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Half Diallel Analysis and Heat Stress Tolerance Indices for Grain Yield in Bread Wheat

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ABSTRACT

Heterosis and combining ability were determined in bread wheat using 6 x 6 half diallel analysis under normal and late planting dates during seasons 2019/2020 and 2020/2021 at Al-Matana Agricultural Research Station, Agricultural Research Center, Luxor governorate. Mean squares due to genotypes, parents, crosses, general (GCA) and specific combining ability (SCA) were significant or highly significant for the most traits. Days to heading (DH), plant height (PH), spike length (SL) under both dates in addition spikes/plant (NS/P), biological yield/plant (BY/P), harvest index (HI) and 1000 grains weight under normal date and grain yield/plant (GY/P), grains/spike (NG/S) under late date were controlled by additive gene action. The rest traits were controlled by dominance gene action. Under normal date, Sids 14 proved to be a good combiner for NS/P and BY/P. All crosses showed positive highly significant heterobeltiosis for GY/P. The crosses P1XP5 and P3XP4 showed significant or highly significant positive SCA for BY/P, GY/P, number and weight of grains/spike. Under late date, Gemmeiza 11 and Misr 2 proved as good combiner for BY/P, GY/P and NG/S. Significant positive GCA effects found for GY/P of Shandaweel 1. SCA effects were positive significant or highly significant for BY/P and GY/P of the four crosses P1XP3, P1XP5, P2XP6 and P4XP6. The crosses P2XP6, P3XP4, P3XP6 and P4XP6 showed highly significant heterobeltiosis for GY/P. It could be concluded that the two crosses of P1XP5 and P2XP6 were the most heat tolerance with high yield and could be used to obtain segregating populations to apply selection.

***Keywords*:** heterosis, combining, additive, variance, dominance

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the main staple grain crop not only in Egypt but also world people. Because of the increased inhabitants, a limited wheat cultivated area and the shortage in water resources, local wheat production in Egypt could not cover the consumption (Hossain *et al.*, 2021). Thus, increasing the wheat productivity is crucial objective to meet the increase in consumption. In Egypt wheat total cultivated area is estimated at 1.4 million hectare, and the total production amounted to approximately 8.9 million tons, total consumption about 18 million tons. So, Egypt is the largest importer of wheat in the world (FAO, 2020). Wheat cultivation is widespread in Egypt between latitudes 25°N and 31°N. Majority of the wheat area situated in the Delta region by 65%, and small areas by 18% and 17% in Middle and Upper Egypt, respectively (Majeed *et al.*, 2015). Upper Egypt region situated in the southern of Egypt; the region is characterized by high temperature (Mohiy and Salous 2022).

Abiotic stresses, especially heat stress, is the major threats to sustainable wheat production. High-temperature stress not only affect growth and productivity of wheat (El-Rawy *et al.* 2018) but also had a severe impact on grain quality through the reduced accumulation of carbohydrates, gluten, and proteins (Riaz *et al.*, 2021). Heat stress had extensive damages almost in all developmental phases and organs of plant. The different plant phenology phases had genetic behavior to tolerate heat stress according the intensity and duration of heat. The early anthesis stage and pollen grains are the most sensitive to heat stress (Djanaguiraman, 2020). Heterosis is important measure in determining the direction of breeding programs. Heterosis in wheat has not yet been commercially exploited therefore, the heterosis can be exploited to achieve a more success in wheat production under terminal heat stress (Kumar *et al*. 2021).

The heterosis has a direct effect on the breeding method to improve the cultivars . Furthermore, giving idea about the general combining ability of parents and their usefulness in wheat breeding programs (Kumar *et al.*, 2020). Heterosis study could help the wheat breeders to eliminate the crosses with low productivity during early generation. Heterosis is useful in breeding programs, especially for traits controlled by non-additive gene action.

General combining ability GCA is the mean performance of a genotype in his hybrids, GCA is a measure of additive gene action whereas, specific combining ability SCA is the performance of a genotype in a specific cross, GCA is a measure of dominance gene action (Begna, 2021).

The magnitude of GCA variance was greater than the SCA variance suggesting a greater additive gene action. The estimate of GCA is used to predict additive gene effects of parents thus GCA could be an effective method for selection of parents (El Hanafi *et al.* 2022). Combining ability effects for grain yield components can serve as selection criteria to follow-up breeding for suitable biological yield in wheat (Shamuyarira *et al.* 2022).

Soughi and Khodarahmi 2021 revealed that cultivar with the best general combining ability for grain yield and

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biomass can be applied in hybridization programs to increase these traits.

The first step to improve wheat genotypes for heat tolerance, is the assessment of genetic diversity of cultivated germplasms for heat tolerance, second select the high heat tolerance genotypes. For this, estimation of combing ability effects gives valuable information for the selection of favorable parents to start an effective breeding program. Combining abilities give a thought for the evaluation of the genetic potential of grain yield under normal and heat conditions. Furthermore, it also defines the breeding value of parental lines to produce wheat hybrids (Romanus *et al.*, 2017).

Therefore, the present study was performed to estimate performance, heterosis and combining ability in F1 hybrids of six bread wheat cultivars under normal and late sowing dates.

MATERIALS AND METHODS

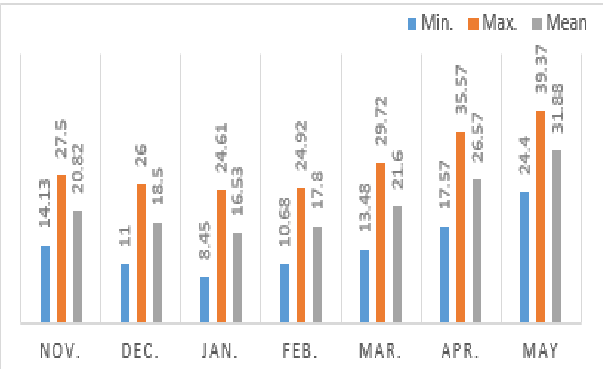
The present study was carried out during the two successive seasons of 2019/2020 and 2020/2021 at the Experimental Farm at Al-Matana Agricultural Research Station, (longitude of 32°38' 23"E and latitude of 25°41' 12" N) Egypt. Six cultivated different cultivars of bread wheat (*Triticum aestivum* L. em. Thell) were employed as parents; their pedigree and origin are listed in Table 1.

Table 1. Names and pedigrees of the studied bread wheat cultivars

S.N.	Genotypes	Pedigree and history	Origin
1	Gemmeiza 11	BOW"S"/KZ"S"//7C/AERY 82/3/GIZA 168/SAKHA 61 GM78922-GM-1GM-2GM-1GM-0GM	Egypt
2	Misr 2	SKAUZ / BAV92 CMSS96M03611S-1M-010SY-010M-010SY-8M-0Y-0S	Egypt
3	Sids 14	BOW"S"/VEE"S"//BOW"S"/TSI/3/ BANI SEWEF1 SD293-1SD-2SD-4SD-0SD	Egypt
4	Giza 171	SAKHA 93/GEMMEIZA 9 GZ 2003-101-1GZ-4GZ-1GZ-2GZ-0GZ	Egypt
5	Shandaweel 1	SITE/MO/4/NAC/TH.AC//3*PVN/3/MIRLO/BUC CMss93B00567S-72Y-010M-010Y-010M-3Y-0M-0THY-0SH.	Egypt
6	Sids 12	BUC//7C/ALD/5/MAYA74/ ON//1160.147/3/BB/GLL /4/ CHAT"S" /6/MAYA/VUL//CMH74A.630/4*SX SD7096-4SD-1SD-1SD-0SD	Egypt

In 2019/2020 season, the six parental cultivars were sown on 20th November. Using hand emasculation and pollination, a fifteen crosses using a half diallel among parents were applied.

In 2020/2021 season, the twenty-one entries, consisting of fifteen F_1 crosses and six parents were evaluated in a randomized complete block design with three replications in two sowing dates; recommended sowing date of 25th November and late sowing date of 25th December (heat stress). The experimental plot was a single row 3 m. long and 30 cm. apart, with 10 cm. between plants within each row. Figure 1 showed the average, minimum, and maximum temperatures at Al-Matana Agricultural Research Station, during the 2020/2021 season.



https://eg.freemeteo.com/weather/egypt

Figure 1. Mean, maximum and minimum temperatures (ºC) at El-Mattana Agric. Res. Station during 2020/2021 season.

