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HETEROSIS AND COMBINING ABILITY IN GRAIN SORGHUM

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ABSTRACT

This investigation was done to estimate the performance, heterosis and combining ability in grain sorghum by using line × tester analysis. Five Egyptian cytoplasmic male sterile lines (females) were crossed with four Indian restorer lines (males) in a line x tester mating design at Shandaweel Research Station, in 2020 summer season. The twenty resulted crosses and, their parental lines (9) plus one check hybrid (SH-305) were assessed in the summer growing seasons, 2021 and 2022 at Shandaweel Res. Sta. The Data were recorded on the following traits, days to 50% flowering, panicle length, plant height, 1000-grain weight and grain yield/plant. Mean squares due to males, females and their interaction were highly significant concerning all studied traits. The best female lines for general combining ability (GCA) effects was BSH-3 and BSH-13 for earliness, and plant height, respectively, BSH-1and BSH-9 for panicle length and grain yield/plant respectively, BSH-1 and BSH-5 for 1000-grain weight. The best restorer lines (males) for GCA effects was Indian exotic-12 for most studied traits. Meanwhile, the best cross for specific combining ability (SCA) effects was ASH-13 x Indian exotic-12 for earliness and grain yield/plant, ASH-13 x Indian exotic-2 for high plant height, ASH-13 x Indian exotic-4 for short plant height, ASH-2 x Indian exotic-2 for panicle length and ASH-1 x Indian exotic-2 for heavy 1000-grain weight. The four crosses, ASH-1 x Indian exotic-4, ASH-1 x Indian exotic-8, ASH-9 x Indian exotic-8 and ASH-13 x Indian exotic-12 had desirable values for heterosis compared to better parent and superior compared to the check hybrid for most studied traits. These crosses will be subjected to large-scale field-testing to verify if they are suitable for release as commercial hybrids.

Key words: ***Sorghum bicolor General combining ability, Specific combining ability, Males, Females, Commercial hybrids.***

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) holds the position of being the world's fifth most significant cereal crop in terms of cultivation area and overall production, following wheat, rice, maize, and barley, as reported by FAOSTAT (2018). Grain sorghum has versatile using including usage as food, fodder, fuel, and in traditional practices. Moreover, sorghum has the potential to achieve substantial grain yields even in challenging environments, as highlighted by Reddy *et al* (2019). In Egypt, grain sorghum in Egypt is considered the fourth most important cereal crop after wheat, rice, and maize. According to (FAOSTAT 2018), area of cultivated grain sorghum is about 380 thousand feddans, produces around 950 thousand metric tonnes of grains, with an average of 2.49 ton/feddan. Grain sorghum is an important summer crop in Upper Egypt, and it is mainly grown in the governorates of El-Fayoum, Sohag, and Assiut. Grain sorghum is tolerant to a wide range of stress situations, such as high temperature, drought, salinity, and low soil fertility. In Egypt, now it's possible to produce high quality grain, high yielding sorghum hybrid with the introduction of a lot of cytoplasmic male sterile and restorer lines. Many studies have been published on heterosis, general and specific combining ability variances and effects on grain sorghum. Some hybrids' grain yields showed high heterosis over the better parent. Abd El-Halim (2003), found multiple variations in heterosis among sorghum crosses, for earliness, plant height, grain weight, and yield /plant. Mahdy *et al* (2010) Found that most hybrids were significantly earlier, noticeably taller, heavier in grain weight, and more productive than their parents and checks. Mahmoud *et a* (2012) discovered that some crosses exceeded the better parent in terms of earliness, tallness, number of green leaves, 1000-grain weight, and grain per plant. Also, they found that both additive and non-additive gene effects had an important role in the inheritance of all studied traits. However the non-additive gene effects had the major contributions to the inheritance of all examined traits. Padmashree *et al* (2014) suggested that while non-additive gene effects may contribute to the effects of specific combining ability (SCA), the impact of general combining ability (GCA) is primarily due to additive effects and interactions between additive effects. Several sorghum studies have consistently reported that both GCA and SCA effects, for both male and female parental lines as well as hybrids, have positive and statistically significant effects on grain yield and its component attributes, regardless of normal or drought conditions. Hassaballa *et al* (2015) reported that the inheritance of traits such as the number of days to 50% flowering, plant height, 1000-grain weight, and grain yield per plant is influenced by both additive and non-additive gene effects. El-Sagheer and Zaree (2020) observed that most crosses exhibited earlier flowering, taller stature, increased number of green leaves, higher 1000 grain weight, and greater grain yield per plant compared to the mid and better-performing parents. This emphasizes the role of non-additive genetic variance in the inheritance of these traits. Furthermore, their study revealed that over half of the hybrids displayed significant and positive heterosis in grain yield and its component traits. El-Sherbeny *et al* (2019) discovered significant variations in all the studied traits among different settings, parents, crosses, lines, testers, and the interaction between lines and testers. They also observed that the expression of these traits was influenced by both additive and non-additive gene action.

