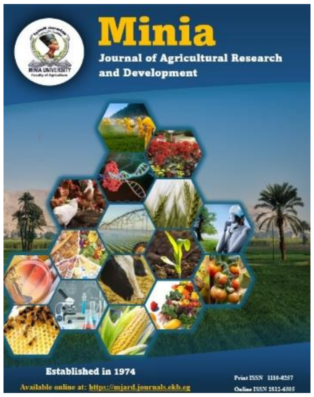
Minia J. of Agric. Res. & Develop., Minia Univ., Vol. 45 (4): 563 - 582, 2025

Minia Journal of Agricultural Research and Development

Journal homepage & Available online at:

https://mjard.journals.ekb.eg



Harnessing Genetic Potential in Yellow Maize: Combining Ability, Heterosis, and Heritability Across Tow Environments.

B. N. Ayad.[1], Fouad, H. M.[2], Salim, M. M. A.[2], AbouBakr. A. M. M.[2]

[1] Maize Research Department, Field Crops Inst., Agric. Res. Center, El Giza, Egypt,
[2] Agronomy Department, Fac. Agric. Minia Univ.

Received: 3 august 2025 Accepted: 10 august 2025

ABSTRACT

Maize (*Zea mays* L.) is crucial for global food security, yet its productivity in Egypt remains below national demand. This study evaluated 45 F_1 hybrids derived from ten diverse inbred lines using a half-diallel mating design across two distinct locations during 2024 growing seasons. Highly significant differences among genotypes and significant genotype × environment interactions were observed for most traits, notably plant height, ear height, kernel number per row, 100-kernel weight, and ear weight/ plot. Both additive and non-additive gene actions contributed to traits variation. Traits such as days to 50% silking and number of rows per ear exhibited high broad and narrow-sense heritability, indicating potential for genetic improvement through selection. Parental lines P3, P4, and P8 were identified as the best general combiners for grain yield and its key components. Strong heterotic responses were detected, particularly for ear weight per plot, with cross P7×P8 achieving 237% heterosis relative to the better parent. Crosses such as P1×P5, P2×P8, and P8×P10 showed favorable specific combining ability effects, making them promising candidates for future breeding programs. Correlation analysis reveald that early flowering, plant height, kernel number per row, and 100-kernel weight were strongly and positively associated with grain yield, highlighting their utility as indirect selection criteria.

Keywords: maize, diallel cross, heterosis, combining ability, heritability, trait association

* Corresponding author: AbouBakr. A. M. M.
E-mail address: balaa7425@gmail.com

INTRODUCTION

Maize (*Zea mays* L.) is a cornerstone crop for global food and feed, ranking alongside wheat and rice in importance. Originally native to the Americas, Maize is now cultivated on over 188 million hectares across temperate, subtropical, and tropical regions, producing more than 106 million metric tons annually. In Egypt, maize is grown on approximately 1.34 million hectares, yielding 7.6 million tons in 2023; however, local production remains insufficient, prompting annual imports exceeding 7.88 million tons to meet increasing demand **(FAOSTAT, 2022).**

Maize possesses one of the most extensively studied genetic systems among cereal crops, supporting breeding strategies focused on hybrid development through general (GCA) and specific (SCA) combining abilities **(Sprague and Tatum, 1942).** GCA reflects additive genetic effects, while SCA captures non-additive effects such as dominance and epistasis **(Griffing, 1956; Hallauer *et al*., 2010).** The genetic variance was previously reported to be mostly due to non-additive for plant, ear heights by **Mohamed *et al*. (2022) and Sedhom *et al*. (2024);** no. of kernels/row by **Mohamed *et al*. (2022), Nadeem *et al*. (2023), Sedhom *et al*. (2024) and Baiumy (2025)** and grain yield/plant by **Eisele *et al*. (2021), Mohamed *et al*. (2022), Nadeem *et al*. (2023), Sedhom *et al*. (2024) and Baiumy (2025).** On the other hand, the additive genetic variance was previously reported to be the most prevalent for earliness by **Keimeso *et al*. (2020), El-Shahed *et al*. (2021), Mohamed *et al*. (2022) and Abd El-Latif *et al*. (2023);** no. of rows/ear **by Mogesse *et al*. (2020), Mohamed *et al*. (2022);100-kernel weight by Keimeso *et al*. (2020) and Mogesse *et al*. (2020).** Diallel analysis remains a powerful approach for identifying superior parental combinations and predicting hybrid performance **(Yu *et al*., 2020).**

Heterosis, or hybrid vigor is central to hybrid breeding, although it does not always correlate with parental performance **(Amiruzzaman *et al*., 2013).** Understanding the genetic basis of heterosis and the relative contribution of additive and non-additive variance is critical for optimizing breeding strategies. Estimates of heritability further guide selection, with narrow-sense heritability reflecting the potential for additive genetic gains and broad-sense heritability indicating the extent of overall genetic control **(Falconer & Mackay, 1996).**

This study aims to: (i) evaluate the performance of 45 maize crosses across two locations; (ii) estimate heterosis relative to better- and mid-parent values; (iii) assess GCA and SCA effects; (iv) estimate broad- and narrow-sense heritability; and (v) identify stable trait associations to support yield-focused breeding strategies.

MATERIAL AND METHODS

A half-diallel cross involving ten genetically diverse yellow maize (*Zea mays* L.) inbred lines was conducted to investigate the inheritance patterns and gene action governing agronomic and yield-related traits. The study involved ten maize inbred lines with diverse genetic backgrounds and geographic origins. These included: P1 (EGAS 1038), derived from the single cross S.C 5177 × 5327; P2 (EGAS 775), from S.C 5147 × 4850; P3 (EGAS 676), originating from S.C 4970 × 5367; P4 (EGAS 724), developed from S.C 4505 × 3930; P5 (EGAS 532), selected from Pool 31 (IITA); P6

(EGAS 232), from S.C 5177 × 5322; P7 (EGAS 1212), derived from Fundulia (288**)**; P8 (EGAS 915), from S.C 5929 × 5489; P9 (EGAS 853), from S.C 5177 × 5322; and P10 (EGAS 133), developed from a Germany population. All parents sourced from Egypt except, P5, P7 and P10 imported from Nigeria, Romania and Germany, respectively

The experiment was carried out across two locations: EGA Seed Company Research Station in Bany-Hedeer, Beni Suef Governorate, and a private farm in Shebeen El-Koom, Menoufia Governorate, during the 2023 and 2024 growing seasons.

In summer 2023, all possible non-reciprocal crosses were made among aforementioned ten inbred lines by hand emasculation and pollination, giving 45 F_1 hybrids. In the following season (2024), the inbred lines and hybrids were evaluated in a randomized complete block design (RCBD) with three replications at each location.

Each plot consisted two rows, each 6 m-long , spaced 70 cm apart, with hills spaced at 25 cm and later thinned to a single plant per hill. Standard agronomic practices were applied uniformly across all plots. Climatic data indicated high temperatures and strong solar radiation with minimal rainfall, supporting robust maize growth. Soil analyses revealed contrasting textures and fertility levels between the two sites, as detailed below. Climatic conditions during the growing season in Beni Suef and Menoufia Governorates (May–September 2024).

The experiment was conducted during the summer growing season, which extended from May to September 2024, in Bany-hedeer, Beni Suef and Shebeen El koom - Menoufia governorates. According to data obtained from the Egyptian Meteorological Authority, the season was characterized by relatively high temperatures. In Beni Suef, maximum temperatures ranged from 31 to 39°C, while in Menoufia they ranged from 30 to 37°C. Minimum temperatures in both locations ranged from 18 to 25°C. Relative humidity levels were moderate to low throughout most of the season, ranging between 40% and 60%, with a notable decrease during July and August. These conditions contributed to a lower incidence of fungal diseases. The season was also marked by high solar radiation and minimal rainfall, providing favorable conditions for maize growth and development, especially during the stages of germination, flowering, and grain filling. Climatic data were obtained from the official website of the Egyptian Meteorological Authority **(www.ema.gov.eg).**

Soil Analysis in Beni Suef and Menoufia Governorates

Soil samples were collected before planting from both experimental sites to determine their physical and chemical properties. The results indicated that the soil in Beni Suef was classified as clay loam with a pH of 7.8, low organic matter content (1.1%), and moderate levels of available nitrogen (45 mg/kg), phosphorus (12 mg/kg), and potassium (170 mg/kg). In contrast, the soil in Menoufia was clay loam in texture with a pH of 7.4, relatively higher organic matter content (1.2%), and higher levels of available nitrogen (60 mg/kg), phosphorus (18 mg/kg), and potassium (200 mg/kg). These differences in soil characteristics were considered when interpreting plant performance and yield data across the two locations.

