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, P₅ × 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 at the end of the growing

duration. This could expose the wheat crop to some damages. Gribson 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), Misr-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		2018/2019		
Month	Day	Maximum	Minimum	Average
Nov.	22 – 30	24.3	13.1	18.7
	Average	24.3	13.1	18.7
Dec.	1 – 10	23.3	11.0	17.2
	11 – 20	23.2	8.7	16.0
	21 – 31	21.7	8.9	15.3
	Average	22.7	9.5	16.1
January	1 – 10	20.1	6.4	13.3
	11 – 20	18.7	6.2	12.5
	21 – 31	19.5	4.7	12.1
	Average	19.4	5.8	16.6
February	1 – 10	23.4	7.7	15.6
	11 – 20	24.5	10.5	17.5
	21 – 28	19.5	7.6	13.6
	Average	22.5	8.6	15.5
March	1 – 10	24.5	9.4	17.0
	11 – 20	28.0	11.9	20.0
	21 – 31	28.0	14.5	21.3
	Average	26.8	11.9	19.4
April	1 – 10	30.9	15.8	23.4
	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 F_1 '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 P_5 to 90.67 for P_2 at normal sowing date, but 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 F_1 -crosses performance ranged from 89.33 for the cross $P_1 \times P_2$ to 74.33 days for the cross $P_1 \times P_5$ under early planting date but is reduced to 81.33 for the cross $P_1 \times P_4$ and 65.00 days for the cross $P_1 \times P_5$ under late planting date. The average number of days to the heading of all F_1 -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 P_5 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 P_5 to 104.8 cm for P_2 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 F_1 -hybrids varied from 99.2 for $P_4 \times P_6$ to 106.2 cm for $P_2 \times P_6$ 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
$\Sigma g_i^2 / \Sigma S_{ij}^2$	-	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 × P₅ 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 P₅ × 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
P ₁	88.67	82.67	102.2	92.2	5.33	4.00	19.03	16.57	0.87	0.75	0.70
P ₂	90.67	84.33	104.8	97.0	4.67	3.33	21.43	17.60	0.82	1.03	1.09
P ₃	86.67	80.67	104.7	94.8	3.67	2.89	21.53	17.27	0.80	1.14	1.22
P ₄	89.33	81.00	103.0	94.7	4.67	3.67	24.23	17.33	0.72	1.65	1.97
P ₅	77.33	77.00	88.8	82.5	4.17	3.33	18.77	12.97	0.69	1.79	1.66
P ₆	84.33	80.67	98.8	87.2	5.00	3.33	19.10	18.93	0.99	0.05	0.05
P ₇	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	-	-	-
P ₁ x P ₂	89.33	79.67	104.3	97.8	5.33	4.00	24.27	17.63	0.73	0.71	0.72
P ₁ x P ₃	86.33	77.33	101.5	99.7	5.00	3.67	24.63	14.53	0.59	1.07	1.09
P ₁ x P ₄	88.67	81.33	103.0	96.5	5.00	3.67	20.37	18.90	0.93	0.19	0.16
P ₁ x P ₅	74.33	65.00	103.5	94.5	5.00	4.00	20.40	12.50	0.61	1.01	0.85
P ₁ x P ₆	86.33	80.00	101.3	95.8	5.67	4.00	20.87	15.50	0.74	0.67	0.58
P ₁ x P ₇	75.33	66.00	101.0	91.0	5.33	4.00	30.63	13.63	0.44	1.45	1.84
P ₂ x P ₃	87.33	76.67	106.5	101.2	5.67	4.00	27.13	15.30	0.56	1.14	1.28
P ₂ x P ₄	88.67	77.67	105.3	100.0	5.33	3.33	22.93	13.83	0.60	1.04	0.98
P ₂ x P ₅	80.33	67.33	102.2	98.2	5.00	3.33	27.73	15.27	0.55	1.17	1.35
P ₂ x P ₆	84.33	80.67	106.2	100.7	4.67	3.67	25.10	15.03	0.60	1.05	1.09
P ₂ x P ₇	79.67	69.00	104.2	94.5	5.33	4.00	29.00	15.13	0.52	1.25	1.5
P ₃ x P ₄	88.33	77.67	104.3	95.2	5.00	4.00	23.97	13.07	0.55	1.19	1.18
P ₃ x P ₅	79.33	77.33	103.0	89.5	3.67	3.67	29.70	13.60	0.46	1.42	1.74
P ₃ x P ₆	85.67	79.00	103.5	91.5	5.33	4.33	25.30	11.57	0.46	1.42	1.49
P ₃ x P ₇	79.67	79.33	99.3	89.8	5.33	3.67	28.40	15.03	0.53	1.23	1.45
P ₄ x P ₅	79.67	78.33	103.2	90.3	5.00	3.67	21.23	12.00	0.57	1.14	0.99
P ₄ x P ₆	85.67	80.00	99.2	92.3	5.33	3.67	25.63	18.13	0.71	0.76	0.81
P ₄ x P ₇	85.33	79.33	102.2	93.8	5.67	5.00	17.93	15.03	0.84	0.42	0.31
P ₅ x P ₆	84.67	78.67	100.5	92.5	5.33	3.67	19.30	11.20	0.58	1.1	0.88
P ₅ x P ₇	84.67	77.33	103.7	96.5	6.00	5.00	19.13	13.53	0.71	0.76	0.61
P ₆ x P ₇	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		-		-

