Effect of heat stress on combining ability and heterosis in some bread wheat genotypes (*Triticum aestivum* L.)

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Abstract

This research was undertaken to investigate 28 genotypes (21 F₁-crosses and their seven parents) for heading date, plant height, 100-grain weight, and grain yield plant⁻¹ under two planting dates (November 21st as regular planting date and 21st of December as late planting date) at El-Mattana, Agricultural Research Station, Luxor governorate, ARC, in 2017/2018 and 2018/2019 growing seasons. Highly significant differences among genotypes, parents, crosses, and parents vs. crosses for all traits investigated under both sowing dates. Heat stress reduced estimates of all studied traits. Three parents (P₁, P₆, and P₇) and seven F₁-hybrids (P₁ × P₂, P₁ × P₃, P₁ × P₅, P₁ × P₇, P₄ × P₇, P₃ × P₆, and P₆ × P₇) were highly tolerant, less susceptible (heat susceptibility index less than one), and less sensitive (less than one) for heat stress. Mean squares due to general (GCA) and specific (SCA) combining ability were highly significant for all studied traits. GCA/SCA ratios' magnitude were lower than one for all studied traits under both planting dates. The parents P₅ and P₇ were having significant adverse GCA effects for heading date, and the parents P₂ and P₄ showed significant positive effects for plant height and grain yield. The hybrid P₂ × P₇ observed significant positive heterosis in grain yield, 100-grain weight, and plant height, however, significantly negative in heading date in addition to satisfactory performance.

**Keywords:** Wheat; Combining ability; Heterosis; Heat stress

Introduction

Wheat (*Triticum aestivum* L.) is one of the essential strategic crops worldwide and in Egypt. Where in Egypt, all people approximately depend on wheat in their food. Despite the importance of wheat, national production is insufficient to meet the local demand due to the high population increase, especially in recent years. The local wheat production is about 8.8 million tons from 3.13 million feddan (FAO, 2018). On the other hand, delaying the sowing date exposes the wheat crop to high temperature sat the end of the growing duration. This could expose the wheat crop to some damages. Gibbson and Paulsen (1999) reported that high-temperature stress is a major environmental factor limiting wheat yield. Every 1°C increase over a mean temperature of 23°C reduces wheat yield by 10%. Besides, delay in planting usually decreases individual plant growth and tillering potential (Shah et al., 2006). Decreasing grain yield in wheat due to the reduction in the number of spikes/unit area, the number of fertile spikes/plant, the number of grains/spike, and grain weight under high-temperature stress were also reported by Lobell et al. (2005). More
breeding efforts are demanded to increase wheat production by improving its yielding ability under a suitable sowing date.

Inbreeding programs, understanding of combining ability and heterosis for parents and crosses are essential. By studying combining ability and estimating the degree of heterosis, evidence about the nature of the gene action, desirable parents, and essential productivity traits will emerge.

Several wheat studies indicated that general and specific combining ability effects for some parental genotypes and hybrids were positive and highly significant for grain yield (Hassan; 2015, Mwadzingeni et al.; 2017, Ahmed and Mohamed; 2009a, Nassar, 2013; Jaiswal et al., 2017; Sharma et al., 2019; Bajaniya et al., 2019; and Ali et al., 2020).

Estimates of average better parent heterosis for grain yield in wheat ranged from 1.03 to 47.60%. Lower estimates were obtained with crosses of adapted parental genotypes (Ahmed and Mohamed, 2009a; Hassan, 2015 and Ali et al., 2020), while the high values most often resulted from studies which involved exotic germplasm or which were performed under environmental stress conditions (Ahmed and Mohamed, 2009a and Hassan, 2015).

Therefore, the current study was undertaken to identify the best combiner parental lines and their crosses based on their general and specific combining abilities for the studied traits under the two sowing dates, in addition, to determining the magnitude of heterosis expression at the two sowing dates.

**Materials and Methods**

**Experimental site:**

The current study was carried out during the 2017/2018 and 2018/2019 growing seasons at El-Mattana, Agricultural Research Station, Luxor governorate, ARC, Egypt. Minimum, maximum, and average monthly temperatures (°C) at El-Mattana of 2018/2019 season are presented in Table 1.

**The genetic materials and diallel fashion:**

The genetic materials used in this study included seven divergent bread wheat parents (Triticum aestivum L.), Sakha-94 (P₁), Mistr-2 (P₂), Sids-1 (P₃), Gimmaza-9 (P₄), Giza-168 (P₅), Shandaweel-1 (P₆), and Sids-12 (P₇). These genotypes were planted in the first season under field conditions on three planting dates November 23rd, December 3rd, and December 14th, to avoid differences in the flowering time and secure enough pollen grains to make hybrids with enough seeds. Each parent was sown in one line, three meters long; the distance between the lines is 50 cm. These genotypes were mated in a diallel fashion without reciprocals to obtain F₁-hybrid seeds.

