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Original Research Article

EVALUATING COMBINING ABILITIES AND HETEROTIC EFFECTS FOR ENHANCED COTTON YIELD

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Abstract *The present research was conducted to evaluate heterosis in diallel crosses, determining general and specific combining abilities for yield-related traits and identifying top-performing genotypes for future breeding programs. A field experiment was conducted using selected genotypes (CIM-599, CIM-602, Shahkar, and NS-181) to produce F1 hybrids through frequent pollinations in a diallel fashion. Twelve F1 hybrids and their four parental genotypes were cultivated in a randomized complete block design with two replications. Yield-related traits were recorded, including plant height, branches per plant, bolls per plant, lint percentage, boll weight, seed cotton yield, seed index, and lint index. Analysis of variance and combining ability effects analysis were performed to assess the significance of the genotypes and their interactions. Significant variability among parental genotypes was observed for yield-related traits, indicating genetic variation in the breeding material. Combining ability analysis revealed the predominance of non-additive gene action. General combining ability (GCA) effects were significant for most traits, with CIM-599 exhibiting the highest GCA effects. Specific combining ability (SCA) and reciprocal combining ability (RCA) effects were significant for various traits and hybrid combinations, indicating their potential for trait improvement. The hybrid combination CIM-599 x Shahkar exhibited substantial mid-parent heterosis for seed cotton yield, boll weight, and lint percentage. This cross also displayed notable SCA effects, indicating its importance for hybrid breeding. These findings highlight the potential of hybrid breeding for trait enhancement. Future breeding programs could leverage the insights gained here to create improved cotton varieties with enhanced yield*.

Keywords: GCA, RCA, SCA, heterosis, gene action

Introduction

The chief objective of cotton breeders is to evaluate new cotton varieties having textile industry quality fiber as well as high lint yield (Khalid et al., 2021). Different breeding methods are being used by cotton breeders worldwide to develop new cotton varieties (Iqbal et al., 2023). Choice of selection method to increase productivity primarily depends upon genetic control of yield related traits, heterosis, and combining ability of the genotypes for parameters under consideration (Shafique et al., 2023). Accomplishment of breeding program is majorly dependent on the selection of parents (Babar et al., 2022). Choice of competent parents leads to a successful breeding program and, after that the selection of the best hybrid crosses (Riaz et al., 2023). Plant breeders have been extensively using diallel analysis to identify parental varieties and hybrid crosses in the initial generations (Bhutta et al., 2023). It provides an efficient and organized method for identifying suitable parental genotypes and hybrid combinations, which ultimately facilitates selecting genotypes of interest to the farmer (Fatima et al., 2022). Knowledge linked to different forms of gene action, heterotic effects and estimation of combining ability can aid in shaping the genetic constitution of cotton crop (Ali et al., 2013; Ali et al., 2014; Abbas et al., 2015; Abbas et al., 2016; Zafar et al., 2022; Babar et al., 2023).

Heterosis breeding is extensively utilized to improve important traits in different crops. It has also become potential means for selecting cotton hybrids (Chaudhry et al., 2022). Due to heterosis, many hybrids have been developed with superior performance and stress resistance (Riaz et al., 2023). The word "heterosis" was first presented by George H. Shull. Heterosis occurs when the F_1 offspring show

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superior yield potential and fiber quality traits compared to pure varieties (Iqbal et al., 2023). This breeding approach helps determine the extremely suitable parents for improving yield contributing traits (Bano et al., 2023). Yield contributing traits benefit from positive and negative heterosis (Nadeem et al., 2022). Positive heterosis occurs due to the superiority of F_1 while the inferiority of F_1 results in negative heterosis. Both are fairly useful in certain situations according to the breeding requirement (Chaudhry et al., 2022; Hassan et al., 2022; Fatima et al., 2023; Hafeez et al., 2021; Iqbal et al., 2023). Commercial heterosis is more useful in cotton than the mid and better parent heterosis (Hassan et al., 2021; Imtiaz et al., 2022). In Commercial heterosis, the hybrids are evaluated in comparison to the already released hybrids rather than merely comparing with their mid/better parents (Khalid et al., 2022; Mudasir et al., 2021). Extent and direction of heterotic effects is of prime importance for identifying a potential hybrid combination (Khalid & Amjad, 2018; Zaghum et al., 2021). So, the potential of a genotype to generate enhanced offspring, which is combining ability, along with heterosis can be valuable in shaping the effectiveness of breeding program for evaluating superior genotypes (Fatima et al., 2022).

