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Original Research Article

ESTIMATION OF HETEROSIS AND COMBINING ABILITY EFFECTS FOR YIELD AND FIBER QUALITY TRAITS IN COTTON (*GOSSYPIUM HIRSUTUM* L.)

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Abstract: *Cotton (Gossypium hirsutum L.) is an important cash crop worldwide, including Pakistan. Cotton is the fiber crop that plays a vital role in Pakistan's economy. Cotton devotes a major part to enhancing foreign exchange earnings and contributes 65 percent of total annual earnings by exporting the raw material and finished products of cotton. Identifying the parents with higher yield contributing traits is essential to enhance the economic yield. The diallel mating design was used because it is the best tool to discriminate between good and bad combiners. All crosses showed significant results except the number of monopodial branches, internodal distance and first fruiting branch node. Traits that showed significant variability were further analyzed for combining ability effects and gene action related to yield contributing traits. From parents NIAB-777 and Tipo-1 showed superior general combiners for most of the traits. Among the crosses NIAB-777 × Tipo-1, C-1 × Tipo-1 and C-1 × Shahkar exhibited high SCA. SCA variance for most of the genotypes was better than GCA and RCA variance. The information devised is really helpful in selecting suitable parents and hybrids for further breeding programs*.

Keywords: RCA, SCA, GCA, Heterosis

Introduction

Cotton (*Gossypium hirsutum* L.) is the major cash crop of tropical and subtropical regions of the world. Cotton is the best natural fiber crop with a large contribution in textiles with an economic impact of $600 billion dollars worldwide (Razzaq et al., 2020). Cotton is Pakistan's major foreign exchange source and provides fuel, feed and fiber (Zafar, Jia, et al., 2022). Cotton is grown as a natural fiber in sixty-five countries. Cotton belt of Pakistan lengthens over 1200km along with Indus River having latitudes of 27˚N to 35˚N. Pakistan, Greece and India is located in 30˚N to 30˚S (Manan et al., 2022).

The genus of the cotton plant is *Gossypium,* and it belongs to the malvaceae family. Fifty species of the genus *Gossypium* has been identified, of which forty-five are diploid, having 26 chromosomes, and five are allotetraploid having 52 chromosomes. Diploid species, mostly *Gossypium arboreum* and *Gossypium herbaceum* are cultivated and known as old-world cotton. From tetraploid species *Gossypium hirsutum* and *Gossypium barbadense* are cultivated on a large scale and are also known as new world cotton. Both diploid and tetraploid species vary from each other based on morphology and quality of fiber. The origin of *Gossypium hirsutum* is tropical America. Flowers of *Gossypium hirsutum* and *barbadense* are creamy and yellow, respectively. Fiber length of *G. hirsutum* is more than *G. barbadense* ranging from 25-30mm. Due to superior fiber quality, upland cotton is grown worldwide (Zafar, Shakeel, et al., 2022).

Pakistan ranks on 5th position among cotton-producing countries (Hassan et al., 2021). Cotton provides employment to people and strengthens the country's financial system (Babar et al., 2023; Chaudhry et al., 2022a). In Pakistan 99% of cultivated area is covered by G. *hirsutum.* Cotton is growing across Punjab and Sindh, but Punjab is the leading province in terms of area and production. Production from Punjab is 80%, and from Sindh is 18% (Bano et al., 2023).

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Production of edible oil from cotton is 65-70% in Pakistan. In cotton seed, 16-25% edible oil contents are present. There are two kinds of fiber: fuzzy fiber and lint fiber. Cotton fiber contains 1.3% protein, 1.2% pectin, 1.2% ash, 0.6% waxes and 0.3% sugars. Most important part of cotton is lint which plays a significant role in textile industry. Cotton is cultivated primarily for fiber which consists of 94% cellulose and 0.1-0.4% lignin (Mudasir et al., 2021). Lint cellulose is used as raw material in various industries (Chaudhry et al., 2022b).