**Evaluation trials:**

In the second season, two experiments were conducted; the 1st (D₁) on November 21st (normal planting date) and the 2nd (D₂) on 21st of December (late planting date). Each experiment included the 7 parents and their 21 F₁-hybrids and was conducted with three replicates in a Randomized Complete Block Design (RCBD). Each of the parental and F₁-crosses was represented by two rows of plants per replicate. A single row plot 3 m long spaced 30 cm apart and plant spaced 10 cm within each row represented each genotype. The agricultural practices were followed as recommended for wheat production at two planting dates.
Table 1. Minimum, maximum, and average monthly temperature (°C) at El-Mattana Station from sowing to physiological maturity during the 2018/2019 season

| Season     | Month     | Day       | Maximum | Minimum | Average |
|------------|-----------|-----------|---------|---------|---------|
|            | Nov.      | 22 – 30   | 24.3    | 13.1    | 18.7    |
|            | Average   |           | 24.3    | 13.1    | 18.7    |
|            | Dec.      | 11 – 20   | 23.2    | 8.7     | 16.0    |
|            |           | 21 – 31   | 21.7    | 8.9     | 15.3    |
|            | Average   |           | 22.7    | 9.5     | 16.1    |
|            | January   | 11 – 20   | 18.7    | 6.2     | 12.5    |
|            |           | 21 – 31   | 19.5    | 4.7     | 12.1    |
|            | Average   |           | 19.4    | 5.8     | 16.6    |
|            | February  | 11 – 20   | 24.5    | 10.5    | 17.5    |
|            |           | 21 – 28   | 19.5    | 7.6     | 13.6    |
|            | Average   |           | 22.5    | 8.6     | 15.5    |
|            | March     | 11 – 20   | 28.0    | 11.9    | 20.0    |
|            |           | 21 – 31   | 28.0    | 14.5    | 21.3    |
|            | Average   |           | 26.8    | 11.9    | 19.4    |
|            | April     | 11 – 20   | 32.1    | 16.5    | 24.3    |
|            |           | 21 – 30   | 34.9    | 18.1    | 26.5    |
|            | Average   |           | 32.6    | 16.8    | 24.7    |
|            | May       | 1 – 15    | 40.1    | 23.1    | 31.6    |
|            | Average   |           | 40.1    | 23.1    | 31.6    |

Meteorological Authority at El-Mattana, Luxor.

Measurements:

For each genotype, ten guarded plants were taken randomly from each replicate to registering observation on days to heading (day), plant height (cm.), 100-grain weight (g), and grain yield/plant (g).

Statistical procedures

1- Mean performance and analysis of variance:

Analysis of variance was performed according to Gomez and Gomez (1984) for a single experiment.

Revised least significant differences (LSD') at 0.05 levels of probability were used to compare means according to El-Rawi and Khalafalla (1980).

- Heat tolerance, heat susceptibility index, and sensitivity.

Heat tolerance (HT) computed according to the following equation:

\[
HT = \frac{\text{Grain yield for individual genotype under stress conditions (D2)}}{\text{Grain yield for the same genotype under normal conditions (D1)}}
\]

Heat susceptibility index (HSI) was calculated according to Fisher and Maurer (1978) method. The sensitivity was computed according to Falconer (1990). To calculate each HSI and sensitivity for parental genotypes and their crosses, the
yield means of parents and crosses were used, respectively.

2- Combining ability analysis

General (GCA) and specific (SCA) combining ability variances and their effects were calculated using a standard method for analysis of conflict in a randomized complete block design according to Griffing (1956), method II model I.

3- Heterosis:

Heterosis was calculated as the percentage of deviation of F₁'s mean from the mean better parent, according to Bahatt (1971).

Results and Discussion

A-Mean performance of genotypes

Analysis of variance

There were highly significant differences among genotypes and their components (parents, crosses, and P vs. C) for all investigated traits under both sowing dates, indicating high genetic diversity among them (Table 2).

Days to heading

Data in Table 3 showed that the average days from sowing to heading for parental genotypes ranged from 77.33 for P₅ to 90.67 for P₂ at normal sowing date, but it is reduced to 77.00 and 84.33 days for the same genotypes at late sowing date. The average overall parents were 85.29 days at normal sowing date but are reduced to 80.48 days under late sowing date, indicating a reduction of 5.64% in days to heading due to heat stress. The F₁-crosses performance ranged from 89.33 for the cross P₁ × P₂ to 74.33 days for the cross P₁ × P₅ under early planting date but is reduced to 81.33 for the cross P₁ × P₄ and 65.00 days for the cross P₁ × P₅ under late planting date. The average number of days to the heading of all F₁-crosses reduced from 83.79 to 76.43 days at regular and late dates, respectively, showing an 8.78% reduction in heading time. The results showed that P₅ possesses genes for earliness where all of its crosses were early either under regular or late planting dates. In this connection, the crosses were earlier and higher in reduction% than parents from early to late sowing dates. The delaying date of planting reduced the number of days from sowing to heading. In this line, with applying late sowing, significant shortening of the period of ear growth and flowering period was noticed because starting the flowering stage when the atmospheric temperature starts rising (Saini et al., 1986). Also, these results agree with those reported by Ahmed and Mohamed (2009a), Hassan (2015), Jaiswal et al. (2017), Ahmed et al. (2017), Sharma et al. (2019), Bajaniya et al. (2019), and Ali et al. (2020).