The objective of this study was to identify the best lines, both restorer and cytoplasmic male sterile, based on their general combining ability (GCA) effects for inclusion in a crossing program. Additionally, the study aimed to estimate the heterosis and specific combining ability (SCA) effects of the crosses.

MATERIALS AND METHODS

Twenty hybrids were developed from crossing between five cytoplasmic male sterile (CMS) Egyptian lines (A-lines) and four restorer Indian lines (R-lines) (Table 1) by a line x tester mating design at Shandaweel Agric. Res. Sta. in 2020 season. The hybrids along with their respective parent lines underwent evaluation in the consecutive seasons of 2021 and 2022, alongside the reference hybrid (SH-305).In the two seasons, the genotypes were sown on June 20_{ht} and June 22nd, respectively, following a randomized complete blocks design (RCBD) with three replications.

Each genotype was represented by a single row plot, measuring 4.0 meters in length, with a spacing of 60 cm between the rows and 20 cm between hills. Thinning occurred 21 days after the sowing date, resulting in two plants remaining per hill. All recommended cultural practices and plant protection measures for sorghum production were implemented timely. Data collection involved recording observations on marked and guarded plants in each row.

The recorded traits included plant height (cm), panicle length (cm), 1000-grain weight (g) and grain yield per plant (g), adjusted at 14% grain moisture. The number of days to 50% flowering was recorded for the entire row.

Combined analysis of variance across the two years was performed after homogeneity test according to Sndecor and Cochran (1989). Line × Tester analysis was done according to Kempthorne (1957) to estimate general combining ability (GCA) effects for parents (females and males) and specific combining ability (SCA) effects for hybrids.

Heterosis (H) relative to the better parent and its superiority over the standard check (SC) were calculated using the formula proposed by Bhatt (1971).

$$H\% = \frac{\overline{F_1} - \overline{B.P}}{\overline{B.P}} x100 \;\&\; Superiorty\ \% = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} x100$$

Significance was tested by the appropriate LSD test.

Table 1. Name and, origin of the nine parents of grain sorghum genotypes.

NO.	Line	Origin
Restorer -lines (testers) (R-lines)		
1	Indian exotic-2	India
2	Indian exotic-4	India
3	Indian exotic-8	India
4	Indian exotic-12	India
CMS -lines (A-lines)		
5	A SH-1	Egypt
6	A SH-3	Egypt
7	A SH-5	Egypt
8	A SH-9	Egypt
9	A SH-13	Egypt

RESULTS AND DISCUSSION

The combined analysis across the two years (Table 2) revealed significant($P \leq 0.05$ or $P \leq 0.01$) mean squares due to years (Y), genotypes (G) and their interaction (G×Y) for all studied traits, except (G×Y) for plant height. Meanwhile, the results in Table (3) showed that mean squares due to parents (P) and crosses (C), (males M, females F and M× F) were significant ($P \leq 0.01$) for all studied traits. Also, the results indicated that significant ($P \leq 0.01$) mean squares were found for parents vs. crosses (P vs C), indicating the presence of significant heterosis. Mean squares due to the interaction (P×Y) were significant ($P \leq 0.01$) for days to 50% flowering and grain yield/plant, also those due to the interaction (P vs C×Y) were significant ($P \leq 0.01$) for days to 50% flowering. Meanwhile, mean the squares due to the interactions (C×Y), (F×Y), (M×Y) and (F× M×Y) were not significant for all traits, except for (M ×Y) for grain yield/plant and (F× M×Y) for 1000-grain weight and grain yield/plant which were significant ($P \leq 0.05$ or $P \leq 0.01$).

