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Identification of early-flowering white maize inbred lines through line × tester analysis

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Abstract

Eighty S_1 white maize inbred lines were developed from four populations (20 per population) and top-crossed with two testers: Giza-2 (T1) and SC-10 (T2), producing 160 top-cross hybrids. These hybrids, the original inbred lines, the testers, and the commercial check Giza-2 were evaluated in 2023 at Al-Azhar University, Assiut, Egypt for days to 50% anthesis and silking. Highly significant differences were observed among genotypes, including parents, crosses, and their interactions. Significant variation was also found among lines, testers, and line × tester interactions for both earliness traits. Several inbred lines exhibited significant and desirable negative general combining ability (GCA) effects for earliness. These included IL-7 and IL-17 from population-1; IL-2, IL-7, IL-10, IL-12, IL-15, IL-17, IL-18, and IL-19 from population-2; IL-1, IL-4, IL-8, IL-11, and IL-20 from population-3; and IL-2, IL-3, IL-7, IL-18, and IL-19 from population-4. Giza-2 (T1) was earlier flowering than SC-10 (T2). Significant and negative specific combining ability (SCA) effects were detected for both testers, suggesting a predominance of non-additive gene action ($\sigma^2A/\sigma^2 D < 1$). Several top-cross hybrids showed significantly negative SCA effects and heterosis for both traits, including IL-5 × Giza-2 and IL-17 × Giza-2 (population-1); IL-10 × Giza-2 and IL-4 × SC-10 (population-2); IL-13, IL-15, and IL-19 × SC-10 (population-3); and IL-14 and IL-18 × Giza-2 (population-4). These hybrids flowered earlier than their parents and the commercial check.

Keywords: breeding for earliness, maize, combining ability, heterosis.

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1. Introduction

Maize (*Zea mays* L.) ranks as the third most important cereal crop globally, serving as a vital source of nutrition for both humans and livestock. Maize is a versatile crop with a wide genetic diversity and can grow successfully in a wide range of environmental conditions. According to FAOSTAT (2023), Egypt cultivated around 900,000–1,000,000 hectares of maize, producing 7.5–8 million tons with an average yield of 7.2 tons/ha (about 22 ardeb/feddan) (Ardeb = 5.44 imperial or 5.619 U.S. bushels, feddan = 4200 m² = 0.420 hectares = 1.037 acres) above the global average of 5.8 tons/ha. Globally, maize covers over 200 million hectares, with production exceeding 1.2 billion tons. Egypt ranks among the top five countries worldwide, following the United States, China, Brazil, Argentina, and Ukraine. Despite this, Egypt imports over 8 million tons of yellow maize annually. However, the gap between production and consumption in Egypt is expected to widen in the coming years due to continuous population growth. Reducing the production-consumption gap requires the development of high-yielding hybrids adapted to local conditions, which emphasizes the importance of combining ability in maize breeding programs. Several studies, including those conducted by Wali *et al.* (2010) and Hefny (2010), employed the line × tester mating design to assess general and specific combining ability effects of inbred lines and their resulting hybrids. Combining ability of inbred lines plays an important role in breeding programs. The concepts of general combining ability (GCA) and specific combining ability (SCA), as defined by Sprague and Tatum (1942), are valuable tools for evaluating the performance of inbred lines in hybrid combinations. According to Hallauer (1975), an effective tester should be easy to use and capable of accurately distinguishing the genetic potential of lines, thereby contributing to maximizing genetic improvement. According to Rojas and Sprague (1952) and El-Zeir *et al.* (2000) reported that in relatively unselected lines, additive gene action or GCA tends to be more influential. In contrast, Nawar and El-Hosary (1984) and Attia (1992), who stated that the genetic variance component attributed to specific combining ability (SCA) for grain yield and other agronomic traits was generally greater than that of general combining ability (GCA). This suggests that non-additive gene action plays a more significant role in previously selected lines for grain yield. Plant breeding has widely used heterosis (hybrid vigor) to improve important traits in crops, especially early maturity and grain yield in maize (Liu *et al.*, 2022). Therefore, the development of superior hybrids largely relies on the genetic improvement of the base populations used in breeding programs. The S1 progeny selection scheme is commonly applied to enhance the performance of the population itself. This approach aids to eliminate of deleterious recessive alleles that become homozygous through inbreeding, while subsequent selection increases the frequency of favorable alleles across all genetic loci. Theoretically, S_1-based selection is expected to utilize additive genetic variance better than intra-population selection methods. The present study aimed to evaluate the combining ability for earliness traits and to estimate the heterosis to identify superior hybrids.

2. Materials and methods

The present investigation was carried out during three successive seasons from 2021 to 2023 at Experimental Farm, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt. Eighty S1 white maize inbred lines were derived from four populations; IW-86, IW-108, IW-326, and IW-335 (20 S1 inbred lines from each). All these white maize inbred lines were obtained from the National Maize Research Program (NMRP), Field Crops Research Institute, Agricultural Research Center (ARC), along with two testers [(Giza-2(T1) and Single Cross-10(T2)]. In addition, 160 top-cross hybrids derived from these inbred lines and commercial check (Giza-2) were grown to evaluate earliness traits including days to 50% anthesis and days to 50% silking in the present study.

2.1 Making the top-cross hybrids

In the first season (2021), four populations; IW-86, IW-108, IW-326, and IW-335 were sown as spaced plants on May 31st. From each population, 250 plants were grown, and 30 vigorous, disease-free plants were selected before silking and self-pollinated. After harvest, the 30 selfed ears (S1's) that produced enough grains were selected. In the second season (2022), 30 S1 inbred lines from each population were grown in isolated plots for crossing with two testers; Giza-2(T1) and Single Cross-10 (T2). In the third season (2023), 20 S1 inbred lines from each population, along with 160 top-cross hybrids, two testers; (Giza-2(T1) and Single Cross-10 (T2) and commercial check (Giza-2) were grown in a Randomized Complete Block Design (RCBD) with three replications. Each experimental plot consisted of a single row, 4.0 meters long and 70 cm wide, with 25 cm spacing between hills within the row (total area: 2.8 m^2). Plants were thinned to one plant per hill, 21 days after planting and prior to the first irrigation.

2.2 Agricultural practices and fertilization regimes

All other agricultural practices were followed according to the recommendations of Agricultural Research Center, Egypt. Nitrogen fertilization at the rate of 120 kg N/feddan was added in two equal doses of urea before the first and second irrigation. Fertilization with calcium superphosphate was performed with soil preparation and before sowing. Weed control was performed chemically with Stomp herbicide before the first irrigation and just after sowing and manually by hoeing twice, the first was before the second irrigation and the second was before the third irrigation. Irrigation was applied by flooding after three weeks for the second. Pest control was performed when required by spraying plants with Lannate (Methomyl) 90% (manufactured by DuPont, USA) against corn borers.

2.3 The studied characters

The studied traits included earliness traits, namely; days to 50% anthesis (DA, days) and days to 50% silking (DS, days) were assessed as follows:

1) Days to 50% anthesis (DA, days): It was estimated as number of days from the sowing date until 50% of plants plot-1 shed their pollen on base plot.

2) Days to 50% silking (DS, day): It was estimated as number of days from the sowing date until 50% of plants plot-1 appearance their silks on base plot.

2.4 Pedigree of parental materials

The pedigree of four populations, two testers, and commercial check used in this study are presented in Table (1).

Table (1): Names, pedigrees, and origins of the parental materials (four source populations, two testers, and the commercial check Giza-2) used in the study.

Name	Designation	Origin
Population-1 (IW-86)	Coach 22	Mexico, 1965
Population-2 (IW-108)	Ver 141	Mexico, 1965
Population-3 (IW-326)	LLera	India, 1968
Population-4 (IW-335)	Tamps Tuxp Group 2 × Eto Blanco F_3	India, 1968
Giza-2 (Tester T_1 & Commercial Check)	Gm. 300, 327, 332, 357 (L12; L15)	Egypt (ARC)
Single Cross-10 (T_2)	White Sd-7 × Sd-63	Egypt (ARC)

ARC = Agricultural Research Center; IL = Inbred Line; W = White grains.

2.5 Statistical analysis

2.5.1 Line × tester analysis

Data of the tested crosses experiment were further subjected to differences among top-crosses were found significant, line × tester analysis according to Kempthorne (1957). The sum of squares for F1 hybrids was partitioned into their components, *i.e.* males (testers), females (inbred lines) and females (lines) × males (testers) interaction (Table 2).

Table (2): Analysis of variance and expected mean squares (E.M.S.).

Source of Variation (S.O.V.)	Degrees of Freedom (d.f.)	Mean Square (M.S.)	Expected Mean Squares (E.M.S.)
Replications	r−1	M_0	–
Genotypes	g−1	M_G	–
Parents (P)	p−1	M_P	–
Parents vs. Checks (P vs. C)	1	M_{PvsC}	–
Crosses (C)	c−1	M_C	–
Lines (L)	l−1	M_1	$\sigma^2 + r\sigma^2_{fm} + rt\sigma^2_f$
Testers (T)	t−1	M_2	$\sigma^2 + r\sigma^2_{lt} + rl\sigma^2_m$
Lines × Testers (L × T)	(l−1)(t−1)	M_3	$\sigma^2 + r\sigma^2_{lt}$
Error	(r−1)(g−1)	M_4	σ^2
Total	rg−1	–	–

r = number of replications, l = number of lines, t = number of testers, c = number of crosses, g = total number of genotypes, σ^2 = error variance, σ^2_f = variance due to female (line) GCA, σ^2_m = variance due to male (tester) GCA, σ^2_{lt} = variance due to line × tester interaction, σ^2_{fm} = interaction of females × males (expanded form sometimes included in derivation).

2.5.2 Estimating GCA and SCA variances and effects

The model used to estimate general (GCA) and specific (SCA) combining ability effects of X_{ijkth} observation is as follows:

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where: μ = overall population mean, g_i = GCA effect of the i-th line parent, g_j = GCA effect of the j-th tester parent, s_{ij} = SCA effect of the ij-th cross combination e_{ijk} = random error associated with the ijk-th observation, i = number of line parents, j = number of tester parents, k = number of replications.

2.5.3 Estimation of GCA effects for lines ($\hat{g}_i(l)$)

The general combining ability (GCA) effect of the i^{th} line was estimated as:

$$\hat{g}_i(l) = \left(\frac{Y_{i..}}{tr}\right) - \left(\frac{Y_{...}}{ltr}\right)$$

Where: $Y_{i..}$= total of the i^{th} line across all testers and replications, $Y_{...}$ = grand total of all lines and testers across replications, t = number of testers, r = number of replications, and l = number of lines.

2.5.4 Estimation of GCA effects for testers

The general combining ability (GCA) effect of the j^{th} tester was estimated as:

$$\hat{g}_i(t) = \left(\frac{Y_{.j.}}{tr}\right) - \left(\frac{Y_{...}}{ltr}\right)$$

Where: $Y_{.j.}$ = total of the j^{th} tester across all lines and replications, $Y_{...}$ = grand total of all lines and testers across replications, l = number of lines, r = number of replications, t = number of testers.

2.5.5 Estimation of SCA effects for crosses

The specific combining ability (SCA) effect of the cross between the i^{th} line and j^{th} tester was estimated as:

$$\hat{s}_{ij}(lt) = \left(\frac{Y_{ij.}}{r}\right) - \left(\frac{Y_{i..}}{tr}\right) - \left(\frac{Y_{.j.}}{lr}\right) + \left(\frac{Y_{...}}{ltr}\right)$$

Where: $Y_{ij.}$ = total of the cross between the i^{th} line and j^{th} tester across all replications, $Y_{i..}$ = total of the i^{th} line across all testers and replications, $Y_{.j.}$ = total of the j^{th} tester across all lines and replications, $Y_{...}$ = grand total of all lines and testers across replications, r = number of replications, l = number of lines, t = number of testers.

2.5.6 Estimation of standard errors (SE) for combining ability effects

The standard errors of the general and specific combining ability effects were estimated as follows:

$$SE(GCA\ for\ lines) = \sqrt{\frac{M_e}{rt}}$$

$$SE(GCA\ for\ testers) = \sqrt{\frac{M_e}{rl}}$$

$$SE(SCA\ for\ crosses) = \sqrt{\frac{M_e}{r}}$$

Where: M_e = mean square error, r = number of replications, l = number of lines, t = number of testers.