Objectives

The existing evidence has exhibited the great importance of both general and specific combing ability and heterotic effects. F_1 hybrids evaluation has shown the significance of combining ability and heterotic effects estimation in cotton to select better crosses for direct use or further breeding work. Therefore, this research was initiated to address the following objectives:

- To evaluate the extent of heterosis in diallel crosses,
- To determine general and specific combining abilities for yield and its related traits,
- Evaluation of best-performing genotype to utilize in the future breeding program.

Materials and methods

The field experiment was conducted during the 2019 main cropping season at Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. To carry out the investigations, selected genotypes (CIM-599, CIM-602, Shahkar, and NS-181) were sown in pots, filled with loamy soil in a glasshouse during the winter season 2018-19 to produce F_1 hybrids. Frequent pollinations were done to obtain enough F_1 seeds in diallel fashion. At the time of maturity, Seed cotton was handpicked from crossed balls. Field plantation of twelve F_1 hybrids accompanied by their 4 parents was done during May 2019 under RCBD with two replications, maintaining 2.5 ft row-to-row and 30 cm plant-to-plant distance. Field practices, from the day of sowing to maturity were strictly followed.

Genetic Material used for experiment:

	Parents	4	CIM-602 x CIM-599
1	CIM-599	5	CIM-602 x Shahkar
2	CIM-602	6	CIM-602 x NS-181
3	Shahkar	7	Shahkar x CIM-599
4	NS-181	8	Shahkar x CIM-602
	Crosses	9	Shahkar x NS-181
1	CIM-599 x CIM-602	10	NS-181 x CIM-599
2	CIM-599 x Shahkar	11	NS-181 x CIM-602
3	CIM-599 x NS-181	12	NS-181 x Shahkar

Estimation of Characters

At maturity, five random plants will be selected to take data of the following traits from each genotype. Height of plant (cm), Monopodial branches/plant, Sympodia per plant, Number of boll/plants, Lint percentage (GOT%), Boll weight (g), Seed cotton yield (g), Seed index (g), Lint index (g)

Biometrical Analysis

For significance assessment of genotypes, analysis of variance calculated by Statistix 8.1. Further analysis for combining ability effects DOSBox was used.

Results and discussion

The data recorded from parental genotypes and F_1 hybrids were averaged and subjected to analysis of variance. The analysis of variance pointed out that the mean due to parental genotype was significant for all the characters, indicating substantial variability among the parents for these traits. Significant differences in the results indicated the genetic variation in the breeding material for yield and its related attributes. Similar results were also observed by (Fatima et al., 2022; Rehman et al., 2017; Imtiaz et al., 2022). So, these entries can be used for advance breeding programs. The Present study evaluated the combining ability and the heterotic effect in American upland cotton. Four cotton genotypes were crossed in diallel mating design to obtain F1 hybrids for that purpose. Different parameters such as plant height, monopodial branches/plant, sympodia per plant, number of boll/plants, lint percentage, boll weight, seed cotton yield, seed index, and lint index were recorded to assess the yield and performance of cotton cultivars.

