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Heterosis, Earliness, and Morpho-Physiological Traits in Red and Yellow Maize F_1 Crosses under Drought Stress

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Cross Mark

ABSTRACT

This study aimed to evaluate eight inbred lines of red and yellow maize and their half-diallel crosses and estimate of heterosis for earliness and morpho-physiological traits under normal and water-stress. Mean squares due to maize genotypes and their partitioning into parents, crosses and parents *vs.* crosses (P × C) were significant or highly significant for all traits under normal and water stress conditions, indicating wide diversity among parental material and enough genetic variability adequate for further biometrical assessment, and presence of significant heterosis under both irrigation treatments. P_5 (L-49) and P_7 X P_8 under normal, P_2 (Red-B) and P_6 X P_8 under water-stress were the earliest genotypes in anthesis and silking dates and anthesis-silking interval (ASI) when compared to other genotypes, which would be a good indicator for earliness. There were 17 and 11 crosses for anthesis date, 14 and 8 crosses for silking date, 23 and 9 crosses for ear position, manifested negative significant or highly significant heterosis over mid and better parents, respectively under drought-stress condition. There were 26 and 20 crosses for chlorophyll content, 12 and 4 crosses for ear leaf area, all the 28 evaluated crosses for stem diameter and biomass yield/plant, recorded highly significant positive heterosis relative to their mid and better parent, respectively under drought-stress condition. The highest positive heterobeltiosis were recorded by the crosses, P_3 X P_5 (476.35%), P_4 X P_8 (503.49%) and P_5 X P_8 (469.06%), and therefore, these crosses could be considered the best cross combinations for producing high biomass yield/plant.

***Keywords*:** Maize, mean performance, earliness, heterosis, drought

INTRODUCTION

In Egypt and around the world, maize (*Zea mays* L.) is the second most significant grain crop. According to FAOSTAT (2023), Egypt produced 7.5 million tons of grains in 2022 on 1,027,057 hectares (about 2.44 million feddan) with an average yield of 7.3 tons' ha-1 (approximately 22ard/fed). The same survey states that Egypt's average productivity is fifth in the world, behind the United States, France, Germany, and Italy. But planting maize in soils with little water-holding capacity would put the plants at risk of drought stress, which could lead to low grain yields. Furthermore, because of the anticipated future scarcity of irrigation water, maize breeders must focus heavily on creating drought-tolerant cultivars that can provide large grain yields in both water-stressed and non-stressed environments. According to Chapman *et al*. (1996), maize is especially vulnerable to dryness during the flowering stage.

Drought tolerance might be increased by improving the ability of the crop to extract water from the entire soil profile (Wright and Nageswara, 1994). Roots are the principal plant organ for nutrient and water uptake. The ability to grow deep roots is currently the most accepted target trait for improving drought tolerance, but genetic variation has been reported for several traits that may affect drought response. Since genetic solutions are unlikely to cover more than 30% of the gap between potential and realized yield under water stress, hence, the understanding of genetics and further applying to improve drought tolerance is a key component to stabilize global maize production (Sheoran *et al*. 2022).

Maize breeders make great and continuous efforts to improve and increase the yielding ability of this crop. Hybridization in corn started as early as by the work of (East 1908 and Shull 1909), who clearly indicated that hybridization is the opposite of inbreeding. The concept of general (GCA) and specific (SCA) combining ability was introduced by (Sprague and Tatum 1942) and its mathematical modeling was set about by (Griffing 1956) in his classical paper in conjunction with the diallel crosses.

So, the main objectives of the present investigation were: 1) Evaluating eight inbred lines of red and yellow maize and their half-diallel twenty-eight F_1 crosses, in addition three commercial hybrids under normal irrigation and water stress conditions, and 2) Estimating of heterosis over mid parents and better parent (heterobeltiosis) under normal irrigation and water stress conditions.

MATERIALS AND METHODS

A field experiment was conducted at the privet farm at Nawasa Village, Aga District, Dakahlia Governorate, Egypt during the summer seasons 2023 and 2024. In the first growing season 2023, the eight parental red and yellow maize inbred lines were sown *i.e.*, Red-A, Red-B, Red-C, L-6, L-49, L-69, L-125, and A-63, and hence hand hybridization in a half-diallel fashion (excluding reciprocals) was done to produce 28 F_1 crosses. These genetic materials which were used in this investigation as parents represent a wide range of diversity for several agronomic traits. The four red and yellow inbred lines *i.e.* Red-A, Red-B, Red-C and A-63, and two commercial single crosses (SC-Yacout-5, SC-Gold-21) were obtained by Quality Techno-Seeds Company (QTSC). While the other four yellow inbred lines (L-6, L-49, L-69 and L-125) and the commercial single cross SC-168 were obtained from the

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Agricultural Research Center (ARC). The names and pedigree of these parental maize inbred lines are presented in Table 1.

Table 1. Parental inbred lines and the studied commercial single crosses names and their origin.

No	Genotypes names	Origin	Source	Grain Color
P_1	Red-A	Locally product	QTSC	Red
P_2	Red-B	Locally product	QTSC	Red
P_3	Red-C	Locally product	QTSC	Red
P_4	L-6	Locally product	ARC	Yellow
P_5	L-49	Locally product	ARC	Yellow
P_6	L-69	Locally product	ARC	Yellow
P_7	L-125	Locally product	ARC	Yellow
P_8	A-63	Locally product	QTSC	Yellow
Checks	SC-Yacout-5	Locally product	QTSC	Red
	SC-Gold-21	Locally product	QTSC	Yellow
	SC-168	Locally product	ARC	Yellow

In the evaluated season 2024, 39 maize genotypes included 28 F_1crosses with the 8 parental inbred lines along with three commercial single crosses (SC-Yacout-5, SC-Gold-21 and SC-168) as control under two irrigation treatments (normal irrigation and water stress conditions). Two separate field experiments were conducted, with a 5-meter buffer zone separating the two irrigation treatments, the first represents normal irrigation treatment (plants watered every 10-12 days, as control treatment) and the second represents water stress treatment (plants watered every 20-24 days until harvest to achieve severe drought stress through planting after sowing according to Kiani *et al.* (2007). Each irrigation treatment was arranged as a separate experiment in a randomized complete block design (RCBD) with three replications. Each replicate consisted of 39 genotypes as well as two borders, each genotype was planted in one ridge, 3 m long and 60 cm apart with 25 cm between plants.

Two seeds were manually dropped in each ridge and then the thinning was done after 15 days after sowing. Planting dates were done on May 15th and 25th in the first season, and May 20th in the second season. Hoeing in both seasons was practiced before and after the first irrigation. The other agricultural practices were applied as recommended.

The traits studied:

Earliness and morpho-physiological traits were measured: tasseling date (day), anthesis date (day), silking date (day), anthesis-silking interval (ASI, day), total chlorophyll content (SPAD values according to Castelli *et al.*(1996), ear leaf area/plant (cm^2) (Calculated by the following formula: maximum length x maximum width x 0.75 (Sticker, 1964), stem diameter (cm), plant height (cm), ear height (cm), ear position index (ratio of ear height / plant height) and biomass yield/plant (g) were recorded.

Statistical analyses:

The data were analyzed on a plot mean basis. All obtained data were subjected to the statistical analysis of the randomized complete block design to test the differences among various genotypes under each irrigation treatment according to Snedecor and Cochran (1977). While, mean squares for genotypes (parents and F_1's) were partitioned among parents, F_1 crosses and parents *vs*. crosses according to Mather and Jinks (1982) as presented in Table 2. Treatments were compared using the least differences values (LSD) at 5% and 1% levels of probability according to Gomez and Gomez (1984).

Table 2. Form of analysis of variance

S.O.V	D.F.	M.S	E.M.S
Replication (r)	r-1	Mr	$\sigma^2_e + g\,\sigma^2_r$
Genotypes (G.)	g-1	Mg	$\sigma^2_e + r\,\sigma^2_g$
Parents (P.)	p-1	Mp	$\sigma^2_e + r\,\sigma^2_p$
F_1 crosses	F-1	Mc	$\sigma^2_e + r\,\sigma^2_c$
P. vs F_1	1		$\sigma^2_e + r\,\sigma^2_h$
Error	(g-1)(r-1)	M_e	σ^2_e

Estimation of heterosis:

Heterosis as proposed by Mather and Jinks (1982) was determined for individual crosses as the percentage deviation of F_1 means from mid-parent (MP) and better parent (BP) means and expressed as percentages for each normal and stress conditions as follows:

1-Heterosis over the mid parents (HMP) % = $(F_1\text{-}MP)/MP \times 100$

2-Heterosis over the better parents (HBP) % = $(F_1 - BP)/BP \times 100$

Where: F_1 = mean values of the 1st generation, MP = value of the mean of the mid parents computed by utilizing the median mean of the two parents and BP = value of mean of the better parents.