Plant height

Average plant height for parental genotypes varied from 88.8 for P₅ to 104.8 cm for P₂ under favorable sowing date, while it decreased to 82.5 and 97.0 cm for the same parents under unfavorable sowing date (Table 3). The average of all parents was 98.9 cm at early date, but it decreased to 90.4 cm at a late date, indicating an 8.59% reduction in plant height due to delaying the sowing date. Mean plant height for F₁-hybrids varied from 99.2 for P₄ × P₆ to 106.2 cm for P₂ × P₆ at normal
Table 2. Mean squares from ANOVA combined the F1-hybrids of bread wheat genotypes under normal (N) and late (L) sowing dates

| S.O.V        | df | Days to heading (days) | Plant height (cm) | 100-grain weight (g) | Grain yield/plant (g) |
|--------------|----|------------------------|-------------------|----------------------|----------------------|
|              |    | 5.71                   | N     | L     | N     | L     | N     | L     | N     | L     |
| Reps         | 2  |                        |        |        | 2.61  | 7.75  | 20.76 | 17.79 | 0.15  | 0.20  | 6.86  | 7.73  |
| Genotypes (G)| 27 |                        | 61.62**| 69.47**| 48.82**| 63.62**| 1.02**| 0.62**| 43.21**| 18.67**|
| Parents (P)  | 6  |                        | 78.08**| 20.98**| 139.22**| 97.10**| 0.73**| 0.38**| 15.38**| 10.23**|
| Crosses (C)  | 20 |                        | 58.08**| 74.38**| 11.76**| 40.41**| 0.75**| 0.57**| 42.02**| 19.31**|
| P vs. C      | 1  |                        | 33.59**| 262.10**| 247.58**| 326.86**| 8.04**| 3.11**| 233.94**| 56.38**|
| GCA          | 6  |                        | 43.70**| 22.54**| 27.45**| 43.14**| 0.24**| 0.16**| 27.59**| 5.01** |
| SCA          | 21 |                        | 11.84**| 22.26**| 11.77**| 12.88**| 0.36**| 0.21**| 9.32** | 6.33** |
| Error        | 54 |                        | 2.21   | 6.07   | 2.50   | 3.80   | 0.11  | 0.07  | 3.78  | 1.85  |
| \(\Sigma g_s^2/\Sigma g_0^2\) | -  |                        | 0.29   | 0.001  | 0.14   | 0.26   | -0.04 | -0.03 | 0.23  | -0.02 |

*, **; Significant at 0.05 and 0.01 levels of probability, respectively.

planting date, while it reduced to 89.5 for P3 × P3 to 101.2 cm for P2 × P3 at a late date (Table 3). The average plant height of all F1-hybrids decreased from 102.9 cm at the desired date to 94.9 cm at the undesirable date, reflecting a reduction of 7.77% in plant height. The cross P2 × P3 was the tallest one under normal and late planting dates. This result may be because P2 is the tallest parent and passed its target genes to this cross (Table 3). These results are in line with those obtained by El-Beially and El-Sayed (2002), Ahmadi et al. (2003), Ahmed and Mohamed (2009a), Wajid et al. (2011), Ezatollah et al. (2013), Hassan (2015), Hassan (2016), Jaiswal et al. (2017), Ahmed et al. (2017), Sharma et al. (2019), Bajaniya et al. (2019) and Ali et al. (2020).

**100-grain weight**

For 100-grain weight, the average of parental genotypes exhibited that the heavier averages were 5.33 and 4.00 g for P1. The lighter averages were 3.67 and 2.89 g for P3 normal and late planting dates, respectively. The average of all parents for 100-grain weight decreased from 4.53 at a normal date to 3.46 g at a late planting date, indicating a 23.62% reduction in 100-grain weight (Table 3). The heavier averages of 100-grain weight for F1-hybrids were 6.00 and 5.00 g for P3 × P7, but the lighter averages were 3.67 for P3 × P5 and 3.33 g for P2 × P4 and P2 × P5 under early and late sowing dates, respectively. The average of all F1-hybrids for 100-grain weight was 5.17 and 3.90 g under normal and late planting dates, respectively (Table 3). The F1-hybrids were heavier and higher in reduction% than parents from early to late sowing dates. 100-grain weight overall genotypes were decreased by heat stress; the decrease reached to 26.55% from the normal planting date. This reduction may be due to the high-temperature effects during the grain filling period (Table 1). These results agree with those obtained by Samra et al. (1989), who showed that high temperature during the month of maturity might have a forced effect on the maturity of the late plant crop and lower grain weight. These findings are in line with those reported by El-Beially and El-Sayed.
### Table 3. Mean performance of the eight parents and F1's hybrids for days to heading, plant height, and 100-grain weight under normal (N) and late (L) sowing dates

