

# Genetic Analysis of some inbred lines and its F1 Crosses of Red and Yellow Maize for Earliness and Morpho-Physiological Traits Under Water-Deficit Condition

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## Abstract

This study aimed to evaluate the combining ability and type of gene action for eight inbred lines of red and yellow maize and their half-diallel crosses for earliness and morpho-physiological traits under normal and water-deficit. For every examined earliness and morpho-physiological trait under both normal and drought-stress conditions, the mean squares for general combining ability (GCA) and specific combining ability were highly significant. This suggests that both additive and non-additive gene effects are important in the inheritance of these traits. The GCA/SCA (Baker ratio) ratio was less than unity for all examined earliness and morpho-physiological traits under both normal and drought-stress conditions, indicating that the inheritance of these qualities was mostly impacted by non-additive genetic factors, which were more important. For the majority of earliness and morpho-physiological features under drought stress, P1 (Red-A), P2 (Red-B), P4 (L-6), and P5 (L-49) were the best general combiners. Heritability in the broad sense was more than 0.82 for the morpho-physiological and earliness characteristics under normal irrigation and water stress situations, emphasizing the importance of the dominant influence rather than additive. Narrow sense heritability estimates ( $h^2n.s$ ) under normal irrigation and water stress conditions were found to be significantly lower than those of broad sense because the majority of genetic variance for all studied traits was due to non-additive genetic effects. This led to the conclusion that selection procedures that are known to be effective in shifting gene frequency when both additive and non-additive traits are present should be used.

**Key words:** Combining ability, Drought, Genetic Components, Heritability, Maize.

## التحليل الوراثي لبعض السلالات النقية وهجائنها من الجيل الأول من الذرة الحمراء والصفراء من حيث التبرير والصفات المورفولوجية والفسولوجية في ظل ظروف نقص المياه

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## المستخلص

هدفت هذه الدراسة إلى تقييم القدرة على التألف ونوع الفعل الجيني لثمانية سلالات نقية من الذرة الحمراء والصفراء، بالإضافة إلى تهجيناتها النصف تبادلية، وذلك فيما يتعلق بصفات التبرير في النضج والخصائص المورفولوجية والفسولوجية في ظل الظروف العادية وظروف نقص المياه. أظهرت متوسطات مربعات القدرة العامة على التهجين (GCA) والقدرة الخاصة على التهجين دلالة إحصائية عالية لجميع صفات النضج المبكر والخصائص المورفولوجية والفسولوجية المدروسة في كلتا الحالتين، مما يشير إلى أن التأثيرات الجينية المضافة وغير المضافة تلعب دوراً هاماً في وراثة هذه الصفات. وكانت نسبة GCA/SCA (نسبة بيكر) أقل من واحد لجميع صفات النضج المبكر والخصائص المورفولوجية والفسولوجية المدروسة في كلتا الحالتين، مما يوحي بأن التأثيرات الجينية غير المضافة كانت أكثر أهمية، وأنها تؤثر بشكل أساسي على وراثة هذه الصفات. وكانت أفضل السلالات ذات القدرة العامة على التهجين هي: P1 (Red-A) و P2 (Red-B) و P4 (L-6) و P5 (L-49) لمعظم صفات النضج المبكر والخصائص المورفولوجية والفسولوجية في ظل ظروف نقص المياه. في ظل ظروف الري العادية والإجهاد المائي، تجاوزت نسبة التوريث بالمعنى الواسع 0.82 لصفات النضج المبكر والخصائص المورفولوجية والفسولوجية، مما يبرز أهمية التأثير السائد مقارنةً بالتأثير الإضافي. ولأن معظم التباين الوراثي لجميع الصفات المدروسة كان ناتجاً عن تأثيرات وراثية غير إضافية، وجد أن تقديرات نسبة التوريث بالمعنى الضيق ( $h^2n.s$ ) في ظل ظروف الري العادية والإجهاد المائي أقل بكثير من تقديرات نسبة التوريث بالمعنى الواسع، وذلك لأن غالبية التباين الوراثي لجميع الصفات المدروسة يعود إلى تأثيرات وراثية غير تجميعية. وقد أدى ذلك إلى استنتاج مفاده أنه ينبغي استخدام إجراءات الانتخاب المعروفة بفعاليتها في تغيير التكرار الجيني عند وجود كل من الصفات التجميعية وغير التجميعية.

**الكلمات المفتاحية:** الذرة، الجفاف، القدرة على التألف، المكونات الوراثية، التوريث

## 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<sup>-1</sup> (approximately 22 ard fed<sup>-1</sup>). 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-

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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.

The importance of maize genotypes in drought resistance was highlighted by a number of researchers. More ears/plant (Edmeades *et al.* 1993 and Ribaut *et al.* 1997), more kernels/ear (Ribaut *et al.* 1997), and a shorter anthesis-silking interval (ASI) were traits of maize genotypes that were demonstrated to be tolerant (Bolanos and Edmeades, 1996).

In order to perform quick and precise indirect selection for drought resistance, a number of researchers examined the relationships between yield and other plant characteristics under soil moisture stress. According to Bolanos and Edmeades (1996), CIMMYT created certain drought-tolerant populations of tropical maize while preserving their potential yield. Understanding genetics and using it to increase drought tolerance is crucial to stabilizing global maize output since genetic treatments are unlikely to overcome more than 30% of the difference between potential and realized yield under water stress (Seema *et al.*, 2022). Corn breeders work hard and consistently to enhance and boost this crop's producing capacity. The work of East (1908) and Shull (1909), who made it abundantly evident that hybridization is the antithesis of inbreeding, marked the beginning of hybridization in maize. Sprague and Tatum (1942) proposed the idea of general (GCA) and specific (SCA) combining ability, and Griffing (1956) established its mathematical modeling in his seminal study in connection with the diallel crossings.

The present study aimed to assess the general and specific combining abilities to identify superior parental lines and optimal hybrid combinations using half-diallel analysis for improving morpho-physiological traits and earliness in red and yellow maize under water-stress conditions, thereby facilitating the development of genotypes better adapted to arid and desertification-affected environments; and determine the most effective breeding strategy for maximizing genetic improvement in drought tolerance by elucidating the genetic basis of morpho-physiological traits and earliness through the analysis of gene action and heritability under both normal irrigation and water-stress conditions, ultimately supporting the development of resilient maize cultivars capable of sustaining productivity in water-limited and land-degraded agroecosystems.

## Materials and Methods

During the summers of 2023 and 2024, a field study was carried out at the private farm in Nawasa Village, Aga District, Dakahlia Governorate, Egypt. The eight parental red and yellow maize inbred lines—Red-A, Red-C, L-6, L-49, L-69, L-125, and A-63—were sowed in the first growing season of 2023. As a result, 28 F<sub>1</sub> crosses were produced by hand hybridization in a half-diallel method (excluding reciprocals). The genetic materials utilized as parents in this study show a great deal of variability for a number of agronomic parameters.

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 Agricultural Research Center (ARC). Table 1 lists these parental maize inbred lines' names and ancestry.

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

| No     | Genotypes names | Origin          | Source | Grain Color |
|--------|-----------------|-----------------|--------|-------------|
| P1     | Red-A           | Locally product | QTSC   | Red         |
| P2     | Red-B           | Locally product | QTSC   | Red         |
| P3     | Red-C           | Locally product | QTSC   | Red         |
| P4     | L-6             | Locally product | ARC    | Yellow      |
| P5     | L-49            | Locally product | ARC    | Yellow      |
| P6     | L-69            | Locally product | ARC    | Yellow      |
| P7     | L-125           | Locally product | ARC    | Yellow      |
| P8     | 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      |

Each of the 39 maize genotypes used in the evaluated season 2024 included 28 F<sub>1</sub>S crosses, eight parental inbred lines, and three commercial single crosses (SC-Yacout-5, SC-Gold-21, and SC-168) as a control. These crosses were

successively sown under two irrigation treatments (normal irrigation and water stress conditions), with a 5-meter gap between each irrigation treatment. According to Kiani *et al.* (2007), two distinct field experiments were carried out: the first represents normal irrigation treatment (plants watered every 10–12 days, as a 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).

A randomized complete block design (RCBD) with three replications was used to create individual experiments for each irrigation treatment. Each replication had two boundaries and 39 genotypes. Each genotype was planted in three ridges that were 3 m long, 60 cm apart, and 25 cm apart. Each ridge received two hand dropped seeds, and 15 days after seeding, the thinning was completed. In the first season, planting took place on May 15 and 25, and in the second season, on May 20. Prior to and following the initial irrigation, hoeing was done in both seasons. The other farming methods were used as advised.