The following characters were recorded based on plot mean to each of the parents and F_1 crosses: heading date (HD), (days from sowing to 50% of spikes emergence from flag leaf sheath), plant height (PH) in cm, (the distance from the base of the main culm to the top of the spike, excluding awns), spike length (SL) in cm, (from the base of the main spike to its tip excluding awns as average 10 random spikes), biological yield (BY/P) in grams, (the total biomass produced by the plant during the season, excluding the root), number of spikes/plant (NS/P), (number of tillers with fertile spikes/plant), grain yield/plant (GY/P) in grams, (average grain weight of individual guarded plant), harvest index% (HI), (the ratio of grain yield per plant to biological yield per plant), weight of grains/spike (WG/S) in grams, number of grains/spike (NG/S), (average number of grains per main spike of the 10 plants) and 1000-grains weight (1000 GW) in grams, (the weight of 1000-grains sample/plot).

Heterosis (H) was determined as the percentage of deviation of the F_1 mean from the mean of the better parent B.P as follows: H B.P. % = $(\overline{F1} - \overline{B.P}) / \overline{B.P} \times 100$

Genetical analysis of the data obtained was performed according to Griffing (1956), method 2, model 1. Mean data, better parent heterosis for all of the traits were analyzed by Microsoft Excel, general and specific combining ability effects were analyzed by the AGDR software from CIMMYT.

Heat tolerance indices

1- Heat susceptibility index HSI= $[1-(Ys/Yp)]/[1-(\bar{Y}s/\bar{Y}p)]$ (Fischer and Maurer, 1978)
2- Tolerance (TOL) = Yp – Ys (Rosielle and Hamblin, 1982)
3- Mean productivity (MP) = (Ys + Yp)/2 (Fernandez, 1992)
4- Geometric mean productivity (GMP) $=\sqrt{Y_s x Y_p}$ (Fernandez, 1992)

5- Stress tolerance index (STI) = (Ys . Yp)/ $\bar{Y}_P^2$ (Fernandez, 1992)
6- Yield stability index (YSI) = YS / YP (Bouslama and Schapaugh, 1984)
7- Harmonic mean (HM) = [2(Ys . Yp)/ (Ys+Yp)] (Chakherchaman *et al*., 2009)
8- Sensitivity heat index (SHI) = (Yp – Ys)/ Yp (Farshadfar and Javadinia, 2011)
9- Heat resistance index (HI) = [(Ys (Ys/Yp)]/ $\bar{Y}s$ (Lan, 1988)
10- Relative heat index (RHI) = [(Ys/Yp)/ ($\bar{Y}s/\bar{Y}p$)] (Fischer *et al*., 1998)

Modified stress tolerance index (MSTI) = K.STI (Farshadfar and Sutka, 2002)

11- K_1MSTI = (Y_p^2 /$\bar{Y}_p^2$) x STI
12- K_2MSTI = (Y_s^2 /$\bar{Y}_s^2$) x STI, Where, Y s, Y p, $\bar{Y}$ s and $\bar{Y}$p are yield under late (heat stress) and normal dates for each genotype, yield mean in late (heat stress) and normal dates for all genotypes, respectively.

RESULTS AND DISCUSSION

A- Analysis of variance

Means squares due to genotypes, parents and crosses were significant (p≤0.05 or 0.01) for the most studied traits under the two planting dates expect for grain yield/plant of parents under normal date and spike length of genotypes under late date. With exception days to heading and spike length under normal planting date and number of spikes per plant under the two dates means squares due to parents vs crosses were significant (p≤0.05 or 0.01) for studied traits under both dates. It's observed that variation under normal was higher than variation under late date (heat stress) for most traits of most sources of variation (Table 2). Indicating, the selection for studied traits could be more effective under recommended planting date. Similar results were found by Aboshosha *et al.* (2018) and Hassan *et al.* (2020).

Mean squares due to a GCA were significant (p≤0.05 or 0.01) for all studied traits under two dates expect for grain yield/plant and number of grains/spike under normal date and spikes/plant and harvest index under late date (heat stress). Mean squares due to SCA were significant (p≤0.05 or 0.01) for all traits under both planting date with exception number of spikes and 1000 grain weight under normal date and DH and SL under both dates (Table 2). Indicating the importance role both of additive and non-additive effects in expression of these traits.

Table 2. Mean squares for the studied traits in 6 x 6 half diallel crosses of bread wheat under normal N and late L dates

S.V.	Date	Reps	Genotype	Parents (P)	Crosses (C)	P vs C	GCA	SCA	Error	GCA/ SCA	C.V. %
d.f.	-	2	20	5	14	1	5	15	40	-	-
DH	N	4.06	26.28**	54.49**	18.07**	0.23	88.84**	5.43	3.21	4.70	2.05
	L	20.97	3.18*	3.92**	2.44**	9.91**	4.46*	2.76	1.72	0.20	0.97
PH	N	3.24	81.56**	40.63**	81.56**	378.78**	137.50**	62.91**	7.18	0.17	2.4
	L	3.44	50.74**	44.46**	54.17**	34.30**	119.91**	27.69**	4.33	0.49	1.24
SL	N	4.26	3.97**	6.43**	3.36**	0.26	12.48**	1.14	0.64	2.84	6.47
	L	0.2	0.98	0.58**	1.18**	0.13**	1.95*	0.66	0.75	0.00	8.24
NS/P	N	9.69	3.98**	5.60**	3.52**	2.3	9.69**	2.07	1.16	1.05	11.03
	L	2.8	3.03*	5.30**	2.43**	0.01	2.15	3.32**	1.34	0.00	6.11
BY/P	N	15.53	452.26**	423.20**	192.67**	4231.80**	744.98**	354.68**	35.86	0.15	7.06
	L	27.1	263.61**	40.87**	348.72**	185.65**	208.08**	282.12**	19.68	0.00	1.06
GY/P	N	34.71	56.10**	4.07	23.56*	771.90**	13.19	70.40**	11.46	0.00	12.86
	L	12.78	40.86**	63.02**	35.54**	4.59**	42.34**	40.37**	1.46	0.01	3.43
HI	N	16.97	35.86**	43.10**	18.68*	240.19**	52.77**	30.23**	9.07	0.13	9.64
	L	12.11	155.66**	185.40**	155.75**	5.70*	29.9	197.58**	15.37	0.00	0.59
NG/S	N	95.4	129.72**	48.15*	58.33**	1536.91**	26.89	163.99**	16.21	0.00	7.18
	L	2.44	52.69**	48.34**	52.90**	1.42**	130.95**	26.60**	7.62	0.69	2.5
WG/S	N	0.12	0.63**	0.28*	0.31**	6.92**	0.49**	0.68**	0.08	0.00	9.3
	L	0.02	0.29**	0.08**	0.29**	1.40**	0.29**	0.29**	0.03	0.00	21.83
1000	N	8.92	43.42**	34.61*	42.15**	105.41**	116.46**	19.08	10.6	1.44	6.01
GW	L	18.22	57.22**	27.22**	31.37**	569.15**	23.90**	68.33**	5.59	0.00	0.65

***, ** significant at 0.05 and 0.01 levels of probability, respectively, DH = days to 50% heading, PH = plant height, SL = spike length, NS/P = number of spikes/plant, BY/P = biological yield/plant, GY/P = grain yield/plant, HI= harvest index, NG/S = number of grains/spike, WG/S = weight of grains/spike, 1000GW = 1000 grains weight.**

B- Mean Performance

The means of all traits nearly for the parents and crosses decreased in the late planting (heat stress) compared to normal date (Table 3).