| Genotypes | Days to heading (days) | Plant height (cm) | 100-grain weight (gm) | Grain yield/plant (gm) |
|-----------|------------------------|-------------------|-----------------------|------------------------|
|           | N | L | N | L | N | L | N | L | HT | HSI | S |
| P1        | 88.67 | 82.67 | 102.2 | 92.2 | 5.33 | 4.00 | 19.03 | 16.57 | 0.87 | 0.75 | 0.70 |
| P2        | 90.67 | 84.33 | 104.8 | 97.0 | 4.67 | 3.33 | 21.43 | 17.60 | 0.82 | 1.03 | 1.09 |
| P3        | 86.67 | 80.67 | 104.7 | 94.8 | 3.67 | 2.89 | 21.53 | 17.27 | 0.80 | 1.14 | 1.22 |
| P4        | 89.33 | 81.00 | 103.0 | 94.7 | 4.67 | 3.67 | 24.23 | 17.33 | 0.72 | 1.65 | 1.97 |
| P5        | 77.33 | 77.00 | 88.8 | 82.5 | 4.17 | 3.33 | 18.77 | 12.97 | 0.69 | 1.79 | 1.66 |
| P6        | 84.33 | 80.67 | 98.8 | 87.2 | 5.00 | 3.33 | 19.10 | 18.93 | 0.99 | 0.05 | 0.05 |
| P7        | 80.00 | 77.00 | 90.0 | 84.3 | 4.17 | 3.67 | 17.63 | 16.60 | 0.94 | 0.34 | 0.29 |
| Mean (p)  | 85.29 | 80.48 | 98.9 | 90.4 | 4.53 | 3.46 | 20.25 | 16.75 | - | - | - |
| P1 x P2   | 89.33 | 79.67 | 104.3 | 97.8 | 5.33 | 4.00 | 24.27 | 17.63 | 0.73 | 0.71 | 0.72 |
| P1 x P3   | 86.33 | 77.33 | 101.5 | 99.7 | 5.00 | 3.67 | 24.63 | 14.53 | 0.59 | 1.07 | 1.09 |
| P1 x P4   | 88.67 | 81.33 | 103.0 | 96.5 | 5.00 | 3.67 | 20.37 | 18.90 | 0.93 | 0.19 | 0.16 |
| P1 x P5   | 74.33 | 65.00 | 103.5 | 94.5 | 5.00 | 4.00 | 20.40 | 12.50 | 0.61 | 1.01 | 0.85 |
| P1 x P6   | 86.33 | 80.00 | 101.3 | 95.8 | 5.67 | 4.00 | 20.87 | 15.50 | 0.74 | 0.67 | 0.58 |
| P1 x P7   | 75.33 | 66.00 | 101.0 | 91.0 | 5.33 | 4.00 | 30.63 | 13.63 | 0.44 | 1.45 | 1.84 |
| P2 x P3   | 87.33 | 76.67 | 106.5 | 101.2 | 5.67 | 4.00 | 27.13 | 15.30 | 0.56 | 1.14 | 1.28 |
| P2 x P4   | 88.67 | 77.67 | 105.3 | 100.0 | 5.33 | 3.33 | 22.93 | 13.83 | 0.60 | 1.04 | 0.98 |
| P2 x P5   | 80.33 | 67.33 | 102.2 | 98.2 | 5.00 | 3.33 | 27.73 | 15.27 | 0.55 | 1.17 | 1.35 |
| P2 x P6   | 84.33 | 80.67 | 106.2 | 100.7 | 4.67 | 3.67 | 25.10 | 15.03 | 0.60 | 1.05 | 1.09 |
| P2 x P7   | 79.67 | 69.00 | 104.2 | 94.5 | 5.33 | 4.00 | 29.00 | 15.13 | 0.52 | 1.25 | 1.5 |
| P3 x P4   | 88.33 | 77.67 | 104.3 | 95.2 | 5.00 | 4.00 | 23.97 | 13.07 | 0.55 | 1.19 | 1.18 |
| P3 x P5   | 79.33 | 73.33 | 103.0 | 89.5 | 3.67 | 3.67 | 29.70 | 13.60 | 0.46 | 1.42 | 1.74 |
| P3 x P6   | 85.67 | 79.00 | 103.5 | 91.5 | 5.33 | 4.33 | 25.30 | 11.57 | 0.46 | 1.42 | 1.49 |
| P3 x P7   | 79.67 | 79.33 | 99.3 | 89.8 | 5.33 | 3.67 | 28.40 | 15.03 | 0.53 | 1.23 | 1.45 |
| P4 x P5   | 79.67 | 78.33 | 103.2 | 90.3 | 5.00 | 3.67 | 21.23 | 12.00 | 0.57 | 1.14 | 0.99 |
| P4 x P6   | 85.67 | 80.00 | 99.2 | 92.3 | 5.33 | 3.67 | 25.63 | 18.13 | 0.71 | 0.76 | 0.81 |
| P4 x P7   | 85.33 | 79.33 | 102.2 | 93.8 | 5.67 | 5.00 | 17.93 | 15.03 | 0.84 | 0.42 | 0.31 |
| P5 x P6   | 84.67 | 78.67 | 100.5 | 92.5 | 3.53 | 3.67 | 19.30 | 11.20 | 0.58 | 1.1 | 0.88 |
| P5 x P7   | 84.67 | 77.33 | 103.7 | 96.5 | 6.00 | 5.00 | 19.13 | 13.53 | 0.71 | 0.76 | 0.61 |
| P6 x P7   | 86.00 | 77.33 | 103.0 | 92.3 | 4.67 | 3.67 | 20.25 | 16.75 | 0.83 | 0.45 | 0.38 |
| Mean (C)  | 83.79 | 76.43 | 102.90 | 94.93 | 5.17 | 3.90 | 24.10 | 14.86 | - | - | - |
| Mean (G)  | 84.17 | 77.44 | 100.9 | 92.7 | 5.01 | 3.68 | 22.17 | 15.81 | - | - | - |
| LSD\(_{0.05}\) (P) | 1.94 | 5.83 | 2.46 | 3.71 | 0.32 | 0.50 | 3.47 | 3.65 | - | - | - |
| LSD\(_{0.05}\) (C) | 2.05 | 4.27 | 2.69 | 3.03 | 0.57 | 0.39 | 3.09 | 2.08 | - | - | - |
| LSD\(_{0.05}\) (G) | 2.21 | 4.42 | 2.36 | 3.02 | 0.49 | 0.38 | 3.02 | 2.11 | - | - | - |
| Red.% of P | 5.64 | 8.59 | 23.62 | 17.28 | - | - | - | - |
| Red.% of C | 8.78 | 7.77 | 24.56 | 38.34 | - | - | - | - |
| Red.% of G | 8.00 | 8.13 | 26.55 | 28.69 | - | - | - | - |