There are many factors which contribute to the low production of cotton crop. Climate change, introduction of new insect pest, reduction in sowing area and slow marketing system are the important factors which cause a drastic shift in cotton production (Khalid et al., 2021). There is a need to develop high-yielding cotton cultivars to meet the demand. Developing potential cultivars can mitigate the factors contributing to low cotton production. Plant breeders need genetic variation to develop high-yielding varieties for any breeding program (Solanki et al., 2014). One of the most important genetic factors is identifying and utilizing genetically distinct parents (Sawarkar et al., 2015). Limited knowledge of combining ability and low genetic variability are the two factors which affect the selection of appropriate parents for hybridization programs (Khokhar et al., 2018). Therefore, adequate knowledge of gene action and mode of inheritance are essential for plant breeders to produce potential cultivars with desirable traits (Ranganatha et al., 2013; Ali et al., 2015). Information related to all genetic variability parameters is for improving the cotton crop (Ashokkumar et al., 2013; Ameer et al., 2012; Batool et al., 2023; Bibi et al., 2018; Hafeez et al., 2021; Imran et al., 2015; Masood et al., 2014). Genetic variation and combining ability are two important tools to determine genetic values of different populations (Shahzad et al., 2020). Combining ability analysis provides information about additive and non-additive gene action, which control yield and fiber traits (Ali et al., 2014ab; Ali et al., 2013; Wu et al., 2010).

The research was planned to find good general combiner and those crosses that show high specific combing ability effects and find the extent of heterosis over better parent, mid parent and standard heterosis for yield and its related trait in cotton. The study's main objective was to determine those parents and crosses showing good combining ability based on GCA, SCA and RCA effects. There is also a need to improve quality parameters to improve a variety.

The objectives of the study were:

- Determine those parents and crosses showing good combining ability based on GCA, SCA and RCA effects.
- Select the best general and specific combiner for yield and fibre-related traits and proceed to further selection.

Materials and Methods

The research was performed at the experimental site of the Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, during the Kharif season 2021. Four parents were collected from the department i.e., NIAB-777, C-1, TIPO-1 and SHAHKAR and were crossed in a diallel fashion to produce 16 cross combinations. When flowering, these lines were crossed with each other following emasculation and pollination. In some of the flower buds selfing was also done to get the pure seed of parent. The maximum number of crosses was made. The F_1 crossed seed and parents were planted in the field the next year using a randomized complete block design (RCBD) with two replications. From each line five plants were tagged to record observations. The distance between rows (R×R) of 75cm and plant-to-plant (P×P) of 45cm was maintained.

There were direct and indirect crosses using the following parents:

Parents:

NIAB-777
C-1
TIPO-1
SHAHKAR

Crosses:

NIAB-777 × C-1	TIPO-1 × NIAB-777
NIAB-777 × TIPO-1	TIPO-1 × C-1
NIAB-777 × SHAHKAR	TIPO-1 × SHAHKAR
C-1 × NIAB-777	SHAHKAR × NIAB-777
C-1 × TIPO-1	SHAHKAR × C-1
C-1 × SHAHKAR	SHAHKAR × TIPO-1

From sowing to harvesting of cotton suggested, agronomic practices were maintained. Five guarded plants were chosen for the data collection process and labeled. At the time of maturity on individual plants the data were recorded. To assemble the data for each character, the successive methodology was selected.

Morphological traits

Following morphological and fiber attributes, data were collected to analyze it further.

Plant height (PH), Boll Weight (BW), Number of sympodial branches (NOS), Seed index (SI), Ginning out-turn percentage (GOT), Number of bolls (NOB), Seed cotton yield (SCY), Number of nodes per plant (NON), Cotton seed yield (CSY), Fiber micronaire (MV), Fiber strength (FS), Fiber length (FL) and Uniformity (UR)

Statistical analysis

The information and data collected were then subjected towards statistical means for further analysis and examination. Heterosis and combining ability were computed through the DOSBox software.

Results and Discussion

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The analysis of variances showed significant differences among the four parents for number of bolls, plant height, number of nodes per plant, number of sympodial branches, seed cotton yield, cotton seed yield, boll weight, ginning out-turn percentage, seed index, micronaire value, fiber strength, fiber length and uniformity ratio. Analysis of variance revealed that the GCA, SCA and RCA effects were significant for all the characters (Kiani et al., 2007). Parents NIAB-777 and Tipo-1 showed superior general combiners for most traits (Lukonge et al., 2008). Among the crosses NIAB-777 × Tipo-1, C-1 × Tipo-1 and C-1 × Shahkar proved best for plant height, number of bolls, fiber length and strength and seed cotton yield (Khan et al., 2009). Tipo-1 × Shahkar, NIAB-777 × Shahkar and C-1 × Shahkar were the best specific combiners for most traits. C-1 × Tipo-1, NIAB-777 × Tipo-1, and C-1 × Shahkar showed good heterotic patterns among all crosses (Karademir et al., 2009).