Regarding parents, days to heading ranged from 82.33 of Gimmeiza 11 to 93.67 of Misr 2 under normal date and from 74.33 of Sids 12 to 77.33 of Sids 14 under late date. The best parents under normal date were Misr 2 for plant height (115.00 cm), Gemmeiza 11 for each of spike length (14.27 cm), harvest index (32.50%), grains/spike (53.00) and weight of grains/spike (2.91 gm), Sids 14 for spikes/plant (11.67) and biological yield/plant (92.00 gm), Sids 12 for grain yield/plant (22.75 gm) and 1000 grains weight (55.63 gm) (Table 3). While, under late date (heat stress), the best parents were Shandaweel 1 for each of plant height (101.33 cm), spikes/plant (9.63), grain yield/plant (21.33 gm), harvest index (46.07%) and weight of grains/spike (2.63 gm), Sids 12 for spike length (12.63 cm), Gemmeiza 11 for each of biological yield/plant (50.00 gm) and number of grains/spike (55.10) and Giza 171 of 1000 grains weight (52.00 gm) (Table 3).

Regarding the crosses, the two crosses P_1XP_4 and P_5XP_6 were the earliest in days to heading by 83.33 and 73.33 days under normal and late (heat stress) dates, respectively. The best crosses under normal date were P_2XP_4 for plant height (122.50 cm), P_1XP_6 for spike length (14.60 cm), P_1XP_5 for grains/spike (64.90) and P_1XP_4 for weight of grains/spike (3.66 gm), P_3XP_4 for each of spikes/plant (11.43), biological yield/plant (101.90 gm), P_1XP_3 for grain yield/plant (32.75 gm), P_3XP_6 for harvest index (36.00%) and P_4XP_6 for 1000 grain weight (62.53 gm) (Table 3).

Table 3. Means of the studied traits for the 6 parents and 15 F1's crosses of bread wheat under normal (N) and late (L) dates

Trait	DH		PH; cm.		SL; cm.		NS/P		BY/P; gm.	
Genotype	N	L	N	L	N	L	N	L	N	L
P_1	82.33	75.67	105.00	98.33	14.27	12.43	8.57	7.17	61.00	50.00
P_2	93.67	77.33	115.00	101.00	10.23	11.97	10.90	8.35	64.50	44.33
P_3	90.00	77.33	107.50	91.33	10.90	11.47	11.67	7.97	92.00	40.00
P_4	89.00	76.33	107.50	95.67	12.63	11.97	8.67	6.03	62.00	41.92
P_5	87.00	76.67	105.00	101.33	12.57	12.50	11.20	9.63	76.00	46.33
P_6	83.33	74.33	107.50	100.00	12.97	12.63	9.30	6.43	75.50	41.50
P_1 x P_2	85.67	74.33	110.00	99.67	11.43	12.20	9.60	8.30	71.33	53.75
P_1 x P_3	85.33	75.33	117.50	95.67	12.37	11.97	11.23	8.35	95.00	56.00
P_1 x P_4	83.33	75.67	112.50	91.67	13.27	12.27	7.40	7.60	82.00	37.75
P_1 x P_5	85.67	75.33	107.50	99.67	13.30	13.67	8.63	8.80	89.00	67.00
P_1 x P_6	87.00	76.00	105.00	100.33	14.60	12.27	8.27	8.17	86.00	38.50
P_2 x P_3	93.00	76.67	115.00	100.33	11.67	11.00	9.43	6.57	91.40	39.08
P_2 x P_4	90.67	76.00	122.50	99.00	10.33	11.13	9.43	7.80	93.40	65.50
P_2 x P_5	90.00	76.00	115.00	99.67	11.80	11.77	10.20	7.20	89.00	45.50
P_2 x P_6	89.00	75.00	121.00	99.67	12.73	11.80	9.37	8.75	91.60	55.71
P_3 x P_4	89.00	74.67	112.50	93.00	12.17	12.47	11.43	7.63	101.90	44.25
P_3 x P_5	88.67	76.00	110.00	89.00	11.83	12.37	10.47	5.63	98.70	36.00
P_3 x P_6	87.33	76.67	115.00	94.00	12.67	11.50	10.30	6.52	100.50	34.00
P_4 x P_5	87.67	75.33	107.50	89.67	11.43	12.17	10.37	7.40	89.80	42.50
P_4 x P_6	87.33	74.67	117.50	92.67	12.80	12.37	9.37	8.40	80.00	58.67
P_5 x P_6	85.67	73.33	111.67	100.67	13.63	11.97	8.90	7.13	90.00	43.00
LSD 5%	2.96	2.16	4.42	3.45	1.32	1.45	1.77	1.91	9.88	7.32
LSD 1%	3.96	2.90	5.92	4.62	1.76	1.94	2.37	2.56	13.22	9.79

Trait	GY/P; gm.		HI%		NG/S		WG/S		1000GW; gm.	
Genotype	N	L	N	L	N	L	N	L	N	L
P_1	20.00	20.50	32.50	40.97	53.00	55.10	2.91	2.56	54.83	46.55
P_2	21.00	19.17	29.50	43.24	51.45	54.30	2.61	2.44	50.77	45.00
P_3	21.27	10.17	22.00	25.56	41.53	49.10	2.14	2.18	51.60	44.35
P_4	20.17	17.50	29.00	41.76	48.55	45.35	2.61	2.36	53.67	52.00
P_5	19.50	21.33	25.50	46.07	46.75	55.00	2.17	2.63	46.33	47.85
P_6	22.75	12.25	30.50	31.76	48.25	49.50	2.69	2.49	55.63	50.35
P_1 x P_2	25.50	20.75	35.50	38.61	53.55	59.70	2.88	3.39	53.87	57.00
P_1 x P_3	32.75	19.00	34.00	34.06	56.60	56.43	3.22	3.42	57.03	60.55
P_1 x P_4	23.75	15.50	34.00	41.09	62.55	45.75	3.66	2.46	58.37	53.65
P_1 x P_5	30.25	21.75	34.00	32.49	64.90	51.55	3.44	2.93	53.10	56.90
P_1 x P_6	26.75	16.50	31.00	42.93	63.20	53.33	3.52	2.71	55.70	50.80
P_2 x P_3	25.25	17.50	27.00	44.87	64.65	53.87	3.33	2.68	51.73	49.73
P_2 x P_4	30.60	10.25	32.50	15.85	50.25	53.55	2.59	2.59	51.50	48.15
P_2 x P_5	26.00	17.25	30.00	37.93	63.15	52.05	3.08	2.78	48.67	53.47
P_2 x P_6	31.00	22.50	33.33	40.47	56.70	55.15	3.32	3.07	58.63	55.73
P_3 x P_4	32.00	18.50	32.00	41.83	62.80	48.60	3.48	2.57	55.43	52.87
P_3 x P_5	28.33	14.00	29.00	39.18	55.80	47.20	2.80	2.62	50.23	55.45
P_3 x P_6	32.00	15.25	36.00	44.85	59.20	44.43	3.49	2.36	59.17	53.07
P_4 x P_5	28.75	13.50	33.50	31.91	55.53	45.57	2.97	2.64	53.50	58.00
P_4 x P_6	27.75	21.75	34.50	37.14	58.05	48.90	3.63	2.68	62.53	54.95
P_5 x P_6	27.25	17.25	31.00	40.18	60.90	49.80	3.39	2.73	55.57	54.73
LSD 5%	5.59	1.99	4.97	6.47	6.64	4.55	0.47	0.30	5.37	3.90
LSD 1%	7.47	2.67	6.65	8.65	8.89	6.09	0.63	0.40	7.19	5.22

P_1, Gemmeiza 11, P_2, Misr 2, P_3, Sids 14, P_4, Giza 171, P_5, Shandaweel 1, P_6, Sids 12, DH = days to 50% heading, PH = plant height, SL = spike length, NS/P = number of spikes/plant, BY/P = biological yield/plant, GY/P = grain yield/plant, HI= harvest index, NG/S = number of grains/spike, WG/S = weight of grains/spike, 1000GW = 1000 grains weight.

While, under late date (heat stress) the best crosses were P5XP6 for plant height, P1XP5 for each of spike length (13.67 cm), spikes/plant (8.80) and biological yield/plant (67.00 gm), P2XP6 for grain yield/plant (22.50 gm), P2XP3 of harvest index (44.87%), P1XP2 for number of grains/spike (59.70), and the cross P1XP3 for each of weight of grains/spike (3.42 gm) and 1000 grain weight (60.55 gm). Generally, all studied traits of the F1's crosses were reduced with the planting in late date. This may be due to the negative effect of high temperature on pollen grains that caused reduction in number and size of spike grains. These results are in line with those reported by Motawea (2017) and Fouad (2019 a and b).