2.5.6.1 Estimation of variance components

The variance components were estimated

from the line × tester ANOVA mean squares (Kempthorne, 1957) as follows:

$$\sigma^2 = M_4$$

$$\sigma^2_{\{lt\}} = \frac{M_3 - M_4}{r}$$

$$\sigma^2_f = \frac{M_1 - M_3}{rt}$$

$$\sigma^2_m = \frac{M_2 - M_3}{rl}$$

The relative importance of additive vs. non-additive gene action was assessed using the ratio:

$$\frac{2\sigma^2_{GCA}}{2\sigma^2_{GCA} + \sigma^2_{SCA}}$$

where σ^2_{GCA} is the average of variance due to lines (σ^2_f) and testers (σ^2_m), and σ^2_{SCA} is the variance due to line × tester interaction.

2.5.7 Heterosis estimates

Heterosis was estimated according to the method of Hallauer and Miranda (1981). Two types of heterosis were calculated.

2.5.7.1 Better-parent heterosis (heterobeltiosis)

It was calculated as the percentage deviation of the F_1 mean from the mean of the better parent:

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where: $\overline{F_1}$ = mean performance of the F_1 cross, $\overline{BP}$ = mean performance of the better parent

2.5.7.2 Mid-parent heterosis

It was calculated as the percentage deviation of the F_1 mean from the average of its two parents:

$$\text{Mid - parent heterosis (\%)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

Where: $\overline{MP} = \frac{P_1 + P_2}{2}$, P_1, P_2 = mean performances of the two parents

2.5.8 Significance of heterosis

The significance of heterosis was tested using the Least Significant Difference (LSD) method at the desired probability level. The test statistic was calculated as:

$$LSD = \overline{S_d} \times t_\alpha$$

Where: $\overline{S_d}$ = standard error of the difference between means, t_α = tabulated *t* value at a specified level of probability with the appropriate error degrees of freedom.

The standard error of the difference ($\overline{S_d}$) was estimated separately for better-parent and mid-parent heterosis as follows:

1. For better-parent heterosis:

$$\overline{S_d} = \sqrt{\frac{2M_{se}}{r}}$$

2. For mid-parent heterosis:

$$\overline{S_d} = \sqrt{\frac{3M_{se}}{2r}}$$

Where: M_{se} = mean square error (pooled error), r = number of replication.

3. Results and Discussion

Eighty S1 white maize inbred lines were developed from four populations; population 1 (IW-86), population 2 (IW-108), population 3 (IW-326), and population 4 (IW-335), with 20 S1 inbred lines from each. Two testers were used: Giza-2 (T1) and Single Cross-10 (T2). A total of 160 top-cross hybrids were generated from these inbred lines (80 inbred lines crossed with the two testers), in addition to the commercial check Giza-2. All these genotypes were evaluated for days to 50% anthesis and days to 50% silking in the present study.

3.1 Analysis of variance for the studied populations

3.1.1 Days to 50% anthesis (DA, day)

Analysis of variance for days to 50% anthesis (DA) was conducted for 22 white maize parents (20 inbred lines from each of the four studied populations and 2 testers), along with 40 top-cross hybrids from each population. The results are presented in Table (3). In population-1 (IW-86), the results showed highly significant ($P \leq 0.01$) mean squares due to genotypes and their components; parents, crosses, and parent vs. cross (P vs. C) interaction indicating a wide range of genetic diversity for this trait. Moreover, the mean squares for lines, testers, and line × tester interaction were also highly significant, suggesting that both additive and non-additive gene actions contributed significantly to the genetic control of days to 50% anthesis. The mean square values for testers were higher than those for lines, indicating a greater influence of testers on the performance of the hybrids for this population. In population-2 (IW-108), the results were shown in Table (3), showed highly significant mean squares due to genotypes and their components; parents, crosses, and the parent vs. cross (P vs. C) interaction for days to 50% anthesis, indicating the presence of wide genetic variability among genotypes and their components. Additionally, the mean squares for lines, testers, and line × tester interaction were also highly significant, suggesting that both additive and non-additive genetic effects played a major role in controlling this trait. Significantly, the mean square values for testers were higher than those for lines, indicating a greater influence of testers on the performance of the hybrids for this population. In population-3 (IW-326), the analysis of variance for days to 50% anthesis revealed highly significant differences among genotypes and their components; parents, crosses, and parent vs. cross (P vs. C) interaction. This indicates the presence of important genetic variability for this trait in Population 3. Furthermore, the mean squares for lines, testers, and line × tester interaction were also highly significant. These results suggest that both additive and non-additive gene actions play a significant role in the inheritance of days to 50% anthesis. Testers showed higher mean square values than lines, indicating their greater influence on hybrid performance in this population. In population-4 (IW-335), the results revealed highly significant (P ≤ 0.01) mean squares for genotypes and their components; parents, crosses, and the parent vs. cross (P vs. C) contrast indicating substantial genetic variability among the genotypes and their components. Furthermore, the mean squares for lines, testers, and line × tester interactions were also highly significant, suggesting that both additive and non-additive genetic effects contributed significantly to the expression of this trait. Additionally, testers recorded higher mean square values than lines, indicating their stronger influence on hybrid performance for days to 50% anthesis in this population. Our results agree with the findings of Ali (2003), Rehan and Kamara (2016), Abed and Hammadi (2018), El-Refaey *et al*. (2018), El-Shamarka *et al*. (2020), Turk Ferial *et al*. (2020), Fayyad and Hammadi (2021), Saeed Menna *et al*. (2022), Shaaban *et al*. (2022) and Lal *et al*. (2023), who also found high genetic variability among studied genotypes and important additive and non-additive genetic effects.

Table (3): Analysis of variance for days to 50% anthesis and days to 50% silking in four populations of white maize involving 22 parents (20 inbred lines and 2 testers) and their 40 top-cross hybrids in 2023 season.

S.O.V	D.F	Population-1		Population-2		Population-3		Population-4	
		Anthesis	Silking	Anthesis	Silking	Anthesis	Silking	Anthesis	Silking
Replications	2	0.46	0.21	0.04	0.28	0.34	0.49	0.12	0.88
Genotypes	61	13.52**	15.26**	12.87**	18.51**	11.68**	20.41**	14.22**	16.72**
Parents (P)	21	15.58**	12.33**	14.28**	16.40**	7.92**	12.58**	8.82**	8.15**
P vs. C	1	90.29**	405.96**	180.25**	428.90**	290.54**	697.72**	311.94**	477.59**
Crosses (C)	39	10.45**	6.82**	7.82**	9.12**	6.56**	7.25**	9.49**	9.52**
Lines (L)	19	4.76**	3.58**	5.23**	9.18**	5.93**	6.18**	7.02**	6.03**
Testers (T)	1	266.68**	136.06**	146.16**	63.35**	73.47**	69.85**	155.96**	173.88**
L × T	19	2.65**	3.25**	3.13**	6.20**	3.67**	5.03**	4.26**	4.36**
Error	122	0.29	0.19	0.08	0.28	0.12	0.17	0.14	0.30

* and ** denote significant at 0.05 and 0.01% level of probability, respectively.

3.1.2 Days to 50% silking (DS, day)

Analysis of variance for days to 50% silking (DS) was carried out for 22 white maize parents including 20 inbred lines derived from each of the four studied populations along with 2 testers, as well as 40 top-cross hybrids representing each population. The results are summarized in Table (3). In population-1 (IW-86), the results of variance analysis for days to 50% silking (DS), revealed highly significant differences (P ≤ 0.01) among genotypes and their components; parents, crosses, and the parent vs. cross (P vs. C) interaction, indicating a wide extent of genetic diversity for days to 50% silking. Additionally, the analysis showed that lines, testers, and their interactions (line × tester) also had highly significant effects, demonstrating the involvement of both additive and non-additive gene action in controlling days to 50% silking. Testers exhibited greater mean square values than lines, pointing to their more significant role concerning hybrid performance in this population. In population-2 (IW-108), the results revealed that genotypes, along with their components; parents, crosses, and the parent vs. cross (P vs. C) interaction showed highly significant differences for days to 50% silking. This reflects a high level of genetic variability among the tested materials. Furthermore, the significant mean squares observed for lines, testers, and line × tester interaction, indicate that both additive and non-additive genetic effects were important in the inheritance of this trait. The higher mean square values recorded for testers compared to lines suggest that testers had a stronger impact on the performance of the hybrids regarding days to 50% silking within this population. In population-3 (IW-326), the analysis of variance for days to 50% silking, showed highly significant differences among genotypes, including parents, hybrids (crosses), and the parent vs. cross (P vs. C) comparison. These results point to a wide genetic variation within this population for the studied trait. In addition, the mean squares for lines, testers, and their interaction (line × tester) were also highly significant, which means that both additive and non-additive genetic effects played important roles in controlling days to 50% silking. It was also clear that testers had higher mean square values than lines, indicating their greater influence on the performance of the hybrids in this population. In population-4 (IW-335), the results showed highly significant differences ($P \leq 0.01$) among genotypes, including parents, hybrids (crosses), and the parent vs. cross (P vs. C) comparison, which indicates the presence of considerable genetic variation for this trait. In addition, the mean squares for lines, testers, and the line × tester interaction were also highly significant. This means that both additive and non-additive genetic effects played an important role in inheritance of this trait. Moreover, testers had higher mean square values than lines, showing that testers had a greater impact on hybrid performance for days to 50% silking in the population 4. Similar trends were also recorded by Ali (2003), Matin *et al*. (2016), Abed and Hammadi (2018), Turkey Omnya *et al*. (2018), Aboyousef (2019), Tafa *et al*. (2020), Gad *et al*. (2021), Italia *et al*. (2022), Saeed Menna *et al*. (2022), and Lal *et al*. (2023), who emphasized the role of additive and non-additive gene actions in breeding for early flowering traits.

