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Heterosis and Combining Ability of F_1 Bread Wheat Diallel Crosses

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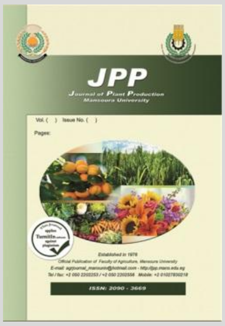

ABSTRACT

Heterosis and combining ability were estimated in bread wheat using 6x6 half diallel crossing at two seasons 2020/2021 and 2021/2022 at private farm at Bany Omran Village, Diermawas City, El Minia Governorate, Egypt. Results indicated that the mean squares of genotypes, crosses, parents, general and specific combining ability were significant ($P < 0.05$ or < 0.01) for most tested traits. The σ^2_g/σ^2_s ratio was less than unity, showing that non-additive gene action was more important for deciding performance of all traits. Cultivar parent, Sids 14 was an effective general combiner for biological yield/plant, grain yield/plant and number of grains/spike. Except for four crosses P1XP6, P2XP5, P2XP6 and P3XP6, all crosses gave positive significant ($P < 0.01$) heterosis for grain yield/plant. Heterosis of grain yield/plant over mid-parents and better parent ranged from 3.98% (P3xP6) to 33.14% (P4xP6) and 2.94% (P3xP5) to 26.97% (P4xP5), respectively. The four parents P4, P6, P3 and P1 gave significant and positive GCA effects for grain yield plant^{-1} and eight crosses had positive and highly significant SCA effects. P2xP3, P3xP4 and P4xP6 crosses exhibited highly desirable heterotic effects for most traits. Association among mean XP and GCA effects were positively substantial ($P < 0.05$ or 0.01) for days to heading, plant height, spike length, number of spikes/plant, biological yield/plant, grain yield/plant, weight of spike, weight of grains/spike and 1000 grain weight.

Keywords: Wheat, Heterosis, Diallel analysis, Combining ability.

INTRODUCTION

Among cereal crops, wheat is considered one of most significant crops in the world. Owing to its adaptation and several uses. Its high production makes it a primary food source for one-third of the population around the world. Compared to other food crops, wheat provides the world's diet with more calories and protein. Wheat is the primary winter grain crop in Egypt and several other countries.

The diallel cross is a common method in plant breeding to obtain knowledge about genetic attributes of parent cultivars or heritability values and combining ability (El-Saadoown *et al*. 2017 and Muthoni and Shimelis, 2020). Additionally, the diallel cross technique gives breeders early knowledge of the genetic behavior of the characters under study during the first generation (El-Hosary *et al*., 2019).

General combining ability measures average performance of a line in combination of crosses, whereas specific combining ability identifies unexpected performance differences based on mean performance (Begna, 2021). Furthermore, general combining ability is related to ad-ditive gene effects accompanied by epistasis of additive x additive and offering greater theoretical flexibility. In contrast, specific combining ability is regarded as non-fixable and involves non-additive gene action that may result from dominance and/or epistasis. The text highlights existing research gaps in identifying genetically superior and diverse wheat parent genotypes for yield improvement (Darwish *et al*., 2024). Highly significant GCA and SCA effects were found for all traits revealing the significance of genetic variations, both additive and non-additive. Similarly, the ratio of GCA/SCA was higher than one for the most traits, revealing that additive gene effects were more important than dominance in expressing these traits (Hoda El-Safy *et al*., 2020, Al-timimi *et al*., 2021, Marwa El-Nahas and Ali, 2021, Nassar *et al*., 2022 and Fouad *et al*., 2022).

Heterosis refers to a progeny exhibiting superior traits to one or both parents, particularly in crop breeding. This yield advantage is crucial for meeting future food demands across various crops (Paril *et al*., 2024). When Ahmad and Gupta (2024) studied heterosis in some promising wheat crosses, they found significant heterosis for biological yield/plant, plant height, productive tillers, spike length, no. of grains/spike, harvest index, yield/plant and thousand grain weight. These crosses show potential for developing high-yielding wheat varieties and improving crop performance. Crosses with higher heterosis can be utilized to identify transgressive segregants, which can enhance bread wheat production and traits that contribute to yield (Khan *et al*., 2024). The varieties Sakha 95, Giza 171, and Misr 3 can be utilized in various hybridization programs to develop hybrids characterized by economic traits that enhance bread wheat productivity (Hussein and Manal Zaater, 2024). The high levels of heterosis observed in cross combinations indicated significant genetic variation between the parental cultivars, highlighting strong potential for the commercial utilization of heterosis in wheat (Reddy *et al.*, 2023). The cycle of static global wheat productivity could be interrupted via heterosis breeding. The majority of heterosis arises from additive effects rather than dominance effects. This highlights the importance of utilizing GCA to achieve higher yields, while emphasizing the need to develop heterotic pools to optimize SCA and dominance effects (Adhikari *et al*., 2020). So, this present investigation was conducted to determine combining ability and heterosis in F_1 bread wheat crosses using half-diallel crosses technique for certain quantitative traits.

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MATERIALS AND METHODS

The current investigation was conducted during two seasons of 2020/2021 and 2021/2022 at a private farm of Bany Omran Village, Diermawas City, El Minia Governorate, Egypt. In this study, six Egyptian cultivars of bread wheat were used as parents; their pedigree is outlined in Table 1.