### The traits studied

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 of plant (cm<sup>2</sup>) (calculated using the 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 (g)) were all recorded.

### Diallel analyses

- 1. Estimation of combining ability analysis:** Griffing (1956) technique 2 (fixed model 1) was used to evaluate the data in order to estimate the impacts of general combining ability (GCA) and specialized combining ability (SCA). The parents were regarded as fixed. The following is an expression of GCA's relative relevance to SCA:

$$\frac{K^2 \text{GCA}}{K^2 \text{SCA}} = \frac{Ms \text{ GCA} - Ms e / (p + 2)}{Ms \text{ SCA} - Ms e}$$

Where, P is the number of parents and Ms is the average squares. K<sup>2</sup> is the average squares of the impacts.

**Table 2. Analysis of variance from method 2 model 1 and the expectation of mean square.**

| Source of variance              | d.f         | SS | MS | EMS                                             |
|---------------------------------|-------------|----|----|-------------------------------------------------|
| General combining ability, GCA  | P-1         | Sg | Mg | $\sigma^2 e + (P+2) (1/P-1) \sum g_i^2$         |
| Specific combining ability, SCA | P (P-1)/2   | Ss | Ms | $\sigma^2 e + 2/P (P-1) \sum_i \sum_j s_{ij}^2$ |
| Error                           | (r-1) (c-1) | Se | Me | $\sigma^2 e$                                    |

Where, Me is equal to the primary randomized full block design's error mean squares divided by the number of replications (Me = Me/r).

P is the number of parents.

- 2. Genetic components:** To compare the genotypes for each characteristic in each trial, analysis of variance was calculated (Steel *et al.* 1996). The data were submitted to diallel analysis in accordance with Mather and Jinks (1982) and Hayman (1954a,b). Diallel cross variations are caused by variations in the genotypes of the mother or parents or by interactions between them. Diallel analysis is divided into two stages (Mather and Jinks, 1982).
- 3. Gene action:** In accordance with Hayman (1954a, b), Jinks (1954), and Whitehouse *et al.* (1958), gene action was identified. Before using diallel analysis, there are a few prerequisites.

With the following presumptions, the analysis of variance of diallel crosses is a valid test:

- Normal diploid segregation.
- Homozygous parents.
- Absence of maternal effect.
- No linkage.
- No epistasis.
- No multiple alleles.
- No genotype by environment interactions.

### The validity to hypotheses:

The array variance (Vr) and parent-array progeny covariance (Wr) for the characteristics under study were calculated using the diallel analysis of Hayman (1954a).

For testing the validity of the hypothesis, the following tests were made, according the procedure, described by Hayman (1958), as follows:

- a) Uniformity test of (Wr, Vr), using  $t^2$  test, at 4 and (n-2) degrees of freedom:

$$t^2 = \frac{n-2}{4} \frac{(\text{Var. Vr} - \text{Var. Wr})^2}{(\text{Var. Vr})(\text{Var. Wr}) - \text{Cov}^2(\text{Vr, Wr})}$$

Where:

Var. Vr = Variance of the array variance (Vr).

Var. Wr = Variance of parent - array covariance (Wr).

Cov. (Vr, Wr) = Covariance between Vr and Wr.

n = Number of parents in diallel cross.

- b) Another test of the hypothesis was performed by regression coefficient (b), using the formula:

$$b = \frac{\text{Cov.}(Wr, Vr)}{(\text{Var. Vr})}$$

Standard error (b) =  $\{(\text{Var. Wr} - b \text{ Cov. Wr Vr}) / (\text{Var. Vr} (n-2))\}^{1/2}$ .

The deviation of b from zero and unity was tested as follows:

$$H_0: b = 0 = (b - 0) / \text{S.E.}(b)$$

$$H_0: b = 1 = (1 - b) / \text{S.E.}(b)$$

The parental array points along the regression line in the geometric representation of the diallel data are represented by these pairs of (Wr, Vr) values. The significance (b = 0) and departure from unity (b = 1) of the linear regression of Wr and Vr were checked against the table value of "t" for n-2 degrees of freedom.

The analysis of variance of diallel tables developed by Hayman (1954) using parental,  $F_1$  data was used, as shown in Table 3. (Mather and Jinks, 1982).

**Table 3. The analysis of variance of diallel tables**

| Item           | df                    | SS                                                                  |
|----------------|-----------------------|---------------------------------------------------------------------|
| A              | P -1                  | $S(yr. + y.s)^2 / 2n - 2y..^2 / n^2$ .                              |
| B              | $\frac{1}{2} p (p-1)$ | $Sy^2 rs + y^2.. / n^2 - S(4rs - ysr)^2 / 2 - ((yr-ty.s)^2 / 2n)$ . |
| b <sub>1</sub> | 1                     | $(y.. - ny.)^2$ .                                                   |
| b <sub>2</sub> | p-1                   | $((yr.. + y.s - nyr)^2 / n(n-2)) - (2y.. - ny.)^2 / n^2 (n-2)$ .    |
| b <sub>3</sub> | $\frac{1}{2} p(p-3)$  | $Bss - b_1ss - b_2ss$ .                                             |

When the following elements are included in the analysis of variance:

a: Examines the impacts of additive.

b: Examines the effects of dominance

b<sub>1</sub>: Evaluates  $F_1, s'$  mean deviation from their mid-parental values.

b<sub>2</sub>: Tests asymmetry of gene distribution at loc-I exhibiting dominance.

b<sub>3</sub>: This item is comparable to Griffing's particular combining ability and tests the portion of dominance deviation that is exclusive to each  $F_1$ .

P: is the number of parents.

Yrs: is the score of the crosses between inbreds r and s; i.e, the entry in the  $r^{th}$  row and the  $s^{th}$  column, where  $r = n-1$  and  $s = 1-n$  in a  $n \times n$  diallel crosses.

Yr= Is the sum of the  $r^{th}$  array ( $r^{th}$  row).

y.s = The sum of the  $s^{th}$  array ( $s^{th}$  column).

y...= Is the sum of all entries in the diallel table.

y.= is the sum of score of parental families.

### Variation's genetic components

The techniques described by Hayman (1954b) and Mather and Jinks (1982) for computing genetic components of variance after a diallel analysis. The method provided by Singh and Chaudhry (1985) was used to determine these genetic factors. To learn more about the genetic behavior of the qualities under investigation, the collected data for each trait were then subjected to diallel cross analysis, as outlined by Hayman (1954b):

Where:

$V_o$  = Variance of the parents.

$V_r$  = Variance of one array (rth array).

$V_{1L1}$  = Mean variance of one array.

$W_r$  = The covariance between the parents and their off-spring in one array (th array).

$W_o1$  = The mean covariance between the mean and the arrays.

$V_o1$  = The variance of the means of the arrays

$ML1-ML0$  = The difference between the mean of the parents and the mean of their  $n_2$  progeny

$E$  = The expected environmental component of variation.

$D$  = Component of variation due to the additive effects.

$H_1$  = Component of variation due to the dominance effects of the genes.

$h^2$  = Dominance effect as the algebraic sum over all loci in heterozygous phase in all crosses.

$F_r$  = The covariation of additive and dominance effects in a single array.

$F$  = The mean of  $F_r$  over the arrays.

$H_2$  = Dominance indicated a symmetry of positive and negative effects of genes; where  $H_2 = H_1 [1 - (u-v)^2]$ .

$U$  = Proportion of positive genes in the parents = 0.5.

$V$  = Proportion of negative genes in the parents (or of the genes with positive (negative) effects, and where:  $u + v = 1$ ).

The aforementioned elements were evaluated using Hayman's standard error (1954 b). The following genetic parameters were estimated using the aforementioned statistics and the techniques described by Hayman (1954 b):

### Estimation of genetic variance components

Mather and Jinks (1982) and Hayman (1954b) used diallel analysis to calculate genetic components of variance. The method provided by Singh and Chaudhry (1985) was used to determine these genetic factors.

The genetic parameters,  $\hat{D}$ ,  $\hat{F}$ ,  $\hat{H}_1$ ,  $\hat{H}_2$ ,  $\hat{h}^2$  and  $\hat{E}$ , were calculated using Hayman (1954) formula, where:

- The expected environmental variance, which is the same as the observed one.

$$E = \frac{\text{Error S.S} + \text{Rep S.S}}{d.f} / r.$$

- Additive genetic variance  $D = V_{oLo} - E$ .

