International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(8): 800-804
www.biochemjournal.com
Received: 13-05-2025
Accepted: 16-06-2025

RS Khandait
PG Scholar, Department of Agricultural Botany, Genetics and Plant Breeding, Post Graduate Institute, Akola, Dr. PDKV, Akola, Maharashtra, India

Dr. SB Deshmukh
Professor (CAS) and Cotton Breeder, Cotton Research Unit, Dr. PDKV, Akola, Maharashtra, India

Dr. JP Khatod
Assistant Professor , Agricultural Botany, Dr. PDKV, Akola, Maharashtra, India

Corresponding Author:
RS Khandait
PG Scholar, Department of Agricultural Botany, Genetics and Plant Breeding, Post Graduate Institute, Akola, Dr. PDKV, Akola, Maharashtra, India

Assessment of heterosis and combining ability for yield and fibre quality traits in upland cotton (*Gossypium hirsutum* L.) using line x tester analysis

RS Khandait, SB Deshmukh and JP Khatod

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i8Sl.5261

Abstract
The present study was carried out at the Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, to assess heterosis and combining ability for yield and fibre quality traits in upland cotton. A total of 40 F1 hybrids, developed through a line × tester mating design involving five female lines and eight male testers during kharif 2023, were evaluated along with 13 parents and two standard checks in a randomized block design with three replications during kharif 2024. Significant variation was observed among genotypes for all traits studied, indicating substantial genetic diversity. Among the hybrids, AKH-081 X Suraj, Phule-688 X Surabhi, and AKH-081 X MCU-5VT exhibited the highest standard heterosis for seed cotton yield over both checks. In terms of fibre quality traits, AKH-09-5 X Suraksha showed superior performance for upper half mean length, fibre strength, and uniformity ratio. RHC-1651 X Suchitra demonstrated the most desirable negative heterosis for fibre fineness. General combining ability (GCA) analysis revealed AKH-081, Suchitra, and Surabhi as strong general combiners for yield and quality traits, while AKH-09-5 and Sunata showed favorable GCA effects for fibre strength and uniformity. Specific combining ability (SCA) analysis identified Phule-688 × Surabhi, RHC-1651X Suraj, and AKH-081 X Sunata as promising crosses for yield and fibre attributes. These findings provide valuable insights for selecting superior hybrids and parents for cotton improvement programms.

Keywords: Upland cotton, line x tester, heterosis, combining ability, seed cotton yield, fibre quality, GCA, SCA

Introduction

Cotton (*Gossypium* spp.) stands out as the most crucial natural fibre crop on a global scale, maintaining its status as a sustainable and primary raw material for the textile industry. It provides valuable products such as cotton lint for export, cottonseed oil for the edible oil industry, and cottonseed cake used in livestock feed. Given its widespread cultivation and economic value, cotton contributes significantly to the nation's economy, supporting various sectors including manufacturing, trade, employment, and foreign exchange. Owing to its extensive utility and economic importance, it is often referred to as "White Gold".

The primary focus of cotton breeding is to produce hybrids and varieties that offer both high productivity and desirable fibre traits. The existing genetic diversity within cotton germplasm provides valuable potential for developing improved genotypes with enhanced yield and fibre quality. Cotton crop is highly suitable for exploiting hybrid vigour through heterosis breeding. In recent times, increased emphasis has been placed on intraspecific hybridization, which involves crossing different lines within the same species to enhance desirable traits. Such breeding efforts have demonstrated the effective transfer of useful genes from both cultivated and wild cotton species into commercial varieties.

Materials and Methods

The study was conducted at the experimental field of Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. Five female parents (lines) were crossed with eight testers in line x tester design during kharif 2023. Forty F1 hybrids along with thirteen parents and two standard checks were evaluated in randomised block design with three replications during kharif 2024.

All the agronomical practices were carried out according the recommendations. The field observations on 5 plants from each genotype and replication were recorded for seed cotton yield per plant (g) and fibre quality traits i.e. upper half mean length (mm), fibre strength (g/tex), fibre fineness (µg/ inch) uniformity ratio. Analysis of variance (ANOVA) were performed according to the methods outlined by Panse and Sukhatme (1967) [10]. Analysis of standard heterosis will be carried out as per standard method given by Meredith and Bridge (1972) [9]. ANOVA for combining ability was based on the methodology given by Kempthorne (1957) [5].