Table 2. Combined analysis of variance for five studied traits across the two years.

SOV	df	Mean squares				
		Days to 50% flowering	Plant height (cm)	Panicle length (cm)	1000-grain weight (g)	Grain yield/plant (g)
Years (Y)	1	43.02222**	467.2222**	63.0125**	49.6125**	408.0056**
Rep/Years.	4	2.022222	1.022222	0.6708333	1.194444	12.63889
Genotypes (G)	29	44.32567**	8043.723**	103.48894**	29.20311**	1328.904**
G × Y	29	4.895785**	14.75096	2.9866379*	1.74181*	24.86762**
Error	116	1.70	17.78	1.85	1.13	13.58

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

Table 3. Line × tester analysis of variance for five traits across two years.

SOV	df	Mean squares				
		Days to 50% flowering	Plant height	Panicle length	1000-grain weight	Grain yield/plant
Genotypes (G)	28	45.73**	8330.95**	105.55**	30.24**	1367.36**
Parents (P)	8	41.78**	4649.87**	45.09**	22.30**	148.89**
P vs. Crosses	1	130.28**	148454.77**	1645.53**	267.22**	27447.71**
Crosses (C)	19	42.95**	2505.94**	49.95**	21.11**	507.75**
Female (F)	4	47.65**	2961.80**	149.06**	38.60**	1122.15**
Male (M)	3	14.47**	597.93**	57.15**	10.36**	294.73**
F × M	12	48.50**	2830.98**	15.11**	17.97**	356.21**
G × Y	28	5.01**	15.19	3.19*	1.80*	25.73**
P × Y	8	7.92**	13.73	5.11	2.31	25.64**
P vs. C × Y	1	23.29**	18.34	0.07	1.28	0.00
C × Y	19	2.83	15.65	2.54	1.62	27.12
F × Y	4	4.07	21.85	3.04	0.57	25.51
M × Y	3	1.17	1.39	3.01	0.32	37.21*
F × M × Y	12	2.83	17.15	2.26	2.29**	25.13*
Error	112	1.74	17.22	1.87	1.14	13.48

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

The mean performance of genotypes across two years (Table 4), showed that days to 50% flowering for the parental lines ranged from 67.50 (B SH-1) to 75.00 (Indian exotic-8) with an average of 73.33 day.

Table 4. Average performance of 20 F1's, nine parents and one check hybrid for five studied traits across two years.