- Variation due to dominant effect of genes ( $H_1$ ).

$$H_1 = V_{oLo} - 4 W_{oLo1} + 4 V_{1L1} - (3n-2) E/P.$$

- Dominance variance adjusted for symmetric positive and negative gene distribution among parents:

$$H_2 = 4 V_{1L1} - 4 V_{oL1} - 2 E.$$

$$\text{or} = H_1 [1 - (u - v)^2].$$

Where:  $\hat{H}_1 = \hat{H}_2$  both gene frequencies are equal.

- Dominance variance overall heterozygous:

$$\text{Loci } \hat{h}^2 = 4(M_{L1} - M_{L0})^2 - 4(P-1) \hat{E} / P^2.$$

### Relative frequency of dominant and recessive alleles:

$\hat{F}$ ; Is the covariance of additive and dominance gene effects, which determines gene symmetry.. It was calculated as Follows :

$$(\hat{F}) = 2 V_{oL0} - 4 W_{oL01} - 2 (P-2) \hat{E} / P.$$

Tests of significance, among parameters, were made, using the standard error estimation technique, suggested by Hayman (1954a,b). Each of these parameters measures a special genetical component of variation as follows "D"

represents the additive genetic variance and "F" is an indicator of the relation frequency of dominant versus recessive alleles in the parents.

"H<sub>1</sub>" = Represents variance due to non-additive effects.

"H<sub>2</sub>" = Represents variance due to non-additive effects, correlated for gene distribution to positive and negative genes, when they are equal, then, H<sub>1</sub> equals H<sub>2</sub>.

h<sup>2</sup> = Represents overall dominance effects of heterozygous loci.

To test accuracy of these parameters, the mean square.

#### Estimates of genetic ratios:

The following elements and ratios were computed using the estimations of genetic variance:

1.  $(\hat{H}_1 / \hat{D})^{1/2}$  = The mean degree of dominance, When the mean degree of dominance is less than one, it indicates partial dominance; when it is equal to one, it indicates total dominance; and when it is larger than one, it indicates overdominance.
2.  $(\hat{H}_2 / 4 \hat{H}_1)$  = The proportion of genes with positive and negative effects in the parents, The ratio is smaller than its maximum value of 0.25 and U = V = 0.5 at all loci when positive and negative alleles are distributed unevenly among the parents, where U and V are the frequencies of positive and negative alleles in the parents, respectively.
3.  $(KD / KR) = (4 \hat{D} \hat{H}_1)^{1/2} + \hat{F} / (4 \hat{D} \hat{H}_1)^{1/2} - \hat{F}$  :

The proportion of both dominant and recessive alleles in the parents. According to Mather and Jinks (1982), heritability estimations in both wide and narrow meanings for every characteristic examined were derived as follows:

$$\text{Heritability in narrow sense } (h^2_n) = \frac{0.5 D + 0.5 H_1 + 0.25 H_2 - 0.5 F}{0.5 D + 0.5 H_1 - 0.25 H_2 - 0.5 F + E} \times 100$$

$$\text{Heritability in broad sense } (h^2_b) = \frac{0.5 D + 0.5 H_1 + 0.5 H_2 - 0.5 F}{0.5 D + 0.5 H_1 - 0.25 H_2 - 0.5 F + E} \times 100$$

## Results and Discussion

### Variance analysis for combining ability

The mean squares of the general combining ability (GCA) and specific combining ability (SCA) of half-diallel crosses for morpho-physiological characteristics and maize earliness under non-drought (normal irrigation) and water-stress conditions are shown in Table 4. The mean squares for general combining ability (GCA) and specialized combining ability were highly significant for all evaluated morpho-physiological features and earliness under both normal and drought-stress situations. This implies that the inheritance of these qualities is significantly influenced by both additive and non-additive gene effects.

The GCA/SCA (Baker ratio) ratio was less than unity for every tested morpho-physiological quality and earliness under both normal and drought-stress circumstances, indicating that non-additive genetic factors were more substantial and predominantly controlled the inheritance of these traits. Comparable results were published by Rahman *et al.* (2018), Kamara *et al.* (2019), Alipour and Rastegari (2020), Kamara *et al.* (2021), Belay (2022), Abo-Elwafa *et al.* (2023), Amegbor *et al.* (2023), Sedhom *et al.* (2023) and Elsheikh (2024).

**Table 4. The mean squares of general (GCA) and SCA combining abilities as well as the GCA/SCA ratio for all morpho-physiological features and earliness under normal and drought-stress situations.**

| S.O.V       | df | Tasseling date (day) |         | Anthesis date (day) |        | Silking date (day) |        | ASI (day) |        |
|-------------|----|----------------------|---------|---------------------|--------|--------------------|--------|-----------|--------|
|             |    | N                    | D       | N                   | D      | N                  | D      | N         | D      |
| GCA         | 7  | 4.18**               | 11.54** | 4.16**              | 4.12** | 4.27**             | 2.14** | 0.54**    | 0.58** |
| SCA         | 28 | 5.25**               | 10.22** | 5.52**              | 6.58** | 6.15**             | 8.56** | 0.67**    | 0.36** |
| Error       | 70 | 0.28                 | 0.36    | 0.26                | 0.35   | 0.23               | 0.35   | 0.01      | 0.09   |
| Baker ratio |    | 0.61                 | 0.69    | 0.60                | 0.56   | 0.58               | 0.33   | 0.61      | 0.76   |

**Table 4: Continued**

| S.O.V       | df | Chlorophyll content |         | Ear leaf area (cm <sup>2</sup> ) |            | Stem diameter (Cm) |        |
|-------------|----|---------------------|---------|----------------------------------|------------|--------------------|--------|
|             |    | N                   | D       | N                                | D          | N                  | D      |
| GCA         | 7  | 83.22**             | 60.55** | 39709.90**                       | 10299.24** | 0.13**             | 0.05** |
| SCA         | 28 | 29.16**             | 32.29** | 24057.81**                       | 14647.53** | 0.20**             | 0.18** |
| Error       | 70 | 5.58                | 1.39    | 626.38                           | 496.79     | 0.0042             | 0.0022 |
| Baker ratio |    | 0.85                | 0.79    | 0.77                             | 0.58       | 0.58               | 0.35   |

**Table 4: Continued**

| S.O.V       | Df        | Plant height (cm) |          | Ear height (cm) |          | Ear position |        |
|-------------|-----------|-------------------|----------|-----------------|----------|--------------|--------|
|             |           | 850.32**          | 277.94** | 336.14**        | 0.01**   | 0.00**       |        |
| GCA         | 4106.42** | 2497.49**         | 902.00** | 422.96**        | 0.00**   | 0.00**       |        |
| SCA         | 12.07     | 6.01              | 11.85    | 5.82            | 0.00     | 0.00         |        |
| Error       | 0.47      | 0.41              | 0.38     | 0.61            | 0.71     | 0.69         |        |
| Baker ratio |           | 1811.96**         | 850.32** | 277.94**        | 336.14** | 0.01**       | 0.00** |

**General combining ability effects (gi)**

High positive GCA effects would be interesting for all studied characteristics, with the exception of earliness traits (tasseling, anthesis and silking dates, and anthesis-silking interval, ASI), plant and ear heights, and ear location, where negative GCA effects would be favorable from a breeder's standpoint.

Based on the general combining ability effects (GCA), the best general combiners were: P1 (Red-A), P3 (Red-C) and P5 (L-49) under normal-irrigation, and P1 (Red-A), P2 (Red-B), P4 (L-6) and P5 (L-49) under drought-stress for days to 50% tasseling; P1 (Red-A), P3 (Red-C) and P8 (A-63) under normal-irrigation, and P1 (Red-A) and P2 (Red-B) under drought-stress for days to 50% anthesis; P1 (Red-A) and P2 (Red-B) under both conditions, and P3 (Red-C) under normal-irrigation for days to 50% silking; P3 (Red-C) under both conditions, and P5 (L-49) and P6 (L-69) under normal-irrigation for anthesis-silking interval (ASI); P4 (L-6), P5 (L-49) and P8 (A-63) under normal-irrigation, and P3 (Red-C), P4 (L-6), P7 (L-125) and P8 (A-63) under water-stress for chlorophyll content; P4 (L-6) and P8 (A-63) under both normal and water-stress conditions, and P5 (L-49) under normal-irrigation for ear leaf area; P8 (A-63) under both normal and water-stress conditions, and P4 (L-6) and under normal-irrigation for stem diameter trait; P1 (Red-A), P3 (Red-C) and P7 (L-125) under both normal and water-stress conditions, and P2 (Red-B) under normal-irrigation, and P4 (L-6) and P6 (L-69) under water-stress for plant height; P1 (Red-A), P2 (Red-B) and P7 (L-125) under normal, and P5 (L-49), P6 (L-69) and P7 (L-125) under water-stress for ear height; P4 (L-6) and P8 (A-63) under normal, P6 (L-69) under water-stress, and P5 (L-49) and P7 (L-125) under both normal and stress conditions for ear position, as shown in Table 5. Similar results were obtained by Rahman *et al.* (2018), Kamara *et al.* (2019), Alipour and Rastegari (2020), Kamara *et al.* (2021), Belay (2022), Abo-Elwafa *et al.* (2023), Amegbor *et al.* (2023), Sedhom *et al.* (2023) and Elsheikh (2024).