The heterosis effect significance for F_1 values for the mid and better parents were tested agreeing to the subsequent recipe:

LSD for heterosis over mid parents = $t_{(0.05\ or\ 0.01)}$ x $(3MS_e/2r)^{1/2}$

LSD for heterosis over better parents = $t_{(0.05\ or\ 0.01)}$ x $(2MS_e/r)^{1/2}$

Where: t= value of tabulated "t" at stated level of probability for degrees of freedom of the experimental error, MS_e = experimental error mean squares from the analysis of variance, and r = replicates number.

RESULTS AND DISCUSSION

Analysis of variance

It is apparent from the results as shown in Table 3 that mean squares due to maize genotypes and their partitioning into parents, crosses and parents *vs*. crosses (P × C) were significant or highly significant for all studied earliness and morpho-physiological traits *i.e.* tasseling date (day), anthesis date (day), silking date (day), ASI (day), chlorophyll content, ear leaf area (cm^2), stem diameter (cm), plant height (cm), ear height (cm), ear position and biomass yield/plant under normal irrigation and water stress conditions. These results indicate the wide diversity among the parental material and enough genetic variability adequate for further biometrical assessment. Mean squares due to parents *vs*. crosses, as an indication to average heterosis overall crosses, were significant or highly significant for all studied earliness and morpho-physiological traits under both irrigation intervals, indicating the presence of significant heterosis under both irrigation treatments. These results agree with the results of Golbashy *et al.* (2010), Ertiro *et al.* (2017), Sayed *et al.* (2020), Iseghohi, *at al.* (2022), Amegbor *et al.* (2023), Elsheikh (2024) and Menkir *et al*. (2024).

Table 3. Mean squares of maize genotypes, parents, crosses and parents versus crosses for all earliness and morpho-physiological traits and biomass yield/plant under normal and water stress conditions.

		Tasseling date (day)		Anthesis date (day)		Silking date (day)		ASI (day)	
S.O.V	DF	N	D	N	D	N	D	N	D
Replications	2	2.19	0.53	1.62	1.81	1.12	1.23	0.05	0.49
Genotypes	35	15.11**	31.45**	15.74**	18.26**	17.32**	21.82**	1.93**	1.21**
Parents	7	17.95**	64.09**	31.80**	23.79**	29.09**	24.09**	1.17**	0.70*
Crosses	27	14.57**	18.58**	11.91**	16.52**	14.71**	19.58**	2.15**	1.35**
P V Cross	1	10.01**	150.48**	6.75**	26.46**	5.48**	66.46**	1.38**	1.23*
Error	70	0.85	1.09	0.79	1.05	0.70	1.05	0.02	0.26
Total	107	5.54	11.01	5.70	6.69	6.15	7.85	0.65	0.58

Table 3. Continued

		Chlorophyll content		Ear leaf area (cm^2)		Stem diameter (Cm)	
S.O.V	DF	N	D	N	D	N	D
Replications	2	10.81	7.15	5677.76	716.181	0.01	0.15**
Genotypes	35	119.91**	113.84**	81564.68**	41333.62**	0.55**	0.45**
Parents	7	198.60**	203.29**	83899.02**	49497.19**	0.07**	0.02*
Crosses	27	96.50**	68.07**	44232.96**	13496.54**	0.23**	0.09**
P V Cross	1	201.10**	723.46**	1073180.9**	735789.90**	12.60**	13.41**
Error	70	16.73	4.17	1879.15	1490.37	0.01	0.01
Total	107	50.37	40.10	28015.51	14508.74	0.19	0.16

Table 3. Continued

		Plant height (cm)		Ear height (cm)		Ear position		Biomass Y/plant (g)	
S.O.V	DF	N	D	N	D	N	D	N	D
Replications	2	114.53*	274.34**	33.40	26.78	0.001	0.002*	951.62	215.898*
Genotypes	35	10942.58**	6504.16**	2331.57**	1216.79**	0.02**	0.01**	266471.99**	167022.24**
Parents	7	9968.71**	3066.93**	510.99**	2060.00**	0.05**	0.03**	7420.71*	2542.74**
Crosses	27	1959.30**	1544.36**	957.92**	374.25**	0.00**	0.00**	114671.63**	43866.48**
P V Cross	1	260308.2**	164479.4**	52164.13**	18062.88**	0.07**	0.09**	6178440.75**	4643584.17**
Error	70	36.22	18.04	35.54	17.45	0.0007	0.0004	3275.86	52.97
Total	107	3605.19	2144.46	786.54	409.93	0.0055	0.0036	89324.61	54672.13

Mean performance of parents and its F_1 crosses:

Mean performance was considered as the first important selection index in the choice of parents and the parents with high mean performance will result in superior hybrids. The results exhibited some parents were superior to grand means for studied traits. There were relatively large variations in all genotypes for these traits (Table 4).

The parental inbred line P7 (L-125) (49.0 days) and P_2 X P_6 (47.33 days) had the shortest days to 50% tasseling date under normal irrigation, while P_4 (L-6) (52.00 days) and P_3 X P_5 (52.33 days) had the shortest days to 50% tasseling date under water stress conditions (Table 4), which would be a good indicator for earliness. P5 (L-49) (52.00 days) and the cross P_7 X P_8 (47.00 days) under normal watering, and P2 (Red-B) (56.00 days) and the cross P_6 X P_8 (52.67 days) under water stress were the earliest genotypes in anthesis date. While P_2 (Red-B) (53.00) and cross P_7 X P_8 (52.67 days) under normal irrigation and P_4 (L-6) (57.00 days) and the cross P_1 X P_8 (55.00 days) under water stress had the shortest days to 50% silking when compared to other genotypes. Regarding anthesis-silking interval (ASI), P8 (0.8 day) and the cross P_2 X P_5 (0.9 day) under normal irrigation, and P_2 (Red-B) (1.40 days), P_1 X P_3, P_3 X P_5 and P_3 X P_8 (1.07 days) under drought-stress recorded the shortest values of anthesis-silking interval (ASI) trait, as shown in Table 4.

For chlorophyll content, P_5 (L-49) and P4 X P7 under normal, and P_7 (L-125) and P_2 X P_6 under water stress conditions recorded the highest values of chlorophyll content, 71.90, 58.07 and 63.85% respectively. Regarding ear leaf area (cm^2), P_8 (853.13 cm^2), (645.25 cm^2) under both normal and water-stress conditions, and P_5 X P_8 (997.00 cm^2) under normal and P_4 X P_5 (720.88 cm^2) under water stress conditions exhibited the greatest values of ear leaf area per plant. Also, out of the tested 28 F_1 crosses, there were three crosses namely, P4 X P5, P5 X P8 and P_6 X P_7 under normal, and four crosses (P2 X P5, P4 X P5, P4 X P8 and P_6 X P_7) under stress surpassed significantly over the three commercial hybrids *i.e.* SC-Yacout-5, SC-Gold-21 and SC-168 in ear leaf area. P_1 (Red-A) (1.83 cm) and (1.37cm) under both conditions, and cross P4 X P8 (3.23 cm) under normal and crosses P_5 X P_8 and P_1 X P_8 (2.50 cm) under water-stress condition recorded the highest values of stem diameter. Also, there were five crosses namely, P_1 X P_8, P_2 X P_4, P_4 X P_5, P_4 X P_8 and P_5 X P_8, under normal, and three crosses (P_1 X P_8, P_4 X P_8 and P_5 X P_8) under stress surpassed significantly over the two commercial hybrids *i.e.* SC-Gold-21 and SC-168 in stem diameter, as shown in Table 4.

For plant height (cm), P8 (261.67 cm and 240.00 cm) under both conditions, and cross P1 X P8 (320.67 cm) under normal and cross P6 x P8 (292.33 cm) under water-stress recorded the highest values of plant height. On the other hand, P2 (Red-B) (107.33 cm) under normal and P6 (L-69) (124 cm) under drought, and cross P4 X P7 (221.00 cm and 204.67 cm) under both conditions recorded the lowest values of plant height. Also, out of the tested 28 F1 crosses, there were six crosses (P2 X P3, P2 X P5, P3 X P8, P4 X P6, P4 X P7 and P5 X P7) under normal, and three crosses (P1 X P7, P4 X P7 and P5 X P7) under stress surpassed significantly over the three commercial hybrids i.e. SC-Yacout-5, SC-Gold-21 and SC-168 in shortness of plant height, as shown in Table 8. These hybrids can be recommended for use in breeding programs to develop short-stemmed varieties that are resistant to lodging and can be planted at high density.