Grain yield plant\(^{-1}\)
The average grain yield/plant for parental genotypes indicated that the higher averages were 24.23 for $P_4$ and 18.93 g for $P_6$. Still, the lower averages were 17.63 for $P_4$ and 12.97 g for $P_5$ under normal and late planting dates, respectively. The averages of grain yield plant$^{-1}$ overall parents were 20.25 and 16.75 gm under normal and late planting dates, respectively (Table 3). Mean of grain yield plant$^{-1}$ for $F_1$-hybrids exhibited that the higher averages were 30.63 for $P_1 \times P_7$ and 18.90 g for $P_1 \times P_4$, but the lower averages were 17.93 for $P_4 \times P_7$ and 11.20 g for $P_5 \times P_6$ under normal and late planting dates, respectively. Average of grain yield plant$^{-1}$ for $F_1$-hybrids was 24.10 and 14.86 g under normal and late planting dates. Grain yield plant$^{-1}$ overall genotypes decreased by heat stress; the decreased value reached 28.69% from the normal planting date. This reduction may be due to the negative effect of high temperature on grain filing rate. These results are in line with those obtained by Dencic et al. (2000), Hoffman and Burucs (2005), Mohamed (2007), Ahmed and Mohamed (2009a), Hassan (2015), Hassan (2016), Jaiswal et al. (2017), Ahmed et al. (2017), Sharma et al. (2019), Bajaniya et al. (2019) and Ali et al. (2020).

**Heat tolerance, heat susceptibility index, and sensitivity**

Three parents ($P_1$, $P_6$ and $P_7$) and three $F_1$-hybrids ($P_1 \times P_4$, $P_4 \times P_7$ and $P_6 \times P_7$) had highly tolerant for heat stress, heat susceptibility index less than one (less susceptible) and also gave values less than one (less sensitive) insensitivity test, since they gave intermediate yield compared to yield under normal ones.

**B- Combining ability**

**Analysis of variance**

From the results in Table 2, mean squares due to GCA and SCA were significant or highly significant for all studied traits under normal and late planting dates. This reveals the importance of the additive and non-additive effects for inheritance of these studied traits.

GCA/SCA ratios’ magnitude was lower than one for 100-grain weight and grain yield plant$^{-1}$ under both planting dates, except grain yield plant$^{-1}$ under normal planting date. This indicates that the non-additive (dominance, over dominance and epistasis) effects seem more important than additive effects in these traits' inheritance mechanisms. The preponderance of non-additive variance in expression of these traits in wheat have also been reported by Dhadhal et al. (2006), Lohithaswa et al. (2013), Barot et al. (2014), Pansuriya et al. (2014), Ahmed et al. (2017), Ahmed and Mohamed (2009a) and Bajaniya et al. (2019) for 100-grain weight; Sharma and Garg (2005), Vanparyya et al. (2006), Singh et al. (2013), Ahmed and Mohamed (2009a) and Bajaniya et al. (2019) for grain yield per plant. Because of these studies, it could be concluded that grain yield is a complex character compared to its components. Thus, as the quantitative character becomes complex, and the contribution of non-additive gene action would be more. The present finding was partially in harmony with those obtained by Ahmed and Mohamed (2009a), Jaiswal et al. (2017), Sharma et al. (2019), and Ali et al. (2020), which indicated that GCA was more important than SCA in the inheritance of most studied traits. Nassar (2013) and
Hassan (2015) stated that both additive and non-additive variation had an important role in controlling most traits’ inheritance.