3.2 Mean performance of the populations

3.2.1 Days to 50% anthesis (DA, day)

Mean performance for days to 50% anthesis (DA) of 22 white maize parents including 20 inbred lines from each of the four studied populations and two testers; (Giza-2 (T1) and Single Cross-10 (T2) as well as their 40 top-cross hybrids per population and the commercial check Giza-2, is presented in Table (4). In population-1, the results showed that the mean number of days to 50% anthesis among the inbred lines ranged from 46.28 days (IL-14) to 53.32 days (IL-8), with an overall average of 50.11 days. For the two testers, the mean values were 49.71 days for the tester Giza-2(T1) and 55.70 days for the tester SC-10(T2), with an average of 52.71 days. Top-cross hybrids with the tester Giza-2(T1) ranged from 45.51 days (IL-17 × Giza-2(T1) to 49.67 days (IL-20 × Giza-2(T1), with an overall average of 47.40 days. On the other hand, top-cross hybrids with the tester SC-10 (T2) ranged from 49.06 days (IL-2 × SC-10(T2) to 52.51 days (IL-5 × SC-10 (T2), with an average of 50.38 days. These results indicate that the average number of days to 50% anthesis for the hybrids derived from the tester Giza-2(T1) was lower than that of the parents and the commercial check Giza-2, reflecting a negative heterotic effect for days to 50% anthesis in this population. Results showed that inbred line-2, inbred line-4 inbred line-7, inbred line-10, inbred line-13, inbred line-18 and the tester Giza-2 (T1) were the earliest genotypes in days to 50% anthesis, whereas inbred line-3, inbred line-5, inbred line-8, inbred line-9, inbred line-12, inbred line-15, inbred line-16, inbred line-17 and the tester SC-10 (T2) were the latest in days to 50% anthesis . Furthermore, the earliest top-cross hybrids involving the tester Giza-2 (T1) were IL-4 × Giza-2 (T1), IL-7 × Giza-2(T1), IL-10 × Giza-2 (T1), IL-17 × Giza-2(T1) and IL-18 × Giza-2 (T1). Conversely, the latest hybrids in anthesis were; IL-6 × Giza-2 (T1), IL-9 × Giza-2 (T1), IL-11 × Giza-2 (T1), IL-13 × Giza-2 (T1), IL-15 × Giza-2 (T1), IL-16 × Giza-2 (T1), IL-19 × Giza-2 (T1) and IL-20 × Giza-2 (T1). The earliest top-cross hybrids involving the tester SC-10 (T2) were IL-2 × SC-10(T2), IL-10 × SC-10(T2) and IL-19 × SC-10(T2). In contrast, the latest anthesis dates of top-cross hybrids were observed in IL-1 × SC-10 (T2), IL-5 × SC-10 (T2), IL-6 × SC-10 (T2), IL-11 × SC-10 (T2) and IL-20 × SC-10 (T2). In population-2, the results in Table (4), showed that the mean number of days to 50% anthesis among the inbred lines ranged from 48.75 days (IL-2) to 55.93 days (IL-1), with an overall average of 52.30 days. For the two testers, the mean values were 49.71 days for the tester Giza-2 (T1) and 55.70 days for the tester SC-10(T2), with an average of 52.71 days. Top-cross hybrids with the tester Giza-2 (T1) ranged from 46.17 days (IL-10 × Giza-2 (T1) to 51.11days (IL-8 × Giza-2 (T1), with an overall average of 49.17 days. On the other hand, top-cross hybrids with the tester SC-10 (T2) ranged from 49.78 days (IL-18 × SC-10 (T2) to 54.07 days (IL-3 × SC-10 (T2), with an average of 51.38 days. These results indicate that the average number of days to 50% anthesis for hybrids derived from both testers Giza-2 (T1) and SC-10 (T2) was lower than the mean of their respective parents (inbred lines and testers). Furthermore, the top-cross hybrids derived from tester Giza-2 (T1) recorded a lower mean than both the maternal inbred lines average and the commercial check Giza-2 itself, indicating a negative heterotic effect for days to 50% anthesis was detected in this population. Inbred line-2, inbred line-7, inbred line-8, inbred line-9, inbred line-10 inbred line-11, inbred line-12, inbred line-15, inbred line-17 and the tester Giza-2 (T1) were the earliest genotypes in days to 50% anthesis, whereas inbred line-1, inbred line-3, inbred line-4, inbred line-13, inbred line-14, inbred line-18, inbred line-19, inbred line-20 and the tester SC-10 (T2) were the latest. Furthermore, the earliest top-cross hybrids involving the tester Giza-2 (T1) were IL-2 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-10 × Giza-2 (T1), IL-16 × Giza-2 (T1), IL-17 × Giza-2 (T1), IL-18 × Giza-2 (T1) and IL-19 × Giza-2 (T1). Conversely, the latest hybrids in anthesis were; IL-1 × Giza-2 (T1), IL-3 × Giza-2 (T1), IL-4 × Giza-2 (T1), IL-5 × Giza-2 (T1), IL-8 × Giza-2 (T1), IL-9 × Giza-2 (T1), IL-11 × Giza-2 (T1), IL-13 × Giza-2 (T1), IL-14 × Giza-2 (T1) and IL-20 × Giza-2 (T1). The earliest top-cross hybrids involving SC-10 (T2) were IL-2 × SC-10 (T2), IL-7 × SC-10 (T2), IL-11 × SC-10 (T2), IL-12 × SC-10 (T2), IL-15 × SC-10 (T2), IL-18 × SC-10 (T2) and IL-19 × SC-10 (T2). In population-3, the results showed that the mean number of days to 50% anthesis among the inbred lines ranged from 50.25 days (IL-4) to 55.42 days (IL-19), with an overall average of 52.20 days. For the two testers, the mean values were 49.71 days for the tester Giza-2 (T1) and 55.70 days for the tester SC-10 (T2), with an average of 52.71 days. Top-cross hybrids with the tester Giza-2 (T1) ranged from 47.10 days (IL-11 × Giza-2 (T1) to 51.04 days (IL-17 × Giza-2 (T1), with an overall average of 48.85 days. On the other hand, top-cross hybrids with the tester SC-10 (T2) ranged from 46.79 days (IL-13 × SC-10 (T2) to 52.09 days (IL-17 × SC-10 (T2), with an average of 50.42 days. These results indicate that the average number of days to 50% anthesis for hybrids derived from both testers Giza-2 (T1) and SC-10 (T2) was lower than the mean of their respective parents (inbred lines and testers). Additionally, hybrids derived from tester Giza-2 (T1) recorded a lower mean than both the maternal inbred lines average and the commercial check Giza-2 itself, suggesting the involvement of dominance and non-additive gene action in the genetic control of this trait. Among all genotypes, the maternal inbred lines; IL-1, IL-2, IL-3, IL-4, IL-6, IL-9, IL-10, IL-11, IL-12 and Giza-2(T1) were the earliest in reaching to 50% anthesis, while IL-7, IL-13, IL-15, IL-16, IL-17, IL-18, IL-19 and SC-10 (T2) were the latest. The earliest top-cross hybrids involving the tester Giza-2(T1) were; IL-1 × Giza-2 (T1), IL-3 × Giza-2 (T1), IL-4 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-8 × Giza-2 (T1), IL-11 × Giza-2 (T1), IL-13 × Giza-2 (T1), IL-18 × Giza-2 (T1) and IL-20 × Giza-2 (T1). On the other hand, the latest hybrids involving the tester Giza-2 (T1) to reach 50% anthesis included; IL-2 × Giza-2 (T1), IL-5 × Giza-2 (T1), IL-10 × Giza-2 (T1), IL-14 × Giza-2 (T1), IL-15 × Giza-2 (T1), IL-17 × Giza-2 (T1) and IL-19 × Giza-2 (T1). The earliest top-cross hybrids involving the tester SC-10 (T2) were; IL-4 × SC-10 (T2), IL-8 × SC-10 (T2), IL-10 × SC-10 (T2), IL-12 × SC-10 (T2), IL-13 × SC-10 (T2), IL-15 × SC-10 (T2), IL-19 × SC-10 (T2) and IL-20 × SC-10 (T2). In contrast, the latest anthesis dates were observed in IL-5 × SC-10 (T2), IL-6 × SC-10 (T2), IL-7 × SC-10 (T2), IL-9 × SC-10 (T2), IL-11 × SC-10 (T2), IL-16 × SC-10 (T2), IL-17 × SC-10 (T2) and IL-18 × SC-10 (T2). In population- 4, the results in Table (4) showed that the mean number of days to 50% anthesis among the inbred lines ranged from 49.83 days (IL-2) to 55.32 days (IL-10), with an overall average of 52.46 days. For the two testers, the mean values were 49.71 days for the tester Giza-2 (T1) and 55.70 days for the tester SC-10 (T2), with an average of 52.71 days. Top-cross hybrids with the tester Giza-2 (T1) ranged from 47.51 days (IL-7 × Giza-2 (T1) to 51.44 days (IL-6 × Giza-2 (T1), with an overall average of 48.64 days. On the other hand, top-cross hybrids with the tester SC-10 (T2) ranged from 49.00 days (IL-2 × SC-10 (T2) to 53.35 days (IL-6 × SC-10 (T2), with an average of 50.92 days. These results indicate that the average number of days to 50% anthesis for the top-cross hybrids derived from both testers Giza-2 (T1) and SC-10 (T2) was lower than the mean of their respective parents (inbred lines and testers). Furthermore, hybrids derived from tester Giza-2 (T1) recorded a lower mean than both the maternal inbred lines average and the commercial check Giza-2, reflecting the influence of dominance and other non-additive gene actions. Among all genotypes, the inbred lines; IL-1, IL-2, IL-3, IL-8, IL-13, IL-14, IL-18, IL-19 and the tester Giza-2 (T1) were the earliest in reaching to 50% anthesis, while IL-5, IL-6, IL-7, IL-10, IL-11, IL-12, IL-15, IL-17 and the tester SC-10 (T2) were the latest. The earliest top-cross hybrids involving the tester Giza-2 (T1) were; IL-1 × Giza-2 (T1), IL-2 × Giza-2 (T1), IL-4 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-14 × Giza-2 (T1), IL-18 × Giza-2 (T1) and IL-19 × Giza-2 (T1). On the other hand, the latest hybrids involving the tester Giza-2 (T1) to reach 50% anthesis included; IL-6 × Giza-2 (T1), IL-10 × Giza-2 (T1), IL-13 × Giza-2 (T1), IL-15 × Giza-2 (T1), IL-16 × Giza-2 (T1), IL-17 × Giza-2 (T1) and IL-20 × Giza-2 (T1). The earliest top-cross hybrids involving the tester SC-10 (T2) were; IL-2 × SC-10 (T2), IL-3 × SC-10 (T2), IL-5 × SC-10 (T2), IL-10 × SC-10 (T2), IL-19 × SC-10 (T2) and IL-20 × SC-10 (T2). On the contrary, the latest anthesis dates were observed in IL-4 × SC-10 (T2), IL-6 × SC-10 (T2), IL-8 × SC-10 (T2), IL-9 × SC-10 (T2), IL-13 × SC-10 (T2), IL-16 × SC-10 (T2) and IL-17 × SC-10 (T2). The early flowering in some hybrids in our study matches the findings of Rehan and Kamara (2016), El-Refaey *et al*. (2018), Aboyousef (2019), Tafa *et al.* (2020), Fayyad and Hammadi (2021), Italia *et al*. (2022), Shaaban *et al.* (2022) and Lal *et al*. (2023).

3.2.2 Days to 50% silking (DS, day)

Mean performance for days to 50% silking (DS) of 22 white maize parents including 20 inbred lines from each of the four studied populations and two testers (Giza-2 (T1) and Single Cross-10 (T2) along with their 40 top-cross hybrids per population and the commercial check Giza-2 is presented in Table (4). In population-1, data on days to 50% silking showed that the mean number of days to 50% silking among the inbred lines ranged from 51.04 days (IL-14) to 58.75 days (IL-20), with an overall average of 55.08 days. For the two testers, the mean values were 53.43 days for the tester Giza-2 (T1) and 56.62 days for the tester SC-10 (T2), with an average of 55.02 days. Top-cross hybrids involving Giza-2 (T1) had silking dates ranging from 48.67 days (IL-7 × Giza-2 (T1) to 53.23 days (IL-20 × Giza-2 (T1), with an average of 50.92 days. In contrast, hybrids involving the tester SC-10 (T2) ranged from 50.53 days (IL-7 × SC-10 (T2) to 54.76 days (IL-6 × SC-10 (T2), with an average of 53.05 days. These results indicate that hybrids derived from both the tester Giza-2 (T1) and the tester SC-10 (T2) tended to silk earlier than both the parental lines and the commercial check Giza-2. A negative heterotic effect was observed for days to 50% silking trait in this population, suggesting that non-additive gene action, including dominance and possibly overdominance, plays a significant role in the inheritance of this trait. Among all genotypes, the maternal inbred lines; IL-1, IL-2, IL-3, IL-4, IL-7, IL-14, IL-18 and the tester Giza-2 (T1) were the earliest in reaching to 50% silking, while IL-5, IL-8, IL-9, IL-10, IL-13, IL-15, IL-19, IL-20 and the tester SC-10 (T2) were the latest. The earliest top-cross hybrids involving the tester Giza-2 (T1) were; IL-5 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-17 × Giza-2 (T1), and IL-18 × Giza-2 (T1). On the other hand, the latest hybrids involving the tester Giza-2 (T1) to reach 50% silking included; IL-15 × Giza-2 (T1), IL-16 × Giza-2 (T1) and IL-20 × Giza-2 (T1). The earliest top-cross hybrids involving the tester SC-10 (T2) were; IL-7 × SC-10 (T2), IL-8 × SC-10 (T2), IL-15 × SC-10 (T2), IL-16 × SC-10 (T2) and IL-19 × SC-10 (T2). In contrast, the latest silking dates were observed in IL-1 × SC-10 (T2), IL-5 × SC-10 (T2), IL-6 × SC-10 (T2) and IL-18 × SC-10 (T2). In population-2, the results in Table (4) showed that the mean number of days to 50% silking among the inbred lines ranged from 53.52 days (IL-2) to 61.63 days (IL-4), with an overall average of 57.01 days. For the two testers, the mean values were 53.43 days for the tester Giza-2 (T1) and 56.62 days for the tester SC-10 (T2), with an average of 55.02 days. Top-cross hybrids involving the tester Giza-2 (T1) had silking dates ranging from 50.33 days (IL-10 × Giza-2 (T1) to 56.81 days (IL-9 × Giza-2 (T1), with an average of 52.93 days. In contrast, hybrids involving the tester SC-10 (T2) ranged from 52.00 days (IL-7 × SC-10 (T2) to 57.83 days (IL-3 × SC-10 (T2), with an average of 65.39 days. These results indicate that the average number of days to 50% silking for hybrids derived from both testers Giza-2 (T1) and SC-10 (T2) was lower than the mean of their respective parents (inbred lines and testers).

Table (4): Mean performance of days to 50% anthesis and days to 50% silking in white maize involving 22 parents (20 inbred lines and 2 testers), 40 top-cross hybrids and a commercial check across four populations in 2023 season.