Table 1. Pedigrees of the tested bread wheat cultivars.

Genotypes	Pedigree
Sakha 95 (P1)	PASTOR / SITE / MO //3/ CHEN // AEGILOPS SQUAROSA (TAUS) // BCN //4/ WBLL1
Giza 168 (P2)	MRL/ BUC// SERI
Giza 171 (P3)	SAKHA 93//GEMMEIZA 9
Sids 14 (P4)	BOW "S" / VEES" // BO W"S" / TSI/3/ BANI SWEF 1
Misr 2 (P5)	SKAUZ//BAV92
Misr 3 (P6)	ATTLA*2/PBW652/ /KACHU

In 2020/2021 season, the six parental cultivars were sown at various dates (15th, 25th November and 5th December) to overcome the differences among the parents in flowering date. Using a half diallel schema, 15 F1 crosses among 6 parents through manual hybridization were performed.

In 2021/2022 season, 21 genotypes included 15 F_1-crosses, and 6 parental cultivars were sown in a Randomized Completely Blocks Design (RCBD) with 3 replicates. The replicate was a one row 3 m. long, 30 cm apart and 10 cm intra-plot.

The measured traits were determined depending on plot mean of the F_1 and their parental cultivars; days to 50% heading (DH), plant height in cm (PH), spike length in cm (SL), number of spikes plant^{-1}(NS/P), biological yield plant^{-1} in g (BY/P), grain yield plant^{-1} in g (GY/P), harvest index% (HI), weight/spike in g (WS), number of spikelets spike^{-1}(NST/S), number of grains spike^{-1} (NG/S), weight of grains spike^{-1} in g (WG/S), 1000 grains weight in g (1000-GW).

The general (GCA) and specific (SCA) combining ability were determined based on Griffing (1956) for method 2 model 1 (fixed model). The heterosis (H) was calculated as the percentage of difference between the F_1 mean and the mean of mid parents (M.P) and mean of the better parent (B.P), as follows; H M.P. % = (F_1 – M.P) / M.P ×100, H B.P. % = (F_1 – B.P) / B.P ×100. Rank correlation coefficients calculated between per se performance of parents and their GCA effects in F_1's; between per se performance of F_1 crosses and their SCA effects for studied traits and the significance of the rank correlation coefficient was tested according to Steel *et al*. (1997).

RESULTS AND DISCUSSION

A- Analysis of variance

Parents, genotypes and cross means squares exhibited substantial ($p < 0.05$ or 0.01) for all tested traits expect days to 50% heading of genotypes. Parents versus crosses mean squares were significant ($p < 0.05$ or 0.01) for all tested traits except harvest index (Table 2). Suggesting, the effectiveness of selection for tested traits. General combining ability variances were substantial (p < 0 .05 or 0.01) for all tested traits. Specific combining ability variances due to were substantial ($p < 0.05$ or 0.01) for all tested traits expect spike length (Table 2). Indicating the significance of additive and nonadditive effects in these traits' expression. The results are in agreement with those found by Aboshosha *et al*. (2018), Hassan *et al*. (2020) and Fouad *et al*. (2022).

B- Combining ability

The general and specific combining ability (GCA & SCA) showed significant mean squares (p < 0 .05 or 0.01) for tested all traits excluding SL of SCA were non-significant (Table 2) which indicates the relevance of both nonadditive and additive gene effects for governing the heritability of these tested traits. The variances of GCA were higher than those of SCA for all tested traits except DH, HI and NST/S. The relative significance of nonadditive and additive gene action plays a critical role in designing an effective hybridization program. Combining ability, as a guide of gene action, reflects a genotype's potential to contribute superior traits to its offspring. The estimate of a pure line is determined by its capacity to create superior crosses when combined with other pure lines. When GCA and SCA mean squares were substantial, it becomes crucial to identify which gene action type primarily influences progeny performance. To address this issue, the extent of the mean squares is examined to estimate the relative significance of GCA and SCA, both of which are highly substantial. Accordingly, the GCA/ SCA ratio is utilized to define the type of genetic variation involved. For all tested traits, except SL, the $\sigma^2 g/\sigma^2 s$ ratio was less than unity, indicating that non- additive effects mainly influence the inheritance of characters of the study. The acceptance results for the higher importance of GCA versus SCA variance were detected by AL Saadoon *et al*. (2017) and Jatav *et al*. (2017), El-Hosary *et al*. (2019), El Hanafi *et al*. (2022) and Kumari and Sharma (2022).

Table 2. Mean squares in 6 parents diallel cross in bread wheat for all tested characters.