The genotype crosses NIAB777 × CI, NIAB777 × Topo, NIAB777 × Shahkar, and CI × Shahkar was shown as good specific combiners from all other crosses for ginning out turn percentage, which give smaller values for variances (Sawarkar et al., 2015). The significant results for RCA were found in these hybrids i.e., NIAB777 × Topo, NIAB777 × Shahkar and Topo × Shahkar (Panhwar et al., 2008). For seed cotton yield crosses NIAB777 × CI, NIAB777 × Topo, CI × Topo and CI × Shahkar were shown as good specific combiners (Imran et al., 2012). All crosses were highly significant from reciprocal combining ability except CI × Topo (Khokhar et al., 2018).

Parents CI, Topo and Shahkar were shown as good general combiners for fibre strength. The genotype crosses NIAB777 × Shahkar and Topo × Shahkar were shown as good specific combiner from all other crosses, giving smaller variances value (Rauf et al., 2006). The significant results for RCA were found in these hybrids i.e., NIAB777 × Shahkar, CI × Shahkar and Topo × Shahkar (Abro et al., 2009). Parents Topo and Shahkar were observed as good general combiners for fiber length. The genotype crosses NIAB777 × Topo, NIAB777 × Shahkar and CI × Topo were shown as good specific combiner from all other crosses, giving smaller variances value (Yehia & El-Hashash, 2019). The significant results for RCA were found in NIAB777 × Shahkar hybrid (Patil & Patil, 2003).

Conclusion

SCA variation was discovered to be superior to GCA and RCA variance for the majority of genotypes.

Table 1: Analysis of variance (ANOVA) mean square values of various traits studied

SOV	DF	NOB	PH	NON	NOS	SCY	CSY	BW	GOT	SI	MV	FS	FL	UR
Replication	1	2.52	168.61	72.00	140.28	3.70	11.52	0.10	52.32	0.78	1.36	1.16	1.20	2.57
Genotype	15	126.14*	200.42*	36.37*	29.83*	1015.4*	780.41*	0.47*	243.23*	1.73*	0.36*	16.23*	3.73*	8.54*
Error	15	37.64	26.11	6.13	4.61	13.32	53.65	0.12	19.28	0.65	0.07	3.22	0.82	2.45
total	31													

Plant height (PH), Boll Weight (BW), Number of sympodial branches (NOS), Seed index (SI), Ginning out-turn percentage (GOT), Number of bolls (NOB), Seed cotton yield (SCY), Number of nodes per plant (NON), Cotton seed yield (CSY), Fiber micronaire (MV), Fiber strength (FS), Fiber length (FL) and Uniformity (UR)

Table 2: Analysis of variance (ANOVA) for genetic components (mean square values) of various traits

SOV	DF	NOB	PH	NON	NOS	SCY	CSY	BW	GOT	SI	MV	FS	FL	UR
GCA	3	90.18*	196.28**	5.23	6.55	273.42**	31.75	0.37**	2.53	1.9**	0.30**	14.49**	2.3**2	5.23*
SCA	6	27.28	78.33**	18.89**	12.41*	310.36**	289.55**	0.16*	183.78**	1.03*	0.14*	4.41*	1.79**	5.24*
RCA	6	85.30*	74.06*	23.96**	21.60**	822.19**	670.09**	0.24*	118.99**	0.17	0.16**	8.64**	1.72*	2.83
Error	15													

Plant height (PH), Boll Weight (BW), Number of sympodial branches (NOS), Seed index (SI), Ginning out-turn percentage (GOT), Number of bolls (NOB), Seed cotton yield (SCY), Number of nodes per plant (NON), Cotton seed yield (CSY), Fiber micronaire (MV), Fiber strength (FS), Fiber length (FL) and Uniformity (UR)

Table 3: General combining ability (GCA) effects of four parents

Parents	NOB	PH	NON	NOS	SCY	CSY	BW	GOT	SI	MV	FS	FL	UR
NIAB-777	3.0666*	7.0794**	0.6250 ns	0.1563 ns	5.8394**	2.4519 ns	-0.0703 ns	0.7006 ns	0.5938**	-0.1250*	-0.5469 ns	-0.0062 ns	-0.7750*
C-1	1.4603ns	-0.3706 ns	-1.0000 ns	-0.7188 ns	-2.4056**	-1.5244 ns	-0.2597**	-0.2125 ns	0.0938 ns	0.1563*	1.1906**	-0.0250 ns	-0.6000 ns