**Combining ability effects**

**General combining ability effects:**

Mean values and additive gene action for characters under consideration are usually considered the primary criteria for selecting favorable parents. Genetically, the GCA effect is associated with additive gene action. A highly significant negative GCA value for the trait of days to heading was obtained for the parental genotypes \(P_5\) and \(P_7\) under normal and late sowing dates, which contributed to improving the duration to heading in their crosses (Table 4). Two parents (\(P_2\) and \(P_4\)) recorded significantly positive GCA effects for plant height under different sowing dates, contributing to increased plant high in their crosses.

For 100-grain weight, the parents \(P_1\) and \(P_7\) displayed significantly positive GCA effects under normal and late sowing dates, respectively. These parents are considered to be good combiners for grain weight.

Parental genotypes such as \(P_2\) and \(P_4\) had positive and highly significant GCA effects for grain yield/plant under normal and late sowing dates, indicating that they would be good parents of high grain yielding offspring. The parents selected for a particular trait were not always acceptable for other traits. For example, \(P_2\) and \(P_4\) had high mean grain yield and highly significant positive GCA effects, but its longer duration to heading under different environments is not desirable. Also, \(P_3\) and \(P_7\) had a shorter duration to heading and highly significant negative GCA effects, but it exhibited low mean grain yield, which is not desirable. These results are in harmony with those obtained by Ali (2006), Ahmed and Mohamed (2009a), Hassan (2015), and Ali et al. (2020).

**Specific combining ability effects:**

Superior hybrids were selected based on both hybrid performance and SCA effects. Among the 21 \(F_1\)-hybrids, four crosses (\(P_1 \times P_5\), \(P_1 \times P_7\), \(P_2 \times P_5\), five and \(P_2 \times P_7\)) showed highly significant negative SCA effects for days to heading under different sowing dates (Table 4). These crosses were considered the best combinations for earliness.

Five crosses; \(P_1 \times P_5\), \(P_2 \times P_6\), \(P_2 \times P_7\), \(P_5 \times P_7\), and \(P_6 \times P_7\), exhibited highly significant positive SCA effects for plant height in both sowing dates. This indicates that these hybrids were considered the best combinations for tallness.

The hybrids \(P_2 \times P_3\), \(P_2 \times P_7\), \(P_3 \times P_6\), and \(P_5 \times P_7\) had significantly positive SCA effects for 100-grain weight in early and late sowing dates. One cross only, \(P_2 \times P_7\), showed significant positive SCA effects for grain yield and gave the highest grain yield in their performance under early and late sowing dates. Considering the two main traits, earliness and grain yield, the cross \(P_2 \times P_7\) could be selected as a good hybrid combination. It exhibited a highly significant positive SCA effect for grain yield and a highly significant negative SCA effect for days to heading under both sowing dates. These results are in agreement with those obtained by Ali (2006), Ahmed and Mohamed (2009a), Hassan (2015) and Ali et al. (2020).
Table 4. General (GCA) and specific (SCA) combining ability effects for days to 50% heading, plant height, 100-grain weight, and grain yield plant\(^1\) of the parents and their F\(_1\)'s under normal (N) and late (L) planting dates