S.V.	d.f.	Mean squares											
		DH	PH	SL	NS/P	BY/P	GY/P	HI	WS	NST/S	NG/S	WG/S	1000-GW
Reps	2	91.62	33.68	27.07	2.19	356.95	99.16	81.61	0.32	9.31	543.59	2.28	6.26
Genotypes	20	33.67	92.44**	2.54**	4.44**	251.41**	33.22**	20.97**	1.11**	8.40**	145.25**	0.75**	28.97**
Parents (P)	5	8.06**	67.19**	1.55*	4.66**	103.24*	28.45**	32.88**	1.41**	3.89**	57.85**	0.28**	14.81**
Crosses (C)	14	27.36**	95.79**	2.25**	3.33**	232.98**	24.89**	17.68*	1.00**	4.82**	155.42**	0.49**	15.83**
P vs C	1	250.17**	171.80**	11.43**	18.86**	1250.19**	173.79**	7.63	1.12**	81.14**	439.81**	6.87**	283.61**
GCA	5	8.99**	70.79**	2.22**	3.56**	131.80**	19.37**	6.54*	0.73**	2.78**	80.58**	0.28**	12.06**
SCA	15	11.97**	17.49**	0.39	0.79**	67.80**	8.31**	7.14**	0.25**	2.81**	37.69**	0.24**	8.85**
Error	40	7.32	18.1	0.62	0.58	31.91	0.43	7.49	0.21	0.62	6.23	0.03	0
$\sigma^2 g/\sigma^2 s$	-	-0.04	0.58	1.29	0.58	0.14	0.17	-0.02	0.34	0	0.15	0.02	0.05
C.V. %	-	3.1	4.13	6.18	10.4	7.98	2.8	8.2	9.53	3.65	3.77	5.65	0.04

*** Significant at 0.01 level, ** Significant at 0.05 level.**

Days to 50% heading (DH), Plant height (PH), Spike length (SL), Number of spikes plant^{-1} (NS/P), Biological yield plant^{-1} (BY/P), Grain yield plant^{-1} (GY/P), Harvest index (HI), Weight/spike (WS), Number of spikelets spike^{-1} (NST/S), Number of grains spike^{-1} (NG/S), Weight of grains spike^{-1} (WG/S), 1000 grains weight (1000-GW).

1- General combining ability effects

The effect of general combining ability $\hat{g}_i$ for each parent of the tested characters appeared in Table 3. High positive effects were detected for all characters excluding days to 50% heading. Negative combining ability effects concerning days to 50% heading are preferred in wheat.

The parental cultivar P1 (Sakha 95) gave positive substantial GCA effects for biological yield plant^{-1}, grain yield plant^{-1} and No. of spikelets/spike. The parental cultivar P2 (Giza 168) gave positive substantial GCA effects for spike length, plant height, weight of spike, No. of grains/spike and 1000 grain weight, and substantial negative effects for days to 50% heading. However, other traits, produced significant undesirable or negligible GCA effects. So, it could be used to shorten the time it takes for wheat to mature. The parental cultivar P3 (Giza 171) expressed substantial ($P < 0.01$) and positive GCA effects and seemed to be the best combiner for grain yield plant^{-1}, number of grains spike^{-1}, weight of grains spike^{-1} and thousand grain weight. Similarly, the parental cultivar P4 (Sids 14) exposed positive substantial ($P < 0.01$) GCA effects and appeared to be the best combiner for number of spikes plant^{-1}, biological yield plant^{-1}, grain yield plant^{-1}, number of grains spike^{-1}, weight of grains spike^{-1} and thousand grain weight. The parental cultivar P5 (Misr 2) gave positive substantial ($P < 0.01$) GCA effects for spikes plant^{-1} and harvest index. The parental cultivar P6 (Misr 3) expressed positive substantial ($P < 0.01$) GCA effects for grain yield plant^{-1} and substantial negative effects for days to 50% heading. However, it gave substantial undesirable or unsubstantial GCA effects for the remaining characters. The data obtained indicated that yield and associated traits possessing earliness would present a tremendous chance for selection. These outcomes are in line with the acquired by Haridy *et al.* (2021), Abro *et al.* (2021), Roy *et al.* (2021), Mahdy *et al.* (2022), Fouad and Mohamed (2023) and Dawwam *et al.* (2023).

Table 3. Estimates of the effects of general combining ability of 6 parental cultivars for all tested characters.

Parents	DH	PH	SL	NS/P	BY/P	GY/P	HI	WS	NST/S	NG/S	WG/S	1000-GW
P1	0.96	-1.46	-0.35	0.33	3.39*	0.53**	-0.78	-0.09	1.10**	-3.02**	0.04	-0.41**
P2	-1.25*	5.70**	0.77**	-1.24**	-6.96**	-3.09**	-1.19	0.53**	-0.50*	1.25*	-0.07	1.54**
P3	-0.21	-1.44	0.36	-0.28	1.69	0.69**	0.24	0.14	0.11	1.29*	0.28**	0.88**
P4	0.92	0.4	0.21	0.37*	3.20*	1.09**	-0.06	-0.02	-0.47*	5.13**	0.14**	0.28**
P5	0.83	-0.53	-0.56*	0.48*	-2.71*	0	1.36*	-0.25*	-0.08	-1.67*	-0.15**	-2.02**
P6	-1.25*	-2.66*	-0.43*	0.34	1.39	0.78**	0.42	-0.30*	-0.16	-2.98**	-0.23**	-0.25**
S.E. gi	0.5	0.79	0.15	0.14	1.05	0.12	0.51	0.09	0.15	0.47	0.03	0
S.E. gi-gj	0.78	1.23	0.23	0.22	1.63	0.19	0.79	0.13	0.23	0.72	0.05	0.01

Sakha 95 (P1), Giza 168 (P2), Giza 171 (P3), Sids 14 (P4), Misr 2 (P5) and Misr 3 (P6)
*** Significant at 0.01 level, ** Significant at 0.05 level.**

