailia location.

Table 4: Mean performance of evaluated crosses for plant height at Menay and Ismailia locations in 2022 season.

Lines	Plant height							
	Menya			Means	Ismailia			Means
	T_1	T_2	T_3		T_1	T_2	T_3	
L_1	220.83	194.89	213.78	209.83	201.00	175.33	190.67	189.00
L_2	204.67	211.11	201.44	205.74	148.67	153.67	168.33	156.89
L_3	208.67	207.89	191.22	202.59	176.00	189.67	169.33	178.33
L_4	207.44	199.67	221.44	209.52	160.33	177.33	163.67	167.11
L_5	204.67	227.11	214.78	215.52	163.67	167.33	176.33	169.11
L_6	218.56	214.11	188.94	207.20	169.00	185.33	160.00	171.44
L_7	220.89	220.00	226.28	222.39	155.00	175.33	190.33	173.55
L_8	209.44	213.89	214.00	212.44	171.33	159.67	187.00	172.67
L_9	192.11	218.33	187.89	199.44	169.33	163.33	183.33	172.00
Means	209.70	211.89	206.64	209.41	168.26	171.89	176.55	172.23
S.C 128	206.67				169.33			
T.W.C 324	252.78				167.00			
LSD 0.05	21.78				13.76			
LSD 0.01	28.56				18.04			

Regarding ear height, as shown in Table (5), the results showed that the mean performance of ear height ranged from 95.44 cm for the cross (L9 × T1) to 136.22 cm for the cross (L4 × T3) at the Menya location. Similarly, at the Ismailia location, the mean performance ranged from 75.00 cm for the cross (L2 × T3) to 111.67 cm for the cross (L8 × T3). It is worth noting that the single cross (L3 × T1) exhibited a significantly lower ear placement value at both locations. Additionally, the crosses (L9 × T1) and (L4 × T3) showed significantly lower ear placement values at the Menya and Ismailia locations, respectively, when compared to the check hybrid SC128. These results suggest that both testers (T2 and T3) can be utilized in the development of maize hybrids with shorter plant height and lower ear placement, particularly at the Ismailia location.

For the number of kernels per row, as shown in Table (6), the mean performance ranged from 27.67 for the cross (L7 × T2) to 38 for the cross (L6 × T1) at the Menya location. Similarly, at the Ismailia location, the mean performance ranged from 37.78 for the cross (L6 × T1) to 43.89 for the cross (L3 × T3). It is worth noting that all single crosses exhibited desirable values compared to the check SC 128 at the Menya location. However, at the Ismailia location, three out of the nine single crosses showed lower values compared to SC 128.

Table 5: Mean performance of evaluated crosses for ear height at Menay and Ismailia locations in 2022 season.

Lines	Ear height							
	Menya			Means	Ismailia			Means
	T_1	T_2	T_3		T_1	T_2	T_3	
L_1	112.67	115.44	116.11	114.74	110.33	88.00	101.33	99.89
L_2	113.22	112.67	105.22	110.37	90.67	84.00	75.00	83.22
L_3	107.78	116.11	97.33	107.07	83.33	99.33	90.33	91.00
L_4	130.11	129.11	136.22	131.81	84.67	102.00	83.67	90.11
L_5	122.11	123.78	121.33	122.41	93.33	92.00	90.00	91.78
L_6	128.11	130.22	103.11	120.48	108.33	99.67	91.67	99.89
L_7	124.11	119.00	124.39	122.50	92.67	98.00	99.00	96.56
L_8	120.39	117.83	116.00	118.07	100.67	75.67	111.67	96.00
L_9	95.44	114.00	97.10	102.18	89.67	87.67	88.00	88.45
Means	117.10	119.80	112.98	116.63	94.85	91.82	92.30	92.99
S.C 128	121.56				101.33			
T.W.C 324	140.89				89.00			
LSD 0.05	10.00				11.85			
LSD 0.01	13.11				15.54			

Table 6: Mean performance of evaluated crosses for number of kernels per row at Menay and Ismailia locations in 2022 season.

Lines	No. of kernels/ear							
	Menya			Means	Ismailia			Means
	T1	T2	T3		T1	T2	T3	
L1	35.33	30.33	34.67	33.44	39.50	39.89	42.11	40.50
L2	32.00	34.00	33.33	33.11	40.22	38.78	41.11	40.04
L3	33.33	36.33	32.00	33.89	37.56	36.67	43.89	39.37
L4	35.67	31.00	35.67	34.11	35.56	37.33	43.11	38.67
L5	36.00	30.67	37.00	34.56	40.56	40.56	38.33	39.82
L6	38.00	36.67	35.00	36.56	37.78	36.06	43.78	39.21
L7	36.33	27.67	33.67	32.56	39.44	38.78	39.67	39.30
L8	35.67	30.33	31.67	32.56	35.67	38.44	41.44	38.52
L9	31.33	34.33	32.00	32.55	39.00	36.56	43.22	39.59
Means	34.85	32.37	33.89	33.70	38.37	38.12	41.85	39.45
S.C 128	37.33				41.11			
T.W.C 324	30.67				43.33			
LSD 0.05	6.31				3.81			
LSD 0.01	8.27				4.99			

Regarding the 100-kernel weight, as shown in Table (7), the mean performance ranged from 33.83 for the cross (L3 × T1) to 54.67 for the cross (L1 × T2) at the Menya location. Similarly, at the Ismailia location, the mean performance ranged from 37.11 for the cross (L6 × T3) to 45.39 for the cross (L1 × T1). It is worth mentioning that all single crosses exhibited high mean performance for this trait at both the Menya and Ismailia locations. The best single cross for this trait was (L4 × T1) at the Menya location, which showed significant superiority over SC 128. At the Ismailia location, the best single cross was (L1 × T1).