**Table 5. The general combining ability impacts (gca) of all parental genotypes for morpho-physiological characteristics and maize earliness under both normal and drought-stress circumstances.**

| Parents    | Tasseling date (day) |         | Anthesis date (day) |         | Silking date (day) |         | ASI (day) |         |
|------------|----------------------|---------|---------------------|---------|--------------------|---------|-----------|---------|
|            | N                    | D       | N                   | D       | N                  | D       | N         | D       |
| P1 (Red-A) | -0.46**              | -0.93** | -0.75**             | -0.69** | -0.56**            | -0.68** | 0.09**    | 0.06    |
| P2 (Red-B) | -0.19                | -1.20** | -0.28               | -0.66** | -0.79**            | -0.88** | 0.42**    | -0.13   |
| P3 (Red-C) | -0.86**              | 0.83**  | -0.35*              | 0.34    | -0.56**            | -0.34   | -0.06*    | -0.51** |
| P4 (L-6)   | 0.54**               | -1.17** | -0.18               | 0.21    | -0.16              | -0.24   | 0.04      | 0.30**  |
| P5 (L-49)  | -0.56**              | -0.53** | 0.45**              | -0.23   | 0.01               | 0.06    | -0.25**   | 0.01    |
| P6 (L-69)  | 0.71**               | 0.73**  | 1.22**              | 0.41*   | 1.01**             | 0.86**  | -0.35**   | 0.03    |
| P7 (L-125) | -0.09                | 0.73**  | 0.45**              | 0.21    | 0.34*              | 0.56**  | 0.02      | 0.20*   |
| P8 (A-63)  | 0.91**               | 1.53**  | -0.55**             | 0.41*   | 0.71**             | 0.66**  | 0.10**    | 0.06    |
| LSD gi 5%  | 0.31                 | 0.36    | 0.29                | 0.35    | 0.30               | 0.35    | 0.05      | 0.17    |
| LSD gi 1%  | 0.42                 | 0.47    | 0.38                | 0.46    | 0.40               | 0.46    | 0.07      | 0.23    |

**Table 5. Continued**

| Parents    | Chlorophyll content |         | Ear leaf area (cm <sup>2</sup> ) |          | Stem diameter (cm) |         |
|------------|---------------------|---------|----------------------------------|----------|--------------------|---------|
|            | N                   | D       | N                                | D        | N                  | D       |
| P1 (Red-A) | -5.27**             | -2.63** | -5.51                            | -3.38    | -0.01              | 0.02    |
| P2 (Red-B) | -2.82**             | -2.03** | -4.01                            | -1.55    | 0.00               | -0.02   |
| P3 (Red-C) | 0.37                | 2.97**  | -56.03**                         | -35.80** | -0.07**            | -0.07** |
| P4 (L-6)   | 2.89**              | 1.75**  | 22.43**                          | 35.48**  | 0.07**             | 0.00    |
| P5 (L-49)  | 3.40**              | -2.41** | 19.30*                           | -5.33    | 0.00               | 0.02    |
| P6 (L-69)  | -0.01               | -1.88** | -44.31**                         | -12.81   | -0.14**            | -0.06** |
| P7 (L-125) | -0.12               | 1.34**  | -64.55**                         | -34.08** | -0.09**            | -0.04** |
| P8 (A-63)  | 1.57*               | 2.88**  | 132.69**                         | 57.46**  | 0.24**             | 0.15**  |
| LSD gi 5%  | 1.39                | 0.70    | 14.77                            | 13.15    | 0.04               | 0.03    |
| LSD gi 1%  | 1.85                | 0.92    | 19.60                            | 17.46    | 0.05               | 0.04    |

**Table 5. Continued**

| Parents    | Plant height (cm) |         | Ear height (cm) |         | Ear position |         |
|------------|-------------------|---------|-----------------|---------|--------------|---------|
|            | N                 | D       | N               | D       | N            | D       |
| P1 (Red-A) | -12.29**          | -3.18** | -5.24**         | -0.18   | 0.02**       | 0.01**  |
| P2 (Red-B) | -9.56**           | -0.95   | -2.21*          | 4.06**  | 0.03**       | 0.03**  |
| P3 (Red-C) | -12.86**          | -2.52** | -1.17           | 3.03**  | 0.03**       | 0.02**  |
| P4 (L-6)   | 4.84**            | -2.12** | -1.31           | -1.18   | -0.03**      | -0.01   |
| P5 (L-49)  | 3.48**            | -1.32   | -1.37           | -4.28** | -0.02**      | -0.02** |
| P6 (L-69)  | 0.94              | -2.82** | 3.53**          | -5.11** | 0.00         | -0.02** |
| P7 (L-125) | -3.09**           | -9.05** | -3.67**         | -7.04** | -0.02**      | -0.01** |
| P8 (A-63)  | 28.54**           | 21.95** | 11.46**         | 10.69** | -0.02**      | 0.00    |
| LSD gi 5%  | 2.05              | 1.45    | 2.03            | 1.42    | 0.01         | 0.01    |
| LSD gi 1%  | 2.72              | 1.92    | 2.70            | 1.89    | 0.01         | 0.01    |

**Specific combining ability effects (S<sub>ij</sub>)**

The most desirable crosses were those that showed the highest positive specific combining ability (SCA) effects for all the traits under study, with the exception of the flowering traits (days to 50% tasseling, days to 50% anthesis, days to 50% silking, and anthesis-silking interval ASI), plant and ear heights, and ear position, where favorable SCA effects should be the lowest negative ones.

The best cross combinations among the 28 F1 crosses under study, according to the specific combining ability effects (SCA), were: 9 crosses under normal and 14 crosses under water-stress for tasseling date; 9 crosses under normal, and 13 crosses under water-stress for anthesis date; 10 crosses under normal, and 12 crosses under water-stress for silking date; 11 crosses under normal, and 5 crosses under water-stress for anthesis-silking interval (ASI); 9 crosses under normal, and 12 crosses under water-stress for chlorophyll content; 13 crosses under normal, and 14 crosses under water-stress for ear leaf area; 19 crosses under normal, and 23 crosses under water-stress for stem diameter; 4 crosses under normal, and 5 crosses under water-stress for plant height; 6 crosses under normal, and 7 crosses under water-stress for ear height; 13 crosses under normal, and 12 crosses under water-stress for ear position, as shown in Table 6. Similar results were reported by Rahman *et al.* (2018), Kamara *et al.* (2019), Alipour and Rastegari (2020), Kamara *et al.* (2021), Belay (2022), Abo-Elwafa *et al.* (2023), Amegbor *et al.* (2023), Sedhom *et al.* (2023) and Elsheikh (2024).