Genotypes	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	1000-grain weight (g)	Grain yield/plant (g)
Crosses					
ASH-1 x Indian exotic-2	68.00	209.33	34.67	32.83	97.50
ASH-1 x Indian exotic-4	71.67	214.33	34.67	31.83	103.83
ASH-1 x Indian exotic-8	72.17	196.67	36.5	30.75	99.50
ASH-1 x Indian exotic-12	70.83	200.00	35.92	28.58	95.00
ASH-2 x Indian exotic- 2	66.67	195.00	35.33	28.00	85.67
ASH-2 x Indian exotic-4	69.17	200.33	31.00	27.83	76.50
ASH-2 x Indian exotic-8	68.67	197.33	32.00	32.25	87.00
ASH-2 x Indian exotic-12	68.50	188.33	34.17	30.17	94.00
ASH-5 x Indian exotic-2	70.00	188.00	28.17	31.50	88.00
ASH-5 x Indian exotic-4	69.50	226.17	29.83	32.67	85.00
ASH-5 x Indian exotic-8	72.83	234.50	30.00	32.5	80.00
ASH-5 x Indian exotic-12	72.17	240.50	31.33	31.42	77.00
ASH-9 x Indian exotic-2	74.50	188.00	34.00	30.75	83.17
ASH-9 x Indian exotic-4	66.50	245.83	33.67	30.33	93.00
ASH-9 x Indian exotic-8	68.83	205.83	37.25	28.17	96.50
ASH-9 x Indian exotic-12	68.17	187.17	38.00	29.50	96.00
ASH-13 x Indian exotic-2	71.50	249.17	31.67	26.42	72.00
ASH-13 x Indian exotic-4	70.67	194.33	29.58	28.67	79.17
ASH-13 x Indian exotic-8	66.67	206.67	29.92	31.50	83.00
ASH-13 x Indian exotic-12	63.00	227.83	35.83	28.83	101.50
Average of crosses	69.50	209.77	33.18	30.23	88.67
Parents					
B SH-1	67.50	123.50	24.83	27.08	56.50
B SH-3	69.33	128.67	24.58	30.17	60.00
B SH-5	68.17	127.67	24.5	27.92	59.50
B SH-9	71.83	122.00	23.33	25.92	64.50
B SH-13	73.17	116.83	27.58	25.75	52.50
Indian exotic-2	74.67	182.00	27.25	30.83	63.50
Indian exotic-4	73.00	164.00	30.83	28.33	65.00
Indian exotic-8	75.00	173.67	30.67	25.67	63.00
Indian exotic-12	70.67	181.33	25.17	26.25	69.17
Average of parental lines	73.33	175.25	28.48	27.77	65.17
Check SH- 305	71.00	189.67	34.50	29.50	86.83
L.S.D. 0.05	1.47	4.77	1.54	1.20	4.17

Whereas days to 50% flowering, for the crosses ranged from 63.00 (ASH-13 x Indian exotic-12) to 74.50 (ASH-9 x Indian exotic-2) with an average of 69.50 day. Overall, the majority of the F1 crosses exhibited earlier flowering compared to their parental lines. While 10 crosses were significantly earlier than the check hybrid SH-305. Plant height for the parental lines ranged from 116.83 cm (B SH-13) to 182.00 cm (Indian exotic-2) with a mean of 175.25 cm, while for the crosses it ranged from 187.17 cm (ASH-9 x Indian exotic-12) to 249.17 cm (ASH-13 x Indian exotic-2) with an average of 209.77 cm. Also, fifteen crosses were significantly taller than the check hybrid SH-305. For panicle length, the means of parental lines ranged from 23.33 cm (B SH-9) to 30.83 cm (Indian exotic-4) with an average of 28.48 cm, while for the crosses it ranged from 28.17 cm (ASH-5 x Indian exotic-2) to 38.00 cm (ASH-9 x Indian exotic-12) with an average of 33.18 cm. Three crosses were significantly higher in panicle length than the check hybrid SH-305. For 1000-grain weight the means of parental lines ranged from 25.67 g (Indian exotic-8) to 30.83 g (Indian exotic-2) with an average of 27.77 g, while for the crosses it ranged from 26.42 (ASH-13 x Indian exotic-2) to 32.83 g (ASH-1 x Indian exotic-2) with an average of 30.23 g, ten crosses were significantly heavier in 1000-grain weight than the check hybrid SH-305. For grain yield, the parental lines varied from 52.50 g (B SH-13) to 69.17 g (Indian exotic-12) with an average of 65.17 g, while, for the crosses it varied from 72.00 (ASH-13 x Indian exotic-2) to 103.83 (ASH-1 x Indian exotic-4) with an average of 88.67 g. The nine crosses, ASH-1 x Indian exotic-2, ASH-1 x Indian exotic-4, ASH-1 x Indian exotic-8, ASH-1 x Indian exotic-12, ASH-2 x Indian exotic 12, ASH-9 x Indian exotic 4, ASH-9 x Indian exotic-8, ASH-9 x Indian exotic-12 and ASH-13 x Indian exotic-12 out-yielded the check hybrid SH-305. These crosses can be evaluated on a large scale as promising crosses. Moreover, the data showed that the mean of crosses was significantly higher than mean of parents for plant height, panicle length, 1000-grain weight and grain yield/plant, indicating that presence of heterosis for these traits.