For ear height (cm), means of ear height for all studied genotypes are presented in Table 4. The differences between ear height for parents ranged from 73.33 to 111.67 cm under normal and from 54.33 to 140.00 cm under drought. The highest parent was P8 under both conditions, Meanwhile, parents P6 (L-69) under both conditions was the lowest parents. Regarding the differences between ear heights for all crosses were highly significant. Cross P5 X P8 (167.00 and 137.67 cm) under both conditions was the highest ear height, however cross P1 X P7 (96.00 and 94.33 cm) under both conditions was the lowest ear placement. Four crosses (P1 X P7, P2 X P5, P4 X P7 and P5 X P7) out of the evaluated 28 crosses were significantly lower ear placement over the three commercial hybrids i.e. SC-Yacout-5, SC-Gold-21 and SC-168 under normal irrigation. On the other hand, five crosses (P1 X P7, P2 X P5, P3 X P8, P4 X P7 and P5 X P7) were significantly lower ear placement over the three commercial hybrids i.e. SC-Yacout-5, SC-Gold-21 and SC-168 under drought condition. It may indicate that ear height is greatly influenced by genetic structure and different agronomic treatments, especially watering treatments.

Concerning ear position, the differences between ear positions for parents were highly significant under both normal and drought conditions. Ear position for parental inbred lines ranged from 0.41 to 0.71 under normal irrigation, and 0.44 to 0.69 under drought condition. The highest positions were for P2 (Red-B) under both conditions, and lowest positions were for P4 (L-6), P5 (L-49) and P8 under normal and P4 (L-6), P5 (L-49) and P6 (L-69) under drought. For ear position revealed that all crosses were non-significant. Ear positions for crosses ranged from 0.41 to 0.54 under normal conditions, and from 0.42 to 0.53 under drought. It may indicate that ear position is greatly influenced by different agronomic treatments, especially irrigation treatments. These results are supported by those concluded by Sultan *et al.* (2010), Ertiro *et al.* (2017), Sayed *et al.* (2020), Iseghohi, *at al.* (2022), Amegbor *et al.* (2023), Elsheikh (2024) and Menkir *et al*. (2024).

Table 4. Means performance of parental inbred lines and their single crosses of maize for earliness and morpho-physiological traits under normal irrigation and drought-stress conditions.

	Tasseling date (day)		Anthesis date (day)		Silking date (day)		ASI (day)	
	N	D	N	D	N	D	N	D
P1 (Red-A)	52.33	58.67	52.67	59.67	55.67	61.33	2.10	2.50
P2 (Red-B)	51.33	54.00	52.33	56.00	53.00	57.33	3.10	1.40
P3 (Red-C)	51.00	66.00	53.00	62.67	55.00	64.00	2.10	1.73
P4 (L-6)	54.33	52.00	54.33	56.00	56.67	57.00	2.10	2.07
P5 (L-49)	51.00	57.00	52.00	59.00	53.67	61.00	2.10	1.73
P6 (L-69)	57.00	62.00	61.33	63.67	62.67	65.00	1.90	2.10
P7 (L-125)	49.00	58.67	56.67	59.67	57.67	61.00	2.20	2.80
P8 (A-63)	53.00	62.67	54.67	61.67	60.00	62.00	0.80	1.53
LSD 5%	0.28	0.32	0.26	0.32	0.27	0.32	0.04	0.16
LSD 1%	0.38	0.43	0.34	0.42	0.36	0.42	0.06	0.21
1. P1 X P2	50.33	54.00	53.67	55.67	55.00	58.00	4.10	3.13
2. P1 X P3	50.33	54.00	53.33	55.67	56.00	57.00	1.90	1.07
3. P1 X P4	49.33	53.00	53.67	58.67	55.67	60.00	2.10	2.40
4. P1 X P5	49.33	59.00	55.67	60.67	57.67	62.00	2.90	1.73
5. P1 X P6	50.00	52.33	52.00	55.67	54.67	58.00	2.10	2.07
6. P1 X P7	51.33	58.00	53.67	58.67	53.00	62.00	1.10	2.40
7. P1 X P8	56.33	53.00	53.00	53.67	58.00	55.00	2.90	2.40
8. P2 X P3	52.33	53.00	53.33	56.00	56.67	57.00	3.10	1.73
9. P2 X P4	53.33	58.00	54.67	59.67	56.67	61.00	2.90	2.07
10. P2 X P5	50.33	56.00	53.67	58.00	54.67	61.00	0.90	3.07
11. P2 X P6	47.33	58.00	52.67	59.67	53.67	61.00	2.10	2.07
12. P2 X P7	52.33	54.00	55.00	56.67	56.67	58.00	2.10	1.40
13. P2 X P8	55.67	57.00	57.33	60.67	59.67	62.00	3.10	2.07
14. P3 X P4	50.00	55.00	53.67	56.67	54.00	58.00	1.10	2.07
15. P3 X P5	48.00	52.33	56.67	56.67	57.67	57.00	2.10	1.07
16. P3 X P6	51.00	54.00	53.67	56.67	54.67	58.00	1.10	2.07
17. P3 X P7	53.00	57.00	56.33	58.67	58.67	60.00	3.10	2.07
18. P3 X P8	51.00	61.00	51.33	62.67	53.67	63.00	3.10	1.07
19. P4 X P5	51.00	54.00	53.33	56.00	55.67	58.00	3.10	2.40
20. P4 X P6	52.33	57.33	53.33	61.00	56.67	62.00	2.10	3.07
21. P4 X P7	55.00	58.00	57.33	61.00	59.67	63.00	2.10	2.73
22. P4 X P8	52.00	59.00	51.33	62.00	53.67	63.00	3.10	3.73
23. P5 X P6	53.00	54.00	56.00	56.00	57.67	58.00	1.20	2.13
24. P5 X P7	54.00	58.00	56.00	58.00	57.67	61.00	2.30	2.43
25. P5 X P8	53.00	57.33	57.00	59.33	58.67	63.00	1.20	3.47
26. P6 X P7	53.00	60.00	53.67	60.00	56.67	63.00	1.80	2.43
27. P6 X P8	52.67	57.67	56.00	52.67	57.67	60.00	2.70	1.87
28. P7 X P8	48.67	55.00	47.00	54.67	52.67	58.00	3.60	2.53
LSD 5 %	0.53	0.60	0.48	0.59	0.51	0.59	0.08	0.29
LSD 1%	0.70	0.80	0.64	0.78	0.68	0.78	0.11	0.39
SC-Yacout-5	54.00	59.00	56.00	61.00	57.00	62.00	1.00	1.00
SC-Gold-21	54.00	58.00	55.00	60.00	56.00	62.00	1.00	2.00
SC-168	57.00	61.00	59.00	63.00	60.00	65.00	1.00	2.00

Table 4. Continued

	Chlorophyll content		Ear leaf area (cm^2)		Stem diameter (cm)	
	N	D	N	D	N	D
P1 (Red-A)	46.47	47.38	538.63	456.63	1.83	1.37
P2 (Red-B)	52.34	42.44	500.63	375.25	1.73	1.27
P3 (Red-C)	63.65	53.26	375.88	265.50	1.80	1.27
P4 (L-6)	66.83	53.66	555.38	454.38	1.53	1.17
P5 (L-49)	71.97	44.04	519.38	355.88	1.67	1.20
P6 (L-69)	57.77	33.07	281.75	237.00	1.37	1.13
P7 (L-125)	55.92	58.07	439.88	351.00	1.67	1.27
P8 (A-63)	59.90	54.65	853.13	645.25	1.73	1.27
LSD 5%	1.26	0.63	13.34	11.88	0.03	0.03
LSD 1%	1.67	0.83	17.71	15.77	0.04	0.04
1. P1 X P2	52.33	44.53	884.50	617.25	2.33	2.07
2. P1 X P3	53.95	58.05	740.75	606.13	2.23	1.97
3. P1 X P4	60.95	54.27	698.25	607.50	2.50	2.07
4. P1 X P5	67.91	48.33	700.88	564.38	2.23	2.03
5. P1 X P6	61.73	46.80	683.00	595.63	2.30	1.90
6. P1 X P7	60.37	51.55	578.75	487.88	2.37	2.03
7. P1 X P8	54.27	53.84	832.63	497.50	3.03	2.50
8. P2 X P3	58.63	53.27	520.50	478.75	2.27	1.97
9. P2 X P4	70.93	53.47	753.13	585.63	2.80	2.17
10. P2 X P5	64.91	48.41	791.00	684.38	2.47	2.10
11. P2 X P6	64.43	63.85	684.63	587.38	2.50	2.03
12. P2 X P7	52.31	50.93	736.25	572.50	2.20	1.90
13. P2 X P8	60.80	58.88	839.75	631.38	2.67	2.17
14. P3 X P4	64.17	55.64	752.25	614.38	2.23	1.83
15. P3 X P5	63.10	57.35	736.88	595.63	2.47	2.00
16. P3 X P6	65.05	57.27	808.88	655.63	2.33	2.07
17. P3 X P7	62.00	56.54	603.50	507.38	2.27	1.93
18. P3 X P8	66.63	63.57	776.38	576.38	2.63	2.13
19. P4 X P5	58.33	59.18	982.63	720.88	2.80	2.20
20. P4 X P6	55.77	60.43	719.50	657.13	2.53	2.13
21. P4 X P7	71.90	52.31	580.00	500.63	2.23	1.90
22. P4 X P8	70.37	53.37	878.88	683.13	3.23	2.47
23. P5 X P6	61.37	50.13	607.13	507.38	2.13	1.93
24. P5 X P7	60.86	50.25	589.88	503.75	2.40	2.10
25. P5 X P8	70.75	52.64	997.00	581.88	2.93	2.50
26. P6 X P7	69.83	56.79	915.88	694.63	2.37	2.10
27. P6 X P8	63.36	58.27	825.50	623.38	2.47	2.07
28. P7 X P8	66.87	57.41	721.63	613.75	2.73	2.23
LSD 5 %	2.35	1.18	24.96	22.23	0.06	0.06
LSD 1%	3.13	1.56	33.14	29.51	0.08	0.08
SC-Yacout-5	60.87	55.57	877.50	599.13	3.07	2.53
SC-Gold-21	53.67	60.87	863.63	600.25	2.77	2.27
SC-168	59.10	47.40	866.75	633.75	2.43	2.13