Inbred line	Population-1				Population-2				Population-3				Population-4			
	Anthesis		Silking		Anthesis		Silking		Anthesis		Silking		Anthesis		Silking	
	Giza -2 (T_1)	S C-10 (T_2)	Giza -2 (T_1)	S C-10 (T_2)	Giza -2 (T_1)	S C-10 (T_2)	Giza -2 (T_1)	S C-10 (T_2)	Giza -2 (T_1)	S C-10 (T_2)	Giza -2 (T_1)	C-10 (T_2)	Giza -2 (T_1)	S C-10 (T_2)	Giza -2 (T_1)	S C-10, (T_2)
Inbred-1	47.69	51.32	51.38	54.35	49.92	51.55	54.02	54.55	47.69	49.94	52.17	52.98	47.29	50.91	50.26	54.44
Inbred-2	47.03	49.06	50.75	53.46	48.00	50.03	51.75	54.17	49.84	50.48	50.21	53.76	46.33	49.00	51.04	51.92
Inbred-3	47.28	49.22	50.71	53.17	49.59	54.07	51.91	57.83	48.29	50.55	52.74	54.33	48.90	49.45	51.75	51.35
Inbred-4	45.54	49.90	51.30	52.96	50.17	51.14	53.88	53.00	46.25	49.13	50.49	51.35	47.71	51.96	50.05	54.42
Inbred-5	46.86	52.51	49.94	54.40	50.09	51.35	52.60	56.90	49.59	51.90	52.78	56.92	48.50	50.19	51.17	54.47
Inbred-6	48.72	51.95	51.21	54.76	49.38	52.42	51.94	55.08	48.85	51.90	52.16	54.04	51.44	53.35	53.94	56.17
Inbred-7	46.06	49.83	48.67	50.53	47.97	49.97	53.63	52.00	48.00	51.23	49.78	53.73	47.51	51.11	49.45	53.15
Inbred-8	47.26	50.40	51.27	51.45	51.11	51.47	54.87	55.72	48.20	49.66	51.64	52.75	48.62	51.65	51.31	54.38
Inbred-9	48.09	49.81	50.90	52.58	50.90	52.44	56.81	56.94	48.38	51.00	52.23	57.13	48.23	52.35	51.06	55.26
Inbred-10	45.65	49.33	51.02	53.29	46.17	52.25	50.33	55.13	50.56	49.85	52.62	52.66	49.44	50.08	52.04	53.83
Inbred-11	48.06	51.63	50.36	53.53	49.69	50.90	54.17	53.52	47.10	51.42	51.75	53.14	48.15	51.00	51.17	54.50
Inbred-12	47.67	50.36	51.39	53.25	49.22	50.17	52.07	53.17	49.15	49.85	53.92	52.77	48.29	51.25	53.42	54.00
Inbred-13	48.19	50.46	50.54	53.00	49.93	51.30	53.67	53.83	48.17	46.79	52.81	52.21	49.40	51.49	51.37	54.59
Inbred-14	47.00	49.80	50.75	52.74	50.52	52.35	54.46	55.73	50.45	50.89	52.60	53.87	46.50	50.95	49.78	55.43
Inbred-15	48.97	49.74	52.44	52.41	49.13	50.65	51.89	52.78	50.56	49.37	53.25	52.46	50.27	49.50	52.47	54.71
Inbred-16	48.58	50.53	52.94	52.21	48.08	51.93	51.33	54.30	49.31	51.60	51.98	56.26	50.90	52.35	53.68	54.82
Inbred-17	45.51	50.17	48.94	53.50	48.22	51.30	52.22	52.91	51.04	52.09	53.42	55.07	50.58	51.71	53.38	55.18
Inbred-18	45.88	50.82	50.00	54.00	48.83	49.78	51.53	52.83	48.24	51.00	52.65	54.52	46.52	51.27	50.73	53.76
Inbred-19	48.24	49.06	50.71	52.13	46.78	50.75	50.98	53.77	49.86	49.83	52.59	51.55	47.53	49.51	51.17	51.91
Inbred-20	49.67	51.66	53.25	53.31	49.79	51.81	54.62	53.56	47.50	49.83	51.92	52.69	50.67	49.30	52.92	52.02
Hybrids mean	47.40	50.38	50.92	53.05	49.17	51.38	52.93	54.39	48.85	50.42	52.18	53.71	48.64	50.92	51.61	54.01
Inbred-1	50.73		52.70		55.93		56.88		50.75		56.85		50.83		56.08	
Inbred-2	48.74		53.75		48.75		53.52		51.33		53.40		49.83		54.17	
Inbred-3	50.97		53.86		55.38		57.75		51.00		58.48		51.42		54.42	
Inbred-4	48.39		52.98		55.75		61.63		50.25		53.48		51.98		54.70	
Inbred-5	51.15		56.50		52.20		56.40		52.17		59.23		53.83		59.67	
Inbred-6	52.36		55.00		52.00		56.63		51.50		54.98		53.70		55.77	
Inbred-7	46.36		51.50		51.18		57.70		52.70		55.38		53.17		55.31	
Inbred-8	53.32		57.17		50.93		55.71		51.75		58.73		50.75		54.30	
Inbred-9	50.90		57.13		51.68		59.10		51.64		57.30		52.75		56.00	
Inbred-10	47.69		56.00		49.58		56.75		50.92		57.39		55.32		56.88	
Inbred-11	49.70		54.67		50.88		53.71		50.75		57.91		53.80		56.95	
Inbred-12	52.15		54.83		51.33		56.58		51.13		55.48		55.17		59.17	
Inbred-13	48.69		56.17		53.96		55.58		53.50		57.73		51.46		55.13	
Inbred-14	46.28		51.04		53.23		57.93		52.63		56.73		51.54		56.54	
Inbred-15	52.03		58.50		49.65		53.85		52.80		56.88		53.37		56.67	
Inbred-16	51.36		55.40		52.00		55.21		54.58		60.08		52.50		57.67	
Inbred-17	52.20		55.13		50.38		55.28		53.50		58.98		53.25		58.88	
Inbred-18	47.94		54.75		54.00		61.50		53.85		58.00		51.42		54.71	
Inbred-19	50.63		55.80		53.50		58.75		55.42		60.72		50.43		56.50	
Inbred-20	50.53		58.75		53.67		59.83		51.83		56.14		52.75		56.00	
Inbred lines mean	50.11		55.08		52.30		57.01		52.20		57.19		52.46		56.27	
Tester Giza -2 (T1)	49.71		53.43		49.71		53.43		49.71		53.43		49.71		53.43	
Tester S C-10 (T2)	55.70		56.62		55.70		56.62		55.70		56.62		55.70		56.62	
Testers mean	52.71		55.02		52.71		55.02		52.71		55.02		52.71		55.02	
Check (Giza -2)	49.71		53.43		49.71		53.43		49.71		53.43		49.71		53.43	
R. L.S.D 5%	0.76		0.63		0.39		0.75		0.49		0.58		0.52		0.78	

R.L.S.D 0.05%, to compare any genotype with the overall mean. T_1 = Tester 1, T_2 = Tester 2.

Furthermore, hybrids derived from the tester Giza-2 (T1) recorded a lower mean than both the maternal inbred lines average and the commercial check Giza-2. This indicates a strong negative heterotic effect for the silking trait in this population. Among all genotypes, the maternal inbred lines; IL-2, IL-8, IL-11, IL-13, IL-15, IL-16, IL-17 and the tester Giza-2 (T1) were the earliest in reaching to 50% silking, while IL-4, IL-9, IL-14, IL-18, IL-19, IL-20 and the tester SC-10 (T2) were the latest. The earliest top-cross hybrids involving the tester Giza-2 (T1) were; IL-2 × Giza-2 (T1), IL-3× Giza-2 (T1), IL-6 × Giza-2 (T1), IL-10 × Giza-2 (T1), IL-15 × Giza-2 (T1), IL-16 × Giza-2 (T1), IL-18 × Giza-2 (T1) and IL-19 ×

Giza-2 (T1). On the other hand, the latest hybrids involving the tester Giza-2 (T1) to reach 50% silking included; IL-1 × Giza-2 (T1), IL-4 × Giza-2 (T1), IL-8 × Giza-2 (T1), IL-9 × Giza-2 (T1), IL-11 × Giza-2 (T1) and IL-14 × Giza-2 (T1). The earliest top-cross hybrids involving the tester SC-10 (T2) were; IL-4 × SC-10 (T2), IL-7 × SC-10 (T2), IL-11 × SC-10 (T2), IL-12 × SC-10 (T2), IL-15 × SC-10 (T2), IL-17 × SC-10 (T2), IL-18 × SC-10 (T2) and IL-20 × SC-10 (T2). In contrast, the latest silking dates were observed in IL-3 × SC-10(T2), IL-5 × SC-10 (T2), IL-8 × SC-10 (T2), IL-9 × SC-10 (T2) and IL-14 × SC-10 (T2). In population-3, the results in Table (4) showed that the mean number of days to 50% silking among the inbred lines ranged from 53.40 days (IL-2) to 60.72 days (IL-19), with an overall average of 57.19 days. For the two testers, the mean values were 53.43 days for the tester Giza-2 (T1) and 56.62 days for the tester SC-10 (T2), with an average of 55.02 days. Top-cross hybrids involving the tester Giza-2 (T1) had silking dates ranging from 49.78 days (IL-7 × Giza-2 (T1) to 53.92 days (IL-12 × Giza-2 (T1), with an average of 52.18 days. In contrast, hybrids involving the tester SC-10 (T2) ranged from 51.35 days (IL-4 × SC-10 (T2) to 57.13 days (IL-9 × SC-10 (T2), with an average of 53.71 days. These results indicate that the average number of days to 50% silking for hybrids resulted from both testers Giza-2 (T1) and SC-10 (T2) was lower than the mean of their respective parents (inbred lines and testers). In addition, hybrids derived from tester Giza-2 (T1) recorded a lower mean than both the maternal inbred lines average and the commercial check Giza-2, indicating a desirable negative heterotic effect for the silking trait in this population. Among all genotypes, the inbred lines; IL-2, IL-4, IL-6, IL-7, IL-12, IL-20 and the tester Giza-2 (T1) were the earliest in reaching to 50% silking, while; IL-3, IL-5, IL-8, IL-11, IL-16, IL-17, IL-18, IL-19 and the tester SC-10 (T2) were the latest. The earliest top-cross hybrids involving the tester Giza-2 (T1) were; IL-2 × Giza-2 (T1), IL-4 × Giza-2 (T1) and IL-7 × Giza-2 (T1). On the other hand, the latest hybrids involving the tester Giza-2 (T1) to reach 50% silking included; IL-5 × Giza-2 (T1), IL-12 × Giza-2 (T1) IL-13 × Giza-2 (T1), IL-15 × Giza-2 (T1) and IL-17 × Giza-2 (T1). The earliest top-cross hybrids involving the tester SC-10 (T2) were; IL-1 × SC-10 (T2), IL-4 × SC-10 (T2), IL-8 × SC-10 (T2), IL-10 × SC-10 (T2), IL-12 × SC-10 (T2), IL-13 × SC-10 (T2), IL-15 × SC-10 (T2), IL-19 × SC-10 (T2) and IL-20 × SC-10 (T2). In contrast, the latest silking dates were observed in IL-3 × SC-10 (T2), IL-5 × SC-10 (T2), IL-9 × SC-10 (T2), IL-16 × SC-10 (T2), IL-17 × SC-10 (T2) and IL-18 × SC-10 (T2). In population-4, data on days to 50% silking for the twenty inbred lines, two testers, their forty top-cross hybrids, and the commercial check Giza-2 are presented in Table (4). The results showed that the mean number of days to 50% silking among the inbred lines ranged from 54.17 days (IL-2) to 59.67 days (IL-5), with an overall average of 56.27 days.