Estimates of heterosis relative to the better parent and superiority relative to check hybrid are presented in Table 5.

Table 5. Estimates of heterosis (%) relative to better parent (B.) and superiority (%) relative to check hybrid (SC) of all studied traits across two seasons.

Cross	Days to 50% flowering		Plant height (cm)		Panicle length (cm)	
	B. parent	SC	B. parent	SC	B. parent	SC
ASH-1 x Indian exotic-2	-6.85**	-4.23**	15.02**	10.37**	27.22**	0.48
ASH-1 x Indian exotic-4	0.00	0.94	30.69**	13.01**	12.43**	0.48
ASH-1 x Indian exotic-8	-4.84**	1.64	13.24**	3.69	19.02**	5.80**
ASH-1 x Indian exotic-12	-1.39	-0.23	10.29**	5.45*	42.72**	4.11**
ASH-2 x Indian exotic- 2	-8.68**	-6.10**	7.14**	2.81	29.66**	2.42*
ASH-2 x Indian exotic-4	-3.49**	-2.58**	22.15**	5.62*	0.54	-10.14
ASH-2 x Indian exotic-8	-9.45**	-3.29**	13.63**	4.04	4.35*	-7.25
ASH-2 x Indian exotic-12	-4.64**	-3.52**	3.86**	-0.70	35.76**	-0.97
ASH-5 x Indian exotic-2	-4.11**	-1.41	3.3**	-0.88	3.36	-18.36
ASH-5 x Indian exotic-4	-3.02**	-2.11**	37.91**	19.24**	-3.24	-13.53
ASH-5 x Indian exotic-8	-3.96**	2.58	35.03**	23.64**	-2.17	-13.04
ASH-5 x Indian exotic-12	0.46	1.64	32.63**	26.80**	24.5**	-9.18
ASH-9 x Indian exotic-2	2.05*	4.93	3.3**	-0.88	24.77**	-1.45
ASH-9 x Indian exotic-4	-7.42**	-6.34**	49.9**	29.61**	9.19**	-2.42
ASH-9 x Indian exotic-8	-9.23**	-3.05**	18.52**	8.52**	21.47**	7.97**
ASH-9 x Indian exotic-12	-5.10**	-3.99**	3.22**	-1.32	50.99**	10.14**
ASH-13 x Indian exotic-2	-2.28*	0.70	36.9**	31.37**	14.8**	-8.21
ASH-13 x Indian exotic-4	-3.42**	-0.47	18.5**	2.46	-4.05*	-14.25
ASH-13 x Indian exotic-8	-12.09**	-6.10**	19.00**	8.96**	-2.45	-13.29
ASH-13 x Indian exotic-12	-13.9**	-11.27**	25.64**	20.12**	29.91**	3.86**

Table 5. Cont.