Table 4. Continued

	Plant height (cm)		Ear height (cm)		Ear position		Biomass yield/plant (g)	
	N	D	N	D	N	D	N	D
P1 (Red-A)	108.33	166.00	75.00	102.33	0.69	0.61	296.3	208.0
P2 (Red-B)	107.33	160.00	76.33	110.33	0.71	0.69	203.3	168.7
P3 (Red-C)	108.00	166.67	75.00	101.00	0.69	0.61	169.3	129.7
P4 (L-6)	201.67	177.33	83.33	77.33	0.41	0.44	181.7	153.0
P5 (L-49)	193.33	172.67	81.67	75.33	0.42	0.44	129.3	108.0
P6 (L-69)	143.33	124.33	73.33	54.33	0.51	0.44	181.3	152.0
P7 (L-125)	204.00	177.67	93.33	83.33	0.46	0.47	150.0	143.3
P8 (A-63)	261.67	240.00	111.67	140.00	0.42	0.58	181.7	148.7
LSD 5%	1.85	1.31	1.83	1.29	0.01	0.01	17.61	2.24
LSD 1%	2.46	1.74	2.44	1.71	0.01	0.01	23.39	2.97
P1 X P2	289.67	258.33	119.00	115.00	0.41	0.44	748.0	675.0
P1 X P3	280.67	265.00	139.00	131.67	0.50	0.50	772.7	639.3
P1 X P4	289.00	268.33	140.00	128.33	0.48	0.48	801.7	728.0
P1 X P5	267.33	273.33	121.00	130.00	0.46	0.47	800.0	718.0
P1 X P6	300.00	280.00	157.67	126.67	0.53	0.45	638.3	573.0
P1 X P7	233.33	218.33	96.00	94.33	0.41	0.43	559.0	515.3
P1 X P8	320.67	287.67	148.33	122.33	0.46	0.42	540.7	457.7
P2 X P3	259.67	251.67	134.00	120.00	0.51	0.48	527.3	479.3
P2 X P4	314.33	293.33	157.00	151.67	0.50	0.52	765.0	674.7
P2 X P5	267.00	257.67	113.67	112.67	0.43	0.44	779.0	677.7
P2 X P6	297.67	280.00	158.33	130.00	0.53	0.47	771.7	669.0
P2 X P7	305.00	285.00	141.67	127.67	0.47	0.45	463.3	404.3
P2 X P8	276.67	259.33	125.00	117.67	0.45	0.45	1018.3	885.0
P3 X P4	274.00	255.00	123.67	126.67	0.45	0.50	596.7	541.0
P3 X P5	312.33	284.00	157.33	127.67	0.50	0.45	928.3	747.3
P3 X P6	301.67	286.67	147.33	136.00	0.49	0.47	638.3	588.7
P3 X P7	284.00	260.67	135.33	128.33	0.48	0.49	610.0	565.0
P3 X P8	263.33	253.33	125.00	112.67	0.47	0.44	663.0	593.0
P4 X P5	298.00	275.00	147.67	126.67	0.50	0.46	813.3	732.7
P4 X P6	267.33	256.67	125.00	120.67	0.47	0.47	741.7	683.0
P4 X P7	221.00	204.67	112.67	107.67	0.51	0.53	638.3	591.0
P4 X P8	301.67	286.00	137.67	126.67	0.46	0.45	1269.7	923.3
P5 X P6	271.00	257.00	130.33	120.00	0.48	0.47	654.0	584.0
P5 X P7	237.67	224.33	109.33	106.67	0.46	0.48	745.0	658.0
P5 X P8	315.00	285.00	167.00	137.67	0.53	0.48	979.3	846.0
P6 X P7	300.33	285.33	143.33	125.00	0.48	0.44	1276.7	658.7
P6 X P8	305.00	292.33	150.00	136.67	0.49	0.47	856.7	755.7
P7 X P8	300.00	290.67	161.67	128.00	0.54	0.44	738.3	641.3
LSD 5 %	3.47	2.45	3.43	2.41	-	-	32.95	4.19
LSD 1%	4.60	3.25	4.56	3.19	-	-	43.75	5.56
SC-Yacout-5	300.67	247.67	125.00	120.00	0.42	0.49	910.7	753.7
SC-Gold-21	270.00	240.00	120.00	115.00	0.44	0.48	781.7	644.3
SC-168	293.33	275.00	143.33	121.67	0.49	0.44	1040.0	654.0

Regarding biomass yield/plant (g), the means of biomass yield/plant for genotype are presented in Table 4. The differences between biomass yield/plant for parents and their F1 crosses were highly significant. The biomass yield/plant for parental inbred lines ranged from 129.3 and 108.0 g for P5 (L-49) to 296.3 and 208.0 g/plant for P1 (Red-A) under normal and drought-stress conditions, respectively. While for F1 crosses, the biomass yield/plant ranged from 540.7 and 457.7 g for cross P1 X P8 under normal and drought-stress conditions, respectively, to 1276.7 g for cross P6 X P7 under normal and 923.3 g for cross P4 X P8 under stress condition. Also, out of the evaluated 28 F1 crosses, there were 3 crosses (P2 X P8, P4 X P8 and P6 X P7) under normal and 2 crosses (P4 X P8 and P6 X P8) under stress surpassed significantly in biomass yield/plant over the best commercial hybrids SC-168 (1040.0 g/plant) under normal and SC-Yacout-5 (753.7 g/plant) under drought stress conditions. Similar results were obtained by Ertiro *et al.* (2017), Sayed *et al.* (2020), Iseghohi *et al*. (2022), Amegbor *et al.* (2023), Elsheikh (2024) and Menkir *et al*. (2024).

Heterosis estimates.

Heterosis is a major reason for the commercial maize industry as well as for the success of breeding efforts in many other crops. Although some progress has been made in understanding the genetic basis of heterosis, there is relatively little information regarding the biochemical, physiological, and molecular basis of this event. In this review, we review the explanation of heterosis. Beginning in the early 1900s, scientists began designing experiments to determine the mechanism of heterosis. Over the years, the majority of the scientific community has attributed heterosis to dominance or over dominance, and recently scientists have reported that epistasis and linkage are major contributors. One common theme throughout the last century has been that no one hypothesis of heterosis holds true for every experiment or every organism (Leyla Cesurer *et al.,* 2002)

Results presnted in Table 5 reveal that 17 and 9 cross combinations manifested negative significant or highly significant heterosis over mid and better parents, respectively, for tasseling date under normal conditions. The highest negative heterosis percentages were exhibited by crosses P1 X P4 (-5.73 %), P2 X P6 (-7.79 %) and P3 X P5 (-5.88 %) over better parent under normal condition. On the other side, under water-stress conditions, there were 17 and 11 crosses manifested negative significant or highly significant heterosis over mid and better parents, respectively, for tasseling date, and the highest negative heterosis percentages were exhibited by crosses namely; P1 X P6 (-10.80 %), P1 X P8 (-9.66 %) and P3 X P6 (-12.90 %) over better parent under drought-stress condition. The results agree with those obtained by Abd El -Aty and Katta (2002), Saleh *et al.,* (2002).