For the two testers, the mean values were 53.43 days for the tester Giza-2 (T1) and 56.62 days for the tester SC-10(T2), with an average of 55.02 days. Top-cross hybrids involving the tester Giza-2 (T1) had silking dates ranging from 49.45 days (IL-7 × Giza-2 (T1) to 53.94 days (IL-6 × Giza-2 (T1), with an average of 51.61 days. In contrast, hybrids involving the tester SC-10 (T2) ranged from 51.35 days (IL-3 × SC-10 (T2) to 56.17 days (IL-6 × SC-10 (T2), with an average of 54.01 days. These results indicate that the average number of days to 50% silking for hybrids derived from both testers Giza-2 (T1) and SC-10 (T2) was lower than the mean of their respective parents (inbred lines and testers). Moreover, hybrids developed from the tester Giza-2 (T1) recorded a lower mean than both the maternal inbred lines average and the commercial check Giza-2. A strong negative heterotic effect was observed for days to 50% silking trait in the population 4, suggesting that non-additive gene action, including dominance and possibly overdominance, plays a significant role in the inheritance of this trait. Among all genotypes, the inbred lines; IL-2, IL-3, IL-4, IL-7, IL-8, IL-13, IL-18 and the tester Giza-2 (T1) were the earliest in reaching to 50% silking, while IL-5, IL-12, IL-16, IL-17 and the tester SC-10 (T2) were the latest. The earliest top-cross hybrids involving the tester Giza-2 (T1) were; IL-1 × Giza-2 (T1) IL-4 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-14 × Giza-2 (T1) and IL-18 × Giza-2 (T1). On the other hand, the latest hybrids involving the tester Giza-2 (T1) to reach 50% silking included; IL-6 × Giza-2 (T1), IL-12 × Giza-2 (T1), IL-15 × Giza-2 (T1), IL-16 × Giza-2 (T1), IL-17 × Giza-2 (T1) and IL-20 × Giza-2 (T1). The earliest top-cross hybrids involving the tester SC-10 (T2) were IL-2 × SC-10 (T2), IL-3 × SC-10 (T2), IL-7 × SC-10 (T2), IL-19 × SC-10 (T2) and IL-20 × SC-10 (T2). On the other hand, the latest silking dates were observed in IL-6 × SC-10 (T2), IL-9 × SC-10 (T2), IL-14 × SC-10 (T2), IL-16 × SC-10 (T2) and IL-17 × SC-10 (T2). Similar results were reported by Ojo *et al*. (2007), Aboyousef (2019), Tafa *et al*. (2020), Italia *et al*. (2022), and Saeed Menna *et al*. (2022), regarding the importance of heterosis for early flowering trait.

3.3 Combining ability analysis

3.3.1 General combining ability effects

3.3.1.1 Days to 50% anthesis (DA, day)

In plant breeding programs, the presence of sufficient genetic variability is a fundamental requirement, because improving success depends on the identification of superior parents exhibiting additive gene effects. Genetically, general combining ability (GCA) is associated with additive gene action and it helps in selecting good parent lines. The estimates of general combining ability effects for the studied parents including (20 inbred lines and 2 testers) for days to 50% anthesis across all studied populations are presented in Table (5). Regarding earliness traits, negative and significant

GCA values are considered desirable in earliness breeding programs, as they indicate the ability of both lines and testers to reduce the time to flowering through additive genetic effects. In the first population (IW-86), general combining ability (GCA) effects for days to 50% anthesis ranged from –1.40 (highly significant negative, IL-10) to 1.77 (highly significant positive , IL-20), with a total of eight inbred lines; IL-2, IL-3, IL-4, IL-7, IL-10, IL-14, IL-17, and IL-18 which exhibited desirable negative and significant (P≤ 0.05 to P≤ 0.01) GCA effects. In general, the maternal inbred lines IL-2, IL-4, IL-7, IL-10, IL-13, IL-14, and IL-18 showed fewer days to 50% anthesis compared to both the average of all maternal inbred lines and the commercial check Giza-2, so these genotypes could be considered the best combiners for days to 50% Anthesis. Thus, such genotypes may possess favorable genes which be utilized in breeding programs designed to improve days to 50% anthesis trait. In the second population (IW-108), GCA effects varied from –1.52** for IL-19 to 1.56** for IL-3. Nine inbred lines; IL-2, IL-7, IL-10, IL-12, IL-15, IL-16, IL-17, IL-18, and IL-19 recorded significant (P≤ 0.05 to P≤ 0.01) negative GCA values. Generally, the maternal inbred line IL-2 was the only one that showed fewer days to 50% anthesis than both the average of all inbred lines and the commercial check Giza-2. Therefore, IL-2 can be considered the best combiner for reducing days to 50% anthesis. For the third population (IW-326), GCA effects ranged from –2.15** for IL-13 to 1.94** for IL-17, with six inbred lines; IL-1, IL-4, IL-8, IL-11, IL-13, and IL-20 showing desirable significant (P≤ 0.05 to P≤ 0.01) negative GCA estimates. These genotypes can be considered the best combiner for reducing days to 50% anthesis. In the fourth population (IW-335), GCA values varied from –2.11** for IL-2 to 2.61** for IL-6. Eight inbred lines; IL-1, IL-2, IL-3, IL-5, IL-7, IL-14, IL-18 and IL-19 exhibited significant (P≤ 0.05 to P≤ 0.01) and negative GCA effects. In this regard, the tester Giza-2 (T1) also recorded negative and highly significant (P ≤ 0.01) GCA effects. These inbred lines recorded the fewest days to 50% anthesis, suggesting they may carry favorable genes for early anthesis. Therefore, they could be considered good general combiners and are recommended for use in breeding programs for reducing days to 50% anthesis in this population. Conversely, the remaining inbred lines in each population, along with the tester SC-10 (T2), exhibited positive and significant (P ≤0.05 to P ≤ 0.01) GCA effects, indicating that these genotypes were the latest in anthesis. Our results confirm the observations of Ali (2003), Fan *et al.* (2007), Sofi (2007), Pavan (2011), Khan (2014), Chen (2015), Heakel Rania and Wafa (2017), Abed and Hammadi (2018), El-Shamarka *et al.* (2020), and Turk Ferial *et al.* (2020), who emphasized the importance of both GCA and SCA in breeding for earliness traits.

3.3.12 Days to 50% silking (DS, day)

The results of GCA estimates for 20 inbred lines and 2 testers of days to 50% silking for four populations are shown in Table (5). The results indicated that several inbred lines exhibited desirable and significant (P ≤ 0.05 to P ≤ 0.01) negative GCA effects. In the first population (IW-86), the general combining ability effects for days to 50% silking ranged from –2.93** for IL-7 to 1.29** for IL-20. Among the tested inbred lines, four inbred lines; IL-7, IL-8, IL-17, and IL-19 showed desirable and significant (P ≤ 0.05 to P ≤ 0.01) negative GCA values.

Table (5): General combining ability (GCA) effects for days to 50% anthesis and silking in white maize involving 22 parents (20 inbred lines and 2 testers) across four populations in 2023 season.

Inbred Line	Population-1		Population-2		Population-3		Population-4	
	Anthesis	Silking	Anthesis	Silking	Anthesis	Silking	Anthesis	Silking
IL-1	0.62**	0.88**	0.46**	0.62**	-0.82**	-0.38*	-0.68**	-0.46*
IL-2	-0.85**	0.12	-1.27**	-0.70**	0.53**	-0.96**	-2.11**	-1.33**
IL-3	-0.64**	-0.05	1.56**	1.21**	-0.22	0.59**	-0.60**	-1.26**
IL-4	-1.17**	0.14	0.38**	-0.22	-1.95**	-2.02**	0.05	-0.58**
IL-5	0.80**	0.18	0.44**	1.09**	1.11**	1.90**	-0.44**	0.00
IL-6	1.45**	0.99**	0.62**	-0.15	0.74**	0.15	2.61**	2.24**
IL-7	-0.94**	-2.39**	-1.31**	-0.85**	-0.02	-1.19**	-0.47**	-1.51**
IL-8	-0.06	-0.63**	1.01**	1.64**	-0.70**	-0.75**	0.36*	0.03
IL-9	0.06	-0.25	1.39**	3.22**	0.05	1.73**	0.51**	0.35
IL-10	-1.40**	0.17	-1.07**	-0.93**	0.57**	-0.31	-0.02	0.13
IL-11	0.96**	-0.04	0.02	0.18	-0.37**	-0.50**	-0.20	0.02
IL-12	0.13	0.33	-0.58**	-1.04**	-0.14	0.40	-0.01	0.90**
IL-13	0.44*	-0.22	0.34**	0.09	-2.15**	-0.44*	0.66**	0.17
IL-14	-0.49*	-0.24	1.16**	1.43**	1.04**	0.28	-1.05**	-0.21
IL-15	0.47*	0.44*	-0.39**	-1.33**	0.33*	-0.09	0.10	0.78**
IL-16	0.67**	0.59**	-0.27*	-0.84**	0.82**	1.17**	1.85**	1.44**
IL-17	-1.05**	-0.77**	-0.52**	-1.09**	1.94**	1.29**	1.37**	1.47**
IL-18	-0.54**	0.01	-0.97**	-1.48**	-0.01	0.64**	-0.88**	-0.57**
IL-19	-0.24	-0.56**	-1.52**	-1.28**	0.21	-0.88**	-1.25**	-1.27**
IL-20	1.77**	1.29**	0.52**	0.43*	-0.97**	-0.65**	0.20	-0.34
S.E (g_i) for Lines	0.22	0.18	0.11	0.21	0.14	0.17	0.15	0.22
S.E (g_i -g_j) for Lines	0.31	0.25	0.16	0.30	0.20	0.24	0.22	0.32
Testers								
Giza-2 (T1)	-1.49**	-1.06**	-1.10**	-0.73**	-0.78**	-0.76**	-1.14**	-1.20**
S C-10 (T2)	1.49**	1.06**	1.10**	0.73**	0.78**	0.76**	1.14**	1.20**
S.E (g_i) for Testers	0.07	0.06	0.04	0.07	0.05	0.05	0.05	0.07
S.E (g_i -g_j) for Testers	0.10	0.08	0.05	0.10	0.06	0.07	0.07	0.10

* and ** denote significant at 0.05 and 0.01% level of probability, respectively. T_1 = Tester 1, T_2 = Tester 2.

Overall, the maternal inbred lines IL-1, IL-7, and IL-14 showed earlier flowering than both the average of all inbred lines and the commercial check Giza-2, as presented in Table (5). These genotypes may be regarded as promising combiners for reducing days to 50% silking. In the second population (IW-108), the GCA effects ranged between –1.48** for IL-18 and 3.22** for IL-9. Nine inbred lines; IL-2, IL-7, IL-10, IL-12, IL-15, IL-16, IL-17, IL-18, and IL-19 demonstrated significant

(P ≤ 0.05 to P ≤ 0.01) negative GCA estimates. This suggests that they can be considered as good general combiners for reducing days to 50% silking. Consequently, these genotypes may carry favorable alleles that could be utilized in breeding programs to enhance earliness in silking trait. In the third population (IW-108), the GCA effects varied from –2.02** for IL-4 to 1.90** for IL-5, with nine inbred lines; IL-1, IL-2, IL-4, IL-7, IL-8, IL-11, IL-13, IL-19, and IL-20 showing negative and significant (P ≤ 0.05 to P ≤ 0.01) GCA values. So, these genotypes can be used as good general combiners. These genotypes appear to have good combining ability effects for reducing days to 50% silking in this population. In the fourth population (IW-108), the GCA estimates ranged from –1.51** (IL-7) to 2.24** (IL-6), with seven inbred lines; IL-1, IL-2, IL-3, IL-4, IL-7, IL-18, and IL-19 exhibiting significant (P ≤ 0.05 to P ≤ 0.01) negative GCA effects. Additionally, the tester Giza-2 (T1) showed negative and highly significant (P ≤ 0.01) GCA effects. These parental lines recorded the fewest days to 50% silking. Therefore, they could be classified as good general combiners and are recommended for use in breeding programs aimed at improving earliness to silking .Conversely, the remaining inbred lines in each population, along with the tester SC-10 (T2), exhibited positive and significant (P ≤ 0.05 to P ≤ 0.01) GCA effects, indicating that these genotypes tend to delay silking, making them less favorable for breeding programs focused on early flowering. Mohammad (2014), Matin *et al*. (2016) and Turkey Omnya *et al*. (2018), who found desirable negative and significant (P≤ 0.05 to P≤ 0.01) GCA effects, which agree with our study.

3.3.2 Specific combining ability effects

3.3.2.1 Days to 50% anthesis (DA, day)

Estimates of specific combining ability (SCA) effects for days to 50% anthesis among top-cross hybrids from the four populations are summarized in Table (6). The results highlighted several top crosses that showed desirable and significant (P ≤ 0.05 to P ≤ 0.01) SCA effects in days to 50% anthesis. For population-1 (IW-86), several top crosses involving the tester Giza-2(T1) showed favorable SCA effects for early anthesis, particularly; IL-4 × Giza-2 (T1), IL-5 × Giza-2 (T1), IL-17 × Giza-2 (T1) and IL-18 × Giza-2 (T1). Likewise, top crosses with the tester SC-10(T2) that exhibited significant and desirable SCA effects included; IL-9 × SC-10 (T2), IL-15 × SC-10 (T2) and IL-19 × SC-10 (T2). So, these top-cross hybrids could be considered the best cross combinations for days to 50% anthesis within this population. In population-2 (IW-108), the top-cross hybrids with the tester Giza-2 (T1) that recorded desirable SCA effects included; IL-3 × Giza-2 (T1), IL-10 × Giza-2 (T1), IL-16 × Giza-2 (T1) and IL-17 × Giza-2 (T1). While top crosses with the tester SC-10 (T2) that exhibited significant and desirable SCA effects were; IL-4 × SC-10 (T2), IL-8 × SC-10 (T2), IL-11 × SC-10 (T2), IL-12 × SC-10 (T2), IL-13 × SC-10 (T2) and IL-

18 × SC-10 (T2). Thus, these crosses can be considered the most effective cross combinations for reducing the number of days to 50% anthesis in this population.