**Table 6. The impact of maize F<sub>1</sub> crosses' specific combining ability (SCA) on morpho-physiological characteristics and earliness in both normal and drought-stressed environments.**

| Crosses    | Tasseling date (day) |         | Anthesis date (day) |         | Silking date (day) |         | ASI (day) |         |
|------------|----------------------|---------|---------------------|---------|--------------------|---------|-----------|---------|
|            | N                    | D       | N                   | D       | N                  | D       | N         | D       |
| P1 X P2    | -0.82                | -0.53   | 0.50                | -1.31** | 0.03               | -0.61   | 1.33**    | 1.03**  |
| P1 X P3    | -0.16                | -2.57** | 0.23                | -2.31** | 0.79               | -2.14** | -0.39**   | -0.67** |
| P1 X P4    | -2.56**              | -1.57** | 0.40                | 0.83    | 0.06               | 0.76    | -0.29**   | -0.13   |
| P1 X P5    | -1.46**              | 3.80**  | 1.76**              | 3.26**  | 1.89**             | 2.46**  | 0.79**    | -0.52*  |
| P1 X P6    | -2.06**              | -4.13** | -2.67**             | -2.37** | -2.11**            | -2.34** | 0.09      | -0.20   |
| P1 X P7    | 0.08                 | 1.53**  | -0.24               | 0.83    | -3.11**            | 1.96**  | -1.27**   | -0.03   |
| P1 X P8    | 4.08**               | -4.27** | 0.10                | -4.37** | 1.53**             | -5.14** | 0.45**    | 0.11    |
| P2 X P3    | 1.58**               | -3.30** | -0.24               | -2.01** | 1.69**             | -1.94** | 0.49**    | 0.19    |
| P2 X P4    | 1.18**               | 3.70**  | 0.93*               | 1.79**  | 1.29**             | 1.96**  | 0.19**    | -0.28   |
| P2 X P5    | -0.72                | 1.07*   | -0.70               | 0.56    | -0.87*             | 1.66**  | -1.53**   | 1.00**  |
| P2 X P6    | -4.99**              | 1.80**  | -2.47**             | 1.59**  | -2.87**            | 0.86    | -0.23**   | -0.01   |
| P2 X P7    | 0.81                 | -2.20** | 0.63                | -1.21*  | 0.79               | -1.84** | -0.59**   | -0.85** |
| P2 X P8    | 3.14**               | 0.00    | 3.96**              | 2.59**  | 3.43**             | 2.06**  | 0.33**    | -0.04   |
| P3 X P4    | -1.49**              | -1.33** | 0.00                | -2.21** | -1.61**            | -1.57** | -1.13**   | 0.09    |
| P3 X P5    | -2.39**              | -4.63** | 2.36**              | -1.77** | 1.89**             | -2.87** | 0.15*     | -0.62** |
| P3 X P6    | -0.66                | -4.23** | -1.40**             | -2.41** | -2.11**            | -2.67** | -0.75**   | 0.36    |
| P3 X P7    | 2.14**               | -1.23*  | 2.03**              | -0.21   | 2.56**             | -0.37   | 0.89**    | 0.19    |
| P3 X P8    | -0.86*               | 1.97**  | -1.97**             | 3.59**  | -2.81**            | 2.53**  | 0.81**    | -0.67** |
| P4 X P5    | -0.79                | -0.97*  | -1.14**             | -2.31** | -0.51              | -1.97** | 1.05**    | -0.09   |
| P4 X P6    | -0.72                | 1.10*   | -1.90**             | 2.06**  | -0.51              | 1.23*   | 0.15*     | 0.56*   |
| P4 X P7    | 2.74**               | 1.77**  | 2.86**              | 2.26**  | 3.16**             | 2.53**  | -0.21**   | 0.06    |
| P4 X P8    | -1.26**              | 1.97**  | -2.14**             | 3.06**  | -3.21**            | 2.43**  | 0.71**    | 1.20**  |
| P5 X P6    | 1.04**               | -2.87** | 0.13**              | -2.51** | 0.33**             | -3.07** | -0.47**   | -0.09   |
| P5 X P7    | 2.84**               | 1.13*   | 0.90*               | -0.31   | 0.99*              | 0.23    | 0.27**    | 0.04    |
| P5 X P8    | 0.84*                | -0.33   | 2.90**              | 0.83    | 1.63**             | 2.13**  | -0.91**   | 1.22**  |
| P6 X P7    | 0.58                 | 1.87**  | -2.20**             | 1.06*   | -1.01*             | 1.43**  | -0.13     | 0.03    |
| P6 X P8    | -0.76                | -1.27** | 1.13**              | -6.47** | -0.37              | -1.67** | 0.69**    | -0.40   |
| P7 X P8    | -3.96**              | -3.93** | -7.10**             | -4.27** | -4.71**            | -3.37** | 1.23**    | 0.10    |
| LSD Sij 5% | 0.84                 | 0.95    | 0.76                | 0.93    | 0.81               | 0.93    | 0.13      | 0.46    |
| LSD Sij 1% | 1.11                 | 1.26    | 1.01                | 1.24    | 1.07               | 1.24    | 0.18      | 0.61    |

**Table 6. Continued**

| Crosses | Chlorophyll content |         | Ear leaf area (cm <sup>2</sup> ) |         | Stem diameter (Cm) |        |
|---------|---------------------|---------|----------------------------------|---------|--------------------|--------|
|         | N                   | D       | N                                | D       | N                  | D      |
| P1 X P2 | -1.49               | -3.97** | 199.46**                         | 75.15** | 0.04               | 0.16** |
| P1 X P3 | -3.05               | 4.55**  | 107.72**                         | 98.27** | 0.01               | 0.11** |
| P1 X P4 | 1.42                | 1.99*   | -13.23                           | 28.37   | 0.14**             | 0.15** |
| P1 X P5 | 7.87**              | 0.21    | -7.48                            | 26.05   | -0.07              | 0.10*  |
| P1 X P6 | 5.11**              | -1.85   | 38.26                            | 64.78** | 0.14**             | 0.04   |
| P1 X P7 | 3.85*               | -0.33   | -45.76*                          | -21.70  | 0.15**             | 0.15** |

| Crosses    | Chlorophyll content |         | Ear leaf area (cm <sup>2</sup> ) |           | Stem diameter (Cm) |        |
|------------|---------------------|---------|----------------------------------|-----------|--------------------|--------|
|            | N                   | D       | N                                | Crosses   | N                  | D      |
| P1 X P8    | -3.94*              | 0.43    | 10.88                            | -103.62** | 0.49**             | 0.43** |
| P2 X P3    | -0.82               | -0.84   | -114.03**                        | -30.93    | 0.04               | 0.15** |
| P2 X P4    | 8.95**              | 0.58    | 40.14*                           | 4.67      | 0.43**             | 0.28** |
| P2 X P5    | 2.42                | -0.32   | 81.14**                          | 144.22**  | 0.16**             | 0.20** |
| P2 X P6    | 5.35**              | 14.59** | 38.38                            | 54.71**   | 0.34**             | 0.21** |
| P2 X P7    | -6.67**             | -1.55   | 110.24**                         | 61.10**   | -0.02              | 0.05   |
| P2 X P8    | 0.14                | 4.86**  | 16.51                            | 28.43     | 0.12*              | 0.13** |
| P3 X P4    | -0.99               | -2.25*  | 91.28**                          | 67.67**   | -0.07              | 0.00   |
| P3 X P5    | -2.57               | 3.62**  | 79.03**                          | 89.72**   | 0.23**             | 0.15** |
| P3 X P6    | 2.78                | 3.01**  | 214.64**                         | 157.21**  | 0.24**             | 0.29** |
| P3 X P7    | -0.15               | -0.94   | 29.51                            | 30.22     | 0.12*              | 0.14** |
| P3 X P8    | 2.79                | 4.55**  | 5.14                             | 7.68      | 0.16**             | 0.15** |
| P4 X P5    | -9.86**             | 6.68**  | 246.33**                         | 143.70**  | 0.43**             | 0.28** |
| P4 X P6    | -9.02**             | 7.40**  | 46.82*                           | 87.43**   | 0.30**             | 0.29** |
| P4 X P7    | 7.22**              | -3.95** | -72.44**                         | -47.80**  | -0.05              | 0.04   |
| P4 X P8    | 4.00*               | -4.43** | 29.19                            | 43.16*    | 0.62**             | 0.42** |
| P5 X P6    | -3.93**             | 1.26**  | -62.43**                         | -21.52**  | -0.04              | 0.08   |
| P5 X P7    | -4.33*              | -1.85   | -59.44**                         | -3.88     | 0.18**             | 0.22** |
| P5 X P8    | 3.88*               | -1.00   | 150.44**                         | -17.29    | 0.38**             | 0.43** |
| P6 X P7    | 8.05**              | 4.16**  | 330.17**                         | 194.48**  | 0.28**             | 0.30** |
| P6 X P8    | -0.11               | 4.11**  | 42.56*                           | 31.70     | 0.06               | 0.08*  |
| P7 X P8    | 3.52                | 0.02    | -41.08*                          | 43.33*    | 0.27**             | 0.22** |
| LSD Sij 5% | 3.72                | 1.86    | 39.37                            | 35.07     | 0.10               | 0.07   |
| LSD Sij 1% | 4.93                | 2.46    | 52.28                            | 46.55     | 0.14               | 0.10   |