(2002), Darwish *et al.* (2006), 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).

Grain yield plant⁻¹

The average grain yield/plant for parental genotypes indicated that the higher averages were 24.23 for P₄ and 18.93 g for P₆. Still, the lower averages were 17.63 for P₇ and 12.97 g for P₅ 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 F₁-hybrids exhibited that the higher averages were 30.63 for P₁ × P₇ and 18.90 g for P₁ × P₄, but the lower averages were 17.93 for P₄ × P₇ and 11.20 g for P₅ × P₆ under normal and late planting dates, respectively. Average of grain yield plant⁻¹ for F₁-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 filling 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 (P₁, P₆ and P₇) and three F₁-hybrids (P₁ × P₄, P₄ × P₇ and P₆ × P₇) 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), Vanpariya *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 P₅ and P₇ under normal and late sowing dates, which contributed to improving the duration to heading in their crosses (Table 4). Two parents (P₂ and P₄) recorded significantly positive GCA effects for plant height under different sowing dates, contributing to increased plant height in their crosses.

For 100-grain weight, the parents P₁ and P₇ 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 P₂ and P₄ 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, P₂ and P₄ had high mean grain yield and highly significant positive GCA effects, but its longer duration to heading under different environments is not desirable. Also, P₅ and P₇ 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 F₁-hybrids, four crosses (P₁ × P₅, P₁ × P₇, P₂ × P₅, five and P₂ × P₇) 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; P₁ × P₅, P₂ × P₆, P₂ × P₇, P₅ × P₇, and P₆ × P₇, 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 P₂ × P₃, P₂ × P₇, P₃ × P₆, and P₅ × P₇ had significantly positive SCA effects for 100-grain weight in early and late sowing dates.

One cross only, P₂ × P₇, showed significant positive SCA effects for grain yield and gave the highest grain yield in their performance under early and late sowing dates (Table 4). Considering the two main traits, earliness and grain yield, the cross P₂ × P₇ 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 F₁'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 ₃	0.48	-1.82	0.63	2.69**	0.90**	0.49**	3.65**	-2.11**
P ₂ x P ₄	0.11	-1.64	-0.02	1.42	0.16	-0.35**	0.31	-1.07
P ₂ x P ₅	-1.78*	-7.79**	0.09	3.03**	0.12	-0.27*	-0.10	-1.23
P ₂ x P ₆	-2.70**	1.29	2.14**	4.08**	-0.51**	0.10	4.26**	-0.55
P ₂ x P ₇	-3.93**	-6.56**	2.13**	2.21*	0.79**	0.91**	2.04*	3.06**
P ₃ x P ₄	1.04	-2.68*	0.15	-0.10	0.19	0.31*	1.39	-0.05
P ₃ x P ₅	-1.52*	1.18	2.09*	-2.32*	-0.84**	0.05	0.14	-0.80
P ₃ x P ₆	-0.11	-1.42	0.64	-1.77	0.53**	0.75**	5.44**	-1.03
P ₃ x P ₇	-3.00**	3.06**	-1.54	-2.01*	0.53**	-0.25*	1.46	-2.88**
P ₄ x P ₅	-2.89**	1.36	2.78**	-1.60	0.08	-0.12	4.74**	0.54
P ₄ x P ₆	-1.81*	-1.23	-3.18**	-1.05	0.12	-0.09	-2.86**	-3.25**
P ₄ x P ₇	1.30	1.92	1.81*	-0.66	0.16	0.10	1.95	-0.60
P ₅ x P ₆	3.63**	1.62	1.43	2.56*	0.42*	-0.01	-2.38*	1.09
P ₅ x P ₇	7.07**	4.10**	6.59**	7.99**	1.08**	0.99**	-0.60	-2.56**
P ₆ x P ₇	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 normaland late sowing dates, better parent heterosis ranged from – 10.67 and – 18.5 to 7.63 and 0.63%, respectively. P₁ × P₅,