Specific combining ability effects

The effects specific combining ability $\hat{S}_{ij}$ for all tested traits appeared in Table 4. Regarding days to 50% heading, the crosses P1XP6, P1XP5, P2XP3, P2XP4 and P2XP5 gave negative substantial ($P < 0.01$) SCA effects. About plant height, two crosses P1XP2 and P2XP6 expressed positive substantial ($P < 0.05$) SCA effects. As number of spikes/plant, the three crosses P1xP3, P4xP5 and P5xP6 exhibited substantial ($P < 0.05$ or 0.01) positive SCA effects. Concerning BY/P, 4 crosses (P1XP2, P1XP3, P3XP4 and P5XP6) exhibited substantial ($P < 0.05$ or 0.01) positive SCA effects. For GY/P, eight crosses (P1XP2, P1XP3, P1XP4, P2XP3, P3XP4, P4XP5, P4XP6 and P5XP6) exhibited positive substantial ($P < 0.01$) SCA effects. Regarding, harvest index and weight of spike, positive substantial ($P < 0.05$) SCA effects were expressed for crosses (P2XP5, P4XP6) and (P1XP2, P1XP6 and P3XP4), respectively. For number of spikelets/spike, the five crosses P1XP2, P1XP4, P2XP3, P4XP6 and P3XP4 had positive substantial ($P < 0.05$ or 0.01) SCA effects. About of grains/spike, eight crosses [P2XP3; P2XP4; P2XP6; P3XP4; P3XP5; P4XP5; P4XP6 and P5XP] had positive substantial ($P < 0.01$) SCA effects. As for weight of grains/spike, seven hybrids [P1XP2; P1XP4; P1XP6; P2XP3; P3XP4; P3XP5 and P5XP6] expressed positive substantial ($P < 0.05$ or 0.01) SCA effects. Twelve crosses demonstrated positive substantial ($P < 0.01$) SCA effects for 1000-grain weight.

Table 4. Estimates of the effects specific combining ability of 15 crosses for all tested characters in F_1-generation.

Crosses	DH	PH	SL	NS/P	BY/P	GY/P	HI	WS	NST/S	NG/S	WG/S	1000-GW
P1 x P2	1.72	6.03*	0.32	0.58	15.18**	3.77**	-1.38	0.57*	2.69**	1.23	0.63**	1.70**
P1 x P3	-1.65	-1.3	0.48	0.95*	9.23**	1.53**	-1.94	-0.38	0.51	-3.40*	0.01	2.17**
P1 x P4	2.55	-4.06	-0.05	0.33	5.35	1.96**	0.21	-0.12	1.65**	-2.66	0.36**	1.97**
P1 x P5	-3.70**	1.56	0.1	-0.45	-2.84	-0.72*	0.13	0.36	-0.07	-2.41	0.09	1.27**
P1 x P6	-3.28**	3.66	-0.16	-0.43	-1.17	-1.80**	-2.02	0.50*	0.48	-1.35	0.25*	1.19**
P2 x P3	-4.45**	-0.68	0.71	0.29	3.47	2.48**	1.86	0.4	2.15**	8.03**	0.21*	3.02**
P2 x P4	-4.24**	2.49	0.76	0.21	-4.64	-0.59	1.48	0.11	-0.4	4.20**	-0.1	0.72**
P2 x P5	-4.15**	-0.37	0.6	0.09	-8.61**	-0.79*	4.05*	-0.53*	0.43	-5.46**	-0.15	2.82**
P2 x P6	1.93	5.74*	0.21	0.11	2.1	-0.26	-0.58	0.09	-0.59	5.70**	-0.05	1.04**
P3 x P4	-0.28	2.56	0.45	0.68	7.72*	2.88**	0.32	0.51*	1.48**	6.74**	0.81**	-0.12**
P3 x P5	2.8	4.46	0.28	-0.43	1.28	-1.05**	-2.3	-0.18	0.46	5.89**	0.30**	2.48**
P3 x P6	-1.45	-1.6	-0.06	0.04	2.33	-1.04**	-2.56	-1.02**	0.27	-6.04**	-0.04	-1.70**
P4 x P5	-0.32	-1.44	0.16	1.44**	3.13	3.24**	2.77	0.37	0.37	3.97**	0.01	-1.02**
P4 x P6	-2.24	4.33	0.13	0.42	2.31	3.68**	3.62*	0.14	0.93*	4.18**	0.16	4.30**
P5 x P6	-2.15	-5.70*	0.12	1.34**	7.43*	2.48**	-0.35	0.45	0.4	6.43**	0.65**	0.30**
S.E. sij	1.38	2.18	0.4	0.39	2.89	0.34	1.4	0.24	0.4	1.28	0.09	0.01
S.E. sij-sik	2.07	3.25	0.6	0.58	4.31	0.5	2.09	0.35	0.6	1.91	0.14	0.02
S.E. sij-skl	1.91	3.01	0.56	0.54	3.99	0.47	1.93	0.33	0.56	1.77	0.13	0.02

*** Significant at 0.01 level, ** Significant at 0.05 level.**
Days to 50% heading (DH), Plant height (PH), Spike length (SL), Number of spikes plant^{-1} (NS/P), Biological yield plant^{-1} (BY/P), Grain yield plant^{-1} (GY/P), Harvest index (HI), Weight/spike (WS), Number of spikelets spike^{-1} (NST/S), Number of grains spike^{-1} (NG/S), Weight of grains spike^{-1} (WG/S), 1000 grains weight (1000-GW).