Data were collected on phenological, traits, plant and ear heights, yield and yield components. ANOVA was performed separately for each location and combined across environments. Heterosis was calculated relative to mid- and better-parent performance. Combining ability effects were estimated using Griffing's Method 2, Model I. Whenever, homogeneity of error variance was found, the combined analysis across experiments was carried out according to **Gomez and Gomez (1984).** Broad- and narrow-sense heritability were estimated based on variance components. Pearson's correlation coefficients were computed for all traits using SPSS **(version 20).**

RESULTS AND DISCUSSION

Data were collected on all genotypes for yield, its components, and various agronomic traits in each location as well as in the combined analysis (Table 1).

The mean squares attributed to locations were significant for all traits under investigation except for the number of rows per ear. Overall, mean values recorded at the Bani Hedeer location were superior to those at Menofia for all traits except number of rows per ear (Table 7). The improvement in these traits at Bani Hedeer could be attributed to the favorable climatic conditions, including optimal temperature and day length, which likely promoted enhanced vegetative growth and improved yield and its components in maize. Therefore, Bani Hedeer can be regarded as a non-stressful environment. These findings are consistent with the results reported by **Turk *et al.* (2020), Abd El-Azeem *et al.* (2021), Abd-Elnaser *et al.* (2022), Abd El-Latif *et al.* (2023), Rezgar *et al.* (2024), and Galal *et al.* (2025).**

The mean squares due to genotypes were significant for all studied traits across both locations and in the combined analysis (Table 2), indicating substantial genetic diversity among the parental materials evaluated and their hybrids. The genotype × location interaction mean squares were significant for plant height, ear height, number of kernels per row, 100-kernel weight, and ear yield per plant, indicating that genotype performance varied between locations. Conversely, for days to 50% tasseling, days to 50% silking, and number of rows per ear, the interaction mean squares were not significant, suggesting consistent genotype performance for these traits across environments.

Significant mean squares were also detected for parents across all traits at both locations and in the combined analysis (Table 1). However, the interaction between parental inbred lines and locations was not significant for any trait except for plant height and ear height (Table 1).This result may reveal higher repeatability of performance of the parental inbred lines under locations. Insignificant parent x location interaction mean squares were detected for all traits except two traits (plant and ear heights) revealing that parents have the same response to location changes. On the contrary, significant interaction was obtained revealing that the parental inbred lines varied in their response from location to another.

Hybrids mean squares were significant for all traits, revealing overall differences between these hybrids. Insignificant interaction mean squares between hybrids and locations were obtained for all traits except, no. of kernels/ row, 100-kernel weight and ear weight/plot (Table 1), indicating that, these hybrids behaved somewhat similarly from location to another. For the exceptional traits, significant interaction was obtained, reflecting that these hybrids responded differently from site to another.

For days to 50% silking, inbred lines No. 2, 3, 4, 9, and 10 exhibited the earliest values across locations. Additionally, fourteen crosses showed significantly earlier silking compared to others. Among them, the cross 3 × 4 recorded the earliest days to 50% silking across the two studied locations.

Table (1). Observed mean squares from analysis of variance for all studied traits at both and across locations.

S.O.V.	d.f.	Days to 50% silking	Days to 50% tasseling	Plant height (cm)	Ear height (cm)	No. of rows / Ear	No. of kernels / row	100 kernels weight (g)	Ear weight/ plot (g)
Bany-Hedeer L1									
Replication	3	19.70	12.42	820.95	1013.47	1.88	35.47	1.22	1.70
Genotypes	54	31.42**	28.48**	2066.47**	749.63**	6.85**	109.79**	73.39**	4.5**
Parent	9	33.47**	35.3**	797.89**	392.38**	7.13**	17.46**	139.88**	1.29**
Cross	44	17.3**	13.92**	402.93**	286.52**	4.54**	53.53**	32.57**	2.08**
Par.vs.cr.	1	634.4**	607.47**	86679.22**	24341.7**	105.91**	3416.27**	1270.69**	140.04**
Error	162	1.13	1.23	47.95	36.72	0.58	3.46	3.29	0.19
Menofia L2									
Replication	3	3.58	1.99	564.05	91.61	0.25	8.77	2.04	2.36
Genotypes	54	30.61**	25.52**	2887.44**	1062.17**	6.92**	83.52**	75.12**	3.56**
parent	9	30.61**	33.62**	1881.94**	1022.85**	5.5**	17.46**	139.88**	1.47**
Cross	44	18.05**	13.22**	653.71**	322.48**	5.14**	52.61**	58.64**	2.43**
Par.vs.cr.	1	583.43**	493.54**	110221.13**	33962.22**	98.33**	2038.06**	217.1**	72.25**
Error	162	0.92	1.06	64.6	52.43	0.86	3.91	5.25	0.14
Combined across locations									
location	1	15.28	24.58	70.40	16.04	1.49	398.24	984.01	17.03
Rep/L	6	11.64	7.21	692.50	552.54	1.06	22.12	1.63	2.03
Genotypes	54	61.22**	53.42**	4822.98**	1742.82**	13.11**	185.82**	135.2**	7.62**
parent	9	63.85**	68.81**	2327.97**	1260.36**	12.43**	34.91**	279.77**	2.69**
Cross	44	34.41**	26.53**	983.98**	565.11**	8.9**	98.96**	79.86**	4.11**
Par.vs.cr.	1	1.5**	1.5**	1.5**	1.5**	204.16*	5365.83**	1269.12**	206.74**
G×L	54	0.82	0.58	130.93**	68.97*	0.66	7.49**	13.3**	0.44**
par.×L	9	0.23	0.12	351.86**	154.86**	0.2	0.001	0.001	0.06
Cr.×L	44	0.94	0.62	72.66	43.89	0.77	7.19**	11.35**	0.41**
Par.vs.cr.Vs.L	1	1.5**	1.5**	1.5**	1.5**	0.07 *	88.5**	218.67**	5.56**
Error	324	1.03	1.14	56.27	44.58	0.72	3.69	4.27	0.17

*and ** denote significance at the 5% and 1% probability levels, respectively.

The mean performances of the tested ten inbred lines and the tested 45 hybrids for earliness traits, plant height, ear height and yield components across locations are present in (Table 2).

Regarding days to 50% tasseling, inbred line No. 9 exhibited the earliest tasseling across the combined locations. However, its performance did not differ significantly from inbred lines No. 2, 3, 4, and 10. Among the hybrids, the cross 3×4 recorded the earliest tasseling across locations. Additionally, thirty-five other crosses did not differ significantly from this hybrid, indicating their superiority in earliness for days to 50% tasseling. Earliness if found in corn is favorable for escaping destructive injuries caused by *Sesamia cretica* ledi *chilo simplex* But and *Pyrausta nubilialis*.

Table (2). Mean performance for all studied traits across locations.