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
P ₁ x P ₂	-0.37	-4.59*	-0.49	0.87	6.60	0.00	5.47	24.32**
P ₁ x P ₃	-1.52	-5.31*	-3.15*	5.17**	0.00	-11.42*	12.73	2.08
P ₁ x P ₄	-0.37	-0.62	0.00	1.95	0.00	-8.25	2.10	-16.90*
P ₁ x P ₅	-10.44**	-18.58**	1.46	2.79	0.00	0.00	7.14	45.72**
P ₁ x P ₆	-0.19	-2.04	-0.91	4.13*	13.40*	0.00	6.81	-33.97**
P ₁ x P ₇	-10.67**	-17.33**	-1.33	-1.42	7.91	0.00	10.44	-6.63
P ₂ x P ₃	-1.50	-7.07**	1.62	4.43**	27.25**	23.18**	42.27**	-21.08**
P ₂ x P ₄	-1.48	-6.04**	0.49	3.17	14.13*	-9.26	11.97	-13.27*
P ₂ x P ₅	-4.36**	-16.53**	-2.93*	1.45	7.91	0.00	7.99	-29.07**
P ₂ x P ₆	-3.62**	-2.22	1.42	4.24*	0.00	10.21	32.98**	-19.33**
P ₂ x P ₇	-6.64**	-14.46**	-0.67	-2.97	15.83*	8.99	20.82**	-15.48*
P ₃ x P ₄	0.38	-3.92*	-0.48	0.42	8.99	11.42*	22.16**	-12.74
P ₃ x P ₅	-3.25*	-1.91	15.99**	-6.42**	-11.99	10.21	13.00	-32.38**
P ₃ x P ₆	0.19	-2.07	-1.32	-3.78*	6.60	30.03**	42.77**	-28.16**
P ₃ x P ₇	-4.40**	0.63	-6.11**	-5.93**	27.82**	0.00	21.38**	-34.34**
P ₄ x P ₅	-4.40**	-0.85	0.23	-5.33**	7.91	0.00	22.22**	-17.73**
P ₄ x P ₆	-1.34	-1.03	-3.85**	-2.75	6.60	0.00	-15.71*	-28.16**
P ₄ x P ₇	0.79	0.42	-0.89	-1.07	31.89**	36.24**	7.94	4.82
P ₅ x P ₆	4.74**	-0.21	1.91	6.42**	7.91	10.21	-6.23	-30.07**
P ₅ x P ₇	7.63**	0.43	15.43**	14.79**	43.88**	39.94**	2.82	-41.63**
P ₆ x P ₇	4.67**	-1.91	4.67**	6.05**	-7.91	0.00	0.17	-32.53**

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

P₁ × P₇, P₂ × P₅, 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 × P₆) 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).