C- Combining ability

1- Analysis of variance

Under normal date, mean squares for GCA and SCA were significant ($P \leq 0.01$) for the most studied traits expect for GY/P and NG/S under normal planting date and NS/P and HI under late of GCA and DH, SL under both dates, NS/P and 1000GW under late date (heat stress) of SCA (Table 2).

Indicating, presence of significant difference among the six parents for GCA and the 15 F_1's crosses for SCA in these traits. Estimates of variance due to GCA, hence additive gene action was greater than variance due to SCA for DH, PH, SL under both dates, NS/P, BY/P, HI and 1000 grain weight under normal and GY/P and NG/S under late date. These finding are not in harmony with GCA/SCA ratio that was higher than unity for most traits except DH, SL, NS/P and 1000 GW under normal date, suggesting role of the additive gene action in inheritance of these four traits. Therefore, improvement of these four traits it could be performed by selection in segregating generation. Meanwhile, estimates of variance due to SCA, hence dominance (non-additive) gene action was higher than GCA for the rest traits (Table 2). Similar results for the greater importance of GCA compared to SCA variance were found by El Hanaf *et al.* (2022), El-Saadoown *et al.* (2017) and Jatav *et al.* (2017) and Kumari *et al.* (2022).

1- General combining ability (GCA) effects

Gemmeiza 11 under normal date, and Sids 12 under both dates showed highly significant negative GCA effects. So, considered the best combiners for days to 50% heading. Misr 2 under both dates and Sids 12 under late date had positive highly significant GCA effects for plant height and so could be used as good combiners for the tallest plant. Under normal planting date, GCA affects for Gemmeiza 11 and Sids 12 were positive highly significant for spike length, Indicating ability to use them as source for spike length. Moreover, Sids 12 showed positive Positive and highly significant GCA for 1000 grain weight. So, Sids12 was a good general combining ability for 1000 grain weight. Sids14 proved to be a good combiner for number of spike/plant and biological yield/plant. Where Sids 14 record highly significant positive GCA effects for the two traits (Table 4).

Under late planting date (heat stress), Comparison between GCA effects for each parent showed that Gemmeiza 11 and Misr 2 proved as good combiner for BY/P, GY/P and NG/S in addition for WG/S of Gemmeiza 11, indicating their superiority as sources of yield improvement in wheat breeding program under late planting date. Significant positive general combining ability effects was found for grain yield/plant of Gemmeiza 11, Misr 2 and Shandaweel 1 (Table 4). Dedaniya *et al* (2019) found similar results.

Table 4. General combining ability GCA effects of the six bread wheat parents for the studied traits under normal (N) and late (L) dates

Trait	Date	P_1	P_2	P_3	P_4	P_5	P_6	S.E. gi	S.E. gi-gj
DH	N	-2.74**	2.76**	1.22*	0.31	-0.24	-1.32*	0.58	0.9
	L	-0.19	0.39	0.56	-0.07	-0.03	-0.65*	0.42	0.66
PH	N	-2.51**	3.87**	0.31	0.62	-2.61**	0.33	0.86	1.34
	L	0.78	2.86**	-2.85**	-2.51**	0.49	1.24*	0.67	1.04
SL	N	0.87**	-1.01**	-0.50*	-0.16	0.07	0.73**	0.26	0.4
	L	0.33	-0.35	-0.3	-0.04	0.29	0.07	0.28	0.43
NS/P	N	-0.75*	0.2	1.00**	-0.36	0.34	-0.43**	0.35	0.54
	L	0.28	0.26	-0.33	-0.3	0.27	-0.18	0.37	0.58
BY/P	N	-6.03**	-3.48*	9.74**	-2.81	1.87	0.69	1.93	2.99
	L	3.24**	2.64*	-4.72**	0.68	-0.05	-1.78	1.43	2.22
GY/P	N	-0.65	-0.48	1.08	-0.13	-0.58	0.76	1.09	1.69
	L	1.72**	0.73*	-2.02**	-0.78*	0.71*	-0.37	0.39	0.6
HI	N	1.84	-0.18	-2.10*	0.72	-1.28	1.01	0.97	1.51
	L	0.86	0	-1.04	-1.61	1.2	0.61	1.27	1.96
NG/S	N	1.79	-0.16	-1.29	-0.77	0.17	0.26	1.3	2.01
	L	2.36**	3.10**	-1.17	-3.13**	-0.24	-0.93	0.89	1.38
WGS	N	0.15	-0.11	-0.09	0.03	-0.16	0.18	0.09	0.14
	L	0.16**	0.08	-0.10*	-0.14	0.03	-0.03	0.06	0.09
1000-GW	N	1.06	-1.67*	-0.31	1.17	-3.19**	2.95**	1.05	1.63
	L	0.62	-1.62**	-0.84	0.57	0.9	0.37	0.76	1.18

P_1, Gemmeiza 11, P_2, Misr 2, P_3, Sids 14, P_4, Giza 171, P_5, Shandaweel 1, P_6, Sids 12, *, ** significant at 0.05 and 0.01 levels of probability, respectively, DH = days to 50% heading, PH = plant height, SL = spike length, NS/P = number of spikes/plant, BY/P = biological yield/plant, GY/P = grain yield/plant, HI= harvest index, NG/S = number of grains/spike, WG/S = weight of grains/spike, 1000GW = 1000 grains weight.

2- Specific combining ability SCA effects

The cross P_1XP_2 under both dates, P_3XP_4 and P_5XP_6 under late date showed negative significant SCA effects for days to heading. The three crosses were raised from crossing good x poor general combiner for days to heading.

Under normal planting date, crosses P_1XP_3, P_3XP_6 and P_4XP_6 showed highly positive significant SCA for each of (PH and NS/P), HI% and 1000GW, respectively. The results revealed two crosses of P_1XP_5 and P_3XP_4 had positive significant ($P \leq 0.05$ or less) SCA for biological, grain yield/plant, number and weight of grains per spike. Three crosses P_1XP_3, P_2XP_4 and P_2XP_6 showed positive significant ($P<0.05$ or 0.01) SCA for traits; plant height, biological and grain yield/plant. The two crosses of P_1XP_6 and P_3XP_6 showed significant positive SCA effects to (BY/P and NG/S) and (GY/P and WG/S), respectively. Two crosses of P_4XP_6 and P_5XP_6 given positive significant ($P \leq$ 0.05 or 0.01) SCA effects for (WG/S and 1000-GW) and (NG/S and WG/S), respectively (Table 5). It`s noteworthy that the promising cross were obtained from (good X good), (good X poor) and (poor X poor) general combiners. Consequently, in the presence of epistatc effects it is not necessary that any parents having GCA effects would also give high of SCA effects in their cross combination. These results were in harmony with those reported by Shaban *et al.* (2018), Chaudhary *et al.* (2022) and Thungo *et al.* (2022). Soughi and Khodarahmi 2021 revealed that cultivars Ehsan and Mehrgan had the highest GCA for grain yield and biomass. It could be applied in hybridization to increase grain yield and biomass. Additive variance of genes in plant height, grain weight/spike and 100 grains weight was more than dominance variance. Furthermore, Ehsan cultivar had the highest GCA for grain yield and biomass and hybrids raised from cross Ehsan×Mehrgan had the highest SCA for grain and biological yield.

Generally, the excellent cross combinations which showed desirable SCA effects, exhibited also high useful heterosis. These results, revealed that dominance (non-addition) gave action played an important role in expression of their traits. Kajla *et al.* (2022) and Singh *et al.* (2022) reached the same conclusion.