Entry		D. to 50% silking	D. to 50% tasseling	Plant height	Ear height	№ of rows/Ear	№ of kernels/row	100 kernels weight
1038×775	**P1xP2**	57.13	56.13	199.25	121.38	16.6	37.38	26.68
1038×676	**P1xP3**	50.63	51.5	225.25	113.25	16.8	39.58	28.93
1038×724	**P1xP4**	52.13	51.88	211.13	108.38	17.35	40.65	29.33
1038×532	**P1xP5**	55.25	55	206.5	114.88	19.25	39.83	26.1
1038×232	**P1xP6**	56.75	56.25	204	112.5	17.45	34.35	28.3
1038×1212	**P1xP7**	58.25	57.63	184.63	104.75	16.5	29.18	25.9
1038×915	**P1xP8**	56.63	55.63	221.88	130.38	18.8	41.48	28.53
1038×853	**P1xP9**	55.75	54.5	201.13	113.75	17.75	38.13	23.78
1038×133	**P1xP10**	54.88	54.38	201.63	109.25	17.6	36.65	24.28
775×676	**P2xP3**	51	51.38	215.25	110.13	15.35	40.88	35.25
775×724	**P2xP4**	52.75	52	214.63	114.38	15.85	43.48	31.88
775×532	**P2xP5**	53.63	53	205.75	106.25	17.95	42.55	24.53
775×232	**P2xP6**	55	54	208.25	111.75	17.55	35.03	27
775×1212	**P2xP7**	55.38	55	214.88	121.5	16.85	34.58	27.5
775×915	**P2xP8**	55	54.5	231.38	133.75	18.1	42.4	30.9
775×853	**P2xP9**	54.5	53.88	210.13	115.63	17.05	39.68	24.08
775×133	**P2xP10**	57.38	57.38	194.63	107.5	15.05	28.03	27.38
676×724	**P3xP4**	50.25	51.25	206.38	100.25	15.4	40.15	34.45
676×532	**P3xP5**	55.75	55	201.63	103.38	16.35	36.38	25.6
676×232	**P3xP6**	51.38	51.38	219.88	110.75	16.35	40.78	30.45
676×1212	**P3xP7**	50.88	52.13	216.63	115.38	16	39.08	32.3
676×915	**P3xP8**	55.38	55.38	205	104.13	16.4	36	26.5
676×853	**P3xP9**	51.5	51.38	225.38	115.5	15.9	38.5	32.53
676×133	**P3xP10**	51.13	51.88	224.38	117.13	15.4	41.18	34.3
724×532	**P4xP5**	53.38	53.63	210.5	108.63	16.2	38.98	27.5
724×232	**P4xP6**	53.38	52.38	216.63	111.13	17.2	39.35	29.93
724×1212	**P4xP7**	55.25	55.88	214	118.5	16.05	42.18	30.5
724×915	**P4xP8**	56.88	56.75	219.5	119.38	16.35	40.95	31.08
724×853	**P4xP9**	53.25	52.63	218	114.13	15.75	42.6	31.2
724×133	**P4xP10**	53	52.13	220.13	117.13	15.75	43.55	32.03
532×232	**P5xP6**	55.88	55	208.75	111.75	19.1	39.08	25.03
532×1212	**P5xP7**	56	55.38	207.5	113.13	17.8	38.15	26.58
532×915	**P5xP8**	58.5	57.75	180	91.88	18.1	35.55	22.38
532×853	**P5xP9**	54.25	53	215	111.75	18.75	38.13	27.58
532×133	**P5xP10**	54.75	54.38	200.13	102.38	17.9	41.7	26
232×1212	**P6xP7**	56.63	56	202.63	116.63	17.15	34.05	27.95
232×915	**P6xP8**	55.38	54.75	223.5	123.63	18.4	39.8	27.9
232×853	**P6xP9**	55	54.25	219	124	16.7	36.85	24.53
232×133	**P6xP10**	56	55.13	217.13	116.25	17	36	27.93
1212×915	**P7xP8**	56	56.25	222	128.13	17.5	41.3	32.25
1212×853	**P7xP9**	55.63	54.88	202.63	114.13	16.95	37.03	24.2
1212×133	**P7xP10**	55.25	55.13	216.63	121.13	16.8	37.38	26.5
915×853	**P8xP9**	55	53.75	229.63	127.13	18.15	45.1	29.43
915×133	**P8xP10**	55	54.75	228.13	130.75	18.05	43.38	31.35
853×133	**P9xP10**	53.25	52.5	220.75	118.75	16.65	40.95	25.43
1038	**P1**	60.63	60	154.88	86.63	16.55	32.8	25.85
775	**P2**	57	56	185.5	103.88	15	30.6	27.85
676	**P3**	56.75	57.25	151	81.25	14.2	31.55	27.35
724	**P4**	56.75	56.88	155.38	83.63	13.6	30.55	29.2
532	**P5**	60.25	59.5	135.25	66.13	17.1	30.3	19.5
232	**P6**	59.5	59.63	158.38	89.63	16.73	29.05	23.43
1212	**P7**	61.25	59.5	153.13	86.63	15.7	28	28.6
915	**P8**	64.5	64.25	134.38	64.13	13.68	26.48	11.53
853	**P9**	55.25	53.63	160.63	86.5	15	31.55	17.45
133	**P10**	57	56.25	184.38	100	15	27	28.25
Mean		55.17	54.70	202.08	109.17	16.7	37.2	27.5
R LSD 5%		3.70	3.91	27.5	24.48	3.11	7.04	7.57

The choice between taller plants with shorter plants with reduced ear height depends on the breeder's objective.

All parental inbred lines except no.2 and the cross 5x8 at the combined across locations gave the lowest mean values for plant height. Although, fifteen hybrids did not differ significantly from the cross 5x8. However, the parental inbred lines no. 2 and twenty four crosses had the highest mean values for plant height. The 2x8 hybrid was the tallest camel ever.

All parental inbred lines, except line No. 2, along with hybrid cross 5×8, recorded the lowest mean values for plant height across the combined locations. However, fifteen hybrids did not differ significantly from cross 5×8. In contrast, inbred line No. 2 and twenty-four hybrid crosses exhibited the highest mean plant heights. Notably, hybrid 2×8 was the tallest among all evaluated genotypes.

From a breeder’s perspective, short maize plants are generally preferred for grain production due to their greater lodging resistance, higher harvest index, suitability for high-density planting, and compatibility with mechanized harvesting. They allocate more energy to grain rather than vegetative growth, improving yield efficiency. On the other hand, tall maize plants are advantageous for silage, fodder, or bioenergy production because of their higher biomass yield and stronger competitiveness against weeds. The choice ultimately depends on the breeding goals, target environment, and end-use, with modern programs often favoring moderately tall plants to balance yield, stability, and adaptability.

All parental inbred lines, except lines No. 8 and 6, as well as the cross 5×8 and twenty-eight other crosses, exhibited the lowest mean values for ear height across the combined locations. Low ear height is a desirable trait in maize breeding programs aimed at improving grain production, mechanization, and optimizing plant density, as it enhances both agronomic performance and operational efficiency.

In terms of rows per ear, inbred lines No. 4 and 8 produced the highest mean values across locations. Additionally, the hybrid combination 1×5, along with thirty-four other crosses, recorded the greatest mean values for this trait.

All parental inbred lines demonstrated the highest mean number of kernels per row across locations. Furthermore, cross 8×9, along with twenty-nine other hybrids, achieved the top mean values for this characteristic.

Inbred lines No. 4, 1, 2, 3, 6, 7, and 10 exhibited the heaviest 100-kernel weights, ranging from 29.02 to 21.63 g. Among the hybrids, cross 2×3 recorded the highest mean 100-kernel weight across environments. However, this cross did not differ significantly from twenty-two other hybrids for this trait.

The mean squares comparing parents versus hybrids, which serve as an indicator of average heterosis, were significant for all evaluated traits at each location and in the combined analysis (Table 1). Moreover, the interaction between parents vs. crosses and locations was significant for all traits, indicating that the overall performance of parental lines and their F_1 hybrids varied between environments.

Mean performance data for ear weight per plot, along with heterosis expressed as the percentage deviation of F_1 mean values from both the mid-parent and the better parent, are presented for Bani Hedeer (L1), Menofia (L2), and the combined analysis (Table 3).

Parental inbred line No. 2 recorded the highest mean ear weight per plot across both locations and in the combined analysis. The remaining parents did not differ significantly from the parent No. 2. Among the hybrids, cross 8×10 recorded the highest ear weight per plot at Bani Hedeer, cross 2×8 at menofia, and 8×10 in the combined across locations recorded the highest values. Additionally, thirty one, twenty two and twenty seven crosses stood out with the top performance at Bani Hedeer, Menofia and the combined across locations, respectively.

In terms of heterosis relative to the mid-parent, forty-one, thirty-three, and thirty-nine crosses exhibited significant positive effects for ear weight per plot at Bani Hedeer, Menofia, and the combined analysis, respectively. When compared to the better parent, forty, thirty-three, and thirty-eight hybrids showed significant positive heterosis in the same order. Notably, the most pronounced desirable heterotic effect was observed in cross 7×8 across both locations, reaching 237.00% relative to the better parent.

Hence, it could be concluded that these crosses offer possibility for improving grain yield in maize. Several investigators reported high heterosis for yield of maize; i.e. **Tafa *et al*. (2020), Talekar *et al.* (2021), Atia *et al*. (2022), Kanhaiya Lal *et al.* (2023), Rezgar *et al.* (2024) and Baiumy (2025).**

The analysis of variance for combining ability across each location and in the combined dataset for all studied traits is presented in Table 4.

The variance attributed to general combining ability (GCA) reflects additive genetic effects as well as additive × additive interactions, whereas the variance due to specific combining ability (SCA) represents the non-additive component of genetic variability, primarily arising from dominance and epistatic effects. The mean squares associated with both GCA and SCA were highly significant across all traits evaluated.

When both GCA and SCA mean squares are significant, it becomes necessary to determine which type of gene action contributes most to the performance of single-cross hybrids. In such cases, the relative magnitudes of the mean squares provide insight into their importance. Therefore, the GCA/SCA ratio was calculated as an indicator of the nature of the underlying genetic variance.

For days to 50% tasseling, days to 50% silking, number of rows per ear, and 100-kernel weight across individual locations and the combined analysis, as well as ear weight per plot at the second location (Menofia), the GCA/SCA ratios were high and substantially exceeded unity. This suggests that additive and additive × additive gene effects accounted for the majority of the genetic variability in these traits.