Combining ability analysis showed that mostly nonadditive type of gene action was governing in almost all characteristics (Fatima et al., 2022; Riaz et al., 2023). The GCA effects were significant in all traits except the monopodial branches. The SCA and RCA effects were significant in all traits except SCA effect which was non-significant for boll number. The parental genotype CIM-599 recorded highest GCA effects for plant height, fruiting branches, boll number per plant, lint percentage, boll weight, seed cotton yield (SCY), seed index and lint index. Hence, overall regarded as the best general combiner in all major traits and could be utilized to enhance these traits through proper selection methods. The parental

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genotype NS-181 was also significant for seed cotton yield (SCY). The hybrid combination NS-181 x CIM-599 for plant height, CIM-602 x Shahkar for monopodial branches per plant, CIM-599 x Shahkar for lint percentage, CIM-599 x Shahkar for boll weight and seed cotton yield, CIM-599 x CIM-602 for seed index, CIM-599 x Shahkar for lint index recorded maximum positive SCA, hence these crosses may be utilized for development of hybrids to boost cotton production. Similar results were found by (IQBAL et al., 2023; Nadeem et al., 2022). The hybrid combinations NS-181 x CIM-602, NS-181 x CIM-599, and Shahkar x CIM-602 showed negative RCA effects for lint index, sympodial branches per plant, and number of bolls per plant, respectively.

The heterotic effect estimation revealed that the crosses CIM-599 x Shahkar obtained a maximum mid-parent heterosis 25.00% for lint index while Shahkar x CIM-599 recorded a maximum mid-parent heterosis 4.01% for seed index. CIM-599 x CIM-602 and CIM-599 x Shahkar recorded a maximum relative heterosis 23% for seed cotton yield, while CIM-599 x Shahkar also showed a maximum relative heterosis 12.0% for boll weight and 17.88% for lint percentage. NS-181 x CIM-602 showed greater mid-parent heterosis 27.68% for boll number per plant. Similar results were found by (Iqbal et al., 2023). The hybrid cross CIM-599 x CIM-602 recorded higher mid-parent heterosis for sympodia per plant. Shahkar x CIM-602 showed the highest negative mid-parent heterosis of 18.18% for monopodial branches per plant, which is more desirable. CIM-602 x NS-181 recorded the highest mid-parent heterosis of 17.89% for the plant height plant. The better parent heterosis was highest in CIM-599 x Shahkar for lint Index (10.39%), Shahkar x CIM-599 for seed index (1.27%), CIM-599 x Shahkar for SCY (16%), CIM-599 x NS-181 for boll weight (7.69%), CIM-599 x Shahkar for lint percentage (7.24%), NS-181 x CIM-602 for boll number per plant (25.40%), Shahkar x CIM-599 for sympodia per plant (14.58%), Shahkar x CIM-602 (20.0%) and CIM-602 x Shahkar for plant height. These crosses could be utilized for hybrid breeding.

Conclusion

Overall, the genotype CIM-599 recorded maximum GCA effects in almost all major traits followed by NS-181, whereas the hybrid combination CIM-599 x Shahkar recorded the highest mid-parent heterosis for three major yield contributing traits: seed cotton yield, boll weight and lint percentage. This cross also showed higher SCA effects for seed cotton yield and weight of boll. These SCA and heterosis results correlate favorably well to highlight the importance of hybrid breeding for improving these traits.

Table 2 Analysis of variance for all traits under studied

SOV	DF	PH	MB	SB	BP	GOT%	BW	SCY	SI	LI
Replication	1	69.61	0.0028	0.02	0.01	6.93**	0.005	3	0.0024	0.16**
Genotype	15	291.73**	0.9**	4.25**	4.09**	25.52**	0.17**	75.83**	0.10**	0.41**
Error	15	56.59	0.02	0.95	1.45	2.62	0.01	9.02	0.01	0.06

Table 3 Combining ability ANOVA for all the studied traits

SOV	DF	PH	MB	SB	BP	GOT%	BW	SCY	SI	LI
GCA	3	287.84**	0.02	4.23**	2.57**	33.45**	0.22**	94.36**	0.08**	0.50**
SCA	6	124.74**	0.08**	1.80**	1.04^{ns}	6.29**	0.08**	33.82**	0.03**	0.13**
RCA	6	96**	0.01	1.40**	2.78**	8.89**	0.02**	13.79**	0.05**	0.13**
Error	15									