Table 7: Mean performance of evaluated crosses for 100 kernels weights at Menay and Ismailia locations in 2022 season.

Lines	100 Kernels weights							
	Menya			Means	Ismailia			Means
	T1	T2	T3		T1	T2	T3	
L1	49.33	54.67	41.33	48.44	45.39	42.67	45.22	44.43
L2	45.00	49.00	37.67	43.89	42.11	43.67	42.89	42.89
L3	33.83	44.67	54.33	44.28	44.33	44.17	44.00	44.17
L4	54.67	48.00	47.67	50.11	36.72	39.67	42.33	39.57
L5	38.67	40.33	42.67	40.56	41.44	44.67	43.22	42.48
L6	47.00	48.67	49.00	48.22	39.56	37.17	37.11	38.57
L7	49.00	40.00	39.67	42.89	43.56	41.67	42.56	42.60
L8	40.67	38.67	41.67	40.34	40.22	43.78	40.33	41.44
L9	43.33	53.00	47.00	47.78	44.22	41.33	42.00	42.52
Means	44.61	46.33	44.56	45.17	41.95	42.09	42.18	126.22
S.C 128	41.67				42.44			
T.W.C 324	40.00				44.44			
LSD 0.05	8.11				4.34			
LSD 0.01	10.63				5.69			

Regarding grain yield per plant, as shown in Table (8), the mean performance ranged from 211.78g for the cross (L4 × T1) to 317.89g for the cross (L1 × T3) at the Menya location. Similarly, at the Ismailia location, the mean performance ranged from 260g for the cross (L4 × T1) to 164.33g for the cross (L7 × T2). It is worth noting that three single crosses exhibited a mean performance higher than the check SC 128 at the Menya location. The best single cross for grain yield per plant at the Menya location was (L2 × T1). Similar studies have been done by Dar (2017), Gami, (2018), Hamouda *et al.* (2021) and Abd-Elnaser *et al.* (2022).

Table 8: Mean performance of evaluated crosses for grain yields per plant at Menay and Ismailia locations in 2022 season.

Lines	Yield/plant							
	Menya			Means	Ismailia			Means
	T1	T2	T3		T1	T2	T3	
L1	243.78	316.60	317.89	292.76	235.67	224.00	218.67	222.78
L2	307.00	250.33	262.56	273.30	283.63	210.67	190.67	195.00
L3	288.33	250.89	302.67	280.63	269.90	200.00	190.33	186.44
L4	211.78	260.89	300.56	257.74	260.00	212.33	212.33	228.22
L5	272.11	276.33	256.56	268.33	283.00	240.67	211.00	181.36
L6	235.33	227.89	258.22	240.48	221.00	167.33	193.75	224.22
L7	241.89	259.78	282.22	261.30	222.67	164.33	203.04	196.68
L8	227.78	269.44	225.78	241.00	208.00	205.33	203.00	205.44
L9	257.67	228.33	284.55	256.85	260.67	222.67	197.67	209.00
Means	253.96	260.05	276.78	263.60	209.96	205.26	201.16	205.46
S.C 128	277.00				269.56			
T.W.C 324	245.89				200.89			
LSD 0.05	25.79				33.81			
LSD 0.01	33.81				44.33			

3.3 Superiority percentages of heterosis

In Table 9, we provide estimates of superiority percentages of heterosis for 27 genotypes in grain yield per plant concerning SC 128 for nine single crosses and relative to TWC 324 for nine three-way crosses and nine topcrosses, across the two study locations. The findings indicate that at the Ismailia location, four single crosses (L1, L4, L6, and L9) in combination with T1, as well as the double cross L4 × T3, displayed significant or highly significant superior performance in grain yield per plant, signifying their desirability. Investigations with similar objectives have been conducted by Ambikabathy *et al.* (2019), Abdulazeez *et al.* (2021), and Hamouda *et al.* (2021).

Table 9: Estimates of Superiority percentages of heterosis of Nine single cross relative to SC 128, nine three way cross and nine top cross relative to TWC 360 for yield per plant at both location (Menya and Ismalia)

Inbred Line	Minya			Ismailia		
	T1	T2	T3	T1	T2	T3
L1	-9.56	5.22	5.65	22.63 **	-10.05	14.23
L2	1.57	-16.80 **	-12.74 *	15.33	-26.08 **	4.38
L3	6.97	-16.62 *	0.59	9.49	-35.50 **	4.20
L4	-21.43 **	-13.29	-0.11	16.24 *	-0.76	16.24 *
L5	0.95	-8.16	-14.73 *	-8.39	-30.15 **	6.07
L6	-12.70	-24.26 **	-14.18 *	31.75 **	-15.65 **	15.51
L7	-10.26	-13.66 *	-6.20	-10.04	-15.01 **	11.15
L8	-15.50 *	-10.45	-24.96 **	12.41	-20.61 **	11.13
L9	-14.36	-24.11 **	-5.43	21.90 **	9.31	8.21

*and ** indicate significance at 0.05 and 0.01 levels, respectively

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