Cross	1000-grain weight (g)		Grain yield/plant (g)	
	B. parent	SC	B. parent	SC
ASH-1 x Indian exotic-2	6.49**	11.30**	53.54**	12.28**
ASH-1 x Indian exotic-4	12.35**	7.91**	59.74**	19.58**
ASH-1 x Indian exotic-8	13.54**	4.24**	57.94**	14.59**
ASH-1 x Indian exotic-12	5.54**	-3.11	37.35**	9.40**
ASH-2 x Indian exotic- 2	-9.19**	-5.08	34.91**	-1.34
ASH-2 x Indian exotic-4	-7.73**	-5.65	17.69**	-11.90
ASH-2 x Indian exotic-8	6.91**	9.32**	38.1**	0.19
ASH-2 x Indian exotic-12	0.00	2.26**	35.9**	8.25**
ASH-5 x Indian exotic-2	2.16	6.78**	38.58**	1.34
ASH-5 x Indian exotic-4	15.29**	10.73**	30.77**	-2.11
ASH-5 x Indian exotic-8	16.42**	10.17**	26.98**	-7.87
ASH-5 x Indian exotic-12	12.54**	6.50**	11.33**	-11.32
ASH-9 x Indian exotic-2	-0.27	4.24**	28.94**	-4.22
ASH-9 x Indian exotic-4	7.06**	2.82**	43.08**	7.10**
ASH-9 x Indian exotic-8	8.68**	-4.52	49.61**	11.13**
ASH-9 x Indian exotic-12	12.38**	0.00	38.8**	10.56**
ASH-13 x Indian exotic-2	-14.32**	-10.45	13.39**	-17.08
ASH-13 x Indian exotic-4	1.18	-2.82	21.79**	-8.83
ASH-13 x Indian exotic-8	22.33**	6.78**	31.75**	-4.41
ASH-13 x Indian exotic-12	9.84**	-2.26	46.75**	16.89**

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

The data showed that, sixteen and eleven crosses were significanty earlier than the better parent and the standared check, respectively. The best crosses for earlines relative to better parent and ckeck, were ASH-13 x Indian exotic-8and ASH-13 x Indian exotic-12. Heterosis for earliness was obatined by many researcher (Abd El-Halim2003, Hafez *et al* 2009, Mahdy *et al* 2011, Saikiran *et a* 2022 and El-kady *et al* (2022). For plant height, 20 and 12 crosses showed positive and significant superiority relative to better parent and standared check, respectively, indieating that these crosses had favorable gene action for tallness. Similar results were obtained by Sayed (2003), El-kady *et al* (2015) and El-kady *et al* (2022). For panicle length, 14 and 6 hybrids were significant or highly significant than the better parent and check, respectively. Similar results were reported by Saikiran *et al* 2022) and El-kady *et al* (2022).For 1000-grain weight, data showed that 13 and 12 crosses had positive and highly significant superiorty values over better parent and the standard check SH-305, respectively. For grain yield/plant 20 and 9 crosses had highly significant superiority over the better parent and check, respectively;these results are in agreement with El-Sagheer (2020). In general, the four crosses ASH-1 x Indian exotic-4, ASH-1 x Indian exotic-8,ASH-9 x Indian exotic-8 and ASH-13 x Indian exotic-12 were the best for heterosis relative to better parent and superiority over the check hybrid for most studied traits.

Estimates of general combining ability (GCA) effects of the parental lines across two years are presented in Table 6. The GCA effects for days to 50% flowering declared thatthe two female lines BSH-3 and BSH-13 and one male R-line Indian exotic-12showed significant and negative GCA effects. These lines could be regarded as excellent general combiners and hold advantageous genes for earliness. For plant height, two female lines (BSH-5 and BSH-13) and one male R-Line (Indian exotic-4) had positive and highly significant GCA effects, that means they had desirable gene action for tallness. For panicle length, two female lines (BSH-1 and BSH-9) and one male R-Line (Indian exotic-12) had positive and highly significant GCA effects, that means they had desirable gene action for tall panicle length. For 1000-grain weight, it observed that two female lines (BSH-1, BSH-5) and one male lines (Indian exotic-8) showed positive and significant or highly significant GCA effects, indicating that these lines had favorable genes for heavy grain weight. For grain yield/plant, the two female lines, BSH-1; BSH-5 and one male line (Indian exotic 12) showed positive and significant GCA effects for grain yield/plant indicating that these lines are good combiners and had favorable genes for grain yield/plant.

Table 6. Estimates of general combining ability effects of parents for five studied traits across the two years.