In contrast, plant height, ear height, and the number of kernels per row across both individual locations and the combined dataset, along with ear weight per plot at the first location (Bani Hedeer) and in the combined analysis, showed GCA/SCA ratios below one. This indicates that non-additive gene action contributed more prominently to the total genetic variability associated with these characteristics.

Additionally, the interaction mean squares between locations and GCA were significant for plant height, 100-kernel weight, and ear weight per plot. Similarly, significant interactions between locations and SCA were observed for plant height, ear height, number of kernels per row, 100-kernel weight, and ear weight per plot.

These findings indicate that the magnitude and nature of gene action were influenced by environmental conditions, with variation observed across locations. For ear height, the GCA × location/GCA ratio was higher and more significant than the SCA × location/SCA ratio, suggesting that additive genetic effects were more sensitive to environmental changes than non-additive effects. However, in another instance for the same trait, the GCA × location/GCA ratio was lower than the SCA × location/SCA ratio, implying that non-additive effects were more influenced by environmental factors in that case.

Table (3). Mean performance for ear weight/ plot and heterosis relative to mid-parent and better parent in both and across studied locations.

Entry		Ear weight/ plot (Kg)			M.P Heterosis foe ear weight/ plot			B.P Heterosis foe ear weight/ plot		
		L1	L2	C	L1	L2	C	L1	L2	C
1038×775	**P1xP2**	3.55	1.8	2.68	75.31**	-12.2	31.29	42**	-28*	7
1038×676	**P1xP3**	3.7	3.25	3.48	112.95**	84.4**	98.57**	92.21**	68.83**	80.52**
1038×724	**P1xP4**	4.1	3.8	3.95	124.66**	105.41**	114.97**	95.24**	80.95**	88.10**
1038×532	**P1xP5**	4.35	3.6	3.98	205.26**	139.26**	171.37**	180.65**	125.00**	152.38**
1038×232	**P1xP6**	2.75	2.2	2.48	92.98*	43.14	67.12*	77.42**	37.50	57.14**
1038×1212	**P1xP7**	2.1	1.4	1.75	50	-1.75	23.89	35.48	-12.50	11.11
1038×915	**P1xP8**	4.6	4.15	4.38	365.82**	309.88**	337.50**	196.77**	159.38**	177.78**
1038×853	**P1xP9**	2.65	2.6	2.63	79.66*	76.27*	77.97*	70.97**	62.5**	66.67**
1038×133	**P1xP10**	3.1	2.3	2.7	86.47**	17.2	48.97	74.65**	-1.08	31.71
775×676	**P2xP3**	4.1	4.1	4.1	85.31**	85.31**	85.31**	64.00**	64.00**	64.00**
775×724	**P2xP4**	4.35	3.85	4.1	89.13**	67.39**	78.26**	74.00**	54.00**	64.00**
775×532	**P2xP5**	3.9	3.1	3.5	105.26**	58.6*	81.6**	56.00**	24.00	40.00**
775×232	**P2xP6**	3	2.68	2.84	57.89*	34.63	46.00	20.00	7.00	13.50
775×1212	**P2xP7**	3.6	2.5	3.05	92**	33.33	62.67*	44.00**	0.00	22.00
775×915	**P2xP8**	4.8	4.35	4.58	228.21**	197.44**	212.82**	92.00**	74.00**	83.00**
775×853	**P2xP9**	3.15	2.35	2.75	61.54*	22.08	41.94	26.00	-6.00	10.00
775×133	**P2xP10**	2	1.35	1.68	-6.43	-44.04*	-26.37	-20.00	-46.00**	-33.00*
676×724	**P3xP4**	3.65	3.65	3.65	81.37**	81.37**	81.37**	73.81**	73.81**	73.81**
676×532	**P3xP5**	2.65	2.95	2.8	64.34	76.95**	70.75*	37.66*	53.25**	45.45**
676×232	**P3xP6**	4	3.5	3.75	148.06**	105.94**	126.45**	107.79**	81.82**	94.81**
676×1212	**P3xP7**	3.85	3.6	3.73	142.52**	126.77**	134.65**	100.00**	87.01**	93.51**
676×915	**P3xP8**	2.9	2.75	2.83	146.81**	134.04**	140.43**	50.65**	42.86**	46.75**
676×853	**P3xP9**	3.7	3.5	3.6	122.56**	113.74**	118.18**	92.21**	81.82**	87.01**
676×133	**P3xP10**	4.8	4	4.4	159.46**	88.24**	121.38**	149.35**	72.04**	114.63**
724×532	**P4xP5**	3.55	2.85	3.2	108.82**	62.43*	85.26**	69.05**	35.71*	52.38**
724×232	**P4xP6**	3.95	4	3.98	132.35**	123.84**	127.99**	88.10**	90.48**	89.29**
724×1212	**P4xP7**	3.95	3.65	3.8	135.82**	117.91**	126.87**	88.10**	73.81**	80.95**
724×915	**P4xP8**	3.85	3.9	3.88	204.95**	208.91**	206.93**	83.33**	85.71**	84.52**
724×853	**P4xP9**	4.15	3.75	3.95	137.14**	117.39**	127.34**	97.62**	78.57**	88.10**
724×133	**P4xP10**	3.95	3.85	3.9	103.87**	74.01**	87.95**	88.10**	65.59**	85.71**
532×232	**P5xP6**	3.75	3.25	3.5	188.46**	125.44**	155.32**	188.46**	120.49**	152.34**
532×1212	**P5xP7**	3.85	2.55	3.2	201.96**	91.78**	145.72**	196.15**	80.95**	136.23**
532×915	**P5xP8**	1.85	2.5	2.18	114.49	172.59**	144.43*	42.31	77.40**	60.56*
532×853	**P5xP9**	3.85	3.1	3.48	185.19**	124.7**	154.61**	175.00**	119.98**	152.73**
532×133	**P5xP10**	3.95	3.1	3.53	156.91**	66.03**	107.07**	122.54**	33.33*	71.95**
232×1212	**P6xP7**	2.9	2.2	2.55	127.45**	61.53	93.4*	123.08**	49.25*	83.85**
232×915	**P6xP8**	4.4	3.85	4.13	410.14**	305.48**	355.3**	238.46**	161.19**	197.40**
232×853	**P6xP9**	2.95	2.85	2.9	118.52**	101.84**	109.99**	110.71**	93.35**	109.08**
232×133	**P6xP10**	3.5	2.7	3.1	127.64**	42.14	80.39**	97.18**	16.13	51.22**
1212×915	**P7xP8**	4.23	4.2	4.21	404.48**	401.49**	402.99**	238.00**	236.00**	237.00**
1212×853	**P7xP9**	2.88	2.25	2.56	116.98**	73.08*	95.24*	105.36**	66.67**	86.36**
1212×133	**P7xP10**	3.65	2.35	3	141.32**	31.47	81.82**	105.63**	1.08	46.34**
915×853	**P8xP9**	3.8	3.55	3.68	316.44**	300**	308.33**	171.43**	162.96**	167.27**
915×133	**P8xP10**	4.95	4.25	4.6	350**	209.09**	271.72**	178.87**	82.80**	124.39**
853×133	**P9xP10**	3.7	2.45	3.08	133.07**	33.33	79.56**	108.45**	5.38	50.00**
1038	**P1**	1.55	1.6	1.58						
775	**P2**	2.5	2.5	2.5						
676	**P3**	1.93	1.93	1.93						
724	**P4**	2.1	2.1	2.1						
532	**P5**	1.3	1.41	1.35						
232	**P6**	1.3	1.47	1.39						
1212	**P7**	1.25	1.25	1.25						
915	**P8**	0.43	0.43	0.43						
853	**P9**	1.4	1.35	1.38						
133	**P10**	1.78	2.33	2.05						
mean		3.25	2.85	3.05						
R LSD 5%		1.61	1.38	1.51						

*and ** denote significance at the 5% and 1% probability levels, respectively.

Table (4). Observed mean squares from analysis of variance for all studied traits at both and across locations.