Results assumed in Table 5 reveal that 11 and 14 cross combinations manifested negative significant or highly significant heterosis over mid and better parents, respectively, for anthesis date under normal conditions. The highest negative heterosis percentages were exhibited by crosses namely; P_1 X P_6 (-15.22 %), P_2 X P_6 (-14.13 %) and P_7 X P_8 (-17.06 %) over better parent under normal condition. On the other side, under drought-stress conditions, there were 17 and 11 crosses manifested negative significant or highly significant heterosis over mid and better parents, respectively, for anthesis date, and the highest negative heterosis percentages were exhibited by crosses namely; P1 X P8 (-10.06 %), P_3 X P_6 (-9.57 %) and P_6 X P_8 (-14.59 %) over better parent under drought-stress condition. The results agree with those obtained by Aly (2013), Izhar *et al.* (2013), Abdel–Moneam *et al*., (2014), Asif, *et al.* (2014), Kamara *et al.* (2014), Rajitha *et al.* (2014), Abdel-Moneam and Ibraheem (2015), Khakwani *et al.* (2020), Iseghohi, *at al*. (2022), Sedhom *et al. (*2023), Abdel–Moneam *et al*., (2024) and Elsheikh (2024).

Table 5 reveal that 11 and 17 cross combinations manifested negative significant or highly significant heterosis over mid and better parents, respectively, for silking date under normal conditions. The highest negative heterosis percentages were exhibited by crosses namely; P_1 X P_6 (-12.77 %), P_2 X P_6 (-14.36 %) and P3 X P6 (-12.77 %) over better parent under normal condition. On the other side, under drought-stress conditions, there were 14 and 8 crosses manifested negative significant or highly significant heterosis over mid and better parents, respectively, for silking date, and the highest negative heterosis percentages were exhibited by crosses namely; P1 X P3 (-7.07 %), P_1 X P_8 (-10.33 %) and P_3 X P_6 (-9.38 %) over better-parent under drought-stress condition. The results agree with those obtained by Jawaharlal *et al.* (2012), Aly (2013), Izhar *et al.* (2013), Abdel–Moneam *et al*., (2014), Asif, *et al.* (2014), Kamara *et al.* (2014), Rajitha *et al.* (2014), Abdel-Moneam and Ibraheem (2015), Khakwani *et al.* (2020), Iseghohi, *at al*. (2022), Sedhom *et al. (*2023), Abdel–Moneam *et al*., (2024) and Elsheikh (2024).

Results (Table 5) reveal that out of the 28 evaluated crosses there were 11 and 12 crosses manifested negative significant or highly significant heterosis over mid and better parents, respectively, for ASI under normal conditions. The highest negative heterosis percentages were exhibited by crosses namely, P1 X P7 (-50.00%), P2 X P5 (-70.97%), P3 X P4 (-47.62%) and P3 X P6 (-47.62%) over better parent under normal condition. On the other side, under drought-stress conditions, there were 8 and 5 crosses manifested negative significant or highly significant heterosis over mid and better parents, respectively, for ASI, and the highest negative heterosis percentages were exhibited by crosses namely, P1 X P3 (-38.46%), P3 X P5 (-38.46%) and P3 X P8 (-30.43 %) over better-parent under drought-stress condition. The results agree with those obtained by Jawaharlal *et al.* (2012), Aly (2013), Abdel–Moneam *et al*., (2014), Kamara *et al.* (2014), Rajitha *et al.* (2014), Abdel-Moneam and Ibraheem (2015), Khakwani *et al.* (2020), Iseghohi, *at al*. (2022), Sedhom *et al. (*2023), Abdel-Moneam *et al*. (2024) and Elsheikh (2024).

Table 5 reveals that out of the 28 evaluated crosses there were 16 and 6 cross combinations manifested positive significant or highly significant heterosis over mid and better parents, respectively, for chlorophyll content under normal conditions. The highest positive heterosis percentages were exhibited by crosses namely, P2 X P6 (11.54%), P6 X P7 (20.88%) and P7 X P8 (11.64%) over better parent under normal condition. On the other side, under drought-stress conditions, there were 26 and 20 crosses manifested positive significant or highly significant heterosis over mid and better parents, respectively, for chlorophyll content, and the highest positive heterosis percentages were exhibited by crosses namely, P2 X P6 (69.10%), P4 X P6 (39.36%) and P6 X P8 (32.85%) over better-parent under drought-stress conditions.

Results in Table 5 reveal that out of the 28 evaluated crosses there were 10 and 3 cross combinations manifested positive significant or highly significant heterosis over mid and better parents, respectively, for ear leaf area under normal conditions. The highest positive heterosis percentages were exhibited by crosses namely, P3 X P6 (115.20%), P4 X P5 (76.93%) and P6 X P7 (108.21%) over better parent under normal condition. On the other hand, under drought-stress conditions, there were 12 and 4 crosses manifested positive significant or highly significant heterosis over mid and better parents, respectively, for ear leaf area, and the highest positive heterosis percentages were exhibited by crosses namely, P2 X P5 (82.38%), P3 X P5 (67.37%), P3 X P6 (146.94%) and P6 X P7 (97.90%) over better-parent under drought-stress conditions. The results agree with those obtained by Aly (2013), Izhar *et al.* (2013), Abdel–Moneam *et al.*, (2014), Asif, *et al.* (2014), Kamara *et al.* (2014), Rajitha *et al.* (2014), Abdel-Moneam and Ibraheem (2015), Khakwani *et al.* (2020), Iseghohi, *at al.* (2022), Sedhom *et al.* *(*2023) and Elsheikh (2024).

Table 5. Percentage of heterosis over mid (M.P) and better parents (B.P) in maize F_1 crosses for studied earliness and morpho-physiological traits under normal and drought stress conditions.

Trait	Tasseling date (day)				Anthesis date (day)			
	N		D		N		D	
Cross	MP	BP	MP	BP	MP	BP	MP	BP
P1 X P2	-2.89**	-1.95*	-4.14**	0.00	2.22**	1.90**	-3.75**	-0.60
P1 X P3	-2.58**	-1.31	-13.37**	-7.95**	0.95	0.63	-8.99**	-6.70**
P1 X P4	-7.50**	-5.73**	-4.22**	1.92*	0.31	-1.23	1.44	4.76**
P1 X P5	-4.52**	-3.27**	2.02**	3.51**	6.37**	5.70**	2.25**	2.82**
P1 X P6	-8.54**	-4.46**	-13.26**	-10.80**	-8.77**	-15.22**	-9.73**	-6.70**
P1 X P7	1.32*	4.76**	-1.14	-1.14	-1.83**	-5.29**	-1.68*	-1.68*
P1 X P8	6.96**	7.64**	-12.64**	-9.66**	-1.24*	-3.05**	-11.54**	-10.06**
P2 X P3	2.28**	2.61**	-11.67**	-1.85*	1.27*	0.63	-5.62**	0.00
P2 X P4	0.95	3.90**	9.43**	11.54**	2.50**	0.61	6.55**	6.55**
P2 X P5	-1.63*	-1.31	0.90	3.70**	2.88**	2.55**	0.87	3.57**
P2 X P6	-12.62**	-7.79**	0.00	7.41**	-7.33**	-14.13**	-0.28	6.55**
P2 X P7	4.32**	6.80**	-4.14**	0.00	0.92	-2.94**	-2.02**	1.19
P2 X P8	6.71**	8.44**	-2.29**	5.56**	7.17**	4.88**	3.12**	8.33**
P3 X P4	-5.06**	-1.96*	-6.78**	5.77**	0.00	-1.23	-4.49**	1.19
P3 X P5	-5.88**	-5.88**	-14.91**	-8.19**	7.94**	6.92**	-6.85**	-3.95**
P3 X P6	-5.56**	0.00	-15.63**	-12.90**	-6.12**	-12.50**	-10.29**	-9.57**
P3 X P7	6.00**	8.16**	-8.56**	-2.84**	2.74**	-0.59	-4.09**	-1.68*
P3 X P8	-1.92**	0.00	-5.18**	-2.66**	-4.64**	-6.10**	0.80	1.62
P4 X P5	-3.16**	0.00	-0.92	3.85**	0.31	-1.84**	-2.61**	0.00
P4 X P6	-5.99**	-3.68**	0.58	10.26**	-7.78**	-13.04**	1.95**	8.93**
P4 X P7	6.45**	12.24**	4.82**	11.54**	3.30**	1.18	5.48**	8.93**
P4 X P8	-3.11**	-1.89*	2.91**	13.46**	-5.81**	-6.10**	5.38**	10.71**
P5 X P6	-1.85**	3.92**	-9.24**	-5.26**	-1.18	-8.70**	-8.70**	-5.08**
P5 X P7	8.00**	10.20**	0.29	1.75*	3.07**	-1.18	-2.25**	-1.69*
P5 X P8	1.92**	3.92**	-4.18**	0.58	6.88**	4.27**	-1.66*	0.56
P6 X P7	0.00	8.16**	-0.55	2.27**	-9.04**	-12.50**	-2.70**	0.56
P6 X P8	-4.24**	-0.63	-7.49**	-6.99**	-3.45**	-8.70**	-15.96**	-14.59**
P7 X P8	-4.58**	-0.68	-9.34**	-6.25**	-15.57**	-17.06**	-9.89**	-8.38**
LSD 5%	1.30	1.50	1.47	1.70	1.18	1.36	1.45	1.67
LSD 1%	1.73	2.00	1.95	2.26	1.57	1.81	1.92	2.22