Results and Discussion:

In the current investigation, the analysis of variance (ANOVA) revealed statistically significant differences among genotypes for all traits evaluated, indicating the presence of substantial genetic variability among the genotypes for each character studied.

Among the 40 crosses, the standard heterosis for seed cotton yield per plant over check NH-545 ranged from 7.29 to 174.56 percent. The AKH-081 X Suraj (174.56%) showed highest positive significant heterosis followed by Phule-688 X Surabhi (154.39%) and AKH-081 X MCU-5VT (150.79%). Standard heterosis over NHH-715 ranged from-25.57 to 120.42 percent. The AKH-081 X Suraj (120.42%) showed highest positive significant heterosis followed by Phule-688 X Surabhi (104.23%) and AKH-081 X MCU-5VT (101.34%).

For upper half mean length, standard heterosis over NH-545 ranged from-7.87 to 12.87 percent. Highest positive and significant standard heterosis was showed by AKH-09-5 X Suraksha (12.87%) followed by AKH-09-5 X Surabhi (11.80%) and NH-615 X Surabhi (10.49%). In respect of NHH-715, the standard heterosis ranged from-11.25 to 8.73 percent. The cross AKH-09-5 X Suraksha (8.73%) showed highest positive and significant standard heterosis followed by AKH-09-5 X Surabhi (7.69%) and NH-615 X Surabhi (6.43%).