Table 4 Variances for GCA and SCA under studied all the characteristics

	PH	MB	SB	BP	GOT%	BW	SCY	SI	LI
Var GCA	32.44	0.0017	0.46	0.23	4.01	0.02	11.23	0.0089	0.05
Var SCA	96.44	0.0765	1.32	0.32	4.98	0.07	29.3	0.0216	0.1
Ratio	0.33	0.02	0.35	0.71	0.8	0.34	0.38	0.41	0.59

Table 5 General combining ability effects for all the attributes

GCA Effects	PH	SB	BP	GOT%	BW	SCY	SI	LI
CIM-599	6.35**	1.02**	0.58*	2.81**	0.23**	5.01**	-0.14 **	0.34**
CIM-602	-7.40**	-0.08^{ns}	0.26^{ns}	-1.15**	-0.11**	-0.95ns	0.02 ns	-0.17 **
Shahkar	-1.95^{ns}	-0.25^{ns}	-0.11^{ns}	-1.80**	-0.12**	-1.92 **	0.09 **	-0.20 **
NS-181	3.00^{ns}	-0.68**	-0.73 **	0.14 ^{ns}	0.01^{ns}	2.21**	0.02 ns	0.04 ns

Table 6 Specific combing ability effects for all the attributes

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SCA	**PH**	**MB**	**SB**	**GOT%**	**BW**	**SCY**	**SI**	**LI**
CIM-599 x CIM-602	-10.06**	0.121^{ns}	0.73 ^{ns}	-0.68^{ns}	0.04^{ns}	2.16	0.12 *	-0.03 ns
CIM-599 x Shahkar	4.93^{ns}	-0.128^{ns}	0.65 ^{ns}	3.00**	0.25**	4.36**	0.0025 ns	0.45 **
CIM-599 x NS-181	-0.92^{ns}	0.29**	0.43 ^{ns}	0.43 ^{ns}	0.06^{ns}	3.63	-0.18 **	-0.07 ns
CIM-602 x Shahkar	6.91*	-0.171*	0.50 ^{ns}	-0.44 ^{ns}	- 0.12*	1.48	0.0056 ns	-0.05 ns
CIM-602 x NS-181	7.50*	-0.078^{ns}	0.01 ^{ns}	0.48 ^{ns}	0.08$^{n.s}$	0.28	-0.10 ns	0.01 ns
Shahkar x NS-181	-10.36**	0.021^{ns}	-1.14 **	-2.00**	- -0.28**	-5.25**	0.07 ns	-0.24 *

Table 7 Reciprocal combining ability effects for all the attributes

RCA	**PH**	**SB**	**BP**	**GOT%**	**BW**	**SCY**	**SI**	**LI**
CIM-602 x CIM-599	8.22*	0.25^{ns}	-0.07 ^{ns}	0.40 ^{ns}	0.10ns	1.3	0.06 ns	0.10 ns
Shahkar x CIM-599	6.17^{ns}	-0.95^{ns}	0.27 ^{ns}	1.68 ^{ns}	0.05 ns	1.82	-0.23 **	0.15 ns
NS-181 x CIM-599	-10.72*	-1.35**	0.52 ^{ns}	1.54 ^{ns}	0.05ns	0.95	-0.04 ns	0.22 ns
Shahkar x CIM-602	0.90^{ns}	0.19 ^{ns}	-1.72 *	0.27 ^{ns}	0.02 ns	-4.45**	-0.05 ns	0.07 ns
NS-181 x CIM-602	4.60^{ns}	1.07**	-2.25 **	-4.59**	0.22 **	3.87*	0.23 **	-0.55 **
NS-181 x Shahkar	6.72^{ns}	0.50 ^{ns}	0.47 ^{ns}	-0.34 ^{ns}	-0.05 ns	0.8	-0.21**	-0.15 ns