TIPO-1	0.1897ns	-2.7050*	0.6875ns	1.2188*	3.6100**	0.7894ns	0.0934ns	0.1394ns	-0.5938**	0.1750**	1.0031*	-0.6437**	0.8500*
Shahkar	-4.7166*	-4.0037**	-0.3125ns	-0.6563ns	-7.0438**	-1.7169ns	0.2366**	-0.6275ns	-0.0938ns	-0.2063**	-1.6469**	0.6750**	0.5250ns

Plant height (PH), Boll Weight (BW), Number of sympodial branches (NOS), Seed index (SI), Ginning out-turn percentage (GOT), Number of bolls (NOB), Seed cotton yield (SCY), Number of nodes per plant (NON), Cotton seed yield (CSY), Fiber micronaire (MV), Fiber strength (FS), Fiber length (FL) and Uniformity (UR)

Table 4: Specific combining ability (SCA) effects

Crosses	NOB	PH	NON	NOS	SCY	CSY	BW	GOT	SI	MV	FS	FL	UR
NIAB-777×C-1	-2.8228ns	2.2394ns	1.0000ns	0.7813ns	-17.9694**	-17.5013**	-0.0066ns	11.7563**	0.2813ns	0.0375ns	0.7469ns	0.3125ns	-2.3188**
NIAB-777×Tipo-1	4.0228ns	9.6837**	2.0625ns	0.5938ns	9.8350**	2.9650ns	-0.0972ns	6.9919**	-0.5313ns	-0.1062ns	0.5594ns	1.3812**	1.0562ns
NIAB-777×Shahkar	-2.8959ns	-0.5200ns	-3.4375**	-2.5313**	0.3688ns	1.6287ns	0.1822ns	-4.0187*	0.7188*	-0.3250**	-1.9156*	-1.2125**	-1.1187ns
C-1×Tipo-1	-1.0209ns	-4.8037*	-3.0625**	-1.0313ns	-9.6400**	-8.3337*	-0.3678*	-2.4100ns	-0.5313ns	-0.1875ns	0.3219ns	-0.8250*	0.0562ns
C-1×Shahkar	6.2353*	-2.6125ns	-2.5625*	-3.1563**	14.8538**	14.1250**	-0.1109ns	-10.4031**	-0.7813*	0.0188ns	0.8469ns	-0.0438ns	1.6812*
Tipo-1×Shahkar	-1.4516ns	-2.8006ns	1.2500ns	0.9063ns	-4.0444*	-1.0037ns	0.2859ns	-0.9050ns	0.6563ns	0.4000**	1.6094*	0.3500ns	-1.3438*

Plant height (PH), Boll Weight (BW), Number of sympodial branches (NOS), Seed index (SI), Ginning out-turn percentage (GOT), Number of bolls (NOB), Seed cotton yield (SCY), Number of nodes per plant (NON), Cotton seed yield (CSY), Fiber micronaire (MV), Fiber strength (FS), Fiber length (FL) and Uniformity (UR)

Table 5: Reciprocal combining ability (RCA) effects

crosses	NOB	PH	NON	NOS	SCY	CSY	BW	GOT	SI	MV	FS	FL	UR
C-1 × NIAB-777	-6.2500ns	4.7775ns	-3.0000*	-3.7500**	-9.5500**	-6.2700ns	0.3575ns	0.8625ns	0.2500ns	-0.2750ns	1.4750ns	-0.3250ns	-1.2750ns
Tipo-1 × NIAB-777	9.0500**	9.1675**	6.2500**	5.0000**	17.3150**	14.3700**	-0.3400ns	-8.9050**	0.2500ns	-0.1500ns	0.6000ns	-0.8750ns	1.1000ns
Shahkar × NIAB-777	1.1250ns	0.3600ns	3.2500*	3.5000**	27.6600**	26.3925**	0.3325ns	-10.1575**	0.5000ns	0.4000**	-2.0750*	1.8500**	2.1000*
Tipo-1 × C-1	-0.1500ns	-0.6350ns	0.0000ns	1.0000ns	3.6100ns	7.4600ns	0.1000ns	-2.2050ns	0.2500ns	0.2500ns	-1.4500ns	-0.5000ns	-0.2750ns
Shahkar × C-1	7.9500*	-7.2425*	-1.0000ns	-0.5000ns	10.6900**	7.4025ns	-0.4000*	-1.6150ns	0.0000ns	-0.1250ns	-2.9750**	-0.0500ns	-0.8250ns
Shahkar × Tipo-1	8.3925*	7.8950**	3.5000*	3.5000**	34.3975**	30.9425**	0.4500*	-12.8950**	-0.2500ns	0.3750*	-2.8500**	-0.7750ns	0.7000ns