Parent	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	1000-grain weight	Grain yield/plant (g)
Line					
BSH-1	**1.17****	**-4.68****	**2.26****	**0.78****	**10.29****
BSH-3	**-1.25****	**-14.52****	**-0.05**	**-0.66***	**-2.88****
BSH-5	**1.63****	**12.53****	**-3.34****	**1.79****	**-6.17****
BSH-9	**0.00**	**-3.06****	**2.55****	**-0.55***	**3.50****
BSH-13	**-1.54****	**9.73****	**-1.42****	**-1.37****	**-4.75****
LSD f (J_i - J_j) 0.05	**0.52**	**1.66**	**0.55**	**0.43**	**1.47**
LSD f (J_i - J_j) 0.01	**0.68**	**2.18**	**0.72**	**0.56**	**1.93**
Tester					
Indian exotic-2	**0.63****	**-3.87****	**-0.41**	**-0.32**	**-3.40****
Indian exotic-4	**0.00**	**6.43****	**-1.43****	**0.04**	**-1.17**
Indian exotic-8	**0.33**	**-1.57***	**-0.04**	**0.81****	**0.53**
Indian exotic-12	**-0.97****	**-1.00**	**1.88****	**-0.53***	**4.03****
LSD m (J_i - J_j) 0.05	**0.47**	**1.49**	**0.49**	**0.38**	**1.31**
LSD m (J_i - J_j) 0.01	**0.62**	**1.95**	**0.64**	**0.50**	**1.73**

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

Estimates of specific combining ability (SCA) effects across the two years are presented in Table 7. Seven crosses (ASH-1 x Indian exotic-2, ASH-2 x Indian exotic-2, ASH-5 x Indian exotic-2, ASH-5 x Indian exotic-4, ASH-9 x Indian exotic-4 and ASH-13 x Indian exotic-8, ASH-13 x Indian exotic-12) had negative and significant SCA effects for days to 50% flowering, indicating that these crosses represent the best combinations for earliness.

Table 7. Estimates of specific combining ability effects of 20 crosses for all studied traits across the two years.

Crosses	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	1000-grain weight (g)	Grain yield/plant (g)
ASH-1 x Indian exotic-2	-3.30**	8.17**	-0.36	2.16**	1.94
ASH-1 x Indian exotic-4	1.00	2.82	0.65	0.79	6.04**
ASH-1 x Indian exotic-8	1.17*	-6.85**	1.10*	-1.06*	0.01
ASH-1 x Indian exotic-12	1.13*	-4.08*	-1.40*	-1.89**	-7.99**
ASH-2 x Indian exotic- 2	-2.22**	3.62*	2.62**	-1.24*	3.28*
ASH-2 x Indian exotic-4	0.92	-1.35	-0.70	-1.77**	-8.13**
ASH-2 x Indian exotic-8	0.08	3.65*	-1.08	1.88**	0.68
ASH-2 x Indian exotic-12	1.22*	-5.92**	-0.83	1.13*	4.16**
ASH-5 x Indian exotic-2	-1.76**	-30.43**	-1.26*	-0.19	8.90**
ASH-5 x Indian exotic-4	-1.63**	-2.56	1.43*	0.60	3.67*
ASH-5 x Indian exotic-8	1.38**	13.78**	0.21	-0.33	-3.03
ASH-5 x Indian exotic-12	2.01**	19.21**	-0.36	-0.08	-9.53**
ASH-9 x Indian exotic-2	4.37**	-14.84**	-1.32*	1.39*	-5.60*
ASH-9 x Indian exotic-4	-3.00**	32.69**	-0.64	0.60	2.00
ASH-9 x Indian exotic-8	-1.00	0.69	1.56**	-2.33**	3.80*
ASH-9 x Indian exotic-12	-0.37	-18.54**	0.40	0.34	-0.20
ASH-13 x Indian exotic-2	2.91**	33.53**	0.33	-2.11**	-8.52**
ASH-13 x Indian exotic-4	2.71**	-31.60**	-0.74	-0.23	-3.58
ASH-13 x Indian exotic-8	-1.63**	-11.27**	-1.79**	1.84**	-1.45
ASH-13 x Indian exotic-12	-3.99**	9.33**	2.21**	0.50	13.55**
LSD (S_{ij}- S_{ik}) 0.05	1.05	3.32	1.09	0.84	2.94
LSD (S_{ij}- S_{ik}) 0.01	1.38	4.37	1.44	1.12	3.87