S.O.V.	d.f.	Days to 50% silking	Days to 50% tasseling	Plant height	Ear height	№ of rows / Ear	№ of kernels / row	100 kernels weight	Ear weight/ plot
Bany Hedeer (L1)									
GCA	9	18.25**	15.03**	211.42**	162.74**	5.12**	14.72**	33.89**	0.38**
SCA	45	5.78**	5.54**	577.66**	192.34**	1.03**	29.99**	15.24**	1.27**
Error	162	0.28	0.31	11.99	9.18	0.14	0.87	0.82	0.05
GCA/SCA		3.16	2.71	0.37	0.85	4.97	0.49	2.22	0.30
Menofia (L2)									
GCA	9	20.12**	15.91**	335.51**	218.45**	4.69**	15.53**	54.34**	0.9**
SCA	45	5.16**	4.47**	799.13**	274.96**	1.14**	21.95**	11.67**	0.89**
Error	162	0.23	0.26	16.15	13.11	0.21	0.98	1.31	0.04
GCA/SCA		3.90	3.56	0.42	0.79	4.11	0.71	4.66	1.01
combined across locations									
GCA	9	38.15**	30.82**	505.72**	364.22**	9.62**	29.29**	84.64**	1.14**
SCA	45	10.74**	9.86**	1345.75**	450**	2.01**	49.89**	23.63**	2.06**
GCA x L	9	0.22	0.13	41.21**	16.97**	0.19	0.96	3.59**	0.14**
SCA x L	45	0.2	0.15	31.04**	17.3*	0.16	2.06**	3.27**	0.11**
Error	324	0.26	0.29	14.07	11.14	0.18	0.92	1.07	0.04
GCA/SCA		3.55	3.12	0.38	0.81	4.79	0.59	3.58	0.55
GCA x L/GCA		--	--	0.08	0.05	--	--	0.04	0.12
SCA x L/SCA		--	--	0.02	0.04	--	--	0.14	0.05

* and ** denote significance at the 5% and 1% probability levels, respectively.

For traits such as plant height and ear weight per plot, the GCA × location/GCA ratio exceeded the SCA × location/SCA ratio, indicating that additive gene effects were more affected by environmental variation than non-additive ones.

In contrast, for other traits like 100-kernel weight, the GCA × location/GCA ratio was lower than the SCA × location/SCA ratio, highlighting that non-additive genetic components were more environmentally responsive for this trait.

General combining ability effects:

Estimates of general combining ability (GCA) effects ($\hat{g}_i$) for each parental inbred line and each trait, evaluated across the two locations and in the combined analysis, are presented in Table 5. The GCA effects calculated in this study were significantly different from zero. From a breeder’s perspective, the high positive GCA estimates observed for most traits—excluding days to 50% tasseling and silking, as well as plant and ear heights—are particularly valuable.

Table (5). General combining ability effects for all studied traits at the combined across locations.

Parents	GCA effects							
	D. 50% silking	D. 50% tasseling	Plant height	Ear height	№ of rows/Ear	№ of kernels/row	100 kernels weight	Ear weight/ plot
P1	0.81**	0.71**	-4.81**	0.07	0.62**	-0.53*	-0.75**	-0.2**
P2	-0.27	-0.42**	3.52**	4.09**	-0.28*	-0.33	0.7*	0.06
P3	-2.3**	-1.55**	1.57	-4.04**	-0.95**	0.54*	2.71**	0.22**
P4	-1.27**	-1**	1.56	-1.81*	-0.88**	1.99**	2.81**	0.42**
P5	0.74**	0.57**	-9.72**	-8.72**	0.99**	0.15	-2.69**	-0.12*
P6	0.45**	0.34*	1.13	1.39	0.55**	-1.31**	-0.56*	-0.13*
P7	1.07**	1.08**	-2.93**	2.13*	-0.06	-1.69**	0.7*	-0.27**
P8	1.98**	1.98**	0.57	1.37	0.29*	0.81**	-1.6**	0.15**
P9	-0.86**	-1.36**	3.33**	2.24*	0.00	0.91**	-2.08**	-0.18**
P10	-0.36**	-0.35*	5.78**	3.28**	-0.29*	-0.53*	0.76**	0.05
L.S.D gi 0.05%	0.27	0.29	2.01	1.79	0.23	0.52	0.55	0.11
L.S.D gi 0.01%	0.36	0.38	2.64	2.35	0.3	0.68	0.73	0.14
L.S.D gi-gj 0.05%	0.41	0.43	3	2.67	0.34	0.77	0.83	0.16
L.S.D gi-gj 0.01%	0.53	0.56	3.94	3.5	0.44	1.01	1.08	0.21

* and ** denote significance at the 5% and 1% probability levels, respectively.

Parental inbred line no. 1 demonstrated significant negative GCA effects ($\hat{g}_i$) for plant height in the combined data set, suggesting its suitability as a good combiner for producing shorter plant types. Additionally, this line showed significant positive effects for the number of rows per ear in all environments. Conversely, it exhibited either significant undesirable or non-significant effects for the remaining traits.

Parental inbred line no. 2 displayed significant negative GCA effects ($\hat{g}_i$) for days to 50% tasseling, indicating its potential utility as a good combiner in breeding early-maturing genotypes. Earliness of flowering is advantageous for shortening the growing season and avoiding damage from corn pests. Furthermore, this line 2 had significant positive GCA effects ($\hat{g}_i$) for 100-kernel weight. In contrast, it showed either significant undesirable or non-significant effects for the other traits evaluated.

Parental inbred line no. 3 exhibited significant negative GCA effects ($\hat{g}_i$) for days to 50% tasseling, days to 50% silking and ear height, ranking as the best inbred line for earliness-related traits. Additionally, it showed favorable effects for 100-kernel weight, ear weight per plot, and the number of kernels per row in the combined analysis. However, it displayed undesirable effects for the remaining traits.

Parental inbred line no. 4 appeared to be a good combiner for days to 50% tasseling, days to 50% silking, ear height, number of kernels per row, 100-kernel weight, and ear weight per plot. In contrast, it demonstrated either significantly undesirable or non-significant effects for the other traits.

Parental inbred line no. 5 performed as a good combiner for plant height, ear height, and the number of rows per ear but showed undesirable effects for the other evaluated traits.

Parental inbred line no. 6 was identified as a good combiner for the number of rows per ear, while it exhibited either significantly undesirable or negligible effects for the other traits.

Parental inbred line no. 7 showed good combining ability for plant height and 100-kernel weight but displayed either non-significant or less desirable effects for the remaining traits.

Parental inbred line no. 8 proved to be a good combiner for the number of rows per ear, the number of kernels per row, and ear weight per plot, while for other traits, it showed either significant or insignificant effects.

Parental inbred line no. 9 was a good combiner for earliness traits and the number of kernels per row but recorded either significantly undesirable or non-significant effects for other traits.

Parental inbred line no. 10 showed good combining ability for days to 50% tasseling, days to 50% silking, and 100-kernel weight and performed around the average for the other traits.

It is noteworthy that inbred lines with high GCA effects ($\hat{g}_i$) for ear weight per plot also tended to exhibit favorable combining ability for one or more yield-contributing traits. Based on these results, parental inbred lines P3, P4, and P8 appeared to be the most promising general combiners for ear weight per plot and several of its components in the combined analysis across locations.

Specific combining ability:

Specific combining ability (SCA) effects were estimated in the combined analysis (Table 6).

For days to 50% silking, twenty-two crosses showed significant negative SCA effects in the combined analysis. Among these, the crosses P1×P3, P3×P7, and P7×P8 recorded the most desirable negative effects. The remaining crosses exhibited either significant positive or non-significant effects.

Regarding days to 50% tasseling, twenty crosses demonstrated significant negative SCA effects. The most pronounced effect was observed in cross P1×P4, followed by P1×P3 and P3×P6 in the combined analysis.

The crosses P2×P10 and P5×P8 exhibited the most significant negative SCA effects for both plant height and ear height. Additionally, four crosses showed significant negative effects for plant height, and three crosses displayed significant negative effects for ear height.

Regarding the number of rows per ear, ten crosses demonstrated significant positive SCA effects. Notably, crosses P2×P8 and P8×P10 recorded the most desirable results for this trait.

For the number of kernels per row, twenty-four crosses exhibited significant positive effects. Among these, crosses P8×P9, P2×P5 and P8xP10 achieved the highest positive SCA values. The remaining crosses showed either significant positive or non-significant effects.

In terms of 100-kernel weight, fourteen crosses showed significant positive SCA effects, while the other hybrids exhibited non-significant differences.

For ear weight per plot, twenty-four hybrids demonstrated significant positive SCA effects.

In summary, the crosses P1×P5, P1×P8, P2×P3, P2×P8, P3×P7, P3×P10, P5×P6, P5×P9, P6×P8, P7×P8, and P8×P10 were identified as the most promising combinations for ear weight per plot in the combined analysis. These crosses also achieved the highest mean values across environments. Overall, these combinations appeared to be the most favorable, as they showed significant SCA effects not only for ear weight per plot but also for most yield components across the two locations.