Plant height (PH), Boll Weight (BW), Number of sympodial branches (NOS), Seed index (SI), Ginning out-turn percentage (GOT), Number of bolls (NOB), Seed cotton yield (SCY), Number of nodes per plant (NON), Cotton seed yield (CSY), Fiber micronaire (MV), Fiber strength (FS), Fiber length (FL) and Uniformity (UR)

Table 6: Mid parent heterosis

crosses	NOB	PH	NON	NOS	SCY	CSY	BW	GOT	SI	MV	FS	FL	UR
NIAB-777 × NIAB-777	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00 ns
NIAB-777 × C-1	30.78 ns	10.29 ns	-13.04 ns	-17.07 ns	-49.49 **	-62.24 **	5.55ns	76.09 **	3.03ns	-8.77ns	13.17 ns	-0.20ns	-6.06 *
NIAB-777 × Tipo-1	47.27 ns	27.67 **	24.44 ns	17.07 ns	27.40 ns	13.36 ns	-17.06 ns	30.95 **	-3.45ns	-7.14ns	9.84ns	5.15*	1.00 ns

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NIAB-777 × Shahkar	-7.47ns	2.70ns	-7.80*	-6.35**	49.78 ns	64.98 ns	26.81 ns	-44.83 ns	24.14 ns	-1.44ns	-20.46 ns	1.67ns	-0.71 ns
C-1 × NIAB-777	13.32 ns	0.58ns	4.35ns	7.32ns	-24.47 **	-40.61 **	-21.35 ns	69.34 **	-3.03ns	0.88ns	-0.34ns	2.43ns	-3.01 *
C-1 × C-1	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00 ns
C-1 × Tipo-1	3.35ns	-7.49ns	-15.33 *	4.84ns	-19.86 **	-18.70 *	-20.34 *	-10.82 ns	-13.33 ns	0.87ns	4.93ns	-4.38ns	-0.74 ns
C-1 × Shahkar	86.95 ns	-16.04 ns	-23.08 **	-24.41 **	45.86 **	57.67 *	-20.35 ns	-51.46 **	-13.33 ns	-2.33ns	-4.47ns	-3.17ns	0.21 ns
Tipo-1 × NIAB-777	-18.55 ns	7.85**	-12.59 ns	-15.45 ns	-17.06 ns	-36.53 ns	6.74ns	106.56**	-10.34 ns	-1.79ns	4.22ns	12.66 *	-1.59 ns
Tipo-1 × C-1	4.61ns	-6.12ns	-15.33 *	-11.29 ns	29.87 **	-46.83 *	-27.12 *	3.62ns	-20.00 ns	-7.83ns	18.21 ns	-0.63ns	-0.09 ns
Tipo-1 × Tipo-1	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00 ns
Tipo-1 × Shahkar	48.31 ns	3.52ns	7.14ns	7.09ns	61.24 ns	86.15 ns	27.27 ns	-52.68 ns	7.69ns	16.59 *	1.40ns	-1.72ns	-1.34 ns
Shahkar × NIAB-777	-17.50 ns	1.95ns	-26.24 *	-28.57 **	-42.83 ns	-53.53 ns	2.47ns	18.09 ns	10.34 ns	-16.75 ns	0.64ns	-12.83 ns	-5.65 ns
Shahkar × C-1	2.26ns	0.96ns	-17.48 **	-21.26 **	6.25**	20.62 *	7.96ns	-43.24 **	-13.33 ns	2.33ns	25.06 ns	-2.79ns	2.17 ns
Shahkar × Tipo-1	-45.33 ns	-14.01 ns	-12.86 ns	-14.96 ns	-62.61 ns	-70.07 ns	-2.48ns	16.55 ns	15.38 ns	2.37*	30.37 ns	4.56ns	-2.98 ns
Shahkar × Shahkar	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00ns	0.00 ns

Plant height (PH), Boll Weight (BW), Number of sympodial branches (NOS), Seed index (SI), Ginning out-turn percentage (GOT), Number of bolls (NOB), Seed cotton yield (SCY), Number of nodes per plant (NON), Cotton seed yield (CSY), Fiber micronaire (MV), Fiber strength (FS), Fiber length (FL) and Uniformity (UR)

Conflict of interest

Authors declared no conflict of interest.

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