References

- Ahmed, M. S. H., and Mohamed, S. M. S. (2009a) 'Diallel crosses of bread wheat (*Triticum aestivum* L.) at two sowing dates 1. Genetic analysis of yield and its components', *Egypt. J. Plant Breed.* 13: pp. 281 – 301.
- Ahmed, M. S. H. and Mohamed, S. M. S. (2009b) 'Diallel crosses of bread wheat (*Triticum aestivum* L.) at two sowing dates 2. Heterosis, correlation and path analysis among some yield components' *Egypt. J. Plant Breed.* 13: pp. 303 - 318.
- Ahmed, N., Khan A. S., Kashif, M., and Rehman, A. (2017) 'Genetic studies of biomass partitioning in wheat under water stress conditions' *The J. of Animal plant sciences*, 27: pp. 144 - 152.
- Ahmadi, J., Zali, A. A., Yazdi, S. B., Talaie, A., Ghannadha, M. R. and Saeidi, A. (2003) 'A study of combining ability and gene effect in bread wheat under drought stress condition by diallel method' *Iranian J. of Agric. Sci.*, 34 (1): pp. 1 - 8. (C.F. Computer Inter. Agric. Cent. for Information Service).
- Ali, M. A. (2006) 'Combining ability and stability analysis in spring wheat under four soil available water levels,' *Assiut J. of Agric. Sci.*, 37(4): pp. 95 – 118.
- M. Ali, M. A., Hassan, M. S. and Ali, I. A. (2020) 'Combining ability in some genotypes of bread wheat (*Triticum aestivum* L.) under different sowing dates,' *SVU-International J. of Agric. Sci.*, Volume 2 Issue (2): pp. 291 - 305.
- Bahatt, G. M. (1971) 'Heterotic performance and combining ability in diallel cross among spring wheat (*Triticum aestivum* L.),' *Aust J. Agric. Res.*, 22: 3pp. 59 - 368.
- Bajaniya, N., Pansuriga, A. G. Vekaria, D. M., Singh C. and Savaliga, J. J. (2019) 'Combining ability for grain yield and its components in durum wheat (*Triticum durum* Desf.)' *Ind. J. Pure App. Biosci.*, 7: pp. 217 - 224.
- Barot, H. G., Patel, M. S., Sheikh, W. A., Patel, L. P. and Allam, C. R. (2014) 'Heterosis and combining ability analysis for yield and its component traits in wheat (*Triticum aestivum* L.)' *Elec. J. Pl. Br.*, 5(3): pp. 350 - 359.
- Darwish, I. H. I., El-Sayed, E., and Waffa, El-Awady (2006) 'Genetical studies of heading date and some agronomic characters in wheat' *Annals of Agric. Sci. Moshtohor*, 44(2): pp. 427 - 452.
- Dencic, S., Kastori, R., Kobiljski, B. and Duggan, B. (2000) 'Evaluation of grain yield and its components in wheat cultivars and landraces under near-optimal and drought conditions,' *Euphytica* 113: pp. 43 - 52.
- Dhadhal, B. A. and Dobariya, K. L. (2006) 'Combining ability analysis over environments for grain yield and its components in bread wheat (*Triticum aestivum* L.),' *National. J. Pl. Improv.*, 8, 172 - 173.
- El-Beially, I. E. M. A. and El-Sayed, E. A. M.. (2002) 'Heterosis and combining ability for some bread wheat cross' *J. Agric. Sci. Mansoura Univ.*, 27(9): pp. 5735 – 5744.

- El-Rawi, K. and Khalafalla, A. M. (1980) 'Design and analysis of agricultural experiments' *El Mousel Univ.*, Iraq, 19.
- Ezatollah, F., Rafiee, F., and Hasheminasab, H. (2013) 'Evaluation of genetic parameters of agronomic and morpho-physiological indicators of drought tolerance in bread wheat (*Triticum aestivum* L.) using diallel mating design' *Australian J. of Crop Sci.*, 7 (2): pp. 268 - 275.
- Falconer, D. S. (1990) 'Selection in a different environment affects environmental sensitivity (reaction norm) and mean performance' *Genet. Res. Camb.*, 56: pp. 57 - 70.
- FAO (2018) 'Food and Agriculture Organization of United Nations' Vial Delle Terme di Caracalla, 00100. Rome, Italy.
- Fisher, R. A., and Maurer, R. O. (1978) 'Drought resistance in spring wheat cultivars. 1- Grain yield responses', *Aust. J. Agric. Res.*; 29: pp. 897-912.
- Fisher, R. A. and R. O. Maurer. 1978. Drought resistance in spring wheat cultivars. 1- Grain yield responses. *Aust. J. Agric. Res.*; 29: pp. 897 - 912.
- Gomez, K. A., and Gomez, A. A. (1984) 'Statistical Procedures for Agricultural Research' John Wiley & Sons Inc. New York, USA.
- Gribson, L. R. and Paulsen, G. M. (1999) 'Yield components of wheat grown under high-temperature stress during reproductive growth' *Crop Sci.*; 39 (6): pp. 1841 – 1846.
- Griffing, B. (1956) 'Concept of general and specific combining ability in relation to diallel crossing systems' *Aust. J. Biol. Sci.*, 9: pp. 463 - 493.
- Hassan, M. O. M. (2015) 'Combining ability and genetic components in durum wheat under heat stress conditions in reclaimed soils' *M.Sc. Thesis, Fac. of Agric. Assiut Univ., Egypt*.
- Hassan, M. I. (2016) 'Assessment of genetic diversity in bread wheat genotypes based on heat tolerance and SSR markers' *Assiut J. Agric. Sci.*, 47 (5): pp. 37 - 55.
- Hoffman, B. and Burucs, Z. (2005) 'Adaptation of wheat (*Triticum aestivum* L.) genotypes and related species to water deficiency' *Cereal Research Comm.*, 33: pp. 681 - 687.
- Jaiswal, B., S., Prasad, R., Dwivedi, S., Singh, R., Shrivastava, R., Kumar, S. A. and Yadav, R. K. (2017) 'Study of yield and yield components of wheat (*Triticum aestivum* L.) genotypes at grain filling stage under heat regimes' *Int. J. Pure App. Biosci.*, 5(4): pp. 331 - 340.
- Lobell, D. B., Ortiz-Monasterio, IJ., and Asner, GP. (2005) 'Analysis of wheat yield and climatic trends in Mexico' *Field Crops Res.*; 94: pp. 250 – 256.
- Lohithaswa, H. C., Desai, S. A., Hanchinal, R. R., Patil, B. N., Math, K. K., Kalappanavar, I. K., Bandivadder, T. T. and Chandrashekhara, C. P. (2013) 'Combining ability in tetraploid wheat for yield, yield attributing traits, quality and rust resistance over environments' *Karnataka Journal of Agricultural Science*, 26(2): pp. 190 - 193.