GCA effects are helpful in determining the ability of the genotype in hybrid combination, even though SCA effects associated to heterosis indicated that GCA effects were correlated to SCA estimates for their correspondent crosses for some traits. Based on these results, two parents P2, Giza 168 and P6, Misr 3 gave negative substantial ($P < 0.05$) GCA effects for DH (Table 3). About DH, the cross P1XP6 which showed positive substantial SCA effects (Table 4). The four parents P1 (Sakha 95), P3 (Giza 171), P4 (Sids 14) and P6 (Misr 3) gave positive substantial (P < 0.05 or 0.01) GCA effects (Table 3) for grain yield plant^{-1}. With this trait, these previous parents participated in producing the crosses P1XP3, P1XP4, P3XP4 and P4XP6 that showed positive substantial (P < 0.05 or 0.01) SCA effects. Similarly, it was found with the two parents P4, Sids 14 and P5, Misr 2 with their cross for spikes/plant. For number of grains/spike, the three parents P2 (Giza 168), P3 (Giza 171) and P4 (Sids 14) exhibited positive substantial GCA effects. About this trait, these parents participated in producing the crosses P2XP3, P2XP4 and P3XP4 which possessed positive substantial (P < 0.05 or 0.01) SCA effects. Likewise, it was found with the two parents P3, Giza 171 and P4, Sids 14 with their cross in weight of grains/spike. This indicates the additive and dominance gene action present in their crosses. The obtained results were like those obtained by Roy *et al.* (2021), Marwa El-Nahas and Ali (2021), Chaudhary *et al.* (2022), Fouad and Mohamed (2023) and Dawwam *et al.* (2023).

C- Heterosis

1- Mid-parents heterosis in F_1-generation:

Heterotic effect based on mid-parents of the studied crosses appeared in Table 5. Results of heterosis for days to heading were negatively substantial (P < 0.05 or 0.01) for nine crosses (P1XP3), (P1XP5), (P1XP6), (P2XP3), (P2XP4), (P2XP5), (P3XP6), (P4XP6) and (P5XP6) by -4.43, -7.25, -6.86, -8.96, -8.49, -9.16, -5.07, -5.75 and -6.45%, respectively. These previous crosses were earlier than the mid-parents. For plant height, five crosses (P1XP2), (P1XP6), (P2XP4), (P2XP6) and (P4XP6) exhibited positive substantial (P < 0.05 or 0.01) heterosis varied from 6.45% of (P2XP4) to 10.54% of (P1XP2). For spike length, all F_1's crosses showed positive and significant heterosis (P < 0.01), except the cross (P1XP6). All the 15 F_1's crosses showed positive substantial (P < 0.01) heterotic effect varied from 2.48% of hybrid (P1XP6) to 39.28% of hybrid (P4XP5) for number of spikes/plant, from 4.38% of (P2XP6) to 25.72% of (P1XP2) for number of spikelets/spike, from 8.19% of (P2XP5) to 49.20% of (P3XP4) for weight of grains/spike and from 2.05 % of (P3XP6) to 13.90% of (P4XP6) for 1000-grain weight.

With regard to biological yield plant^{-1}, exception the 2 crosses of (P1XP5) and (P2XP4), the rest crosses exhibited substantial (P < 0.05 or 0.01) heterotic effect ranged from 9.88 to 39.86% of (P4XP5) and (P1XP2), respectively. Grain yield/plant exhibited the same trend of heterosis for NS/P, NST/S, WG/S and 1000-GW, with exception one cross (P1XP6) gave non-significant positive heterosis for GY/P. While the other crosses exhibited positively substantial (P < 0.01) heterosis varied from 3.98 to 33.14% of (P3XP6) and (P4XP6), respectively. For harvest index, five crosses (P2XP3), (P2XP4), (P2XP5), (P4XP5) and (P4XP6) exhibited positive substantial (P < 0.01) heterosis values ranged from 6.38% of (P2XP3) to 20.82% of (P2XP5). For weight of spike, 11 F_1's crosses exhibited positive substantial (P < 0.01) heterosis values varied from 6.12% of hybrid (P2XP6) to 19.65% of hybrid (P1XP2). About NG/S, 9 F_1's crosses exhibited positive substantial (P < 0.05 or 0.01) heterosis values varied from 3.99% of cross (P1XP2) to 22.82% of cross (P2XP3). It is crucial to remember that the superiority of heterosis in grain yield/plant for the majority of crosses rely on positive heterosis presented in grain yield components as NS/P, NG/S, WG/S and 1000 GW of the most crosses. Similar results were confirmed with those recorded by El-Saadoown *et al.* (2017), Abdel-Moneam *et al.* (2021), Marwa El-Nahas and Ali (2021) and Fouad and Mohamed (2023).

Table 5. Percent standard heterosis relative to mid-parents in F_1-generation for all tested traits.