Table 1: Estimation of standard heterosis over checks NH-545 and NHH-715

Sr. No.	Hybrids	Seed cotton yield per plant (g)		Upper half mean length (mm)		Fibre strength (g/tex)		Fibre fineness (ug/inch)		Uniformity ratio (%)	
		NH-545	NH-715	NH-545	NH-715	NH-545	NHH-715	NH-545	NH-715	NH-545	NHH-715
1	AKH-09-5 X Suchitra	117.61 **	74.70 **	4.29 **	0.46	10.43 **	4.70 **	-1.43	0.00	1.21	0.00
2	AKH-09-5 X Subhiksha	50.88 **	21.13	9.30 **	5.28 **	10.31 **	4.58 **	7.86 **	9.42 **	3.23 *	1.99
3	AKH-09-5 X Sunata	22.04	-2.02	6.56 **	2.64 **	9.67 **	3.98 **	-19.29 **	-18.12 **	1.21	0.00
4	AKH-09-5 X Suraksha	83.33 **	47.18**	12.87 **	8.73 **	13.61 **	7.72 **	5.71 **	-4.35*	4.03 **	2.79*
5	AKH-09-5 X Nano	51.67 **	21.76	0.72	-2.99 **	4.71 **	-0.72*	-14.29 **	-13.04 **	2.42	1.20
6	AKH-09-5 X Surabhi	77.19 **	42.25 **	11.80 **	7.69 **	11.70*	5.91**	-12.86 **	11.59 **	2.42	1.20
7	AKH-09-5 X MCU-5VT	40.24 *	12.58	10.13 **	6.08 **	4.33 **	-1.09 **	-13.57 **	-12.32 **	0.00	-1.20
8	AKH-09-5 X Suraj	84.46 **	48.08 **	4.65 **	0.80*	1.40 **	-3.86 **	-20.71 **	-19.57 **	1.21	0.00
9	AKH-081 X Suchitra	71.50 **	37.68 **	-1.07 **	-4.71 **	-3.44 **	-8.44 **	-15.00 **	-13.77 **	040	-0.80
10	AKH-081 X Subhiksha	89.32 **	51.99 **	-1.31 **	-4.94 **	0.00	-5.19 **	-2.14	-0.72	1.61	0.40
11	AKH-081 X Sunata	123.68 **	79.58 **	8.70 **	4.71 **	16.92 **	10.86 **	-5.00 *	-3.62	2.82*	1.59
12	AKH-081 X Suraksha	68.54 **	35.31 **	7.39 **	3.44 **	4.33 **	-1.09 **	-16.43 **	-15.22 **	2.82 *	1.59
13	AKH-081 X Nano	103.36 **	63.26 **	2.15 **	-1.61 **	3.18 **	-2.17 **	-25.00 **	-23.91 **	0.40	-0.80
14	AKH-081 X Surabhi	64.18 **	31.81*	0.60	-3.10 **	-3.05 **	-8.08 **	-27.14 **	-26.09 **	-1.21	-2.39
15	AKH-081 X MCU-5VT	150.79 **	101.34 **	3.69 **	-0.11	7.38 **	1.81 **	-14.29 **	-13.04 **	1.21	0.00
16	AKH-081 X Suraj	174.56 **	120.42 **	-3.10 **	-6.66 **	0.76	-4.46 **	-12.14 **	-10.87 **	1.61	0.40
17	Phule-688 X Suchitra	67.78 **	34.70 *	-2.15 **	-5.74 **	3.18 **	-2.17 **	-8.57 **	-7.25 **	2.02	0.80
18	Phule-688 X Subhiksha	102.06 **	62.22 **	-5.96 **	-9.41 **	-1.15 **	-6.27 **	-5.71 **	-4.35 *	1.61	0.40
19	Phule-688 X Sunata	41.62 *	13.70	-2.15 **	-5.74	-1.53 **	-6.63 **	-1.43	0.00	0.40	-0.80
20	Phule-688 X Suraksha	80.29 **	44.74 **	7.39 **	3.44 **	11.83 **	6.03 **	-12.86 **	-11.59 **	2.02	0.80
21	Phule-688 X Nano	24.75	0.15	1.91 **	-1.84 **	8.40 **	2.77 **	-20.71	-19.57 **	2.82*	1.59
22	Phule-688 X Surabhi	154.39 **	104.23 **	4.89 **	1.03**	6.49 **	0.97 **	-13.57 **	-12.32 **	1.61	0.40
23	Phule-688 X MCU-5VT	58.77 **	27.46 *	3.22 **	-0.57	4.96 **	-0.48	-24.29 **	-23.19 **	2.02	0.80
24	Phule-688 X Suraj	56.16 **	25.37	-0.72	-4.36 **	2.93 **	-2.41**	-19.29 **	-18.12 **	2.82*	1.59
25	NH-615 X Suchitra	122.41 **	78.56 **	-1.07 **	-4.71 **	0.76 *	-4.46 **	0.00	1.45	0.81	-0.40
26	NH-615 X Subhiksha	77.50 **	42.50 **	9.77 **	5.74 **	-1.15 **	-6.27 **	-23.57 **	-22.46 **	1.21	0.00
27	NH-615 X Sunata	102.46 **	62.54 **	6.08 **	2.18 **	6.62 **	1.09 **	-14.29 **	-13.04 **	3.23 *	1.99
28	NH-615 X Suraksha	68.46 **	35.24*	7.99 **	4.02 **	7.00 **	1.45 **	-25.71 **	-24.64 **	0.81	-0.40
29	NH-615 X Nano	-7.29	-25.57	1.07 **	-2.64 **	-2.54 **	-7.60 **	-25.00 **	-23.91 **	-0.81	-1.99
30	NH-615 X Surabhi	84.97 **	48.50 **	10.49 **	6.43 **	8.14 **	2.53	-13.57 **	-12.32 **	2.42	1.20
31	NH-615 X MCU-5VT	34.80 *	8.22	8.22 **	4.25 **	1.65**	-3.62	-20.71 **	-19.57 **	2.82*	1.59
32	NH-615 X Suraj	26.10	1.23	4.77**	0.92 *	5.98 **	0.48	-22.86 **	-21.74 **	1.61	0.40
33	RHC-1651 X Suchitra	99.25 **	59.96 **	-0.72	-4.36 **	-3.82 **	-8.81 **	-27.14 **	-26.09 **	0.00	-1.20
34	RHC-1651 X Subhiksha	60.17 **	28.58*	-2.38 **	-5.97 **	-4.33 **	-9.29 **	-12.14**	-10.87 **	0.40	-0.80
35	RHC-1651 X Sunata	81.82 **	45.97 **	2.62 **	-1.15 **	3.18 **	-2.17 **	-8.57 **	-7.25 **	2.82*	1.59
36	RHC-1651 X Suraksha	4.38	-16.20	-7.87 **	-11.25 **	-8.02 **	-12.79 **	-7.14 **	-5.80 **	0.00	-1.20
37	RHC-1651 X Nano	92.32 **	54.39 **	-4.65 **	-8.15 **	-3.18 **	-8.20 **	-11.43 **	-10.14 **	1.21	0.00
38	RHC-1651 X Surabhi	55.26 **	24.65	5.84 **	1.95 **	7.25 **	1.69**	-10.71 **	-9.42 **	0.00	-1.20
39	RHC-1651 X MCU-5VT	43.43 *	15.15	-2.26 **	-5.86**	2.67 **	-2.65**	-5.71 **	-4.35*	0.40	-0.8
40	RHC-1651 X Suraj	44.30 **	15.85	6.08 **	2.18**	6.49 **	0.97 **	-12.14**	-10.87	0.81	-0.40