| Genotypes | Days to heading | Plant height | 100-grain weight | Grain Yield plant\(^1\) |
|-----------|----------------|-------------|------------------|------------------------|
|           | N       | L       | N       | L       | N       | L       | N       | L       |
| P\(_1\)   | 0.50    | -0.56   | 0.41    | 0.79    | 0.14*   | 0.11    | -1.56** | 0.24    |
| P\(_2\)   | 1.98**  | 1.92**  | 2.57**  | 3.99**  | 0.06    | -0.15** | 1.53**  | 0.80*   |
| P\(_3\)   | 0.72*   | 1.03    | 1.40**  | 0.68    | -0.31** | -0.14*  | 2.31**  | -0.39   |
| P\(_4\)   | 2.43**  | 1.85**  | 0.88    | 1.03*   | 0.10    | 0.04    | 2.15**  | 1.24**  |
| P\(_5\)   | -4.02** | -2.34** | -2.39** | -2.65** | -0.20** | -0.04   | -1.63** | -1.07** |
| P\(_6\)   | 0.91*   | -0.01   | -0.44   | -1.21** | 0.10    | -0.08   | -1.20*  | -0.32   |
| P\(_7\)   | -2.53** | -1.89** | -2.43** | -2.63** | 0.10    | 0.26**  | -1.61** | -0.50   |
| P\(_1\) x P\(_2\) | 2.70** | 2.77*   | -0.55   | -0.99   | 0.12    | 0.25*   | -0.64   | 4.26**  |
| P\(_1\) x P\(_3\) | 0.96    | -0.60   | -2.22** | 4.16**  | 0.16    | -0.10   | 0.37    | 1.45*   |
| P\(_1\) x P\(_4\) | 1.59*  | 2.58*   | -0.20   | 0.88    | -0.25   | -0.27*  | 0.90    | -2.28** |
| P\(_1\) x P\(_5\) | -6.30** | -9.56** | 3.58**  | 2.32*   | 0.05    | 0.14    | 0.42    | 3.40**  |
| P\(_1\) x P\(_6\) | 0.78    | 1.18    | -0.62   | 1.88    | 0.42*   | 0.17    | 0.02    | -3.76** |
| P\(_1\) x P\(_7\) | -6.78** | -9.01** | 1.12    | -1.19   | 0.08    | -0.16   | 0.90    | -0.57   |
| P\(_2\) x P\(_1\) | 0.48    | -1.82   | 0.63    | 2.69**  | 0.90**  | 0.49**  | 3.65**  | -2.11** |
| P\(_2\) x P\(_3\) | 0.11    | -1.64   | -0.02   | 1.42    | 0.16    | -0.35*  | 0.31    | -1.07   |
| P\(_2\) x P\(_4\) | -1.78*  | -7.79** | 0.09    | 3.03**  | 0.12    | -0.27*  | -0.10   | -1.23   |
| P\(_2\) x P\(_5\) | -2.70** | 1.29    | 2.14**  | 4.08**  | -0.51** | 0.10    | 4.26**  | -0.55   |
| P\(_2\) x P\(_6\) | -3.93** | -6.56** | 2.13**  | 2.21*   | 0.79**  | 0.91**  | 2.04*   | 3.06**  |
| P\(_2\) x P\(_7\) | 1.04    | -2.68*  | 0.15    | -0.10   | 0.19    | 0.31*   | 1.39    | -0.05   |
| P\(_3\) x P\(_1\) | -1.52*  | 1.18    | 2.09*   | -2.32*  | -0.84** | 0.05    | 0.14    | -0.80   |
| P\(_3\) x P\(_2\) | -0.11   | -1.42   | 0.64    | -1.77   | 0.53**  | 0.75**  | 5.44**  | -1.03   |
| P\(_3\) x P\(_3\) | -3.00** | 3.06**  | -1.54   | -2.01*  | 0.53**  | -0.25*  | 1.46    | -2.88** |
| P\(_3\) x P\(_4\) | -2.89** | 1.36    | 2.78**  | -1.60   | 0.08    | -0.12   | 4.74**  | 0.54    |
| P\(_3\) x P\(_5\) | -1.81*  | -1.23   | -3.18** | -1.05   | 0.12    | -0.09   | -2.86** | -3.25** |
| P\(_3\) x P\(_6\) | 1.30    | 1.92    | 1.81*   | -0.66   | 0.16    | 0.10    | 1.95    | -0.60   |
| P\(_3\) x P\(_7\) | 3.63**  | 1.62    | 1.43    | 2.56*   | 0.42*   | -0.01   | -2.38*  | 1.09    |
| P\(_4\) x P\(_1\) | 7.07**  | 4.10**  | 6.59**  | 7.99**  | 1.08**  | 0.99**  | -0.60   | -2.56** |
| P\(_4\) x P\(_2\) | 3.48**  | -0.16   | 3.97**  | 2.38*   | -0.55** | -0.31*  | -1.20   | -0.98   |
| S.E. gi  | 0.36    | 0.59    | 0.37    | 0.47    | 0.07    | 0.06    | 0.47    | 0.33    |
| S.E. sij | 0.77    | 1.28    | 0.82    | 1.01    | 0.17    | 0.13    | 1.01    | 0.71    |
| S.E. (gi-gj) | 0.40    | 0.64    | 0.43    | 0.53    | 0.10    | 0.07    | 0.53    | 0.37    |
| S.E. (sij-sik) | 1.14    | 1.90    | 1.22    | 1.50    | 0.24    | 0.20    | 1.50    | 1.05    |

*and **: significant at 0.05 and 0.01 levels of probability, respectively.

**C-Heterosis:**

Desirable (negative and significant) better parent heterosis was observed for days to heading in some hybrids under normal and late sowing dates (Table 5), showing earlier heading than the earlierparent at both sowing dates. Under normal and late sowing dates, better parent heterosis ranged from \(-10.67\) and \(-18.5\) to 7.63 and 0.63\%, respectively. P\(_1\) x P\(_5\),
Table 5. Percentages of better parent (BP) heterosis for days to heading, plant height, 100-grain weight, and grain yield/plant of 21 F1-crosses under normal (N) and late (L) planting dates