Table 6. Continued

| Crosses | Plant height (cm) |          | Ear height (cm) |          | Ear position |         |
|---------|-------------------|----------|-----------------|----------|--------------|---------|
|         | N                 | D        | N               | D        | N            | D       |
| P1 X P2 | 53.71**           | 16.37**  | 1.63            | -6.08**  | -0.13**      | -0.08** |
| P1 X P3 | 48.01**           | 24.61**  | 20.59**         | 11.62**  | -0.05**      | -0.02   |
| P1 X P4 | 38.64**           | 27.54**  | 21.73**         | 12.49**  | 0.00         | -0.01   |
| P1 X P5 | 18.34**           | 31.74**  | 2.79            | 17.26**  | -0.03**      | 0.00    |
| P1 X P6 | 53.54**           | 39.91**  | 34.56**         | 14.76**  | 0.01         | -0.02   |
| P1 X P7 | -9.09**           | -15.53** | -19.91**        | -15.64** | -0.08**      | -0.04** |
| P1 X P8 | 46.61**           | 22.81**  | 17.29**         | -5.38**  | -0.03*       | -0.07** |
| P2 X P3 | 24.28**           | 9.04**   | 12.56**         | -4.28*   | -0.04**      | -0.06** |
| P2 X P4 | 61.24**           | 50.31**  | 35.69**         | 31.59**  | 0.00         | 0.01    |
| P2 X P5 | 15.28**           | 13.84**  | -7.57**         | -4.31*   | -0.07**      | -0.05** |
| P2 X P6 | 48.48**           | 37.67**  | 32.19**         | 13.86**  | 0.00         | -0.02*  |
| P2 X P7 | 59.84**           | 48.91**  | 22.73**         | 13.46**  | -0.04**      | -0.05** |
| P2 X P8 | -0.12             | -7.76**  | -9.07**         | -14.28** | -0.05**      | -0.06** |
| P3 X P4 | 24.21**           | 13.54**  | 1.33            | 7.62**   | -0.05**      | 0.00    |
| P3 X P5 | 63.91**           | 41.74**  | 35.06**         | 11.72**  | 0.00         | -0.03** |

| Crosses    | Chlorophyll content |          | Ear leaf area (cm <sup>2</sup> ) |          | Stem diameter (Cm) |         |
|------------|---------------------|----------|----------------------------------|----------|--------------------|---------|
|            | N                   | D        | N                                | Crosses  | N                  | D       |
| P3 X P6    | 55.78**             | 45.91**  | 20.16**                          | 20.89**  | -0.05**            | -0.01   |
| P3 X P7    | 42.14**             | 26.14**  | 15.36**                          | 15.16**  | -0.03**            | 0.00    |
| P3 X P8    | -10.16**            | -12.19** | -10.11**                         | -18.24** | -0.04**            | -0.06** |
| P4 X P5    | 31.88**             | 32.34**  | 25.53**                          | 14.92**  | 0.05**             | 0.01    |
| P4 X P6    | 3.74                | 15.51**  | -2.04                            | 9.76**   | -0.01              | 0.02*   |
| P4 X P7    | -38.56**            | -30.26** | -7.17*                           | -1.31    | 0.06**             | 0.07**  |
| P4 X P8    | 10.48**             | 20.07**  | 2.69                             | -0.04    | 0.01               | -0.03** |
| P5 X P6    | 8.78**              | 15.04**  | 3.36*                            | 12.19    | 0.01**             | 0.03**  |
| P5 X P7    | -20.52**            | -11.39** | -10.44**                         | 0.79     | 0.01               | 0.03**  |
| P5 X P8    | 25.18**             | 18.27**  | 32.09**                          | 14.06**  | 0.08**             | 0.02**  |
| P6 X P7    | 44.68**             | 51.11**  | 18.66**                          | 19.96**  | 0.00               | -0.01   |
| P6 X P8    | 17.71**             | 27.11**  | 10.19**                          | 13.89**  | 0.01               | 0.01    |
| P7 X P8    | 16.74**             | 31.67**  | 29.06**                          | 7.16**   | 0.08**             | -0.03** |
| LSD Sij 5% | 5.47                | 3.86     | 5.41                             | 3.79     | 0.02               | 0.02    |
| LSD Sij 1% | 7.26                | 5.12     | 7.19                             | 5.04     | 0.03               | 0.02    |

#### Genetic components, heritability and degree of dominance

For earliness and morpho-physiological traits, the assumption and test for their validity were the same as previously. The associations between variance and covariance ( $V_r$  and  $W_r$ ) were shown in Table 7. Under normal irrigation and water stress conditions, data showed that " $t^2$ ," which measures uniformity, was insignificant for all earliness and morpho-physiological traits, except of Silking date (day) at drought, ASI (day) at drought, chlorophyll content at normal, ear leaf area at drought, stem diameter and plant height at both conditions and ear height at normal. The findings show that the additive dominance model is valid and that there is no indication of non-allelic interaction variance components or absence of allelic interaction. The second step, which involves evaluating the significance of the main genetic component, namely additive and non-additive, is prompted by the significance differences among genotypes, as given in Table 7.

Significant mean squares for component "a" in this analysis of variance imply significant additive gene effects and recommend selection based on significant general combining ability effects, which were similarly additive effects. The dominance gene effects are significant for selecting the hybrid combinations based on specific combining abilities, as indicated by component "b.". Component "b" has been further subdivided into "b1," "b2," and "b3," where "b1" tests the average deviations of hybrids from their mid-parent values in one direction, or directional dominance; "b2" shows how much the average dominance deviations in a given array differ from other arrays, or how much more dominant genes from the other parental arrays are present in the given array; and "b3" tests the percentage of dominance deviations attributable to a specific hybrid (Table 8). These findings concur with the findings of Hosana *et al.* (2015), Al-Naggar *et al.* (2016a), Sultan *et al.* (2016), Rahman *et al.* (2018), Kamara *et al.* (2019), Alipour and Rastegari (2020), Kamara *et al.* (2021), and Belay (2022).

In the current study, component "a" was significant for all morpho-physiological features and earliness under both normal and water stress conditions, underscoring the importance of additive gene effects and the parents' overall combining capacity. Component 'b' was also significant for all morpho-physiological and earliness traits under both normal and water stress conditions, indicating that dominance gene effects were important in explaining additive x non-additive and non-additive x non-additive gene effects interactions for these traits. Following the division of the "b" component of variation into "b1," "b2," and "b3," dominance effects were separated into three groups: dominance direction, dominance deviations attributed to the parental arrays, and dominance deviations attributable to particular hybrids.

Therefore, "b1" was significant for morpho-physiological characteristics and earliness under normal irrigation and water stress circumstances, indicating that the dominance was unidirectional. The presence of an asymmetrical distribution of genes among the parents for these features is shown by the fact that the 'b2' component, which offers information on the asymmetrical distribution of genes, was found to be significant in every instance.

Furthermore, as Table 8 illustrates, the 'b3' component was significant, indicating that hybrid combinations—more precisely, the hybrids' divergent heterozygosity—were responsible for the dominance.

**Table 7. Testing the validity for additive dominance model for all examined morpho-physiological characteristics and earliness in both drought-stress (D) and normal irrigation (N) circumstances.**

| Trait                            | Cond | t <sup>2</sup> | Regression coefficient (b)±SE | b=0    | b=1     | Wr+Vr    | Wr-Vr    |
|----------------------------------|------|----------------|-------------------------------|--------|---------|----------|----------|
| Tasseling date (day)             | N    | 0.11           | 0.59±0.39                     | 1.51   | 1.06    | 142.16** | 67.62**  |
|                                  | D    | 0.06           | 0.91±0.22                     | 4.22** | 0.42    | 815.24** | 158.73** |
| Anthesis date (day)              | N    | 0.90           | 0.43±0.56                     | 0.76   | 1.03    | 172.43** | 89.28**  |
|                                  | D    | 0.04           | 0.04±0.44                     | 0.10   | 2.16    | 157.47** | 114.82** |
| Silking date (day)               | N    | 0.92           | 0.08±0.28                     | 0.30   | 3.31*   | 228.58** | 148.93** |
|                                  | D    | 2.75*          | -0.22±0.21                    | -1.07  | 5.87**  | 253.85** | 321.20** |
| ASI (day)                        | N    | 0.44           | 0.59±0.24                     | 2.48*  | 1.74    | 1.84**   | 1.29**   |
|                                  | D    | 11.78*         | -0.06±0.13                    | -0.48  | 8.16**  | 1.25**   | 1.01**   |
| Chlorophyll content              | N    | 3.43*          | 0.97±0.63                     | 1.55   | 0.04    | 14100.28 | 3088.93* |
|                                  | D    | 0.83           | 0.53±0.23                     | 2.35   | 2.08    | 12406.74 | 2619.81* |
| Ear leaf area (cm <sup>2</sup> ) | N    | 1.02           | 0.48±0.23                     | 2.12   | 2.28    | 3329519  | 6973702  |
|                                  | D    | 5.00**         | 0.54±0.13                     | 4.03** | 3.42*   | 7823256  | 2497202  |
| Stem diameter                    | N    | 18.69*         | 0.14±0.11                     | 1.29   | 8.16**  | 0.08**   | 0.07**   |
|                                  | D    | 39.40*         | 0.10±0.08                     | 1.35   | 11.80** | 0.04**   | 0.04**   |
| Plant height (cm)                | N    | 8.88**         | 0.58±0.10                     | 5.74** | 4.16**  | 4430326  | 1503868  |
|                                  | D    | 10.33*         | 0.59±0.09                     | 6.35** | 4.39**  | 1296695  | 6353377. |
| Ear height (cm)                  | N    | 16.53*         | 0.41±0.10                     | 4.34** | 6.16**  | 1462543. | 1104865. |
|                                  | D    | 1.61           | 1.11±0.15                     | 7.67** | -0.79   | 1021244. | 163619.9 |
| Ear position                     | N    | 0.02           | 0.83±0.25                     | 3.30*  | 0.67    | 0.00**   | 0.00**   |
|                                  | D    | 1.40           | 0.66±0.17                     | 3.94** | 2.03    | 0.00**   | 0.00**   |