Table (6): Estimates of specific combining ability (SCA) effects for days to 50% anthesis and days to 50% silking of 40 top-cross hybrids in four white maize populations in 2023 season.

Inbred Line	Population-1				Population-2				Population-3				Population-4			
	Anthesis		Silking		Anthesis		Silking		Anthesis		Silking		Anthesis		Silking	
	Giza -2 (T1)	S C-10 (T2)	Giza -2 (T1)	S C-10 (T2)	Giza –2 (T1)	Sc10 (T2)	Giza -2 (T1)	S C-10 (T2)	Giza -2 (T1)	S C-10 (T2)	Giza -2 (T1)	S C-10 (T2)	Giza -2 (T1)	S C-10 (T2)	Giza -2 (T1)	S C-10 (T2)
IL-1	-0.32	0.32	-0.42	0.42	0.29	-0.29	0.46	-0.46	-0.35	0.35	0.36	-0.36	-0.67**	0.67**	-0.89**	0.89**
IL-2	0.48	-0.48	-0.29	0.29	0.09	-0.09	-0.48	0.48	0.46*	-0.46*	-1.01**	1.01**	-0.19	0.19	0.77*	-0.77*
IL-3	0.52	-0.52	-0.16	0.16	-1.13**	1.13**	-2.23**	2.23**	-0.35	0.35	-0.03	0.03	0.87**	-0.87**	1.40**	-1.40**
IL-4	-0.69*	0.69*	0.24	-0.24	0.62*	-0.62*	1.16**	-1.16**	-0.66**	0.66**	0.33	-0.33	-0.98**	0.98**	-0.98**	0.98**
IL-5	-1.33**	1.33**	-1.16**	1.16**	0.47	-0.47	-1.43**	1.43**	-0.37	0.37	-1.31**	1.31**	0.30	-0.30	-0.45	0.45
IL-6	-0.13	0.13	-0.71**	0.71**	-0.41	0.41	-0.85**	0.85**	-0.74**	0.74**	-0.18	0.18	0.18	-0.18	0.09	-0.09
IL-7	-0.39	0.39	0.13	-0.13	0.10	-0.10	1.54**	-1.54**	-0.83**	0.83**	-1.21**	1.21**	-0.66**	0.66**	-0.65*	0.65*
IL-8	-0.08	0.08	0.98**	-0.98**	0.92**	-0.92**	0.30	-0.30	0.05	-0.05	0.21	-0.21	-0.38	0.38	-0.33	0.33
IL-9	0.63*	-0.63*	0.22	-0.22	0.33	-0.33	0.66*	-0.66*	-0.53**	0.53**	-1.69**	1.69**	-0.92**	0.92**	-0.90**	0.90**
IL-10	-0.35	0.35	-0.07	0.07	-1.94**	1.94**	-1.67**	1.67**	1.14**	-1.14**	0.74**	-0.74**	0.82**	-0.82**	0.31	-0.31
IL-11	-0.30	0.30	-0.52*	0.52*	0.50**	-0.50**	1.05**	-1.05**	-1.38**	1.38**	0.07	-0.07	-0.28	0.28	-0.46	0.46
IL-12	0.14	-0.14	0.14	-0.14	0.63**	-0.63**	0.18	-0.18	0.43*	-0.43*	1.34**	-1.34**	-0.34	0.34	0.91**	-0.91**
IL-13	0.36	-0.36	-0.16	0.16	0.42*	-0.42*	0.65*	-0.65*	1.47**	-1.47**	1.06**	-1.06**	0.10	-0.10	-0.41	0.41
IL-14	0.09	-0.09	0.07	-0.07	0.19	-0.19	0.09	-0.09	0.56**	-0.56**	0.13	-0.13	-1.08**	1.08**	-1.62**	1.62**
IL-15	1.10 **	-1.10**	1.08**	-1.08**	0.34	-0.34	0.28	-0.28	1.38**	-1.38**	1.16**	-1.16**	1.52**	-1.52**	0.08	-0.08
IL-16	0.52	-0.52	1.43**	-1.43**	-0.82**	0.82**	-0.76*	0.76*	-0.36	0.36	-1.38**	1.38**	0.41	-0.41	0.63*	-0.63*
IL-17	-0.84**	0.84**	-1.22**	1.22**	-0.44**	0.44**	0.38	-0.38	0.26	-0.26	-0.06	0.06	0.57**	-0.57**	0.30	-0.30
IL-18	-0.98**	0.98**	-0.94**	0.94**	0.63**	-0.63**	0.07	-0.07	-0.60**	0.60**	-0.17	0.17	-1.23**	1.23**	-0.31	0.31
IL-19	1.08**	-1.08**	0.36	-0.36	-0.88	0.88	-0.67*	0.67*	0.79**	-0.79**	1.28**	-1.28**	0.15	-0.15	0.83**	-0.83**
IL-20	0.50	-0.50	1.03**	-1.03**	0.09	-0.09	1.25**	-1.25**	-0.38	0.38	0.38	-0.38	1.82**	-1.82**	1.65**	-1.65**
S.E (sij_i)	0.31		0.25		0.16		0.30		0.20		0.24		0.22		0.32	
S.E (sij_i - sij_k)	0.44		0.36		0.23		0.43		0.28		0.33		0.30		0.45	

* and ** denote significant at 0.05 and 0.01% level of probability, respectively. T_1 = Tester 1, T_2= Tester 2.

Concerning population-3 (IW-326), top crosses involving the tester Giza-2 (T1) with significant ($P \leq 0.05$ to $P \leq 0.01$) and negative SCA effects for Anthesis were; IL-4 × Giza-2 (T1), IL-6 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-9 × Giza-2 (T1), IL-11 × Giza-2 (T1) and IL-18 × Giza-2 (T1). As for the tester SC-10 (T2), the top-crosses were; IL-2 × SC-10, IL-10 × SC-10, IL-12 × SC-10 (T2), IL-13 × SC-10 (T2), IL-14 × SC-10 (T2), IL-15 × SC-10 (T2) and IL-19 × SC-10 (T2). Therefore, these crosses appear to be effective cross combinations for reducing days to 50% anthesis in this population. In population-4 (IW-335), the top-cross hybrids involving the testers Giza-2 (T1) exhibited highly significant SCA effects ($P \leq 0.05$ to $P \leq 0.01$) and recorded fewer days to Anthesis compared to the average of their parents and the commercial check Giza-2, were; IL-1 × Giza-2 (T1), IL-4 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-9 × Giza-2 (T1), IL-14 × Giza-2 (T1) and IL-18 × Giza-2 (T1). Top-crosses hybrids with the tester SC-10 (T2) showing desirable SCA effects were; IL-3 × SC-10 (T2), IL-10 × SC-10 (T2), IL-15 × SC-10 (T2), IL-17 × SC-10 (T2) and IL-20 × SC-10 (T2). This clear reduction in number of days 50% anthesis in this population reflects strong non-additive genetic effects. These superior hybrids consistently outperformed the check variety in earliness, which makes them useful for earliness breeding programs. These results support the conclusions of Rehana *et al*. (2015), Rehan and Kamara (2016), Heakel Rania and Wafaa (2017), El-Refaey *et al*. (2018), Fayyad and Hammadi (2021), Asif *et al*. (2022), Italia *et al*. (2022), and Shaaban *et al*. (2022), who stated that SCA effects play a significant role in the inheritance of earliness traits.

3.3.2.2 Days to 50% silking (DS, day)

Estimates of specific combining ability effects for top-cross hybrids of days to 50% silking in the four populations are presented in Table (6). The estimates of specific combining ability (SCA) effects for days to 50% silking across the four white maize populations revealed several promising top-cross hybrids that showed desirable and significant ($P \leq 0.05$ to $P \leq 0.01$) negative effects for early flowering. These hybrids are considered valuable for maize improvement programs focused on earliness traits. Regarding population-1 (IW-86), the top-cross hybrids with the tester Giza-2 (T1) that showed favorable SCA effects for earliness to silking included; IL-5 × Giza-2 (T1), IL-6 × Giza-2 (T1), IL-11 × Giza-2 (T1), IL-17 × Giza-2 (T1) and IL-18 × Giza-2 (T1). Hybrids involving the tester SC-10 (T2) with desirable SCA effects were; IL-8 × SC-10 (T2), IL-15 × SC-10 (T2), IL-16 × SC-10 (T2) and IL-20 × SC-10 (T2). Accordingly, these crosses could be considered favorable cross combinations for achieving earlier silking in this population. For population-2 (IW-108), the top-cross hybrids with the tester Giza-2 (T1) that showed favorable SCA effects for earliness to silking were; IL-3 × Giza-2 (T1) , IL-5 × Giza-2 (T1) , IL-6 × Giza-2 (T1) , IL-10 × Giza-2 (T1) , IL-16 × Giza-2 (T1) and IL-19 × Giza-2 (T1) . For the tester SC-10 (T2), favorable crosses were; IL-4 × SC-10 (T2), IL-7 × SC-10 (T2), IL-9 × SC-10 (T2), IL-11 × SC-10 (T2), IL-13 × SC-10 (T2) and IL-20 × SC-10 (T2). Thus, these crosses could be considered as potentially promising cross combinations for reducing days to 50% silking in this population. In population-3 (IW-326), some top crosses with the tester Giza-2 (T1) showing desirable SCA values were; IL-2 × Giza-2 (T1), IL-5 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-9 × Giza-2 (T1) and IL-16 × Giza-2 (T1). For the tester SC-10 (T2), the best hybrids which showed favorable SCA effects for earliness to silking included; IL-10 × SC-10 (T2), IL-12 × SC-10 (T2), IL-13 × SC-10 (T2), IL-15 × SC-10 (T2), IL-19 × SC-10 (T2). Thus, these crosses may be among the promising cross combinations for reducing the number of days to 50% silking within this population. For population-4 (IW-335), five top-crosses with the tester Giza-2(T1) that recorded significant ($P \leq 0.05$ to $P \leq 0.01$) and desirable SCA effects were; IL-1 × Giza-2 (T1), IL-4 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-9 × Giza-2 (T1) and IL-14 × Giza-2 (T1). For the tester SC-10 (T2), the effective hybrids were; IL-2 × SC-10 (T2), IL-3 × SC-10 (T2), IL-12 × SC-10 (T2), IL-16 × SC-10 (T2), IL-19 × SC-10 (T2) and IL-20 × SC-10 (T2). These hybrids flowered earlier than both their parent averages and the commercial check Giza-2, as shown in Table (6). This early flowering is a result of strong non-additive genetic effects. These hybrids are valuable for breeding new maize varieties for this population. Similar results were reported by Mosa *et al*. (2008), Pavan (2011), Ali (2013), Mohammad (2014), Heakel Rania and Wafa (2017), Abed and Hammadi (2018), El-Shamarka *et al*. (2020), Turk Ferial *et al*. (2020), Tafa *et al*. (2020), and Lal *et al*. (2023), who stated that non-additive gene action plays a significant role in the inheritance of traits such as silking date in maize.