In cases where high specific combining ability involved only one parent with good general combining ability, such combinations could produce desirable transgressive segregants. This outcome is possible if the additive genetic effects from the good combiner, together with the complementary and epistatic interactions within the hybrid, operate synergistically to suppress undesirable traits and enhance the target character. Therefore, these selected crosses could be of considerable importance in breeding programs employing conventional selection methods.

Table (6). Estimates of specific combining ability effects for all traits at the combined analysis.

Entry		D. 50% silking	D. 50% tasseling	Plant height	Ear height	№ of rows/Ear	№ of kernels/row	100 kernels weight	Ear weight/ plot
1038×775	**P1xP2**	1.23**	0.89	-1.54	8.04**	-0.45	1.04	-0.77	-0.24
1038×676	**P1xP3**	-3.24**	-2.61**	26.41**	8.05**	0.42	2.37**	-0.53	0.4*
1038×724	**P1xP4**	-2.77**	-2.77**	12.3**	0.95	0.91*	2*	-0.24	0.68**
1038×532	**P1xP5**	-1.66**	-1.22*	18.95**	14.35**	0.93*	3.01**	2.04*	1.25**
1038×232	**P1xP6**	0.13	0.26	5.6	1.86	-0.43	-1	2.11*	-0.25
1038×1212	**P1xP7**	1.02*	0.89	-9.71**	-6.63*	-0.77*	-5.8**	-1.55	-0.83**
1038×915	**P1xP8**	-1.52**	-2**	24.04**	19.76**	1.18**	4**	3.37**	1.38**
1038×853	**P1xP9**	0.45	0.21	0.53	2.27	0.43	0.55	-0.9	-0.04
1038×133	**P1xP10**	-0.93*	-0.93	-1.42	-3.27	0.57	0.51	-3.24**	-0.2
775×676	**P2xP3**	-1.79**	-1.59**	8.08*	0.9	-0.13	3.47**	4.35**	0.77**
775×724	**P2xP4**	-1.08*	-1.51**	7.46*	2.93	0.31	4.63**	0.86	0.57**
775×532	**P2xP5**	-2.21**	-2.08**	9.87**	1.71	0.54	5.54**	-0.99	0.51**
775×232	**P2xP6**	-0.54	-0.86	1.52	-2.91	0.57	-0.52	-0.64	-0.14
775×1212	**P2xP7**	-0.78	-0.59	12.2**	6.1*	0.49	-0.6	-1.39	0.21
775×915	**P2xP8**	-2.08**	-1.99**	25.2**	19.11**	1.39**	4.72**	4.3**	1.32**
775×853	**P2xP9**	0.27	0.72	1.19	0.12	0.63	1.9*	-2.05*	-0.18
775×133	**P2xP10**	2.64**	3.21**	-16.75**	-9.04**	-1.08**	-8.31**	-1.59	-1.48**
676×724	**P3xP4**	-1.54**	-1.14*	1.16	-3.06	0.53	0.43	1.43	-0.04
676×532	**P3xP5**	1.95**	1.04*	7.69*	6.97*	-0.4	-1.51	-1.92*	-0.35
676×232	**P3xP6**	-2.14**	-2.36**	15.09**	4.23	0.04	4.36**	0.8	0.61**
676×1212	**P3xP7**	-3.25**	-2.34**	15.9**	8.11**	0.3	3.03**	1.4	0.72**
676×915	**P3xP8**	0.33	0.01	0.78	-2.38	0.35	-2.55**	-2.11*	-0.59**
676×853	**P3xP9**	-0.7	-0.66	18.39**	8.13**	0.15	-0.14	4.39**	0.51**
676×133	**P3xP10**	-1.58**	-1.17*	14.94**	8.72**	-0.06	3.97**	3.33**	1.09**
724×532	**P4xP5**	-1.46**	-0.88	16.58**	9.99**	-0.61	-0.35	-0.13	-0.15
724×232	**P4xP6**	-1.17*	-1.9**	11.85**	2.37	0.83*	1.48	0.17	0.63**
724×1212	**P4xP7**	0.09	0.86	13.29**	9.01**	0.29	4.68**	-0.51	0.59**
724×915	**P4xP8**	0.8	0.84	15.29**	10.64**	0.24	0.96	2.36*	0.26
724×853	**P4xP9**	0.02	0.05	11.03**	4.53	-0.06	2.51**	2.96**	0.66**
724×133	**P4xP10**	-0.73	-1.46**	10.7**	6.49*	0.23	4.9**	0.95	0.38*
532×232	**P5xP6**	-0.68	-0.84	15.26**	9.9**	0.85*	3.05**	0.77	0.7**
532×1212	**P5xP7**	-1.17*	-1.21*	18.07**	10.54**	0.17	2.49**	1.06	0.54**
532×915	**P5xP8**	0.41	0.27	-12.93**	-9.95**	0.12	-2.61**	-0.84	-0.9**
532×853	**P5xP9**	-0.99*	-1.15*	19.31**	9.06**	1.06**	-0.13	4.84**	0.73**
532×133	**P5xP10**	-0.99*	-0.78	1.98	-1.36	0.5	4.89**	0.42	0.55**
232×1212	**P6xP7**	-0.25	-0.36	2.34	3.93	-0.05	-0.14	0.31	-0.1
232×915	**P6xP8**	-2.42**	-2.5**	19.71**	11.69**	0.85*	3.11**	2.55**	1.06**
232×853	**P6xP9**	0.05	0.33	12.45**	11.2**	-0.55	0.06	-0.35	0.16
232×133	**P6xP10**	0.55	0.2	8.13*	2.4	0.04	0.65	0.22	0.14
1212×915	**P7xP8**	-2.41**	-1.74**	22.28**	15.45**	0.57	4.98**	5.65**	1.28**
1212×853	**P7xP9**	0.06	0.22	0.14	0.58	0.31	0.61	-1.92*	-0.04
1212×133	**P7xP10**	-0.82	-0.54	11.69**	6.54*	0.45	2.4**	-2.46**	0.17
915×853	**P8xP9**	-1.48**	-1.8**	23.64**	14.34**	1.16**	6.18**	5.6**	0.66**
915×133	**P8xP10**	-1.98**	-1.81**	19.69**	16.93**	1.35**	5.9**	4.68**	1.36**
853×133	**P9xP10**	-0.89	-0.73	9.56**	4.06	0.25	3.38**	-0.76	0.16
LSD5%(sij)		0.91	0.96	6.74	6	0.76	1.72	1.86	0.37
LSD1%(sij)		1.2	1.27	8.88	7.9	1	2.27	2.45	0.48
LSD5%(sij-sik)		1.34	1.41	9.9	8.81	1.12	2.54	2.73	0.54
LSD1%(sij-sik)		1.76	1.86	13.05	11.62	1.47	3.34	3.6	0.71
LSD5%(sij-skl)		1.27	1.35	9.44	8.4	1.07	2.42	2.6	0.51
LSD1%(sij-skl)		1.68	1.77	12.44	11.08	1.4	3.19	3.43	0.68

* and ** denote significance at the 5% and 1% probability levels, respectively.

Broad-sense (h^2b) and narrow-sense (h^2n) heritability

The estimates of broad-sense (h^2b) and narrow-sense (h^2n) heritability for various maize traits across two locations (Bany Hedeer and Menofia), along with combined data, are presented in (Table 7).

Table (7). Broad-sense (h^2b) and narrow-sense (h^2n) heritability

traits	Bany Hedeer		Menofia		combined	
	h^2b	h^2n	h^2b	h^2n	h^2b	h^2n
Days to 50% silking	87.00	41.70	88.99	49.06	87.99	45.38
Days to 50% tasseling	84.71	37.20	85.24	44.75	84.97	40.97
Plant height	91.32	9.53	91.61	8.23	91.47	8.88
Ear height	82.92	19.83	82.80	14.15	82.86	16.99
No of rows/Ear	73.14	53.14	63.88	50.48	68.51	51.81
No of kernels/row	88.47	13.57	83.57	17.01	86.02	15.29
100 kernels weight	84.17	31.21	76.90	48.50	80.54	39.85
Ear weight/ plot	84.86	6.69	85.79	23.63	85.33	15.16

These estimates provide insights into the genetic control of the studied traits and their potential response to selection.

High heritability estimates were observed for phenological traits such as days to 50% silking and tasseling, with broad-sense heritability exceeding 84% in combined across locations. Narrow-sense values were moderate to high (ranging from 37.20% to 49.06%), indicating that these traits are under strong genetic control and can be improved through selection.

Plant height and ear height showed high h^2b values across locations (above 82%), but very low h^2n values (around 8–19%), indicating that non-additive genetic effects (dominance and epistasis) may play a significant role. This suggests that hybrid breeding strategies may be more effective than selection-based breeding for these traits. lower values, suggesting potential for genetic improvement through selection, albeit at a slower rate.