Under late date (heat stress), SCA effects revealed that the two crosses P_1XP_5 and P_2XP_3 had positive significant (P≤0.05 and 0.01) SCA effects for spike length and plant height, respectively. Estimates of SCA effect were positive significant (P≤0.05 or 0.01) for biological yield and grain yield/plant of four crosses P_1XP_3, P_1XP_5, P_2XP_6 and P_4XP_6, In addition P_2XP_3 and P_3XP_4 for grain yield/plant. For harvest index, three crosses P_2XP_3, P_3XP_4 and P_3XP_6 gave highly significant positive SCA effects. Concerning NG/S, two crosses P_1XP_2 and P_1XP_3 were showed significant (P≤ 0.05 or 0.01) positive SCA effects. Positive significant (P≤0.01) SCA effects were found of three crosses, P_1XP_2, P_1XP_3, and P_2XP_6 for traits WG/S and 1000 GW in addition two crosses P_1XP_5 and P_4XP_5 of 1000 grain weight (Table 5). GCA effects is useful for detecting the validity of the genotype in cross combination, while SCA effects related to heterosis this indicated that GCA effects were related to SCA values of their corresponding hybrids for some trait. Based on this result, the two parents P_1, Gemmizea 11 and P_2, Misr 2 gave positive significant (P≤0.01) GCA effects for grains/spike (Table 4). It produces the cross P_1XP_2 which showed significant positive SCA effects for NG/S (Table 5). Similarly was found with the two parents P_1, Gmmizeia11 and P_5, Shandwel1 with their cross in grain yield per plant. This may explined that additive and dominance gene action present in their crosses to increase these traits. Similar results were reported by Chaudhary *et al.* (2022), Kumari and Sharma (2022) and Thungo *et al.* (2022).

Table 5. Specific combining ability SCA effects of the 15 F1's crosses for studied traits under normal (N) and late (L) dates

Trait	**DH**		**PH**		**SL**		**NS**		**BY/P**	
Cross	**N**	**L**	**N**	**L**	**N**	**L**	**N**	**L**	**N**	**L**
P_1 x P_2	-2.01*	-1.51*	-3.15*	-0.75	-0.79	0.13	0.4	0.15	-3.96	1.15
P_1 x P_3	-0.8	-0.68	7.91**	0.96	-0.36	-0.15	1.24*	0.79	6.49*	10.75**
P_1 x P_4	-1.89	0.28	2.6	-3.38**	0.19	-0.11	-1.24*	0	6.04	-12.89**
P_1 x P_5	0.99	-0.1	0.82	1.63	-0.01	0.96*	-0.71	0.64	8.36*	17.09**
P_1 x P_6	3.40**	1.2	-4.61**	1.54	0.64	-0.22	-0.31	0.45	6.54*	-9.69**
P_2 x P_3	1.36	0.07	-0.97	3.54**	0.82	-0.44	-1.51*	-0.97	0.34	-5.56*
P_2 x P_4	-0.05	0.03	6.22**	1.87	-0.86	-0.57	-0.15	0.23	14.89**	15.46**
P_2 x P_5	-0.18	-0.01	1.95	-0.46	0.38	-0.26	-0.09	-0.94	5.81	-3.81
P_2 x P_6	-0.1	-0.39	5.01**	-1.21	0.65	-0.01	-0.15	1.06	9.59**	8.12**
P_3 x P_4	-0.18	-1.47*	-0.22	1.58	0.47	0.71	1.05	0.65	10.17**	1.57
P_3 x P_5	0.03	-0.18	0.51	-5.42**	-0.1	0.29	-0.62	-1.92**	2.29	-5.95*
P_3 x P_6	-0.22	1.11	2.57	-1.17	0.08	-0.36	-0.01	-0.58	5.27	-6.23*
P_4 x P_5	-0.05	-0.22	-2.3	-5.08**	-0.85	-0.18	0.64	-0.18	5.94	-4.85*
P_4 x P_6	0.7	-0.26	4.76**	-2.83*	-0.13	0.25	0.41	1.27	-2.68	13.04**
P_5 x P_6	-0.43	-1.64*	2.16	2.17	0.47	-0.48	-0.76	-0.57	2.64	-1.9
S.E. sij	1.59	1.16	2.38	1.84	0.71	0.77	0.95	1.03	5.31	3.93
S.E. sij-sik	2.37	1.73	3.54	2.75	1.06	1.15	1.42	1.53	7.92	5.87
S.E. sij-skl	2.2	1.61	3.28	2.55	0.98	1.06	1.32	1.42	7.33	5.43
Trait	GY/P		HI		NG/S		WG/S		1000GW	
Cross	N	L	N	L	N	L	N	L	N	L
P_1 x P_2	0.32	1.05	2.59	0.01	-4.15	3.08*	-0.21	0.48**	0.3	5.57**
P_1 x P_3	6.00**	2.05**	3	-3.51	0.03	4.09**	0.11	0.67**	2.1	8.33**
P_1 x P_4	-1.79	-2.69**	0.19	4.09	5.46*	-4.64**	0.43**	-0.24*	1.95	0.02
P_1 x P_5	5.16**	2.07**	2.19	-7.32**	6.88**	-1.73	0.40**	0.07	1.05	2.95*
P_1 x P_6	0.33	-2.10**	-3.1	3.72	5.08*	0.75	0.15	-0.1	-2.49	-2.62*
P_2 x P_3	-1.67	1.54*	-1.98	8.17**	10.03**	0.78	0.49**	0.01	-0.47	-0.25
P_2 x P_4	4.89**	-6.95**	0.71	-20.28**	-4.89*	2.42	-0.38*	-0.03	-2.19	-3.24*
P_2 x P_5	0.74	-1.44*	0.21	-1.01	7.08**	-1.97	0.30*	0	-0.65	1.75
P_2 x P_6	4.41*	4.89**	1.25	2.12	0.53	1.82	0.21	0.34**	3.17	4.55**
P_3 x P_4	4.73*	4.05**	2.13	6.74**	8.80**	1.74	0.50**	0.12	0.39	0.7
P_3 x P_5	1.51	-1.94**	1.13	1.28	0.86	-2.55	0.01	0.01	-0.45	2.95*
P_3 x P_6	3.85*	0.39	5.84**	7.54**	4.17	-4.62**	0.35*	-0.20*	2.35	1.1
P_4 x P_5	3.14	-3.68**	2.82	-5.42*	0.07	-2.22	0.06	0.08	1.34	4.09**
P_4 x P_6	0.81	5.66**	1.52	0.4	2.49	1.81	0.38*	0.17	4.23*	1.58
P_5 x P_6	0.76	-0.34	0.02	0.63	4.41*	-0.18	0.33*	0.05	1.63	1.03
S.E. sij	3	1.07	2.67	3.48	3.57	2.45	0.25	0.15	2.89	2.1
S.E. sij-sik	4.48	1.6	3.98	5.19	5.33	3.65	0.37	0.23	4.31	3.13
S.E. sij-skl	4.15	1.48	3.69	4.8	4.93	3.38	0.35	0.21	3.99	2.9

***, ** significant at 0.05 and 0.01 levels of probability, respectively, DH = days to 50% heading, PH = plant height, SL = spike length, NS/P = number of spikes/plant, BY/P = biological yield/plant, GY/P = grain yield/plant, HI= harvest index, NG/S = number of grains/spike, WG/S = weight of grains/spike, 1000GW = 1000 grains weight.**

D- Heterobeltiosis

Under normal date, six crosses showed insignificant earliness from the better parent ranged from 0.00 for P3XP4 to 2.80% for P_5XP_6. Indicating these crosses were equal to the better parent in earliness while, other crosses were significant (P≤0.05 or 0.01) late in days to heading compared to the earlier parent. Under late date planting (heat stress), only one cross of P_3XP_4 showed negative significant heterosis by -2.18%, moreover, the cross P_1XP_4 were equal to the earlier parent in days to heading (Table 6). For plant height, seven crosses P_1XP_3, P_1XP_4, P_2XP_4, P_2XP_6, P_3XP_4, P_3XP_6 and P_4XP_6 were showed positive significant (P≤0.05