3.4 Heterosis estimates

3.4.1 Days to 50% anthesis (DA, day)

Heterosis, or hybrid vigor, is the opposite of the deterioration caused by inbreeding. It refers to the improved performance of hybrids compared to their parents. Concerning earliness traits, negative heterosis is preferred because early-flowering genotypes are desirable. The estimates of heterobeltiosis (heterosis over the better parent) and mid-parent heterosis for days to 50% anthesis in 40 top-cross hybrids across four populations are presented in Table (7). In population-1, most hybrids recorded significantly negative heterosis compared to both the better parent (BP) and the mid-parents (MP), indicating that these hybrids flowered earlier than their parents. In population 1, the amount of heterosis observed over the better parent (BP) and mid-parent (MP) when using the tester Giza-2(T1) was represented by 17 and 20 top-cross hybrids, respectively, showing significantly negative F1 heterosis for days to 50% anthesis. The highest negative and significant ($P \leq 0.01$) heterotic effects for Anthesis with the tester Giza-2 (T1) were recorded in the hybrids; IL-17 × Giza-2 (T1) (-8.47**, -10.70**), IL-4 × Giza-2 (T1) (-5.89**, -7.17**), and IL-5 × Giza-2 (T1) (-5.74**, -7.09**) over BP and MP, respectively. Similarly, when using the tester SC-10 (T2), 9 and 20 top-cross hybrids showed significantly negative heterosis over BP and MP, respectively. The hybrids with the most negative values were; IL-8 × SC-10 (T2) (-5.47**, -7.54**) and IL-15 × SC-10 (T2) (-4.40**, -7.65**) over BP and MP, respectively. These three hybrids involving the tester Giza-2 (T1) and the two hybrids involving the tester SC-10 (T2) exhibited strong heterotic effects and appear promising for improving days to 50% anthesis in maize in this population. These results suggest that they have good heterotic effects for developing early-flowering maize in the studied population. In population-2, when using the tester Giza-2 (T1), 10 hybrids showed significantly negative heterosis over the better parent, and 18 over the mid-parent for days to 50% Anthesis. The most early-flowering hybrids were; IL-10 × Giza-2 (T1), which recorded -6.89** and -7.01**%, and IL-19 × Giza-2 (T1), with -5.91** and -9.36** over BP and MP, respectively. Similarly, when using the tester SC-10 (T2), 11 hybrids showed significantly negative heterosis over the better parent and 20 over the mid-parent. The hybrids with the strongest early anthesis were; IL-4 × SC-10 (T2) (-8.19**, -8.23**), IL-1 × SC-10 (T2) (-7.45**, -7.64**), and IL-18 × SC-10 (T2) (-7.82**, -9.25**) over BP and MP, respectively. These two hybrids with the tester Giza-2 (T1) and three with the tester SC-10 (T2) showed strong hybrid vigor and are promising for developing days to 50% anthesis in this studied population. In population-3, the degree of heterosis observed over the better parent (BP) and mid-parent (MP) using the tester Giza-2(T1) revealed that 13 hybrids showed significantly negative heterosis over the better parent, and 19 over the mid-parent for days to 50% anthesis. The highest negative and significant (P≤ 0.01) heterotic effects for Anthesis with the tester Giza-2 (T1) were recorded by the hybrids; IL-4 × Giza-2 (T1) (-6.79**, -7.47**) and IL-11 × Giza-2 (T1) (-5.26**, -6.24**%) over BP and MP, respectively. Using the tester SC-10 (T2), 18 hybrids showed significantly negative heterosis over the better parent, and 20 over the mid-parent. The most negative heterosis values were observed in IL-13 × SC-10 (T2) (-12.54**, -14.30**), IL-19 × SC-10 (T2) (-10.08**, -10.31**), IL-15 × SC-10 (T2) (-6.50**, -9.01**), IL-16 × SC-10 (T2) (-5.45**, -6.42**) and IL-18 × SC-10 (T2) (-5.29**, -6.89**) for BP and MP, respectively. Therefore, the two hybrids with the tester Giza-2 (T1) and the five hybrids with the tester SC-10 (T2) demonstrated strong negative heterosis and suggest that they could be useful in developing the days to 50% anthesis trait in this population. In population-4, several hybrids exhibited notable heterosis for earliness in anthesis when crossed with the tester Giza-2 (T1). Specifically, 15 hybrids showed significantly negative heterosis over the better parent and 18 over the mid-parent for days to 50% anthesis. The most significant negative heterotic effects were observed in IL-2 × Giza-2 (T1) (-6.80**, -6.91**), IL-14 × Giza-2 (T1) (-6.47**, -8.15**), and IL-18 × Giza-2 (T1) (-6.42**, -8.00**), showing their effectiveness in breeding programs targeting early flowering traits in this population. Similarly, with the tester SC-10 (T2), 14 hybrids exhibited significantly negative heterosis over the better parent and 20 over the mid-parent. The strongest negative heterotic values were recorded in IL-10 × SC-10 (T2) (-9.47**, -9.78**), IL-15 × SC-10 (T2) (-7.25**, -9.23**), IL-20 × SC-10 (T2) (-6.54**, -9.08**), IL-5 × SC-10 (T2) (-6.77**, -8.36**), IL-12 × SC-10 (T2) (-7.10**, -7.55**), and IL-11 × SC-10 (T2) (-5.20**, -6.85**). Overall, the three hybrids with the tester Giza-2 (T1) and the six with SC-10 (T2) displayed strong negative heterotic effects, making them promising for breeding early-flowering maize cultivars in this population. Overall, in the studied populations, several top-cross hybrids exhibited maximum negative F1 heterosis for days to 50% anthesis Table (7). This result is confirmed by negative favorable highly significant SCA effects of these top-cross hybrids, Table (6). In population-1, the promising hybrids included IL-4 × Giza-2 (T1), IL-5 × Giza-2 (T1), and IL-17 × Giza-2 (T1). In population 2, the best hybrids were IL-10 × Giza-2 (T1), IL-4 × SC-10 (T2), and IL-18 × SC-10 (T2). For population 3, IL-4 × Giza-2 (T1), IL-11 × Giza-2 (T1), IL-13 × SC-10 (T2), IL-15 × SC-10 (T2), and IL-19 × SC-10 (T2) showed desirable performance. Similarly, in population 4, the top hybrids were IL-14 × Giza-2 (T1), IL-18 × Giza-2 (T1), IL-10 × SC-10 (T2), IL-15 × SC-10 (T2), and IL-20 × SC-10 (T2). Therefore, these hybrids can be used in breeding programs for improving days to 50% Anthesis within these populations.

Table (7): Estimates of heterosis (%) over the better parent (B.P) and mid-parent (M.P) for days to 50% anthesis and silking in 40 top-cross hybrids across four white maize populations in 2023 season.

Inbred Line	Population-1								Population-2							
	Anthesis				Silking				Anthesis				Silking			
	Giza -2 (T1)		S C-10 (T2)		Giza -2 (T1)		S C-10 (T2)		Giza -2 (T1)		S C-10 (T2)		Giza -2 (T1)		S C-10 (T2)	
	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %
IL-1	-4.06**	-5.03**	1.17**	-3.56**	-2.51**	-3.18**	3.14**	-0.56	0.41	-5.50**	-7.45**	-7.64**	1.10**	-2.06**	-3.65**	-3.87**
IL-2	-3.51**	-4.47**	0.66	-6.06**	-5.01**	-5.30**	-0.53	-3.12**	-1.55**	-2.51**	2.62**	-4.21**	-3.14**	-3.22**	1.22**	-1.63**
IL-3	-4.90**	-6.08**	-3.43**	-7.72**	-5.09**	-5.47**	-1.28**	-3.75**	-0.24	-5.61**	-2.35**	-2.64**	-2.84**	-6.61**	2.14**	1.13**
IL-4	-5.89**	-7.17**	3.14**	-4.11**	-3.16**	-3.58**	-0.03	-3.36**	0.91**	-4.87**	-8.19**	-8.23**	0.84*	-6.35**	-6.39**	-10.35**
IL-5	-5.74**	-7.09**	2.65**	-1.72**	-6.53**	-9.14**	-3.72**	-3.83**	0.75**	-1.71**	-1.63**	-4.82**	-1.56**	-4.22**	0.89*	0.69
IL-6	-2.01**	-4.55**	-0.78*	-3.85**	-4.16**	-5.55**	-0.44	-1.88**	-0.67**	-2.90**	0.80**	-2.66**	-2.79**	-5.61**	-2.71**	-2.72**
IL-7	-0.64	-4.11**	7.48**	-2.36**	-5.50**	-7.24**	-1.88**	-6.52**	-3.50**	-4.91**	-2.37**	-6.50**	0.37	-3.49**	-8.16**	-9.03**
IL-8	-4.94**	-8.27**	-5.47**	-7.54**	-4.04**	-7.28**	-9.13**	-9.57**	2.81**	1.57**	1.07**	-3.46**	2.69**	0.54	0.01	-0.79*
IL-9	-3.27**	-4.41**	-2.16**	-6.56**	-4.74**	-7.93**	-7.13**	-7.54**	2.38**	0.40*	1.48**	-2.33**	6.33**	0.97*	0.56	-1.59**
IL-10	-4.30**	-6.28**	3.43**	-4.58**	-4.50**	-6.74**	-4.85**	-5.37**	-6.89**	-7.01**	5.38**	-0.75**	-5.79**	-8.63**	-2.64**	-2.75**
IL-11	-3.30**	-3.32**	3.89**	-2.03**	-5.75**	-6.83**	-2.07**	-3.79**	-0.04	-1.19**	0.05	-4.48**	1.38**	1.12**	-0.36	-2.99**
IL-12	-4.11**	-6.41**	-3.44**	-6.61**	-3.81**	-5.06**	-2.89**	-4.44**	-0.99**	-2.58**	-2.27**	-6.26**	-2.55**	-5.34**	-6.04**	-6.07**
IL-13	-1.03**	-2.05**	3.62**	-3.34**	-5.40**	-7.77**	-5.64**	-6.02**	0.44*	-3.67**	-4.93**	-6.44**	0.46	-1.53**	-3.16**	-4.05**
IL-14	1.57**	-2.07**	7.61**	-2.33**	-0.57	-2.84**	3.33**	-2.02**	1.62**	-1.85**	-1.65**	-3.88**	1.93**	-2.19**	-1.57**	-2.70**
IL-15	-1.51**	-3.75**	-4.40**	-7.65**	-1.85**	-6.30**	-7.43**	-8.94**	-1.06**	-1.12**	2.01**	-3.85**	-2.88**	-3.26**	-2.00**	-4.45**
IL-16	-2.29**	-3.88**	-1.62**	-5.61**	-0.92**	-2.71**	-5.75**	-6.78**	-3.28**	-5.45**	-0.13	-3.56**	-3.92**	-5.50**	-1.65**	-2.89**
IL-17	-8.47**	-10.70**	-3.88**	-7.00**	-8.41**	-9.84**	-2.95**	-4.25**	-3.00**	-3.64**	1.84**	-3.28**	-2.26**	-3.92**	-4.28**	-5.43**
IL-18	-4.31**	-6.05**	5.99**	-1.95**	-6.42**	-7.56**	-1.37**	-3.03**	-1.77**	-5.83**	-7.82**	-9.25**	-3.56**	-10.33**	-6.69**	-10.54**
IL-19	-2.96**	-3.85**	-3.11**	-7.73**	-5.08**	-7.14**	-6.58**	-7.26**	-5.91**	-9.36**	-5.14**	-7.05**	-4.59**	-9.12**	-5.03**	-6.78**
IL-20	-0.09	-0.91*	2.23**	-2.75**	-0.33	-5.06**	-5.84**	-7.58**	0.14	-3.68**	-3.45**	-5.25**	2.22**	-3.56**	-5.40**	-8.01**
R. L.S.D 0.05%	0.76				0.62				0.39				0.74			