Yield components such as number of rows per ear and 100-kernel weight showed moderately high to high heritability in both senses. Number of rows per ear had the highest narrow-sense heritability (h^2n = 51.81% combined), suggesting a good response to selection. On the other hand, number of kernels per row and ear weight/ plot showed high h^2b (above 84%) but relatively low h^2n (13.57–23.63%), implying dominance and epistasis effects are significant.

Ear weight/ plot yield showed consistently high h^2b across locations (85.33–85.79%), but low to moderate h^2n (6.69–23.63%), highlighting the complexity of its inheritance and the influence of environmental factors and non-additive gene action. This reinforces the importance of multi-environment testing and the use of hybrid breeding approaches to exploit heterosis for yield improvement.

Correlation between traits

The correlation analysis across two distinct locations and the combined (Table 8) dataset revealed consistent and statistically significant relationships among germination, phenological, vegetative, ear-related, and yield traits in maize. While some variation in correlation coefficients was observed between environments, the general patterns remained stable, highlighting robust inter-trait associations and their potential relevance for selection in breeding programs.

Phenological Traits and Their Relationship with Yield

Days to 50% silking and days to 50% tasseling were significantly and negatively associated with grain yield in all three datasets (r = -0.71** to -0.74**), suggesting that early-flowering genotypes tend to be more productive. This is consistent with findings by **Aslam *et al.* (2015) and Jilo *et al.* (2018),** who reported that earliness in flowering facilitates better adaptation to drought-prone or terminal stress environments by allowing crops to complete their life cycle under optimal moisture and temperature conditions.

Negative correlations of flowering time with plant height, kernel number per row, and 100-kernel weight further suggest that early-flowering plants tend to exhibit higher reproductive efficiency. Such traits are essential for breeding maize cultivars adapted to shorter growing seasons or changing climate conditions.

Vegetative Traits as Predictors of Yield

Plant height exhibited strong positive correlations with grain yield (r = 0.80** to 0.88**) and with ear height, and number of kernels per row. These findings are in agreement with reports by **Abayomi *et al.* (2015) and Magar *et al.* (2021),** indicating that plant height can serve as a proxy for overall plant vigor and photosynthetic capacity. The positive correlation between plant and ear height (r = 0.91** to 0.93**) further suggests a coordinated developmental pattern that supports efficient assimilate partitioning toward reproductive organs.

While excessive height may increase lodging risk, the observed positive associations suggest that within a moderate range, taller genotypes tend to be more productive, likely due to improved canopy architecture and biomass accumulation.

Ear Characteristics and Their Direct Impact on Yield

High significant correlation between number of kernels per row and ear weight/ plot (r = 0.84** to 0.90**) were among the most strongly associated with grain yield across all datasets. These components directly contribute to sink capacity, confirming their value in yield improvement strategies **(Akter *et al.*, 2021; Badu-Apraku *et al.*, 2011).** The number of rows per ear, although positively correlated with yield (r = 0.35** to 0.47**), showed lower and less consistent correlations, and a negligible or even negative association with kernel weight. This suggests a potential trade-off between row number and individual kernel size.

These results emphasize the importance of prioritizing kernel number per row and ear size traits over row number alone during selection.

Grain Weight and Final Yield

The 100-kernel weight was significantly and positively correlated with yield across all datasets (r = 0.66** to 0.72**). It also correlated positively with other traits such as number of kernels per row, suggesting that heavier kernels are typically produced in more favorable ear architectures. These findings are consistent with the work of **Maphumulo *et al.* (2015),** who reported that grain weight is an important yield component influenced by both source strength and sink capacity.

Integrated Implications for Breeding

The consistently significant and positive associations between yield and traits such as germination percentage, early flowering, plant height, kernel number per row, and kernel weight across environments highlight the importance of these characters as selection criteria in maize breeding programs. The negative association of delayed flowering with yield underscores the need to breed for early maturity, particularly in regions prone to terminal drought or heat stress **Magashi *et al*. (2013).**

In conclusion, the results demonstrate that maize grain yield is a multifactorial trait strongly influenced by both vegetative vigor and reproductive efficiency. Simultaneous selection for key yield-contributing traits, particularly those stable across locations, can significantly enhance genetic gains under variable environmental conditions.

Table (8) Pearson correlation coefficients among germination, phenological, vegetative, ear, and yield-related traits in maize evaluated at two locations and across combined environments.

Trait	location	Traits							
		D. 50% silking	D. 50% tasseling	Plant height	Ear height	No of rows/ Ear	№ of kernels /row	100 kernels weight	Ear Weight / plot
Germination %	Bany-Hedeer	-0.56**	-0.58**	0.57**	0.57**	0.16	0.50**	0.56**	0.70**
	Menofia	-0.70**	-0.70**	0.71**	0.59**	0.2	0.61**	0.49**	0.70**
	Combined	-0.74**	-0.74**	0.74**	0.68**	0.23	0.67**	0.60**	0.79**
D. 50% silking	Bany-Hedeer		0.98**	-0.72**	-0.49**	-0.15	-0.70**	-0.63**	-0.73**
	Menofia		0.96**	-0.73**	-0.55**	-0.03	-0.67**	-0.61**	-0.71**
	Combined		0.97**	-0.74**	-0.54**	-0.09	-0.70**	-0.65**	-0.74**
D. 50% tasseling	Bany-Hedeer			-0.74**	-0.52**	-0.23	-0.72**	-0.61**	-0.74**
	Menofia			-0.74**	-0.59**	-0.11	-0.69**	-0.53**	-0.69**
	Combined			-0.76**	-0.57**	-0.17	-0.71**	-0.60**	-0.73**
Plant height	Bany-Hedeer				0.91**	0.48**	0.85**	0.72**	0.89**
	Menofia				0.93**	0.39**	0.74**	0.47**	0.80**
	Combined				0.93**	0.46**	0.81**	0.63**	0.88**
Ear height	Bany-Hedeer					0.49**	0.76**	0.69**	0.82**
	Menofia					0.46**	0.62**	0.38**	0.67**
	Combined					0.51**	0.71**	0.56**	0.79**
№ of rows/Ear	Bany-Hedeer						0.47**	0.14	0.47
	Menofia						0.42**	-0.18	0.35**
	Combined						0.47**	-0.02	0.43**
№ of kernels/row	Bany-Hedeer							0.63**	0.91**
	Menofia							0.38**	0.84**
	Combined							0.53**	0.90**
100 kernels weight	Bany-Hedeer								0.77**
	Menofia								0.66**
	Combined								0.71**

* and ** denote significance at the 5% and 1% probability levels, respectively.

REFERENCES

Abayomi, Y. A., Ayodele, I. O., and Adewale, B. (2015). Maize breeding for drought tolerance. *Agronomy Journal, 108*(5), 1760-1770.

Abd El-Azeem, M. E., El-Mokadem, M. T., El-Morshidy, M. A., and Hemada, M. M. (2021). Genetic analysis and combining ability of maize inbred lines under different locations and their interaction effects. *Egyptian Journal of Plant Breeding, 25*(3), 591–607.

Abd El-Latif, M. A., Soliman, M. A., and Khalil, R. M. (2023). Combining ability analysis in white maize hybrids for grain yield and related traits. Egyptian Journal of Agricultural Research, 101(2), 321–335.

Abd-Elnaser, M. G., Ahmed M. F., Saleh S. H., Rashed, M. A. and Abd-Ellatif, M. S. (2022). Evaluation of inbred lines of maize in a diallel cross under normal condition and drought stress. Arab Univ. J. Agric. Sci., 30 (2): 215-228.

Akter, F., Rahman, M. M., and Hossain, M. (2021). Correlation between maize yield components and quality traits. *Field Crops Research, 248*, 107-114.

Amegbor, I. K., Abe A., Danquah, J. A., Gloria, B. A. and Frimpong R. O. (2022). Agronomic performance and combining ability estimates of yellow maize inbred lines under adequate and deficit moisture conditions. J. Crop Sci. Biot., 25: 183-197.

Amiruzzaman, M., Islam, M. A., Mahmud, M. A. A., and Rohman, M. M. (2013). Combining ability and heterosis in maize (*Zea mays* L.). *Bangladesh Journal of Agricultural Research*, 38(1), 147–153.

Aslam, M., Nawaz, A., and Sadiq, M. (2015). Genetic variability and correlation among agronomic traits in maize. *Field Crops Research, 181*, 74-81.