or 0.01) heterosis by 9.30, 4.65, 6.52, 5.22, 4.65, 6.98, and 9.30% in addition three crosses P_2XP_3, P_2XP_5 and P_4XP_5 were equal to the tallest parent under normal date. While, under late date planting (heat stress), only the cross P_4XP_5 was surpassed significantly (P≤0.01) the better parent in plant height by 11.51% (Table 6). For spike length, five crosses P_1XP_3, P_1XP_4, P_1XP_6, P_2XP_3, P_5XP_6 showed positive highly significant heterosis ranged from 2.34% of P_1XP_6 to 13.46% of P_1XP_3 under normal date. Three crosses of P_1XP_2, P_1XP_5 and P_3XP_4 were showed positive significant (P≤0.05 or 0.01) heterosis by 1.88, 9.33 and 4.18%, respectively for spike length under late date. For number of spikes/plant, under normal date all crosses were showed negative significant (P≤0.05 or 0.01) heterobeltiosis except only one cross of P_4XP_6 was nearly equal or higher than the highest parent where it gave positive non-significant (0.72) heterosis. While, under late date, five crosses of P_1XP_3, P_1XP_4, P_1XP_6, P_2XP_6 and P_4XP_6 were gave significant (P≤0.01) heterosis by 4.81, 6.05, 13.95, 4.79 and 30.57%, respectively. For biological yield/plant, except three crosses P_1XP_3, P_2XP_3 and P_4XP_6 all the crosses were gave significant (P≤0.01) positive heterosis ranged from 7.28% of P_3XP_5 to 44.81% of P_2XP_4 under normal date. Furthermore, six crosses of P_1XP_2, P_1XP_3, P_1XP_5, P_2XP_4, P_2XP_6 and P_4XP_6 were gave positive significant (P≤0.05 or 0.01) heterosis by 7.5, 12.00, 34.00, 47.74, 25.65 and 39.96%, respectively under late date (Table 6).

Table 6. Better parent heterosis for the studied traits of 15 F1's bread wheat crosses under two normal (N) and late (L) dates

Trait	DH		PH		SL		NS/P		BY/P	
Cross	N	L	N	L	N	L	N	L	N	L
P_1 x P_2	4.05**	-1.76	-4.35*	-1.32	-19.86**	1.88*	-11.93**	-0.60	10.59*	7.50*
P_1 x P_3	3.64*	-0.44	9.30**	-2.71	13.46**	-3.75**	-3.71**	4.81**	3.26	12.00**
P_1 x P_4	1.21	0.00	4.65*	-6.78**	5.01**	-1.34	-14.62**	6.05**	32.26**	-24.50**
P_1 x P_5	4.05*	-0.44	2.38	-1.64	-6.78**	9.33**	-22.92**	-8.65**	17.11**	34.00**
P_1 x P_6	5.67**	2.24*	-2.33	0.33	2.34**	-2.90**	-11.11**	13.95**	13.91**	-23.00**
P_2 x P_3	3.33*	-0.86	0.00	-0.66	7.03**	-8.08**	-19.14**	-21.36**	-0.65	-11.84**
P_2 x P_4	1.87	-0.44	6.52**	-1.98	-18.21**	-6.96**	-13.46**	-6.59**	44.81**	47.74**
P_2 x P_5	3.45*	-0.87	0.00	-1.64	-6.10**	-5.87**	-8.93**	-25.26**	17.11**	-1.80
P_2 x P_6	6.80**	0.90	5.22*	-1.32	-1.80**	-6.60**	-14.07**	4.79**	21.32**	25.65**
P_3 x P_4	0.00	-2.18*	4.65*	-2.79	-3.69**	4.18**	-2.00*	-5.53**	10.76**	5.57
P_3 x P_5	1.92	-0.87	2.33	-12.17**	-5.84**	-1.07	-10.29**	-41.52**	7.28**	-22.30**
P_3 x P_6	4.80**	3.14**	6.98**	-6.00**	-2.31**	-8.97**	-11.71**	-18.20**	9.24**	-18.07**
P_4 x P_5	0.77	-1.31	0.00	11.51**	-9.50**	-2.67**	-7.44**	-23.18**	18.16**	-8.27*
P_4 x P_6	4.80**	0.45	9.30**	-7.33**	-1.29	-2.11**	0.72	30.57**	5.96	39.96**
P_5 x P_6	2.80	-1.35	3.88	-0.66	5.14**	-5.28**	-20.54	-25.95**	18.42**	-7.19
LSD 5%	2.96	2.16	4.42	3.45	1.32	1.45	1.78	1.91	9.88	7.32
LSD 1%	3.95	2.9	5.92	4.62	1.77	1.94	2.38	2.56	13.22	9.79

Trait	GY/P		HI		NG/S		WG/S		1000GW	
Cross	N	L	N	L	N	L	N	L	N	L
P_1 x P_2	21.43**	1.22	9.23**	-10.71**	1.04	8.35**	-0.98**	32.46**	-1.76	22.45**
P_1 x P_3	54.00**	-7.32**	4.62	-16.88**	6.79*	2.42	10.78**	33.31**	4.01	30.08**
P_1 x P_4	17.77**	-24.39**	4.62	-1.61	18.02**	-16.97**	25.75**	-4.18**	6.44*	3.17**
P_1 x P_5	51.25**	1.95	4.62	-29.48**	22.45**	-6.44**	18.35**	11.41**	-3.16	18.91**
P_1 x P_6	17.58**	-19.51**	-4.62	4.78	19.25**	-3.21	21.23**	5.59**	0.12	0.89
P_2 x P_3	18.73**	-8.70**	-8.47**	3.77	25.66**	-0.80	27.59**	9.44**	0.26	10.52**
P_2 x P_4	45.71**	-46.52**	10.17**	-63.34**	-2.33	-1.38	-0.98**	5.91**	-4.04	-7.40**
P_2 x P_5	23.81**	-19.14**	1.69	-17.65**	22.74**	-5.36*	17.68**	5.81**	-4.14	11.74**
P_2 x P_6	36.26**	17.39**	9.29**	-6.41*	10.20**	1.57	23.67**	23.40**	5.39*	10.69**
P_3 x P_4	50.47**	5.71**	10.34**	0.16	29.35**	-1.10	33.64**	8.84**	3.29	1.67
P_3 x P_5	33.23**	-34.38**	13.73**	-14.94**	19.36**	-14.18**	29.48**	-0.60**	-2.65	15.88**
P_3 x P_6	40.66**	24.49**	18.03**	41.24**	22.69**	-10.24**	29.83**	-5.32**	6.35*	5.40**
P_4 x P_5	42.56**	-36.72**	15.52**	-30.73**	14.38**	-17.15**	13.97**	0.48**	-0.31	11.54**
P_4 x P_6	21.98**	24.30**	13.11**	-11.06**	19.57**	-1.21	35.17**	7.58**	12.40**	5.67**
P_5 x P_6	19.78**	-19.14**	1.64	-12.77**	26.22**	-9.45	26.35**	3.59**	-0.12	8.71**
LSD 5%	5.59	1.99	4.97	6.47	6.64	4.56	0.37	0.29	5.37	3.9
LSD 1%	7.47	2.67	6.65	8.66	8.89	6.09	0.49	0.38	7.18	5.22

***, ** significant at 0.05 and 0.01 levels of probability, respectively, DH = days to 50% heading, PH = plant height, SL = spike length, NS/P = number of spikes/plant, BY/P = biological yield/plant, GY/P = grain yield/plant, HI= harvest index, NG/S = number of grains/spike, WG/S = weight of grains/spike, 1000GW = 1000 grains weight.**

For grain yield/plant, under normal date, all crosses gave positive significant (P≤0.01) heterosis ranged from 17.58 of cross P_1XP_6 to 54.00% of cross P_1XP_3. Under late date (heat stress), four crosses showed highly significant heterosis in grain yield/plant by 17.39, 5.71, 24.49 and 24.30% of P_2XP_6, P_3XP_4, P_3XP_6 and P_4XP_6, respectively (Table 6). Similar findings were observed by Bilgin *et al.* (2022) and El Hanaf *et al.* (2022).