***, ** Significant and highly significantly at 0.05 and 0.01 probability levels, respectively.**

Conversely,there were eight crosses exhibited positive and significant SCA effects for lateness. For plant height, eight crosses had positive values and significant SCA effects and eight crosses had negative and highly significant SCA effects. The negative SCA effects indicate that these crosses represent the best combinations for short plant and *vice versa* for the positive SCA effects. For panicle length, five crosses had positive and significant SCA effects. Five crosses showed positive and significant SCA effects for 1000-grain weight, indicating that these crosses represent the best combinations for heavy grain weight.For grain yield/plant, the desirable crosses for SCA effects; were ASH-1 x Indian exotic-4, ASH-2 x Indian exotic-2, ASH-2 x Indian exotic-12, ASH-5 x Indian exotic-2, ASH-5 x Indian exotic-4, ASH-9 x Indian exotic-8 and ASH-13 x Indian exotic-12; these crosses had at least one parent of significant GCA effects. Desirable crosses for SCA effects of studied traits were obtained by many researchers, (Singh and Singh 1995, Abd-El-Mottaleb 2009, El Kady *et al* 2015, Sayed and Mahdy 2016, El-Sherbeny *et al* 2019 and El Kady *et al* 2022).

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قوة الهجين والقدرة على الائتلاف فى الذرة الرفيعة للحبوب

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أجري هذا البحث لدراسة أداء وقوة الهجين والقدرة العامة والخاصة على الائتلاف في هجن الذرة الرفيعة باستخدام تحليل السلالة × الكشاف. تم الحصول على عشرين هجيناً ناتجة من التلقيح بين خمس سلالات عقيمة زكريا وأربع سلالات معيدة للخصوبة فينظامالتزاوج السلالة xالكشاف بمحطة البحوث الزراعية بشندويل في موسم ٢٠٢٠. تم تقييم ٢٠ هجين الناتجة من ٩ سلالات الآباء بالإضافة لهجين المقارنة SH-305 في مزرعة بحوث جزيرة شندويل بسوهاج- مصر في موسمي ٢٠٢١-٢٠٢٢م. لدراسة عدد الأيام حتى تزهير ٥٠%، وطول النبات، وطول القنديل، وزن ال ١٠٠٠- حبة وكذلك محصول الحبوب. وكان التباين الراجع الى الامهات والآباء والتفاعل بينها عالية المعنوية لكل الصفات المدروسة. كانت أفضل الأمهات للقدرة العامة على الائتلاف (GCA) هيBSH-3 وBSH-13 للتبكير وارتفاع النبات على التوالي، BSH-1 وBSH-9 لطول القنديل ومحصول النبات الواحد، BSH-1 وBSH-5 لوزن ١٠٠٠ حبة. من ناحية أخرى، أفضل الاباء ذات القدرة العامة على الائتلاف(GCA)هيIndian exotic-12 فى معظم الصفات المدروسة. أفضل هجين في القدرة الخاصة على الائتلافهيASH-13 x Indian exotic-12 للتبكير ولصفة المحصول، ASH-13 x Indian exotic-4 لصفة قصر طول النبات، وASH-13 x Indian exotic-2 لصفة ارتفاع طول النبات، ASH-2 x Indian exotic-2 لطول القنديل، وASH-1 x Indian exotic-2 لوزن ١٠٠٠ حبة.اظهرت الهجن (ASH-1 x Indian exotic 4 وASH-1 x Indian exotic-8 وASH-9 x Indian exotic-8 ASH-13 x Indian exotic-12) قيم مرغوبة لقوة الهجين بالنسبة لأفضل الآبوين وهجين المقارنة فى معظم الصفات المدروسة. وهذه الهجن ستخضع لاختبارات ميدانية واسعة النطاق للتأكد من ملاءمتها لإطلاقها كهجن تجارية.

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