Table 5. Continued

Trait	Silking date (day)				ASI (day)			
	N		D		N		D	
Cross	MP	BP	MP	BP	MP	BP	MP	BP
P1 X P2	1.23	-1.20	-2.25**	1.16	57.69**	32.26**	60.68**	123.81**
P1 X P3	1.20	0.60	-9.04**	-7.07**	-9.52**	-9.52**	-49.61**	-38.46**
P1 X P4	-0.89	-1.76*	1.41	5.26**	0.00	0.00	5.11**	16.13**
P1 X P5	5.49**	3.59**	1.36	1.64	38.10**	38.10**	-18.11**	0.00
P1 X P6	-7.61**	-12.77**	-8.18**	-5.43**	5.00**	0.00	-10.14**	-1.59**
P1 X P7	-6.47**	-8.09**	1.36	1.64	-48.84**	-50.00**	-9.43**	-4.00**
P1 X P8	0.29	-3.33**	-10.81**	-10.33**	100.00**	38.10**	19.01**	56.52**
P2 X P3	4.94**	3.03**	-6.04**	-0.58	19.23**	0.00	10.64**	23.81**
P2 X P4	3.34**	0.00	6.71**	7.02**	11.54**	-6.45**	19.23**	47.62**
P2 X P5	2.50**	1.86*	3.10**	6.40**	-65.38**	-70.97**	95.74**	119.05**
P2 X P6	-7.20**	-14.36**	-0.27	6.40**	-16.00**	-32.26**	18.10**	47.62**
P2 X P7	2.41**	-1.73*	-1.97**	1.16	-20.75**	-32.26**	-33.33**	0.00
P2 X P8	5.60**	-0.56	3.91**	8.14**	58.97**	0.00	40.91**	47.62**
P3 X P4	-3.28**	-4.71**	-4.13**	1.75*	-47.62**	-47.62**	8.77**	19.23**
P3 X P5	6.13**	4.85**	-8.80**	-6.56**	0.00	0.00	-38.46**	-38.46**
P3 X P6	-7.08**	-12.77**	-10.08**	-9.38**	-45.00**	-47.62**	7.83**	19.23**
P3 X P7	4.14**	1.73*	-4.00**	-1.64	44.19**	40.91**	-8.82**	19.23**
P3 X P8	-6.67**	-10.56**	0.00	1.61	113.79**	47.62**	-34.69**	-30.43**
P4 X P5	0.91	-1.76*	-1.69*	1.75*	47.62**	47.62**	26.32**	38.46**
P4 X P6	-5.03**	-9.57**	1.64*	8.77**	5.00**	0.00	47.20**	48.39**
P4 X P7	4.37**	3.47**	6.78**	10.53**	-2.33**	-4.55**	12.33**	32.26**
P4 X P8	-8.00**	-10.56**	5.88**	10.53**	113.79**	47.62**	107.41**	143.48**
P5 X P6	-0.86	-7.98**	-7.94**	-4.92**	-40.00**	-42.86**	11.30**	23.08**
P5 X P7	3.59**	0.00	0.00	0.00	6.98**	4.55**	7.35**	40.38**
P5 X P8	3.23**	-2.22**	2.44**	3.28**	-17.24**	-42.86**	112.24**	126.09**
P6 X P7	-5.82**	-9.57**	0.00	3.28**	-12.20**	-18.18**	-0.68	15.87**
P6 X P8	-5.98**	-7.98**	-5.51**	-3.23**	100.00**	42.11**	2.75**	21.74**
P7 X P8	-10.48**	-12.22**	-5.69**	-4.92**	140.00**	63.64**	16.92**	65.22**
LSD 5%	1.25	1.45	1.45	1.67	0.21	0.24	0.72	0.83
LSD 1%	1.67	1.92	1.92	2.22	0.28	0.32	0.95	1.10

Table 5. Continued

Trait	Chlorophyll content				Ear leaf area (cm^2)			
	N		D		N		D	
Cross	MP	BP	MP	BP	MP	BP	MP	BP
P1 X P2	5.93*	-0.01	4.93**	-0.84	70.22*	64.21	48.40	35.18
P1 X P3	-2.02	-15.24**	22.51**	15.36**	62.00*	37.53	67.87*	32.74
P1 X P4	7.59*	-8.80*	14.54**	7.43**	27.65	25.73	33.37	33.04
P1 X P5	14.67**	-5.64	9.75**	5.74**	32.49	30.12	38.92	23.60
P1 X P6	18.45**	6.87*	41.50**	16.34**	66.51*	26.80	71.74*	30.44
P1 X P7	17.92**	7.95*	8.79**	-2.24	18.29	7.45	20.82	6.84
P1 X P8	2.03	-9.41**	13.63**	5.53**	19.65	-2.40	-9.70	-22.90
P2 X P3	1.10	-7.88*	25.51**	11.32**	18.77	3.97	49.43	27.58
P2 X P4	19.05**	6.13	26.00**	11.29**	42.64	35.61	41.18	28.89
P2 X P5	4.43	-9.81**	14.06**	11.95**	55.10	52.30	87.21**	82.38*
P2 X P6	17.04**	11.54**	93.05**	69.10**	75.01*	36.75	91.87**	56.53
P2 X P7	-3.37	-6.47	20.01**	1.35	56.57	47.07	57.66*	52.56
P2 X P8	8.34**	1.50	38.74**	21.29**	24.06	-1.57	23.74	-2.15
P3 X P4	-1.64	-3.99	4.47**	4.08**	61.56*	35.45	70.69*	35.21
P3 X P5	-6.94*	-12.32**	30.22**	17.88**	64.62*	41.88	91.71**	67.37*
P3 X P6	7.15*	2.19	73.17**	32.68**	146.00**	115.20**	160.95**	146.94**
P3 X P7	3.70	-2.59	6.16**	1.57	47.96	37.20	64.60*	44.55
P3 X P8	7.86**	4.69	19.35**	17.81**	26.34	-9.00	26.57	-10.67
P4 X P5	-15.95**	-18.94**	34.39**	21.16**	82.86**	76.93*	77.94**	58.65
P4 X P6	-10.49**	-16.56**	82.73**	39.36**	71.90*	29.55	90.09**	44.62
P4 X P7	17.14**	7.58*	-2.52	-6.37**	16.55	4.43	24.32	10.18
P4 X P8	11.04**	5.29	-0.54	-1.46	24.80	3.02	24.25	5.87
P5 X P6	-5.40	-14.73**	51.58**	30.03**	51.57	16.90	71.16*	42.57
P5 X P7	-4.83	-15.44**	14.11**	-1.57	22.99	13.57	42.53	41.55
P5 X P8	7.30*	-1.69	19.53**	6.67**	45.28	16.86	16.24	-9.82
P6 X P7	22.84**	20.88**	71.70**	24.61**	153.84**	108.21**	136.27**	97.90**
P6 X P8	7.69**	5.76	76.19**	32.85**	45.48	-3.24	41.31	-3.39
P7 X P8	15.47**	11.64**	5.05**	1.86	11.62	-15.41	23.21	-4.88
LSD 5%	5.77	6.66	3.33	2.88	61.13	70.59	54.44	62.87
LSD 1%	7.66	8.84	4.42	3.82	81.16	93.72	72.28	83.46