For harvest index, eight crosses P_1XP_2, P_2XP_4, P_2XP_6, P_3XP_4, P_3XP_5, P_3XP_6, P_4XP_5 and P_4xP_6 showed positive highly significant heterosis ranged from 9.23 to 18.03% of P_1XP_2 and P_3XP_6, respectively under normal date. While, under late date, four crosses of P_1XP_6, P_2XP_3, P_3XP_4 and P_3XP_6 were showed positive insignificant or highly significant heterosis ranged from 0.16% of P_3XP_4 to 41.24% of P_3XP_6. For number of grains/spike, under normal date, out of the 15 F1's crosses, thirteen crosses were showed positive significant (P≤0.05 or 0.01) heterosis ranged from 6.79% of P_1XP_3 to 29.35% of P_3XP_4. Moreover, only one cross of P_1XP_2 was record highly significant heterosis by 8.35% compared to the highest parent in NG/S under late date (Table 6). For weight of grains/spike, under normal date with exception two crosses of P_1XP_2 and P_2XP_4, the thirteen crosses were gave positive highly significant heterosis ranged from 10.78% of P_1XP_3 to 35.17% of P_4XP_6. While, under late date with exception three crosses of P_1XP_4, P_3XP_5

and P_3XP_6, the 12 crosses were gave positive highly significant heterosis ranged from 0.48% of P_4XP_5 to 33.31% of P_1XP_3. For 1000 grain weight, four crosses P_1XP_4, P_2XP_6, P_3XP_6 and P_4XP_6 gave positive significant ($P \leq 0.05$ or 0.01) heterosis by 6.44, 5.39, 6.35 and 12.40 %, respectively under normal date. Similarly under late date, these 12 crosses gave positive highly significant heterosis with ranged from 3.17 to 30.08% of crosses P_1XP_4 to P_1XP_3, respectively (Table 6). Similar results were found on wheat by Kumar *et al.* (2021).

E- Correlations between parents means and GCA, and crosses means and SCA effects

High positive significant correlation between mean X_P and their GCA effects was observed for all studied traits with exception grain yield/plant number and weight of grains/spikes under normal planting date (Table 7). The high positive correlation between the parental performance and GCA effects reflects the preponderance of additive effects and vice versa in the inheritance of the concerned traits. The insignificant correlation was offset by a higher correlation between the SCA and hybrid performance. While, under late date (heat stress), positive highly significant ($P \leq 0.01$) was found only for 4 traits days to heading, plant height, grain yield/plant and grains/spike. It was observed that, correlation coefficient between X_P and GCA under normal was higher than correlation coefficient under late planting date for most traits. Indicating the preponderance on non-additive effects under heat stress (Table 7). Based on this results, the best parents in their performance in these traits were Misr 2 and Sids14 by 93.67 and 90.00 for lateness in days to heading (Table 3) where their GCA effects were 2.76 and 1.22 (Table 5) in comparison with the earlier parents Gemmeiza 11 and Sids 12 with mean DH 82.33 and 83.33 and their GCA effects were -2.74 and -1.32 (Table 5). Which parents, these two parents were the best general combiner for earliness. For BY/P, the best parent was Sids 14 follow by Shandwal 1 with means performance 92.00 and 76.00 gm (Table 3) and their GCA effects were 9.74 and 1.87 (Table 5). So, these two parents were the best general combiner for biological yield per plant. For HI, the best two general combiners were Gemmeiza11 and Sids12 where their means and GCA effects were 32.50 and 30.50% and 1.84 and 1.01, respectively (Tables 3 and 5). For 1000GW, the best general combiners were Sids12, Gize171 and Gemmeiza11. The best two parents in PH were Misr 2 followed by Giza171. For SL, the best general combiners were Gemmeiza11 followed by Sids12. Sids14 followed by Shandwel1 were the best combiner for NS/P (Table 5).

Under late date (heat stress), the highest correlation coefficient between X_P and GCA effect was found for days to heading (0.96) (Table 7). So, Sids12 followed by Gemmeiza 11 were the best two parents for general combiner for earliness in heading. For plant height the Misr 2 followed by Sids 12 were the best general combiners based on their mean performance and GCA effects.

Regarding grain yield per plant the correlation coefficient between it and GCA was 0.85. Indicating, Gammeiza11 followed by Shandwel 1 were the best general combiners for GY/P because it achieved the highest mean of GY/P by (20.50 and 21.33 gm.) (Table 3) and the high GCA by 1.72 and 0.71, respectively (Table 5). Based on the results mentioned before, the correlation between mean performance and GCA would be an indication about its general combining ability for the parents.

Correlation coefficients between X_{F1} and SCA effect were positive ($P \leq 0.01$) for all studied traits under both dates except DH under normal planting date (0.38) (Table 7), therefore, it could be concluded that the mean performance of DH of the $F_{1's}$ crosses is not an indication of its SCA. Under normal planting date, the highest correlation coefficients were found between SCA effects and each of GY/P (0.95) and NG/S (0.96) (Table 7). Therefore, the best cross in GY/P was P_1XP_3 (32.75 gm.) (Table 3) and its SCA was the highest (6.00) (Table 7). Also, the cross P_2XP_3 was second cross by 64.65 grains/spike and the first cross in SCA by 10.03. The remains studied traits showed significant correlation between X_{F1} and SCA but low in magnitude correlation between them. Al-Naggar *et al.* (2015) in wheat found that the correlation between mean performance and GCA would give an indication to use the means of the parents to predict of cross value.

Under late date (heat stress) was positive significant correlation between X_{F1} and SCA ranged from 0.79 of (PH and NG/S) to 0.98 of HI% (Table 7), indicating under late planting date, the mean performance of $F_{1's}$ crosses could be an indication of its specific combining ability especially HI (r = 0.98) (Table 7).

Table 7. Correlation coefficients between means of parents (Xp) and their GCA effects and between means of crosses (X_{F1}) and their SCA effects under normal and late dates

Traits	Xp vs GCA		X_{F1} vs SCA	
	N	L	N	L
DH	0.98**	0.96**	0.38	0.83**
PH	0.95**	0.88**	0.83**	0.79**
SL	0.94**	0.80	0.58**	0.86**
NS/P	0.94**	0.59	0.71**	0.92**
BY/P	0.98**	0.77	0.56**	0.95**
GY/P	0.75	0.85**	0.95**	0.89**
HI	0.96**	0.35	0.72**	0.98**
NG/S	0.76	0.86**	0.96**	0.79**
WG/S	0.79	0.67	0.85**	0.91**
1000-GW	0.96**	0.67	0.76**	0.93**

***, ** significant at 0.05 and 0.01 levels of probability, respectively, DH = days to 50% heading, PH = plant height, SL = spike length, NS/P = number of spikes/plant, BY/P = biological yield/plant, GY/P = grain yield/plant, HI= harvest index, NG/S = number of grains/spike, WG/S = weight of grains/spike, 1000GW = 1000 grains weight.**

F- Indices of heat stress tolerance

Heat stress tolerance indices for the 21 bread wheat genotypes based on grain yield par plant are shown in Table 8.

Results of screening 21 genotypes for heat tolerance under heat stress (late date) and normal planting date, based on MP, GMP, STI, HM, K_1STI and K_2STI revealed that crosses P_1XP_5 and P_2XP_6 were the heat tolerance crosses, while, the two cultivars P_3 (Sids14) and P_6 (Sids 12) were the most heat susceptible genotypes. Therefore, these six indices were the most effective to identify high yielding genotypes under normal and heat conditions. Where, high values of these indices means stress tolerant.

Based on the simple correlation between grain yield and the heat tolerance parameters under normal and late planting (heat stress) dates (Table 9). It's observed that six heat tolerance indices (MP, GMP, STI, HM, K1STI and K2STI) showed positive correlation with grain yield by 0.76, 0.61, 0.62, 0.47, 0.88 and 0.32, respectively under normal planting date and by 0.66, 0.79, 0.78, 0.88, 0.44 and 0.91, respectively under late date (heat stress). Moreover, for the remained stress tolerance indices, the correlation coefficient converted from positive to negative or contrary as HSI, TOL, YSI, SHI, HI and RHI.

A mean score index MSI to increase the selection efficiency for heat tolerance (Aberkane *et al.* (2021) and Thiry *et al.* (2016)) was estimated based on the six heat tolerance indices that were efficient to select the high yielding genotypes and that showed positive correlation with grain yield under both planting dates.

MSI= (score MP + score GMP + score HM + score STI + score K_1STI + score K_2STI) / 6.

The correlation coefficient between MSI and grain yield were 0.86 under normal and 0.93 under late planting date (Table 9). This correlation was higher than those for the six indices estimated individually (Table 9). Based on MSI, two genotypes P_1XP_5 and P_2XP_6 were the most heat tolerance genotypes with high yielding ability.