| Genotypes   | Days to heading | Plant height | 100-grain weight | Grain yield plant⁻¹ |
|-------------|-----------------|--------------|------------------|----------------------|
|             | N   | L   | N   | L   | N   | L   | N   | L   |
| P₁ × P₂     | -0.37| -4.59⁺ | -0.49| 0.87| 6.60| 0.00| 5.47| 24.32⁺⁺ |
| P₁ × P₃     | -1.52| -5.31⁺ | -3.15⁺ | 5.17⁺⁺ | 0.00| -11.42⁺⁺ | 12.73| 2.08 |
| P₁ × P₄     | -0.37| -0.62 | 0.00| 1.95| 0.00| -8.25| 2.10| -16.90⁺ |
| P₁ × P₅     | -10.44⁺⁺ | -18.58⁺⁺ | 1.46| 2.79| 0.00| 0.00| 7.14| 45.72⁺⁺ |
| P₁ × P₆     | -0.19| -2.04 | -0.91| 4.13⁺⁺ | 13.40⁺⁺ | 0.00| 6.81| -33.97⁺⁺ |
| P₁ × P₇     | -10.67⁺⁺ | -17.33⁺⁺ | -1.33| -1.42| 7.91| 0.00| 10.44| -6.63 |
| P₂ × P₃     | -1.50| -7.07⁺⁺ | 1.62| 4.43⁺⁺ | 27.25⁺⁺ | 23.18⁺⁺ | 42.27⁺⁺ | -21.08⁺⁺ |
| P₂ × P₄     | -1.48| -6.04⁺⁺ | 0.49| 3.17| 14.13⁺⁺ | -9.26| 11.97| -13.27⁺⁺ |
| P₂ × P₅     | -4.36⁺⁺ | -16.53⁺⁺ | -2.93⁺⁺ | 1.45| 7.91| 0.00| 7.99| -29.07⁺⁺ |
| P₂ × P₆     | -3.62⁺⁺ | -2.22 | 1.42| 4.24⁺⁺ | 0.00| 10.21| 32.98⁺⁺ | -19.33⁺⁺ |
| P₃ × P₇     | -6.64⁺⁺ | -14.46⁺⁺ | -0.67| -2.97| 15.83⁺⁺ | 8.99| 20.82⁺⁺ | -15.48⁺⁺ |
| P₄ × P₅     | 0.38| -3.92⁺⁺ | -0.48| 0.42| 8.99| 11.42⁺⁺ | 22.16⁺⁺ | -12.74⁺⁺ |
| P₄ × P₆     | -3.25⁺⁺ | -1.91 | 15.99⁺⁺ | -6.42⁺⁺ | -11.99| 10.21| 13.00| -32.38⁺⁺ |
| P₅ × P₆     | 0.19| -2.07 | -1.32| -3.78⁺⁺ | 6.60| 30.03⁺⁺ | 42.77⁺⁺ | -28.16⁺⁺ |
| P₆ × P₇     | -4.40⁺⁺ | 0.63| -6.11⁺⁺ | -5.93⁺⁺ | 27.82⁺⁺ | 0.00| 21.38⁺⁺ | -34.34⁺⁺ |
| P₆ × P₇     | -4.40⁺⁺ | -0.85 | 0.23| -5.33⁺⁺ | 7.91| 0.00| 22.22⁺⁺ | -17.73⁺⁺ |
| P₇ × P₆     | -1.34| -1.03 | -3.85⁺⁺ | -2.75| 6.60| 0.00| -15.71⁺⁺ | -28.16⁺⁺ |
| P₇ × P₇     | 0.79| 0.42| -0.89| -1.07| 31.89⁺⁺ | 36.24⁺⁺ | 7.94| 4.82 |
| P₆ × P₆     | 4.74⁺⁺ | -0.21 | 1.91| 6.42⁺⁺ | 7.91| 10.21| -6.23| -30.07⁺⁺ |
| P₆ × P₇     | 7.63⁺⁺ | 0.43 | 15.43⁺⁺ | 14.79⁺⁺ | 43.88⁺⁺ | 39.94⁺⁺ | 2.82| 41.63⁺⁺ |

⁺, ⁺⁺: Significant at 0.05 and 0.01 levels of probability, respectively.

P₁ × P₇, P₂ × P₃, and P₂ × P₇ expressed desirable (negative and highly significant) earliest better parent heterosis for days to heading in early and late sowing date as it could be expected from SCA effects.

Positive and highly significant better parent heterosis was observed for some hybrids for plant height in both dates (Table 5). The hybrids P₅ × P₇ and P₆ × P₇ were the tallest better parent heterosis under both sowing dates. The range of better parent heterosis for plant height was wide between –6.11 and 15.99% at a normal date and –6.42 and 14.79% at a late date.

Desirable (positive and highly significant) better parent heterosis was observed for 100-grain weight by some hybrids (Table 5). Better parent heterosis ranged from –11.9 to 43.88% and from –11.42 to 39.94% under normal and late sowing dates. Three crosses, P₂ × P₃, P₄ × P₇, and P₅ × P₇, had positive and heaviest grain weight and better parent heterotic values under both sowing dates.

The degree of better parent heterosis differed among hybrids in grain yield. Some hybrids grown in early and late sowing dates showed useful better parent heterosis, indicating the superior grain yield performance compared to the better parent. The range of better parent heterosis was wide between –15.71 (P₄ × P₃) and 42.77% (P₃ × P₆) at the normal date. It ranged from –41.63 and 45.72% under late date,
recorded by \( P_5 \times P_7 \) and \( P_1 \times P_5 \), respectively. These results are in harmony with those obtained by Ahmed and Mohamed (2009b), Hassan (2015), and Ali et al. (2020).

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