**Table 8. Morley-Jones analysis of variance (partitioning of genetic variance to its components) for earliness and morpho-physiological traits in maize F<sub>1</sub>'s hybrids.**

| S.O.V | Df | Tasseling date (day) |         | Anthesis date (day) |        | Silking date (day) |         | ASI (day) |        |
|-------|----|----------------------|---------|---------------------|--------|--------------------|---------|-----------|--------|
|       |    | N                    | D       | N                   | D      | N                  | D       | N         | D      |
| a     | 7  | 4.18**               | 11.54** | 4.16**              | 4.12** | 4.27**             | 2.14*   | 0.54**    | 0.58** |
| b1    | 1  | 3.34**               | 50.16** | 2.25**              | 8.82** | 1.83**             | 22.15** | 0.46**    | 0.41*  |
| b2    | 7  | 5.73**               | 15.72** | 7.95**              | 9.28** | 8.89**             | 9.79**  | 0.66**    | 0.40** |
| b3    | 20 | 5.18**               | 6.29**  | 4.83**              | 5.52** | 5.41**             | 7.44**  | 0.69**    | 0.35** |
| B     | 28 | 5.25**               | 10.22** | 5.52**              | 6.58** | 6.15**             | 8.56**  | 0.67**    | 0.36** |
| TOTAL | 35 | 5.04**               | 10.48** | 5.25**              | 6.09** | 5.77**             | 7.27**  | 0.64**    | 0.40** |

**Table 8. Continued**

| S.O.V | Df | Chlorophyll content |          | Ear leaf area (cm <sup>2</sup> ) |            | Stem diameter (Cm) |        |
|-------|----|---------------------|----------|----------------------------------|------------|--------------------|--------|
|       |    | N                   | D        | N                                | D          | N                  | D      |
| A     | 7  | 83.22**             | 60.55**  | 39709.9**                        | 10299.2**  | 0.13**             | 0.05** |
| b1    | 1  | 67.03**             | 241.15** | 357726.9**                       | 245263.3** | 4.20**             | 4.47** |
| b2    | 7  | 18.13**             | 49.76**  | 7596.3**                         | 10862.6**  | 0.09**             | 0.03** |
| b3    | 20 | 31.12**             | 15.74**  | 13135.9**                        | 4441.5**   | 0.03**             | 0.01** |
| b     | 28 | 29.16**             | 32.29**  | 24057.8**                        | 14647.5**  | 0.20**             | 0.18** |
| TOTAL | 35 | 39.97**             | 37.95**  | 27188.2**                        | 13777.8**  | 0.18**             | 0.15** |

The genetic estimate (KD/KR) is the ratio of the total number of dominant to recessive alleles in all parents. The value of this estimate was more than unity for all of the examined morpho-physiological and earliness qualities under normal irrigation and water stress settings, suggesting an excess of dominant genes in the parents for these features. A significant correlation coefficient between  $Wr+Vr$  and parental averages for morpho-physiological features and earliness under normal irrigation and water stress circumstances suggested that the parents with recessive genes

were in charge of boosting these qualities in F1 populations. However, for morpho-physiological traits and earliness, the correlation coefficient ( $r$ ) between mean values ( $\bar{y}_r$ ) and the order of dominance ( $W_r+V_r$ ) for all arrays was positive under normal irrigation and water stress conditions, suggesting that the decrease genes predominate over the increase genes for these traits.

These results demonstrated that earliness and morpho-physiological characteristics had little heritability in the narrow sense under normal irrigation and water stress settings. However, heritability in the board sense was higher than 0.82 for the morpho-physiological and earliness characteristics under normal irrigation and water stress situations, emphasizing the importance of the dominant influence rather than the additive. Estimates for morpho-

**Table 9. The estimates of genetic variance and its components and genetic ratio for earliness and morpho-physiological traits in  $F_1$ 's crossings under both drought-stress (D) and normal irrigation (N) scenarios.**

|                |   | Tasseling date (day) | Anthesis date (day) | Silking date (day) | ASI (day)   |
|----------------|---|----------------------|---------------------|--------------------|-------------|
| E              | N | 0.30±0.43            | 0.27±0.87           | 0.24±1.25          | 0.01±0.04   |
|                | D | 0.36±0.79            | 0.36±0.63           | 0.35±1.59          | 0.09±0.06   |
| D              | N | 5.69±1.28**          | 10.33±2.62**        | 9.46±3.74*         | 0.38±0.13** |
|                | D | 21.01±2.38**         | 7.57±1.88**         | 7.68±4.78          | 0.14±0.19   |
| F              | N | 9.24±3.02**          | 16.72±6.19**        | 16.30±8.83         | 0.70±0.30*  |
|                | D | 32.19±5.63**         | 14.27±4.44**        | 15.78±11.31        | 0.17±0.45   |
| H1             | N | 23.21±2.94**         | 25.66±6.02**        | 28.83±8.59**       | 3.01±0.29** |
|                | D | 45.60±5.48**         | 29.99±4.32**        | 37.38±11.00**      | 1.40±0.44** |
| H2             | N | 18.06±2.55**         | 18.42±5.24**        | 20.67±7.47**       | 2.40±0.26** |
|                | D | 31.13±4.77**         | 21.57±3.76**        | 28.46±9.57**       | 1.09±0.38** |
| $h^2$          | N | 1.51±1.71            | 0.99±3.51           | 0.79±5.01          | 0.22±0.17   |
|                | D | 24.53±3.20**         | 4.18±2.52           | 10.75±6.42         | 0.16±0.26   |
| $S^2$          | N | 1.45                 | 6.09                | 12.41              | 0.01        |
|                | D | 5.05                 | 3.14                | 20.35              | 0.03        |
| $(H1/D)^{0.5}$ | N | 2.02                 | 1.58                | 1.75               | 2.81        |
|                | D | 1.47                 | 1.99                | 2.21               | 3.12        |
| H2/4H1         | N | 0.19                 | 0.18                | 0.18               | 0.20        |
|                | D | 0.17                 | 0.18                | 0.19               | 0.19        |
| KD/KR          | N | 2.35                 | 3.11                | 2.95               | 1.97        |
|                | D | 3.17                 | 2.80                | 2.74               | 1.46        |
| R              | N | 0.55                 | 0.67                | 0.86               | -0.37       |
|                | D | 0.70                 | 0.41                | 0.58               | -0.49       |
| $r^2$          | N | 0.30                 | 0.45                | 0.74               | 0.14        |
|                | D | 0.49                 | 0.17                | 0.34               | 0.24        |
| $h^2/H2$       | N | 0.08                 | 0.05                | 0.04               | 0.09        |
|                | D | 0.79                 | 0.19                | 0.38               | 0.15        |
| mean of Fr     | N | 14.37                | 23.90               | 23.53              | 1.22        |
|                | D | 45.89                | 20.98               | 23.45              | 0.43        |
| $h^2$ (n.s)    | N | 0.14                 | 0.08                | 0.11               | 0.19        |
|                | D | 0.17                 | 0.13                | 0.05               | 0.28        |
| $H^2$ (b.s)    | N | 0.95                 | 0.95                | 0.96               | 0.99        |
|                | D | 0.96                 | 0.95                | 0.96               | 0.82        |