Crosses	DH	PH	SL	NS/P	BY/P	GY/P	HI	WS	NST/S	NG/S	WG/S	1000-GW
P1 x P2	-1.85	10.54**	9.23**	19.66**	39.86**	32.77**	-4.08*	19.65**	25.72**	3.99*	42.08**	12.16**
P1 x P3	-4.43*	1.05	9.12**	23.46**	34.16**	17.48**	-12.34**	-6.66**	15.04**	-4.29*	24.03**	11.32**
P1 x P4	0.36	-1.62	4.02**	19.24**	22.59**	28.05**	3.32	8.46**	20.02**	-1.05	37.48**	11.05**
P1 x P5	-7.25**	2.67	5.09**	4.05**	5.68	5.68**	-0.15	16.98**	7.88**	-3.98*	26.38**	10.11**
P1 x P6	-6.86**	7.04*	0.59	2.48**	12.92**	0.66	-10.78**	18.69**	10.44**	-2.10	34.97**	9.21**
P2 x P3	-8.96**	3.37	14.24**	19.61**	19.70**	25.70**	6.38**	7.10**	23.58**	22.82**	23.18**	13.06**
P2 x P4	-8.49**	6.45*	13.91**	24.22**	1.14	19.07**	17.22**	10.67**	9.10**	18.05**	12.48**	8.74**
P2 x P5	-9.16**	2.43	13.00**	15.94**	-11.23**	6.24**	20.82**	-5.22**	9.79**	0.13	8.19**	13.42**
P2 x P6	-2.44	10.52**	7.44**	13.95**	12.03**	8.55**	0.97	6.12**	4.38**	19.32**	13.26**	9.10**
P3 x P4	-2.95	4.37	10.14**	29.26**	25.96**	32.24**	3.87	12.32**	19.56**	20.79**	49.20**	5.42**
P3 x P5	-0.37	4.91	8.89**	6.77**	11.59**	4.24**	-6.81**	-4.97**	10.43**	17.75**	31.12**	10.94**
P3 x P6	-5.07*	0.89	3.77**	12.06**	17.94**	3.98**	-11.73**	-23.84**	9.37**	-1.69	19.98**	2.05**
P4 x P5	-3.62	-0.83	7.15**	39.28**	9.88*	32.49**	18.88**	17.50**	9.09**	16.06**	20.91**	3.90**
P4 x P6	-5.75**	7.02*	4.59**	22.71**	13.14**	33.14**	16.35**	10.32**	11.84**	16.96**	28.22**	13.90**
P5 x P6	-6.45**	-4.53	4.29**	30.43**	16.31**	17.75**	0.75	14.64**	5.71**	18.83**	48.49**	6.30**
LSD 5%	3.87	6.08	1.13	1.09	8.07	0.94	3.91	0.66	1.12	3.57	0.25	0.03
LSD 1%	5.17	8.13	1.51	1.46	10.80	1.26	5.23	0.88	1.50	4.77	0.34	0.04

*** Significant at 0.01 level, ** Significant at 0.05 level.**

Days to 50% heading (DH), Plant height (PH), Spike length (SL), Number of spikes plant^{-1} (NS/P), Biological yield plant^{-1} (BY/P), Grain yield plant^{-1} (GY/P), Harvest index (HI), Weight/spike (WS), Number of spikelets spike^{-1} (NST/S), Number of grains spike^{-1} (NG/S), Weight of grains spike^{-1} (WG/S), 1000 grains weight (1000-GW).

2- Better parent heterosis in F_1-generation:

Heterosis based on batter parent of these crosses appeared in Table 6. The results of heterosis for heading were negative substantial (P < 0.05 or 0.01) for six crosses (P1XP5), (P1XP6), (P2XP3), (P2XP4), (P2XP5) and (P3XP6) by -6.57, -5.28, -8.96, -7.46, -7.46 and -4.53%, respectively. All these crosses were significant earlier than the better parent. For plant height, all crosses had lower estimates than the better parent, but the hybrids (P1XP2), (P1XP6), (P1XP3), (P2XP4), (P3XP4), (P2XP6), (P3XP5) and (P4XP6) gave positive heterosis values varied from 0.39% of (P1XP3) to 5.57% (P1XP6). For spike length, except five crosses (P1XP4), (P1XP6), (P3XP6), (P4XP5) and (P5XP6) all the crosses exhibited positively substantial (P < 0.05 or 0.01) heterosis values varied from 1.82% of (P4XP6) to 12.34% of (P2XP3). For number of spikes/plant, ten hybrids (P1XP3), (P1XP5), (P1XP4), (P2XP3), (P2XP4), (P3XP4), (P3XP6), (P4XP5), (P4XP6) and (P5XP6) exhibited positive substantial (P < 0.05 or 0.01) heterosis values varied from 1.67 to 31.96% of (P2XP3) and (P4XP5), severally.

Concerning, biological yield/plant, nine crosses (P1XP2), (P1XP4), (P1XP3), (P1XP6), (P2XP3), (P3XP4), (P3XP6), (P4XP6) and (P5XP6) exhibited positive substantial (P < 0.05 or 0.01) heterosis values with varied from 10.56% of (P4XP6) to 31.51% of (P1XP3). For grain yield/plant, Among the 15 F1's crosses, eleven crosses (P1XP2), (P1XP4), (P1XP3), (P1XP5), (P2XP4), (P2XP3), (P3XP4), (P3XP5), (P4XP5), (P4XP6) and (P5XP6) showed positive and highly substantial heterosis values varied from 2.94% of (P3XP5) to 26.97% of (P4XP5). Regarding harvest index, four crosses (P2XP4), (P2XP5), (P4XP5) and (P4XP6) exhibited positive and highly substantial heterosis values varied from 6.25% of cross (P4XP6) to 15.66% of cross (P2XP4). Among 15 F_1's crosses, eight crosses possessed positive and highly substantial heterosis values ranged from 4.82% of (P1XP2) to 18.05% of (P1XP6) of trait WS and from 6.27% of (P4XP6) to 21.53% of (P2XP3) of trait NG/S.