Aberkane *et al.* (2021) estimated a MSI to improve the selection efficiency under heat stress. They showed wheat lines with good potential under stress were derived from crosses with increase variability for heat adaptive traits

Table 8. Heat stress tolerance indices of 21 bread wheat genotypes based on grain yield/plant

Gen.	GY_p	GY_s	HIS	TOL	MP	GMP	STI
P_1	20	20.5	-0.07	-0.5	20.25	20.25	0.59
P_2	21	19.17	0.25	1.83	20.08	20.06	0.58
P_3	21.27	10.17	1.51	11.1	15.72	14.71	0.31
P_4	20.17	17.5	0.38	2.67	18.84	18.79	0.51
P_5	19.5	21.33	-0.27	-1.83	20.42	20.4	0.6
P_6	22.75	12.25	1.34	10.5	17.5	16.69	0.4
P_1 x P_2	25.5	20.75	0.54	4.75	23.13	23	0.76
P_1 x P_3	32.75	19	1.22	13.75	25.88	24.94	0.9
P_1 x P_4	23.75	15.5	1.01	8.25	19.63	19.19	0.53
P_1 x P_5	30.25	21.75	0.82	8.5	26	25.65	0.95
P_1 x P_6	26.75	16.5	1.11	10.25	21.63	21.01	0.64
P_2 x P_3	25.25	17.5	0.89	7.75	21.38	21.02	0.64
P_2 x P_4	30.6	10.25	1.93	20.35	20.43	17.71	0.45
P_2 x P_5	26	17.25	0.98	8.75	21.63	21.18	0.65
P_2 x P_6	31	22.5	0.8	8.5	26.75	26.41	1.01
P_3 x P_4	32	18.5	1.22	13.5	25.25	24.33	0.85
P_3 x P_5	28.33	14	1.47	14.33	21.17	19.92	0.57
P_3 x P_6	32	15.25	1.52	16.75	23.63	22.09	0.7
P_4 x P_5	28.75	13.5	1.54	15.25	21.13	19.7	0.56
P_4 x P_6	27.75	21.75	0.63	6	24.75	24.57	0.87
P_5 x P_6	27.25	17.25	1.06	10	22.25	21.68	0.68

Gen.	YSI	HM	SHI	HI	RHI	K_1 MSTI	K_2 MSTI
P_1	1.03	20.25	-0.03	1.22	1.56	0.34	0.84
P_2	0.91	20.04	0.09	1.01	1.39	0.37	0.72
P_3	0.48	13.76	0.52	0.28	0.73	0.2	0.11
P_4	0.87	18.74	0.13	0.88	1.32	0.3	0.52
P_5	1.09	20.38	-0.09	1.35	1.67	0.33	0.92
P_6	0.54	15.93	0.46	0.38	0.82	0.3	0.2
P_1 x P_2	0.81	22.88	0.19	0.98	1.24	0.72	1.11
P_1 x P_3	0.58	24.05	0.42	0.64	0.89	1.39	1.09
P_1 x P_4	0.65	18.76	0.35	0.59	1	0.43	0.43
P_1 x P_5	0.72	25.31	0.28	0.91	1.1	1.26	1.51
P_1 x P_6	0.62	20.41	0.38	0.59	0.94	0.66	0.58
P_2 x P_3	0.69	20.67	0.31	0.7	1.06	0.59	0.66
P_2 x P_4	0.33	15.36	0.67	0.2	0.51	0.61	0.16
P_2 x P_5	0.66	20.74	0.34	0.66	1.01	0.63	0.65
P_2 x P_6	0.73	26.07	0.27	0.95	1.11	1.4	1.71
P_3 x P_4	0.58	23.45	0.42	0.62	0.88	1.26	0.98
P_3 x P_5	0.49	18.74	0.51	0.4	0.75	0.66	0.38
P_3 x P_6	0.48	20.66	0.52	0.42	0.73	1.04	0.55
P_4 x P_5	0.47	18.37	0.53	0.37	0.72	0.67	0.34
P_4 x P_6	0.78	24.39	0.22	0.99	1.2	0.97	1.39
P_5 x P_6	0.63	21.13	0.37	0.63	0.97	0.73	0.68

Table 9. Correlation coefficients between heat tolerance indices and grain yield under normal and late planting dates

Planting date\index	HSI	TOL	MP	GMP	STI	YSI	HM
N	0.62	0.76	0.76	0.61	0.62	-0.61	0.47
L	-0.76	-0.64	0.66	0.79	0.78	0.76	0.88
Planting date\index	SHI	HI	RHI	K_1MSTI	K_2MSTI	MSI	
N	0.61	-0.4	-0.61	0.85	0.32	0.86	
L	-0.76	0.89	0.76	0.44	0.91	0.93	

CONCLUSION

Under normal date, all crosses showed positive highly significant heterobeltiosis for GY/P. Under late date (heat stress), Gemmeiza 11 and Misr 2 were proved as good combiner for GY/P. Four crosses P_2XP_6, P_3XP_4, P_3XP_6 and P_4XP_6 showed highly significant better parent heterosis for GY/P.

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تحليل الهجن النصف تبادلية ودلائل تحمل إجهاد الحرارة لمحصول الحبوب في قمح الخبز

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الملخص

اجرى تقدير قوة الهجين والقدرة على الائتلاف فى قمح الخبز باستخدام تحليل الهجن النصف تبادلية 6 x 6 تحت ميعاد الزراعة العادى والمتأخر خلال موسمين زراعيين 2020/2019 و 2021/2020 فى محطة البحوث الزراعية بالمطاعنة ، ووجدت اختلافات معنوية او عالية المعنوية لكل من التراكيب الوراثية والاباء والهجن والقدرة العامة والخاصة على الائتلاف لمعظم صفات الدراسة تحت ميعادين الزراعة ، كما لوحظ تحكم فعل الجين الاضافى فى صفات ميعاد طرد السنابل وارتفاع النبات وطول السنبلة فى كلا ميعادين الزراعة وصفات عدد السنابل للنبات والمحصول البيولوجى ودليل الحصاد ووزن 1000 حبة فى الميعاد العادى وصفات محصول الحبوب للنبات وعدد حبوب السنبلة فى الميعاد المتأخر ، بينما باقى صفات الدراسة كانت محكومة بفعل الجين السيادى ، وفى ميعاد الزراعة العادى كان الصنف سدس 14 أفضل معطى لصفات عدد ايام طرد السنابل وعدد السنابل للنبات والمحصول البيولوجى للنبات ، كما أظهرت كل الهجن الناتجة قوة هجين عالية المعنوية على اساس الاب الافضل لصفة محصول الحبوب للنبات ، كما أظهر الهجينين P1XP5 و P3XP4 تأثيرات موجبة للقدرة الخاصة على الائتلاف معنوية او عالية المعنوية لصفات المحصول البيولوجى ومحصول الحبوب للنبات وعدد ووزن حبوب السنبلة ، بينما فى الميعاد المتأخر كان الصنفين جميزة 11 ومصر 2 معطيان جيدان لصفات المحصول البيولوجى ومحصول الحبوب للنبات وعدد حبوب السنبلة ، كما أظهر الصنف شندويل 1 تأثيرات موجبة معنوية للقدرة العامة على الائتلاف لصفة محصول الحبوب للنبات ، كما وجدت تأثيرات موجبة معنوية او عالية المعنوية للقدرة الخاصة على الائتلاف لصفات المحصول البولوجى ومحصول الحبوب للنبات لأربع هجن هى P1XP3 و P1XP5 و P2XP6 و P4XP6 ، كما سجلت قوة هجين عالية المعنوية على اساس الاب الافضل لصفة محصول الحبوب للنبات لأربعة هجن هى P2XP6, P3XP4, P3XP6, P4XP6 ، ويستخلص من الدراسة ان كلا الهجينين P1XP5، P2XP6 هما الاكثر تحملا لإجهاد الحرارة مع اعلى قدرة محصوليه. ويمكن استخدامهما فى الحصول عى عشائر انعزالية تستخدم لتطبيق برنامج تربية بالانتخاب بالنسب فى الجيل الثانى.