Inbred Line	Population-3								Population-4							
	Anthesis				Silking				Anthesis				Silking			
	Giza -2 (T1)		S C-10 (T2)		Giza -2 (T1)		S C-10 (T2)		Giza -2 (T1)		S C-10 (T2)		Giza -2 (T1)		S C-10 (T2)	
	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %	H (B.P.) %	H (M.P.) %
IL-1	-4.08**	-5.07**	-1.59**	-6.17**	-2.36**	-5.39**	-6.43**	-6.62**	-4.89**	-5.94**	0.15	-4.42**	-5.94**	-8.22**	-2.92**	-3.38**
IL-2	0.25	-1.35**	-1.64**	-5.66**	-5.98**	-6.01**	0.68*	-2.27**	-6.80**	-6.91**	-1.67**	-7.14**	-4.46**	-5.12**	-4.15**	-6.28**
IL-3	-2.87**	-4.11**	-0.89**	-5.25**	-1.29**	-5.74**	-4.03**	-5.58**	-1.64**	-3.29**	-3.82**	-7.67**	-3.14**	-4.03**	-5.64**	-7.51**
IL-4	-6.97**	-7.47**	-2.24**	-7.27**	-5.49**	-5.54**	-3.97**	-6.71**	-4.03**	-6.18**	-0.05	-3.50**	-6.32**	-7.42**	-0.52	-2.23**
IL-5	-0.26	-2.66**	-0.51*	-3.77**	-1.22**	-6.30**	0.53	-1.73**	-2.44**	-6.32**	-6.77**	-8.36**	-4.23**	-9.52**	-3.80**	-6.33**
IL-6	-1.74**	-3.48**	0.78**	-3.17**	-2.38**	-3.77**	-1.70**	-3.14**	3.47**	-0.52	-0.65*	-2.47**	0.95*	-1.21**	0.72	-0.05
IL-7	-3.45**	-6.26**	-2.80**	-5.49**	-6.83**	-8.50**	-2.98**	-4.05**	-4.43**	-7.63**	-3.87**	-6.11**	-7.45**	-9.05**	-3.90**	-5.03**
IL-8	-3.05**	-4.99**	-4.03**	-7.56**	-3.35**	-7.91**	-6.83**	-8.53**	-2.20**	-3.21**	1.77**	-2.96**	-3.97**	-4.74**	0.14	-1.96**
IL-9	-2.69**	-4.55**	-1.24**	-4.98**	-2.25**	-5.66**	0.91**	0.30	-3.00**	-5.87**	-0.77**	-3.47**	-4.43**	-6.67**	-1.32**	-1.86**
IL-10	1.70**	0.49*	-2.09**	-6.49**	-1.52**	-5.04**	-6.99**	-7.62**	-0.56*	-5.87**	-9.47**	-9.78**	-2.60**	-5.64**	-4.92**	-5.13**
IL-11	-5.26**	-6.24**	1.31**	-3.40**	-3.13**	-7.04**	-6.14**	-7.20**	-3.14**	-6.97**	-5.20**	-6.85**	-4.23**	-7.28**	-3.74**	-4.02**
IL-12	-1.14**	-2.53**	-2.50**	-6.68**	0.92**	-0.97**	-4.87**	-5.84**	-2.86**	-7.91**	-7.10**	-7.55**	-0.02	-5.12**	-4.63**	-6.72**
IL-13	-3.11**	-6.67**	-12.54**	-14.30**	-1.15**	-4.98**	-7.79**	-8.68**	-0.63*	-2.35**	0.06	-3.91**	-3.86**	-5.36**	-0.98*	-2.30**
IL-14	1.48**	-1.41**	-3.30**	-6.05**	-1.56**	-4.51**	-4.86**	-4.95**	-6.47**	-8.15**	-1.14**	-4.98**	-6.84**	-9.47**	-1.96**	-2.04**
IL-15	1.71**	-1.36**	-6.50**	-9.01**	-0.33	-3.44**	-7.35**	-7.56**	1.11**	-2.47**	-7.25**	-9.23**	-1.80**	-4.69**	-3.36**	-3.40**
IL-16	-0.81**	-5.43**	-5.45**	-6.42**	-2.71**	-8.41**	-0.63*	-3.58**	2.39**	-0.41	-0.28	-3.23**	0.48	-3.36**	-3.17**	-4.06**
IL-17	2.67**	-1.10**	-2.63**	-4.59**	-0.02	-4.96**	-2.74**	-4.73**	1.75**	-1.75**	-2.88**	-5.07**	-0.10	-4.95**	-2.54**	-4.44**
IL-18	-2.96**	-6.83**	-5.29**	-6.89**	-1.46**	-5.50**	-3.71**	-4.87**	-6.42**	-8.00**	-0.29	-4.28**	-5.04**	-6.17**	-1.74**	-3.43**
IL-19	0.29	-5.15**	-10.08**	-10.31**	-1.58**	-7.87**	-8.95**	-12.14**	-4.38**	-5.07**	-1.82**	-6.70**	-4.22**	-6.90**	-8.12**	-8.21**
IL-20	-4.45**	-6.45**	-3.86**	-7.32**	-2.83**	-5.24**	-6.16**	-6.55**	1.92**	-1.10**	-6.54**	-9.08**	-0.96*	-3.29**	-7.11**	-7.62**
R. L.S.D 0.05%	0.49				0.57				0.52				0.77			

* and **denote significant at 0.05 and 0.01% level of probability, respectively. R.L.S.D 0.05%, to compare any genotype with the overall me.

Similar results were reported by Ali (2003), Fan *et al*. (2007), Ojo *et al*. (2007), Pavan (2011), Mohammad (2014), Abo El-Haress (2015), Chen (2015), Matin *et al*. (2016), Rehan and Kamara (2016), and Turkey Omnya *et al*. (2018), who reported the importance of both heterosis and specific combining ability in improving earliness traits.

3.4.2 Days to 50% silking (DS, day)

Estimates of heterobeltiosis and mid-parent heterosis for days to 50% silking in 40 top-cross hybrids across four populations are shown in Table (7). Most hybrids exhibited significant negative heterosis over both the better parent and mid-parent, indicating their effectiveness in reducing silking time and improving earliness traits for the studied populations. In population-1, the levels of heterosis over the better parent (BP) and the mid-parent (MP) when using the tester Giza-2 (T1) were; 18 hybrids showed significantly negative heterosis over the better parent, and 20 over the mid-parent for days to 50% silking. The highest negative heterotic effects for days to silking when using the tester Giza-2(T1) as a tester were recorded in the nine following hybrids; IL-17 × Giza-2 (T1) (-8.41**, -9.84**), IL-2 × Giza-2 (T1) (-5.01**, -5.30**), IL-3 × Giza-2 (T1) (-5.09**, -5.47**), IL-5 × Giza-2 (T1) (-6.53**, -9.14**), IL-7 × Giza-2 (T1) (-5.50**, -7.25**), IL-11 × Giza-2 (T1) (-5.75**, -6.83**), IL-13 × Giza-2 (T1) (-5.40**, -7.70**), IL-18 × Giza-2 (T1) (-6.42**, -7.56**), and IL-19 × Giza-2 (T1) (-5.08**, -7.14**) over both better parent (BP) and mid parent (MP), respectively. Similarly, using the tester SC-10 (T2), 9 and 20 hybrids showed significantly negative heterosis over BP and MP, respectively. The highest negative and significant (P≤ 0.01) heterotic effects for silking with the tester SC-10 (T2) were observed in hybrids such as; IL-8 × SC-10 (T2) (-9.13**, -9.57**), IL-9 × SC-10 (T2) (-7.13**, -7.54**), IL-13 × SC-10 (T2) (-5.64**, -6.02**), IL-15 × SC-10 (T2) (-7.43**, -8.94**), IL-16 × SC-10 (T2) (-5.75**, -6.78**), IL-19 × SC-10 (T2) (-6.58**, -7.26**) and IL-20 × SC-10 (T2) (-5.84**, -7.58**). Thus, the nine hybrids with the tester Giza-2(T1) and the seven hybrids with the tester SC-10 (T2) exhibited strong negative heterotic effects, making them promise for improving earliness in days to 50% silking in this population. In population-2, the extent of heterosis shown by the hybrids when crossed with the tester Giza-2 (T1) were; 11 hybrids showed significantly negative heterosis over the better parent, and 17 over the mid-parent for days to 50% silking. The highest negative and significant (P≤ 0.01) heterotic effects for early silking with the tester Giza-2 (T1) were observed in the hybrids; IL-10 × Giza-2 (T1) (-5.79**, -8.63**) and IL-19 × Giza-2 (T1) (-4.59**, -9.12**) over the better parent (BP) and mid-parent (MP), respectively. Similarly, when using the tester SC-10 (T2), 9 and 20 top-cross hybrids exhibited significantly negative heterosis over BP and MP, respectively. Among the twenty-top cross hybrids, the hybrids IL-7 × SC-10 (T2) (-8.16**, -9.03**), IL-4 × SC-10 (T2) (-6.39**, -10.35**), IL-12 × SC-10 (T2) (-6.04**, -6.07**), IL-18 × SC-10 (T2) (-6.69**, -10.54**), IL-19 × SC-10 (T2) (-5.03**, -6.78**), and IL-20 × SC-10 (T2) (-5.40**, -8.01**) showed the highest negative heterosis values for days to silking. These hybrids (two involving Giza-2(T1) and six involving SC-10 (T2) exhibited strong heterotic performance and are considered promising for breeding early-flowering maize genotypes within this population. In population-3, the degree of heterosis observed over the better parent (BP) and mid-parent (MP) using the tester Giza-2 (T1) were; 17 hybrids showed significantly negative heterosis over the better parent, and 20 over the mid-parent for days to 50% silking. The highest negative and significant (P≤ 0.01) heterotic effects for days to silking using the tester Giza-2(T1) were observed in the hybrids; IL-7 × Giza-2 (T1) (-6.83**, -9.50**), IL-2 × Giza-2 (T1) (-5.98**, -6.01**), and IL-4 × Giza-2 (T1) (-5.49**, -5.54**) over the better parent (BP) and mid-parent (MP), respectively. Similarly, with tester SC-10 (T2), nine and twenty hybrids showed significant negative heterosis over BP and MP, respectively. The highest negative and significant (P≤ 0.01) heterotic effects for silking with SC-10 (T2) were recorded in the hybrids; IL-19 × SC-10 (T2) (-8.95**, -12.14**), IL-1 × SC-10 (T2) (-6.43**, -6.62**), IL-8 × SC-10 (T2) (-6.83**, -8.53**), IL-10 × SC-10 (T2) (-6.99**, -7.62**), IL-11 × SC-10 (T2) (-6.14**, -7.20**), IL-13 × SC-10 (T2) (-7.79**, -8.68**), IL-15 × SC-10 (T2) (-7.35**, -7.56**), and IL-20 × SC-10 (T2) (-6.16**, -6.55**). These hybrids showed clearly negative heterosis, which means they have good potential for producing early-flowering maize inbred lines within this population. In population-4, the amount of heterosis over the better-parent (BP) and mid-parent (M.P) when using the tester Giza-2(T1) were; 16 hybrids showed significantly negative heterosis over the better parent, and 20 over the mid-parent for days to 50% silking. The highest negative and significant (P≤ 0.01) heterotic effects for days to silking with the tester Giza-2 (T1) were recorded in the hybrids; IL-7 × Giza-2 (T1) (-7.45**, -9.05**), IL-1 × Giza-2 (T1) (-5.94**, -8.22**), IL-4 × Giza-2 (T1) (-6.32**, -7.42**), IL-14 × Giza-2 (T1) (-6.84**, -9.47**), and IL-18 × Giza-2(T1) (-5.04**, -6.17**) over BP and MP, respectively showing the highest significant reductions compared to both the better parent (BP) and mid-parent (MP). Likewise, using the tester SC-10 (T2), nine hybrids exhibited significant negative heterosis over BP, and the twenty hybrids showed it over MP. The most notable reductions were found in three following hybrids; IL-19 × SC-10 (T2) (-8.12**, -8.21**), IL-3 × SC-10 (T2) (-5.64**, -7.51**), and IL-20 × SC-10 (T2) (-7.11**, -7.62**) over BP and MP, respectively. These eight hybrids (five with the tester Giza-2 (T1) and three with the tester SC-10 (T2) demonstrated strong and consistent negative heterotic effects, making them promising hybrids for breeding early-flowering maize cultivars within this population. In general, several top-cross hybrids across the studied populations demonstrated the greatest negative F1 heterosis for days to 50% silking (Table 7). These findings were further supported by their highly significant and favorable negative SCA effects (Table 6). In population-1, the best-performing hybrids were; IL-5 × Giza-2 (T1), IL-11 × Giza-2 (T1), IL-17 × Giza-2 (T1), IL-18 × Giza-2 (T1), IL-8 × SC-10 (T2), IL-15 × SC-10 (T2), IL-16 × SC-10 (T2), and IL-20 × SC-10 (T2). In population-2, promising hybrids included IL-10 × Giza-2 (T1), IL-19 × Giza-2 (T1), IL-4 × SC-10 (T2), IL-7 × SC-10 (T2), and IL-20 × SC-10 (T2). For population-3, hybrids such as; IL-2 × Giza-2(T1), IL-7 × Giza-2 (T1), IL-10 × SC-10 (T2), IL-13 × SC-10 (T2), IL-15 × SC-10 (T2), and IL-19 × SC-10 (T2) observed desirable performance. Similarly, in population-4, the top hybrids were IL-1 × Giza-2(T1), IL-4 × Giza-2 (T1), IL-7 × Giza-2 (T1), IL-14 × Giza-2 (T1), IL-18 × Giza-2 (T1), IL-2 × SC-10 (T2), IL-3 × SC-10 (T2), and IL-19 × SC-10 (T2). So, these hybrids are considered promising and can be used in breeding programs to shorten the time to 50% silking and improve earliness in these populations. The early flowering in some hybrids in our study matches the findings of Ali (2013), Abed and Hammadi (2018), El-Refaey *et al*. (2018), Aboyousef (2019), El-Shamarka *et al*. (2020), Tafa *et al*. (2020), Fayyad and Hammadi (2021), Badr *et al*. (2022), Italia *et al*. (2022) and Shaaban *et al*. (2022), who emphasized the significance of heterosis and specific combining ability, along with the observed variation among hybrids, in their studied materials.

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