For weight of grains/spike, the tested crosses had positive highly substantial heterosis values varied from 1.61% of hybrid (P2XP5) to 43.02% of hybrid (P3XP4). Number of spikelets/spike showed the same trend of heterosis for WG/S, with exception one cross (P2XP6) gave non-significant negative heterosis values for NST/S. Even though the other crosses exhibited positive and substantial (P < 0.01) heterosis values varied from 3.79% of (P4XP5) to 20.59% of (P2XP3). Similarly, for 1000-grain weight, with exception one cross (P4XP5), the rest crosses exhibited positive and substantial (P < 0.01) heterosis values varied from 0.19 to 13.12% of (P3XP6) and (P4XP6), respectively. Results were observed by Kumar *et al.* (2021), Bilgin *et al.* (2022), El Hanafi *et al.* (2022), Nassar *et al.* (2022) and Fouad *et al.* (2022).

Table 6. Percent standard heterosis relative to better parent in F_1-generation for all tested characters.

Crosses	DH	PH	SL	NS/P	BY/P	GY/P	HI	WS	NST/S	NG/S	WG/S	1000-GW
P1 x P2	-0.75	5.07	3.89**	-6.67**	27.34**	11.31**	-12.52**	4.82**	17.60**	1.88	37.42**	8.48**
P1 x P3	-3.36	0.39	5.48**	11.11**	31.51**	16.73**	-14.56**	-17.45**	10.16**	-5.24*	13.83**	7.27**
P1 x P4	0.36	-3.9	1.02	11.56**	17.73**	21.99**	-4.60*	7.16**	12.79**	-3.8	31.36**	8.22**
P1 x P5	-6.57**	-0.11	1.87**	2.67**	5.3	5.02**	-0.71	15.95**	6.49**	-8.31**	22.58**	7.84**
P1 x P6	-5.28*	5.57	0.34	0.89	10.93*	-2.19**	-11.84**	18.05**	8.77**	-8.69**	25.61**	7.15**
P2 x P3	-8.96**	-1.13	12.34**	1.67*	11.01*	4.85**	-5.20*	5.93**	20.59**	21.53**	16.66**	12.63**
P2 x P4	-7.46**	3.52	11.49**	2.04**	-11.20*	4.04**	15.66**	-2.03**	8.55**	12.51**	11.07**	7.90**
P2 x P5	-7.46**	0	4.35**	-8.68**	-19.43**	-10.48**	10.76**	-17.60**	3.96**	-2.46	1.61**	7.52**
P2 x P6	-1.89	3.69	2.43**	-10.09**	0.38	-11.08**	-8.90**	-7.46**	-0.94	13.47**	2.21**	7.52**
P3 x P4	-1.87	2.61	9.61**	23.98**	18.68**	25.21**	-6.33**	0.39	17.24**	16.28**	43.02**	4.21**
P3 x P5	1.49	2.73	2.14**	-2.74**	9.01	2.94**	-9.67**	-16.59**	7.07**	13.54**	17.05**	4.78**
P3 x P6	-4.53*	-1.14	0.56	2.29**	13.61**	1.66	-12.95**	-32.95**	6.29**	-7.44**	3.16**	0.19**
P4 x P5	-2.92	-1.23	0.96	31.96**	5.89	26.97**	10.34**	15.09**	3.79**	7.89**	12.22**	-0.78**
P4 x P6	-4.15	3.14	1.82*	16.51**	10.56*	23.42**	6.25**	8.42**	6.65**	6.27**	14.40**	13.12**
P5 x P6	-4.15	-8.35*	0.85	30.14**	14.66**	13.72**	-1	14.25**	5.46**	15.93**	42.27**	2.18**
LSD 5%	4.46	7.02	1.3	1.26	9.32	1.09	4.52	0.76	1.3	4.12	0.29	0.04
LSD 1%	5.97	9.39	1.74	1.68	12.47	1.45	6.04	1.02	1.73	5.51	0.39	0.05

*** Significant at 0.01 level, ** Significant at 0.05 level.**

Days to 50% heading (DH), Plant height (PH), Spike length (SL), Number of spikes plant^{-1} (NS/P), Biological yield plant^{-1} (BY/P), Grain yield plant^{-1} (GY/P), Harvest index (HI), Weight/spike (WS), Number of spikelets spike^{-1} (NST/S), Number of grains spike^{-1} (NG/S), Weight of grains spike^{-1} (WG/S), 1000 grains weight (1000-GW).

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

Positive substantial (P < 0.05 or 0.01) correlations were found among mean X_P and their GCA effects for DH, BY/P, PH, GY/P, SL, WS, NS/P, WG/S and 1000-GW (Table 7). The high positive association among the cultivar performance and the effects of GCA represents the majority of additive effects.