Table 5. Continued

Trait	Stem diameter (Cm)				Plant height (cm)			
	N		D		N		D	
Cross	MP	BP	MP	BP	MP	BP	MP	BP
P1 X P2	30.84**	27.27**	56.96**	51.22**	168.62**	169.88**	58.49**	61.46**
P1 X P3	22.94**	21.82**	49.37**	43.90**	159.48**	159.88**	59.32**	59.64**
P1 X P4	48.51**	36.36**	63.16**	51.22**	86.45**	166.77**	56.31**	61.65**
P1 X P5	27.62**	21.82**	58.44**	48.78**	77.24**	146.77**	61.42**	64.66**
P1 X P6	43.75**	25.45**	52.00**	39.02**	138.41**	176.92**	92.88**	125.20**
P1 X P7	35.24**	29.09**	54.43**	48.78**	49.41**	115.38**	27.06**	31.53**
P1 X P8	70.09**	65.45**	89.87**	82.93**	73.33**	196.00**	41.71**	73.29**
P2 X P3	28.30**	25.93**	55.26**	55.26**	141.18**	141.93**	54.08**	57.29**
P2 X P4	71.43**	61.54**	78.08**	71.05**	103.45**	192.86**	73.91**	83.33**
P2 X P5	45.10**	42.31**	70.27**	65.79**	77.61**	148.76**	54.91**	61.04**
P2 X P6	61.29**	44.23**	69.44**	60.53**	137.50**	177.33**	96.95**	125.20**
P2 X P7	29.41**	26.92**	50.00**	50.00**	95.93**	184.16**	68.81**	78.13**
P2 X P8	53.85**	53.85**	71.05**	71.05**	49.95**	157.76**	29.67**	62.08**
P3 X P4	34.00**	24.07**	50.68**	44.74**	76.96**	153.70**	48.26**	53.00**
P3 X P5	42.31**	37.04**	62.16**	57.89**	107.30**	189.20**	67.39**	70.40**
P3 X P6	47.37**	29.63**	72.22**	63.16**	140.05**	179.32**	97.02**	130.56**
P3 X P7	30.77**	25.93**	52.63**	52.63**	82.05**	162.96**	51.40**	56.40**
P3 X P8	49.06**	46.30**	68.42**	68.42**	42.47**	143.83**	24.59**	52.00**
P4 X P5	75.00**	68.00**	85.92**	83.33**	50.89**	54.14**	57.14**	59.27**
P4 X P6	74.71**	65.22**	85.51**	82.86**	54.98**	86.51**	70.17**	106.43**
P4 X P7	39.58**	34.00**	56.16**	50.00**	8.96*	9.59	15.31**	15.41**
P4 X P8	97.96**	86.54**	102.74**	94.74**	30.22**	49.59**	37.06**	61.28**
P5 X P6	40.66**	28.00**	65.71**	61.11**	60.99**	89.07**	73.06**	106.70**
P5 X P7	44.00**	44.00**	70.27**	65.79**	19.63**	22.93**	28.07**	29.92**
P5 X P8	72.55**	69.23**	102.70**	97.37**	38.46**	62.93**	38.13**	65.06**
P6 X P7	56.04**	42.00**	75.00**	65.79**	72.94**	109.53**	88.96**	129.49**
P6 X P8	59.14**	42.31**	72.22**	63.16**	50.62**	112.79**	60.48**	135.12**
P7 X P8	60.78**	57.69**	76.32**	76.32**	28.85**	47.06**	39.19**	63.60**
LSD 5%	0.16	0.18	0.12	0.13	8.49	9.80	5.99	6.92
LSD 1%	0.21	0.24	0.15	0.18	11.27	13.01	7.95	9.18

Table 5. Continued

Trait	Ear height (cm)				Ear position			
	N		D		N		D	
Cross	MP	BP	MP	BP	MP	BP	MP	BP
P1 X P2	55.90**	57.27**	8.15**	12.38**	-41.78**	-41.09**	-31.97**	-27.72**
P1 X P3	85.33**	85.33**	29.51**	30.36**	-28.37**	-28.37**	-18.58**	-18.13**
P1 X P4	68.00**	76.84**	42.86**	65.95**	-30.29**	-12.65**	-9.21**	9.16**
P1 X P5	48.16**	54.47**	46.34**	72.57**	-34.13**	-18.21**	-9.84**	8.40**
P1 X P6	110.22**	112.58**	61.70**	133.13**	-24.04**	-12.71**	-13.65**	3.82**
P1 X P7	2.86	14.06**	1.62	13.20**	-40.87**	-28.70**	-20.00**	-7.80**
P1 X P8	32.84**	58.93**	0.96	19.54**	-33.17**	-17.01**	-29.05**	-27.01**
P2 X P3	75.55**	77.09**	13.56**	18.81**	-27.70**	-26.84**	-26.48**	-21.43**
P2 X P4	88.40**	96.66**	61.63**	96.12**	-29.58**	-10.98**	-7.69**	19.08**
P2 X P5	39.18**	43.88**	21.36**	49.56**	-39.91**	-24.71**	-22.49**	0.00
P2 X P6	107.42**	111.58**	57.89**	139.26**	-25.35**	-13.35**	-17.16**	6.87**
P2 X P7	51.79**	66.99**	31.84**	53.20**	-34.27**	-20.00**	-22.99**	-4.96**
P2 X P8	11.94*	32.98**	-5.99*	6.65	-36.62**	-20.59**	-28.61**	-21.84**
P3 X P4	48.40**	56.21**	42.06**	63.79**	-35.10**	-18.67**	-4.79**	13.74**
P3 X P5	92.65**	100.85**	44.80**	69.47**	-27.88**	-10.45**	-13.74**	3.05**
P3 X P6	96.44**	98.65**	75.11**	150.31**	-29.81**	-19.34**	-9.27**	8.40**
P3 X P7	45.00**	60.79**	39.24**	54.00**	-31.25**	-17.10**	-8.36**	4.96**
P3 X P8	11.94*	33.93**	-6.50*	11.55**	-31.73**	-15.22**	-25.28**	-23.56**
P4 X P5	77.20**	78.99**	65.94**	68.14**	17.32**	18.73**	5.34**	5.34**
P4 X P6	50.00**	59.57**	83.29**	122.09**	-9.09**	0.72**	8.40**	8.40**
P4 X P7	20.71**	27.55**	34.02**	39.22**	11.68**	17.24**	16.91**	21.37**
P4 X P8	23.28**	41.20**	16.56**	63.79**	7.87**	9.16**	-12.13**	2.29**
P5 X P6	59.59**	68.17**	85.09**	120.86**	-5.84**	3.20**	6.87**	6.87**
P5 X P7	17.14**	24.95**	34.45**	41.59**	0.73**	4.55**	5.15**	9.16**
P5 X P8	49.55**	72.76**	27.86**	82.74**	25.98**	25.98**	-4.92**	10.69**
P6 X P7	53.57**	72.00**	81.60**	130.06**	-6.49**	-1.03**	-2.94**	0.76**
P6 X P8	34.33**	62.16**	40.65**	151.53**	-4.55**	4.63**	-8.20**	6.87**
P7 X P8	44.78**	57.72**	14.63**	53.60**	18.25**	22.73**	-16.19**	-6.38**
LSD 5%	9.71	8.41	5.89	6.80	0.04	0.04	0.03	0.03
LSD 1%	12.89	11.16	7.82	9.03	0.06	0.05	0.04	0.04

Table 5. Continued

Trait	Biomass yield/plant (g)			
	N		D	
Cross	MP	BP	MP	BP
P1 X P2	199.40**	152.42**	258.41**	224.52**
P1 X P3	231.85**	160.74**	278.68**	207.37**
P1 X P4	235.43**	170.53**	303.32**	250.00**
P1 X P5	275.88**	169.97**	354.43**	245.19**
P1 X P6	167.27**	115.41*	218.33**	175.48**
P1 X P7	150.49**	88.64	193.36**	147.76**
P1 X P8	126.22**	82.45	156.64**	120.03**
P2 X P3	183.01**	159.34**	221.34**	184.19**
P2 X P4	297.40**	276.23**	319.48**	300.00**
P2 X P5	368.34**	283.11**	389.88**	301.78**
P2 X P6	301.21**	279.51**	317.26**	296.64**
P2 X P7	162.26**	127.87**	159.19**	139.72**
P2 X P8	429.00**	400.82**	457.77**	424.70**
P3 X P4	239.98**	228.44**	282.78**	253.59**
P3 X P5	521.65**	448.23**	528.89**	476.35**
P3 X P6	264.07**	252.02**	317.99**	287.28**
P3 X P7	282.05**	260.24**	313.92**	294.19**
P3 X P8	277.78**	264.95**	326.11**	298.88**
P4 X P5	423.04**	347.71**	461.43**	378.87**
P4 X P6	308.63**	308.26**	347.87**	346.41**
P4 X P7	284.92**	251.38**	298.88**	286.27**
P4 X P8	598.90**	598.90**	512.15**	503.49**
P5 X P6	321.03**	260.66**	349.23**	284.21**
P5 X P7	433.41**	396.67**	423.61**	359.07**
P5 X P8	529.80**	439.08**	559.22**	469.06**
P6 X P7	670.62**	604.04**	346.05**	333.33**
P6 X P8	371.99**	371.56**	402.66**	397.15**
P7 X P8	345.23**	306.42**	339.27**	331.39**
LSD 5%	80.72	93.20	10.26	11.85
LSD 1%	107.16	123.74	13.63	15.74

Results given in Table 5 reveal that all the 28 evaluated crosses manifested positive significant or highly significant heterosis over mid and better parents, for stem diameter under normal and drought-stress conditions. The highest positive heterosis percentages were exhibited by crosses namely, P4 X P5 (68.00%), P4 X P8 (86.54%) and P5 X P8 (69.23%) over better parent under normal condition. Whereas, the highest positive heterosis percentages under drought-stress conditions were exhibited by crosses namely, P4 X P5 (83.33%), P4 X P8 (94.74%) and P5 X P8 (97.37%) over better-parent.