Badu-Apraku, B., Fakorede, M. A. B. and Akinwale, R. O. (2011). Maize breeding for developing drought-tolerant cultivars in sub-Saharan Africa. *Field Crops Research, 123*(2), 10-25.

Baiumy, K. A. (2025) Genetic analysis of quantitative traits in maize: evaluation of diallel crosses for normal and delayed growth using various stress tolerance indices. J. of Plant Production, Mansoura Univ., Vol. 16 (4):127 - 135

Eisele, A., Gemenet, D. C., Badu-Apraku, B., and Semagn, K. (2021). Combining ability and genetic control of agronomic traits in tropical maize under diverse environmental conditions. *Euphytica, 217*(8), 1–16.

El-Shahed, H. M., Abu Shosha A. M., El-Ghonemy M. A. M.and Alsebaey R. H. A. (2021). Diallel analysis of eight yellow maize inbred lines for earliness and grain yield. J. Plant Prod., Mansoura Univ., 12 (3): 329-332.

Falconer, D. S., and Mackay, T. F. C. (1996). *Introduction to Quantitative Genetics* (4th ed.). Longman

FAOSTAT. (2022). *Food and Agriculture Data*. Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/faostat/en/

Galal, A. A., Safhi, F. A., Al Aboud, N. M., Aljabri, M., Kucher, D. E., Kamara, M.M., El-Mogy, M. M., Ibrahim, O. M., Abd El-Moneim, D., Hassanin, A. A., El-Soda, M., Mansour, E. and Ali, A. M. (2025). Molecular diversity and genetic potential of new maize inbred lines across varying sowing conditions in arid environment. Sci Rep 15, 2809.

Gomez, K.N. and A.A. Gomez (1984). Statistical Procedures for Agricultural Research. John. Wiley and Sons. Inc., New York, 2nd ed.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences, 9*(4), 463-493.

Hallauer, A. R., Carena, M. J., and Miranda, J. B. (2010). *Quantitative genetics in maize breeding* (2nd ed.). Springer.

Jilo T., Tulu, L., Birhan T.and Beksisa L. (2018) Genetic variability, heritability and genetic advance of maize (*Zea mays* L.) inbred lines for yield and yield related traits in southwestern Ethiopia. Journal of Plant Breeding and Crop Science 10(10):281-289.

Kanhaiya Lal, R., Singh, A., Verma, P., and Sharma, R. (2023). Combining ability and heterosis analysis in maize (*Zea mays* L.) for yield and its attributing traits. *Journal of Maize Genetics and Breeding*, *45*(2), 101–112.

Keimeso, Z., Abakemal D.and Gebreselassie W. (2020). Heterosis and combining ability of highland adapted maize (*Zea mays*. L) DH lines for desirable agronomic traits. African J. Plant Sci., 14 (3): 121-133.

Magar B. T., Acharya S., Gyawali B., Timilsena K., Upadhayaya J., and Shrestha J. (2021) Corrigendum to Genetic variability and traits association in maize (*Zea mays* L.) varieties for growth and yield traits. Heliyon e08144.

Magashi, A. I., Wailare, M.A. and Madaki, A. S. (2013). Heritability of some quantitative characters in five varieties of maize (*Zea mays* l.,) under the influence of various levels of nitrogen. Bayero Journal of Pure and Applied Sciences, 6(2): 35 – 40.

Maphumulo S. G., Derera J., Qwabe F., Fato P., Gasura E. and Mafongoya P. (2015). Heritability and genetic gain for grain yield and path coefficient analysis of some agronomic traits in early-maturing maize hybrids. Euphytica 206:225–244.

Mogesse, W., Zelleke H. and Nigussie M. (2020). General and specific combing ability of maize (*Zea mays* L.) Inbred line for grain yield and yield related traits using 8×8 diallel crosses. American J. BioSci., 8 (3): 45-56.

Nadeem, T., Akbar, M., and Mehmood, A. (2023). Genetic analysis for grain yield and its components in maize. Pakistan Journal of Agricultural Research, 61(4), 305–312.

Rezgar, M. A., Yousif, A. T., and Khalid, H. M. (2024). Evaluation of maize (Zea mays L.) genotypes for grain yield and yield components. *Journal of Crop Science and Biotechnology, 19*(1), 55–67.

Rezgar, M. A., Yousif, A. T., and Khalid, H. M. (2024). Genetic variability and heterosis in maize hybrids for yield-related traits. Journal of Crop Science and Biotechnology, 19(1), 55–67.

Sedhom, S. A. Youstina, Rabie H. A., Awaad H. A., Alomran Maryam M., ALshamrani S. M., Mansour E., and Ali M. M. A. (2024). Genetic potential of newly developed maize hybrids under different water-availability conditions in an arid environment. Life, 14 (453): 1-12.

Sprague, G. F., and Tatum, L. A. (1942). General vs. specific combining ability in corn. *Journal of the American Society of Agronomy, 34*(11), 923-932.

SPSS (version 20): IBM SPSS Statistics for Windows, version 20.0. (2011). IBM Corp.

Tafa Z., Nepir G. and Azmach G. (2020) Estimation of magnitudes of heterosis for grain yield and yield contributing traits of conventional maize (Zea mays L.) single cross hybrids. African Journal of Agricultural Research. 16(12), 1640-1651. DOI: 10.5897/AJAR2020.14849

Talekar, S.C., Suresha P. G., Kachapur R. M., Salakinkop S. R., and Harlapur S. I. (2021) Mid-parent, better-parent and standard heterosis of experimental crosses in maize . International Journal of Tropical Agriculture, 39(3) 285: 290.

Turk, F.M., El-Badawy M. El. M., El Hosary A.A.A. and Mehasen S.A.S (2020). Combining Ability Analysis Using Diallel Crosses among Eight Inbred Lines of maize under Two Planting Dates. Annals of Agric. Sci., Moshtohor, Vol. 58(4): 905 – 914.

Yu, J., Pressoir, G., and Buckler, E. S. (2015). A unified mixed-model method for association mapping that accounts for multiple levels of relatedness. *Nature Genetics, 47*(3), 298-305.

الملخص العربي

استغلال القدرات الوراثية في الذرة الصفراء: القدرة على التالف، قوه الهجين، ودرجة التوريث عبر بيئتين

بشرى نجيب عياد[1]، حسن محمد فؤاد[2]، محمود منصور عبدالمجيد سالم[2]، علاء محمد محمود أبوبكر[2].

[1]قسم بحوث الذرة الشامية - معهد بحوث المحاصيل الحقلية - مركز البحوث الزراعية - الجيزة – مصر.
[2]قسم المحاصيل – كلية الزراعة – جامعة المنيا.

تعد الذرة الشامية من المحاصيل الأساسية لأمن الغذاء العالمي، ومع ذلك فإن إنتاجيتها في مصر لا تلبّي احتياجات السوق. أجريت هذه الدراسة بهدف تقييم 45 هجينا من الذرة الشامية الصفراء تم الحصول عليها من تهجين عشرة سلالات مختلفة باستخدام تصميم التزاوج النصف تبادلى عبر موقعين مختلفتين خلال موسم 2024. تم ملاحظة اختلافات معنوية إحصائية كبيرة بين التراكيب الوراثية، وكذلك تفاعلات التراكيب الوراثية × البيئة لمعظم الصفات، ولاسيما ارتفاع النبات، ارتفاع الكوز، عدد الحبوب في الصف، وزن 100 حبة، محصول الكيزان للقطعه التجريبية. أسهم كل من الفعل الجينى الإضافي وغير الإضافي في تباين الصفات. أظهرت بعض الصفات مثل أيام التزهير بنسبة 50% وعدد الصفوف في الكوز درجة توريث واسعة وضيقة، مما يشير إلى إمكانية تحقيق تحسين وراثي من خلال الانتخاب. تم تحديد السلالات الأبوية P3 و P4 و P8 كأفضل الاباء لصفات محصول الكيزان/ قطعه تجريبية والمكونات الأساسية للمحصول. كانت قيم قوة الهجين عالية، خاصة بالنسبة لوزن الكيزان لكل قطعة تجريبية، حيث حقق الهجين P7×P8 قوه هجين بلغت 237% مقارنة بالأب الأفضل. أظهرت التهجينات P1×P5 وP2×P8 و P8×P10 تأثيرات معنوية عالية للقدرة الخاصة على التالف، مما يجعلها سلالات واعدة لبرامج التربية. أظهر تحليل الارتباط أن التزهير المبكر، وارتفاع النبات، وعدد الحبوب في الصف، ووزن 100 حبة كانت مرتبطة ارتباطًا إيجابيًا وقويًا بمحصول الكيزان / قطعه تجريبية ، مما يبرز أهميتها كمعايير اختيار غير مباشرة.