Higher association coefficient values among X_P and GCA were noted for SL, NS/P (0.96), 1000-GW (0.94), PH, WG/S (0.92), DH, WS (0.89), GY/P (0.88) and BY/P (0.81). On the basis of the results, the best parents for these characters were P1, Sakha 95, P4, Sids14 and P5, Misr 2 by 91.33, 91.33 and 92.67 days for lateness in days to 50% heading when their GCA effects were 0.96, 0.92 and 0.83 comparing with the earlier parents Misr 3, Giza 168 then Giza 171 which recorded for heading 88.33, 89.33 and 89.33 days and their GCA effects were -1.25, -1.25 and -0.21. Therefore, these three cultivars were the most general combiners for earliness. For PH, the shortest cultivars were Misr 3 then Sakha 95 with means performance of 94.54 and 97.21 cm. with GCA effects of -2.66 and -1.46. Therefore, these two parents exhibited as the most general combiners for short in plant height. For SL, the best parents were Giza 168 and Giza 171 with means performance 13.02 and 12.59 cm. and their GCA effects were 0.77 and 0.36. So, these two parents were the most general combiners for spike length. The parents Sakha 95 and Misr 2 were the most combiners for NS/P. Sids14 and Misr 3 cultivars were the most combiners for BY/P. For GY/P, the better two general combiners were Misr 3 and Giza 171 since their means and GCA effects were 23.54 and 22.50 gm. and 0.78 and 0.69, respectively. For WS, the better parent was Giza 168 follow by Giza 171 with performance of means 5.56 and 5.44 gm. and their GCA effects were 0.53 and 0.14. So, these two cultivars were the most general combiners for weight of spike. For WG/S, the better two general combiners were Giza 171 and Sids 14 where their means and GCA effects were 3.04 and 2.79 gm. and 0.28 and 0.14, respectively. Regarding to thousand grain weight, the best three general combiners were Giza 168 and Gize171 and Sids

14. According to the previously mentioned findings, the relationship between mean performance and GCA might be a sign of the parents' overall combining ability. Similar results are regarded by Al-Naggar *et al.* (2015).

Table 7. Association coefficients among parents' means (Xp) and GCA effects and among crosses means (X_{F1}) and SCA.

Traits	Xp vs GCA	X_{F1} vs SCA
DH	0.89*	0.91**
PH	0.92**	0.80**
SL	0.96**	0.89**
NS/P	0.96**	0.66**
BY/P	0.81*	0.86**
GY/P	0.88*	0.77**
HI	0.52	0.90**
WS	0.89*	0.78**
NST/S	0.75	0.84**
NG/S	0.72	0.88**
WG/S	0.92**	0.84**
1000-GW	0.94**	0.77**

*** Significant at 0.01 level, ** Significant at 0.05 level.**
Days to 50% heading (DH), Plant height (PH), Spike length (SL), Number of spikes plant^{-1} (NS/P), Biological yield plant^{-1} (BY/P), Grain yield plant^{-1} (GY/P), Harvest index (HI), Weight/spike (WS), Number of spikelets spike^{-1} (NST/S), Number of grains spike^{-1} (NG/S), Weight of grains spike^{-1} (WG/S), 1000 grains weight (1000-GW).

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قوة الهجين والقدرة على الائتلاف في هجن الجيل الأول لقمح الخبز

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الملخص

تمت دراسة قوة الهجين والقدرة على الائتلاف في قمح الخبز باستخدام طريقة تحليل الهجن النصف دائرية 6X6 خلال موسمين متتاليين 2021/2020 و2022/2021 في مزرعة خاصة بقرية بني عمران، مدينة ديرمواس، محافظة المنيا، مصر. وأشارت النتائج إلى وجود اختلافات معنوية أو عالية المعنوية لكل من التراكيب الوراثية والآباء والهجن والقدرة العامة والخاصة على الائتلاف لمعظم الصفات، بينما كانت نسبة التباين للقدرة العامة على التباين للقدرة الخاصة أقل من الوحدة في كل الصفات، مما يشير إلى زيادة تأثير الجينات غير الإضافية في تحديد أداء تلك الصفات. كان الصنف سدس 14 أفضل معطي لصفات المحصول البيولوجي وعدد حبوب السنبلة ومحصول الحبوب للنبات. كما كانت قوة الهجين لصفة محصول الحبوب للنبات موجبة وعالية المعنوية لجميع الهجن باستثناء أربعة هجن وهم P1xP6، P2xP5، P2xP6 وP3xP6. تراوحت قوة الهجين لمحصول الحبوب للنبات بالنسبة للأب المتوسط والأب الأفضل بين 3.98% (P3xP6) : 33.14% (P4xP6) و2.94% (P3xP5) : 26.97% (P4xP5) على التوالي. أظهرت أربعة من الآباء (P1، P3 ،P6 ،P4) تأثيرات معنوية وموجبة للقدرة العامة على الائتلاف لصفة محصول الحبوب للنبات، بينما أظهرت ثمانية هجن تأثيرات موجبة وعالية المعنوية للقدرة الخاصة على الائتلاف. كما أظهرت ثلاث هجن P2xP3، P3xP4 وP4xP6 تأثيرات مرغوبة ومعنوية لمعظم الصفات. وكان الارتباط بين متوسط الأداء للآباء وتأثيرات القدرة العامة على الائتلاف موجباً ومعنوياً أو عالي المعنوية لصفات ميعاد طرد السنابل وطول النبات وطول السنبلة وعدد السنابل للنبات والمحصول البيولوجي ومحصول الحبوب للنبات ووزن السنبلة ووزن حبوب السنبلة ووزن 1000 حبة.