Table 8 Mid parent heterosis for all the crosses under studied

MP Heterosis (%)	**PH**	**MB**	**SB**	**BP**	**GOT%**	**BW**	**SCY**	**SI**	**LI**
CIM-599 x CIM-602	-3.67	3.7	18.13*	12.29	2.11	10.57*	23.80**	2.72	5.63
CIM-599 x Shahkar	10.96	-11.39	4.29	9.12	17.88 **	12.10*	23.40**	-3.6	25
CIM-599 x NS-181	-18.81	34.25**	-2.46	5.77	7.33	6.87	13.03	-5.90 *	4.52
CIM-602 x CIM-599	-26	16.05	14.54*	13.42	-0.08	4.07*	17.42**	0.74	0.01
CIM-602 x Shahkar	17.42	-15.91*	9.75	0.01	-0.63	-5.88	-5.91	1.76	1.61
CIM-602 x NS-181	17.89	-2.44	10.07	-8.69	-13.79	8.06	-1.43	0.55	-20.28
Shahkar x CIM-599	-4.38	-1.27	17.5	5.03	8.37 **	9.52*	14.78**	4.01	16.18
Shahkar x CIM-602	14.49	-18.18*	6.95	26.95	-2.26	-7.56	17.48	0.16	-3.23
Shahkar x NS-181	-6.31	2.5	-7.07	0.6	-7.51	-14.96**	-14.16*	-3.3	-13.87
NS-181 x CIM-599	5.53	26.03**	16.45	5	-0.71	3.82	8.57	-4.60 *	-7.1
NS-181 x CIM-602	4.59	0.02	-5.81	27.68	11.71	-6.45	18.77	-6.73	10.49
NS-181 x Shahkar	-24	-2.5	-14.24	-6.96	-5.51	-11.81**	-18.17*	3.54	-5.11

Table 9 Better parent heterosis for all the crosses under studied

BP Heterosis (%)	**PH**	**MB**	**SB**	**BP**	**GOT%**	**BW**	**SCY**	**SI**	**LI**
CIM-599 x CIM-602	-23.38**	-6.67	11.53	7.22	-3.84	4.62	12.11	0.65	-2.6
CIM-599 x Shahkar	-3.51	-18.6	1.69	5.78	7.24	6.15	16	-6.13	10.39
CIM-599 x NS-181	-22.73	32.43**	-5.42	-0.72	5.25	7.69	7	-9.41 **	3.85
CIM-602 x CIM-599	-41.14**	4.44	8.14	8.3	-5.9	-1.54	6.33	-1.29	-7.79
CIM-602 x Shahkar	5.62	-17.78*	6.17	-1.54	-4.23	-8.2*	-9.6	1.11	-3.08
CIM-602 x NS-181	-2.51	-11.11	7.07	-10.32	-17.27	3.08	-5.97	-1.24 *	-26.92
Shahkar x CIM-599	-16.85	-9.3	14.58	1.81	-1.41	6.15	7.89	1.27	2.6
Shahkar x CIM-602	2.99	-20.00*	3.46	25	-5.8	-9.84*	12.88	-0.48	-7.69
Shahkar x NS-181	-14.82*	-4.65	-7.6	-2.69	-14.33 **	-16.92**	-14.80*	-4.43	-24.36 **
NS-181 x CIM-599	0.43	24.32**	12.92	-1.44	-2.64	4.62	2.78	-8.16 **	-7.69
NS-181 x CIM-602	-13.51	-8.89	-8.37	25.4	7.2	-10.77	13.31	-8.40 *	1.28
NS-181 x Shahkar	-30.90*	-9.3	14.73	-10	-12.48**	-13.85**	-18.78*	2.33	-16.67 **

Declarations

Data Availability statement

All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

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Conflict of Interest

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