Table 9. Continued

|                       |   | Chlorophyll content | Ear leaf area (cm <sup>2</sup> ) | Stem diameter (Cm) |
|-----------------------|---|---------------------|----------------------------------|--------------------|
| E                     | N | 5.52±4.86           | 661.55±1804.53                   | 0.001±0.01         |
|                       | D | 1.42±5.50           | 489.62±843.73                    | 0.001±0.01         |
| D                     | N | 60.68±14.57**       | 27304.78±5413.59**               | 0.02±0.04          |
|                       | D | 66.35±16.51**       | 16009.44±2531.20**               | 0.001±0.02         |
| F                     | N | 46.46±34.43         | 19807.84±12791.82                | 0.02±0.10          |
|                       | D | 89.62±39.01*        | 22886.76±5981.00**               | 0.001±0.05         |
| H1                    | N | 107.45±33.49**      | 76326.92±12445.05**              | 0.56±0.10**        |
|                       | D | 138.19±37.95**      | 48024.95±5818.86**               | 0.44±0.05**        |
| H2                    | N | 94.60±29.14**       | 69701.59±10827.18**              | 0.48±0.09**        |
|                       | D | 92.61±33.02**       | 38208.44±5062.40**               | 0.41±0.05**        |
| h <sup>2</sup>        | N | 30.58±19.54         | 175779.32±7261.17**              | 2.06±0.06**        |
|                       | D | 118.07±22.15**      | 120501.32±3395.06**              | 2.20±0.03**        |
| S <sup>2</sup>        | N | 188.69              | 26050642.00                      | 0.001              |
|                       | D | 242.30              | 5695095.02                       | 0.001              |
| (H1/D) <sup>0.5</sup> | N | 1.33                | 1.67                             | 5.43               |
|                       | D | 1.44                | 1.73                             | 15.77              |
| H2/4H1                | N | 0.22                | 0.23                             | 0.21               |
|                       | D | 0.17                | 0.20                             | 0.23               |
| KD/KR                 | N | 1.81                | 1.55                             | 1.27               |
|                       | D | 2.76                | 2.41                             | 1.06               |
| R                     | N | -0.72               | -0.64                            | -0.61              |
|                       | D | -0.89               | -0.81                            | -0.52              |
| r <sup>2</sup>        | N | 0.52                | 0.41                             | 0.37               |
|                       | D | 0.79                | 0.66                             | 0.27               |
| h <sup>2</sup> /H2    | N | 0.32                | 2.52                             | 4.34               |
|                       | D | 1.27                | 3.15                             | 5.32               |
| mean of Fr            | N | 84.54               | 39815.41                         | 0.10               |
|                       | D | 132.26              | 35061.72                         | 0.06               |
| h <sup>2</sup> (n.s)  | N | 0.32                | 0.28                             | 0.24               |
|                       | D | 0.31                | 0.13                             | 0.11               |
| H <sup>2</sup> (b.s)  | N | 0.87                | 0.97                             | 0.97               |
|                       | D | 0.96                | 0.96                             | 0.97               |

Table 9. Continued

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |   | Plant height (cm)  | Ear height (cm)  | Ear position |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|--------------------|------------------|--------------|
| E                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | N | 12.80±185.02       | 11.83±22.83      | 0.00±0.001   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 8.39±85.50         | 5.90±19.29       | 0.00±0.001   |
| D                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | N | 3310.10±555.07**   | 158.50±68.50*    | 0.02±0.001** |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 1013.92±256.50**   | 680.76±57.86**   | 0.01±0.001** |
| F                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | N | 4806.14±1311.59**  | 176.75±161.87    | 0.03±0.001** |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 1395.10±606.09*    | 1025.71±136.72** | 0.02±0.001** |
| H1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | N | 12150.65±1276.03** | 2579.14±157.48** | 0.02±0.001** |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 6956.45±589.66**   | 1557.52±133.01** | 0.02±0.001** |
| H2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | N | 10188.14±1110.15** | 2437.33±137.01** | 0.01±0.001** |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 6269.05±513.01**   | 1131.57±115.72** | 0.01±0.001** |
| h <sup>2</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | N | 42701.21±744.51**  | 8553.00±91.88**  | 0.01±0.001** |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 26981.24±344.04**  | 2960.86±77.61**  | 0.01±0.001** |
| S <sup>2</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | N | 273873.61          | 4171.31          | 0.001        |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 58483.70           | 2975.77          | 0.001        |
| (H1/D) <sup>0.5</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | N | 1.92               | 4.03             | 1.18         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 2.62               | 1.51             | 1.24         |
| H2/4H1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | N | 0.21               | 0.24             | 0.13         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 0.23               | 0.18             | 0.14         |
| KD/KR                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | N | 2.22               | 1.32             | 5.33         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 1.71               | 2.98             | 4.86         |
| R                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | N | -0.96              | -0.75            | 0.97         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | -0.90              | -0.86            | 0.85         |
| r <sup>2</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | N | 0.92               | 0.56             | 0.94         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 0.81               | 0.74             | 0.73         |
| h <sup>2</sup> /H2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | N | 4.19               | 3.51             | 0.86         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 4.30               | 2.62             | 1.70         |
| mean of Fr                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | N | 7570.66            | 562.65           | 0.04         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 2647.76            | 1477.71          | 0.02         |
| h <sup>2</sup> (n.s.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | N | 0.08               | 0.09             | 0.11         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 0.09               | 0.12             | 0.13         |
| H <sup>2</sup> (b.s.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | N | 1.00               | 0.98             | 0.94         |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | D | 1.00               | 0.98             | 0.95         |
| <p><b>*, ** Significant and highly significant at 0.05 and 0.01 probability levels, respectively.</b></p> <p>D stands for additive variance, H2 for the percentage of parents' positive and negative genes, H1 for dominance variance, and E for environmental variance.</p> <p><math>\sqrt{H_1/D}</math> = mean degree of dominance    F = Relative frequency of dominant and recessive alleles in the parents</p> <p><math>H_2/4H_1</math> = The proportion of genes with positive and negative effects in the parents. <math>h^2</math> = dominance effect (over all loci in heterozygous phase)</p> <p>KD/KR = The proportion of both dominant and recessive alleles in the parents.    Heritability in narrow sense (<math>h_n^2</math>)</p> <p><math>h^2/H_2</math> = no. of effective genes    Heritability in broad sense (<math>h_b^2</math>)</p> |   |                    |                  |              |

physiological characteristics and earliness in both wide and narrow senses under typical irrigation and water stress circumstances are given in Table 9. Narrow sense heritability estimates ( $h^2$ n.s.) for earliness and morpho-physiological traits under normal irrigation and water stress conditions were found to be significantly lower than those of broad sense because the majority of genetic variance for all studied traits was due to non-additive genetic effects. This led to the conclusion that selection procedures that are known to be effective in shifting gene frequency when both additive and non-additive traits are present should be used. These findings are consistent with the



findings of Abdel-Moneam *et al.*, (2014), Rajitha *et al.* (2014), Hosana *et al.* (2015), Al-Naggar *et al.* (2016a), Sultan *et al.* (2016), Abo-Elwafa *et al.* (2023), Amegbor *et al.* (2023), Sedhom *et al.* (2023) and Elsheikh (2024).

## Conclusion

We may draw the conclusion that, in both normal and drought-stressed environments, both additive and non-additive gene effects play a significant role in the inheritance of all studied morpho-physiological features and earliness. The best general combiners under drought stress were P1 (Red-A), P2 (Red-B), P4 (L-6), and P5 (L-49). Because non-additive genetic effects accounted for the bulk of genetic variance for all tested characteristics, narrow sense heritability estimates ( $h^2_{n.s}$ ) under normal irrigation and water stress situations were found to be much lower than those of wide sense. This led to the conclusion that when both additive and non-additive qualities are present, selection techniques that are shown to be successful in changing gene frequency should be applied.

## Sustainability Statement

This study supports sustainable maize production by identifying genetically superior inbred lines and  $F_1$  hybrids with enhanced earliness and morpho-physiological adaptation under water-deficit conditions. The findings contribute to the development of drought-tolerant maize cultivars that improve water-use efficiency, maintain productivity under limited irrigation, and promote climate-resilient and sustainable agricultural systems.

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## Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

## Author Contributions (CRediT)

First author: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft. Second author: Methodology, Validation, Supervision, Writing – review & editing. Third author: Investigation, Resources, Data curation, Visualization, Writing – review & editing. Fourth author: Supervision, Conceptualization, Project administration, Validation, Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

## Conflict of Interest

The authors declare no conflict of interest.

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