- Mohamed, M. M. (2007) 'Genetic studies on durum wheat breeding for heat tolerance' *M.Sc. Thesis, Faculty of Agric. El-Minia., Univ., Egypt.*
- Mwadingeni, L., Shimelis, H. and Tsilo, T. J. (2017) 'Combining ability and gene action controlling yield and yield components in bread wheat (*Triticum aestivum* L.) under drought-stressed and non-stressed conditions' *Plant Breeding*, Volume 137, issue 4.
- Nassar, S. M. A. M. (2013) 'Genetic variance and combining ability in bread wheat under drought stress conditions' *Ph.D. Thesis, Fac. of Agric. Assiut Univ., Egypt.*
- Pansuriya, A. G., Dhaluk, L. K., Vanpariya, L. G., Savaliya, J. J., Patel, M. B. and Mehta, D. R. (2014) 'Combining ability over environments for grain yield and its components in bread wheat (*Triticum aestivum* L.)' *Int. e. J.*, 3(1): pp. 36 - 46.
- Saini, A. D., Dadhwal, V. K., Phadnawis, B. N. and Nonda, R. (1986) 'Influence of sowing dates on pre-anthesis phenology in wheat' *Indian J. of Agric. Sci.* 56: pp. 503 - 511.
- Samra, J. S. Dhilion, S. S. and Kahlon, P. S. (1989) 'Response of wheat varieties to date of sowing' *Indian J. Agron.* 34: pp. 286 - 289.
- Shah, W. A., Bakht, J., Ullah, T., Khan, A. W., Zubair, M., and Khakwani, A. A. (2006) 'Effect of sowing dates on the yield and yield components of different wheat varieties' *Journal of Agronomy*, 5 (1): pp. 106 – 110.
- Sharma, V., Dodiya, N. S., Dubey, R. B., and Khn, R. (2019) 'Combining ability analysis in bread wheat (*Triticum aestivum* L.) EM. Thell) under different Environmental conditions' *Bangladesh J. Bot.* 48: pp. 89 - 93.
- Sharma, A. K. and Garg, D. K. (2005) 'Combining ability over environments in bread wheat (*Triticum aestivum* L.)' *J. Maharashtra Agric. Univ.*, 30, pp. 153 - 156.
- Singh, K., Singh, U. B. and Sharma, S. N. (2013) 'Combining ability analysis for yield and its components in bread wheat (*Triticum aestivum* L.)' *J. Wheat Res.*, 5(1): pp. 63 - 67.
- Vanpariya, L. G.;V. P. Chovatiaand D. R. Mehta (2006) 'Combining ability studies in bread wheat (*Triticum aestivum*L.)' *National J. Pl. Improv.*, 8(2): pp. 132-137.
- Wajid, A. J., Baloch, M. J., Kumbhar, M. B., Khan, N. U., and Kerio, M. I. (2011) 'Effect of water stress on physiological and yield parameters at anthesis stage in elite spring wheat cultivars' *Sarhad J. Agric.*, 27 (1): pp. 59 - 65.