Plant height of maize plants is preferred as shortness because plants with greater height are likely to lodge during windstorm. Therefore, the plant height heterosis in the negative direction is desirable. The results of heterosis in Table 5 reveal that none of the crosses showed negative heterosis for plant height. The highest positive significant heterotic effect was exhibited by crosses namely, P1 X P8 (196.00%), P2 X P4 (192.86%) and P3 X P5 (189.20%) over better-parent under normal, and P3 X P6 (130.56%), P6 X P7 (129.49%) and P6 X P8 (135.12%) over better-parent under drought-stress condition. These results agree with Abdel–Moneam *et al*., (2014), Asif, *et al.* (2014), Kamara *et al.* (2014), Rajitha *et al.* (2014), Abdel-Moneam and Ibraheem (2015), Khakwani *et al.* (2020), Iseghohi, *at al.* (2022), Sedhom *et al. (*2023) and Elsheikh (2024).

Ear height on maize plants is preferred to have low ear placement because plants with greater ear height are likely to lodge during wind-storm especially during irrigation practice. Therefore, the ear height heterosis in the negative direction is desirable. Results given in Table 5 reveal that all the crosses manifested highly significant positive heterosis over mid-parent and better-parent value for ear height. The highest positive significant heterotic effect was exhibited by crosses namely, P1 X P6 (110.22 and 112.58%), P2 X P6 (107.42 and 111.58%), and P3 X P5 (92.65 and 100.85%) over mid and better parents, respectively, under normal-irrigation conditions. However, under water-stress condition, the highest positive significant heterotic effect was exhibited by crosses namely, P1 X P6 (133.13%), P2 X P6 (139.26%), P3 X P6 (150.31%) and P6 X P8 (151.53%) over better parent.

There were only two crosses, namely, P3 X P8 (-6.50%) and P2 X P8 (-5.99%) showed significant negative heterosis over mid-parents under drought-stress condition.

Ear position on maize plants is preferred to have low ear placement because plants with greater ear height are likely to lodge during windstorm especially during irrigation practice. Therefore, the ear position heterosis in the negative direction is desirable. Results given in Table 5 reveal that most of the studied crosses manifested significant or highly significant negative heterosis over mid-parent and better-parent values for ear position under normal conditions, 22 and 19 crosses, out of the studied 28 crosses, showed significant or highly significant negative heterosis over mid and better-parent, respectively, for ear position, and the highest negative heterosis percentages were recorded by the crosses namely, P1 X P2 (-41.09%), P1 X P7 (-28.70%) and P2 X P3 (-26.84%) over better parent under normal condition. On the other side, there were 23 and 9 crosses showed significant or highly significant negative heterosis over mid-parent and better-parent values for ear position under drought-stress condition, and the highest negative heterosis percentages were recorded by the crosses namely, P1 X P2 (27.72%), P1 X P8 (-27.01%) and P3 X P8 (-23.56%) over better parent under drought-stress condition. The results agree with those obtained by Abdel–Moneam *et al*., (2014), Asif, *et al.* (2014), Kamara *et al.* (2014), Rajitha *et al.* (2014), Abdel-Moneam and Ibraheem (2015), Khakwani *et al.* (2020), Iseghohi, *at al*. (2022), Sedhom *et al. (*2023) and Elsheikh (2024).

Concerning biomass yield/plant, results showed highly significant and positive heterosis, Table 5. All the evaluated 28 crosses recorded highly significant positive heterosis relative to their mid parents, and 26 crosses over better parent under normal conditions. The highest positive heterosis percentages were recorded by the crosses namely, P_3 X P_5 (521.65 and 448.23%), P4 X P8 (598.90 and 598.90%), P_5 X P_8 (529.80 and 439.08%) and P6 X P7 (670.62 and 604.04%) over mid and better parents, respectively, under normal-irrigation conditions. While, under drought-stress, all the evaluated 28 crosses recorded highly significant positive heterosis relative to their mid and better parent, and the highest positive heterosis percentages were recorded by the crosses, P3 X P5 (528.89 and 476.35%), P4 X P8 (512.15 and 503.49%) and P5 X P8 (559.22 and 469.06%) over mid and better parents, respectively. These crosses could be considered the best cross combinations for producing high biomass yield/plant. The results agree with those obtained by Jawaharlal *et al.* (2012), Aly (2013), Izhar *et al.* (2013), Abdel–Moneam *et al*., (2014a), Asif, *et al.* (2014), Kamara *et al.* (2014), Rajitha *et al.* (2014), Abdel-Moneam and Ibraheem (2015), Khakwani *et al.* (2020), Iseghohi, *at al*. (2022), Sedhom *et al. (*2023) and Elsheikh (2024).

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التبكير في النضج، قوة الهجين والصفات المورفو-فسيولوجية لهجن الجيل الأول من الذرة الشامية الحمراء والصفراء تحت ظروف الإجهاد المائي

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الملخص

هدفت هذه الدراسة إلى تقييم ثماني سلالات من الذرة الشامية الحمراء والصفراء والهجن الناتجة منها لصفات التبكير في النضج والصفات المورفولوجية والفسيولوجية تحت الظروف الطبيعية وظروف الإجهاد المائي. كانت متوسطات المربعات الراجعة للتراكيب الوراثية للذرة ومكوناتها الراجعة إلى كل من الآباء والهجن والآباء مقابل الهجن (P × C) معنوية أو عالية المعنوية لجميع الصفات المدروسة تحت الظروف الطبيعية وظروف الإجهاد المائي، مما يشير إلى تنوع واسع بين السلالات الأبوية وتنوع وراثي كافٍ لإجراء تقييم حيوي إضافي، ووجود قوة هجين معنوية تحت كل من معاملات الري والجفاف. كانت (L-49) P_5 و$P_7 X P_8$ تحت الظروف الطبيعية، وP_2 (Red-B) و$P_6 X P_8$ تحت ظروف الإجهاد المائي هي التراكيب الوراثية الأبكر في مواعيد الإزهار وظهور الحريرة والفترة بين اللقاح والحريرة (ASI) عند مقارنتها بالتراكيب الوراثية الأخرى، والتي ستكون مؤشرًا جيدًا للتبكير في النضج. كان هناك 17 و 11 هجينًا لتاريخ نثر اللقاح، و 14 و 8 هجينا لتاريخ ظهور الحريرة، و 23 و 9 هجينا لموضع الكوز، أظهرت قوة هجين سالبة ومعنوية أو عالية المعنوية مقارنة بمتوسط الأبوين وأفضل الأبوين، على التوالي تحت ظروف الجفاف. كان هناك 26 و 20 هجينًا لصفة محتوى الكلوروفيل، و 12 و 4 هجينا لمساحة ورقة الكوز، وجميع الهجن الـ 28 التي تم تقييمها لصفة قطر الساق والمحصول البيولوجي/ نبات أظهروا قوة هجين موجبة وعالية المعنوية مقارنة بمتوسط الأبوين وأفضل الأبوين، على التوالي تحت ظروف الجفاف. تم تسجيل أعلى قوة هجين موجبة مقارنة بأفضل الأبوين بواسطة الهجن $P_3 X P_5$ (476.35٪)، و$P_4 X P_8$ (503.49٪) و $P_5 X P_8$ (469.06٪) لصفة المحصول البيولوجي/نبات، وبالتالي، يمكن اعتبار هذه الهجن أفضل التراكيب الهجينية لإنتاج أعلى محصول بيولوجي/ نبات تحت ظروف الجفاف.

الكلمات الدالة: الذرة الشامية، متوسط الأداء، التبكير في النضج ، قوة الهجين، الجفاف