* Significant at 5% level of significance ** Significant at 1% level of significance

In fibre strength, standard heterosis over NH-545 ranged from-8.02 to 16.92 percent. Highest standard heterosis was showed by AKH-081 X Sunata (16.92%) followed by AKH-09-5 X Suraksha (13.61%) and AKH-09-5 X Surabhi (11.70%). The standard heterosis with respect of NHH-715, ranged from-12.79 to 10.86 percent. The cross AKH-081 X Sunata (10.86%) showed highest standard heterosis followed by AKH-09-5 X Suraksha (7.72%) and AKH-09-5 X Surabhi (5.91%).

For fibre finenss, the standard heterosis over NH-545 ranged from-27.14 to 7.86 percent. The cross AKH-081 X Surabhi (-27.14%) and RHC-1651 X Suchitra (-27.14%) showed highest negative heterosis followed by NH-615 X Suraksha (-25.71%), AKH-081 X Nano (-25.00%) and NH-615 X Nano (-25.00%).The standard heterosis over NHH-715 ranged from-26.09 to 9.42 percent. The cross RHC-1651 X Suchitra (-26.09%) showed highest negative heterosis followed by NH-615 X Suraksha (-24.64%), AKH-081 X Nano (-23.91%) and NH-615 X Nano (-23.91%).

For uniformity ratio the standard heterosis over NH-545 ranged from-1.21 to 4.03 percent. The highest significant positive heterosis observed in crosses AKH-09-5 X Suraksha (4.03%) followed by AKH-09-5 X Subhiksha (3.23%) and NH-615 X Sunata (3.23%) whereas standard heterosis over NHH-715 ranged from-2.39 to 2.79 percent. Out of forty crosses, only AKH-09-5 X Suraksha (2.79%) showed significant positive heterosis over check NHH-715.

Similar finding for standard heterosis for these characters in cotton was also reported earlier by several researchers viz., Rauf *et al.* (2005) [14], Tuteja *et al.* (2006) [20], Isong *et al.* (2019) or seed cotton yield per plant, Tuteja (2014) [19], Pavitra *et al.* (2019) [12] and Bano *et al.* (2023) [2] for upper half mean length, fibre strength, fibre fineness and uniformity ratio.

For seed cotton yield per plant, among the female parents, only AKH-081 (12.162) was found to be the best general combiner for this character, whereas, RHC-1651 (-5.176) exhibited significant negative gca effect. Among the male parents, Suchitra (8.350) and Surabhi (5.116) depicted the highest positive and significant gca effects and found to be best general combiner among the males.

The female parent, AKH-09-5 showed maximum positive significant gca effect for upper half mean length (1.215), fibre strength (1.158) and maximum positive gca effect for uniformity ratio (0.417) whereas NH-615 (-0.215) exhibited significant and negative gca effects which is desirable for fibre fineness.

Table 2: Estimation of general combining ability effects of parents

Sr. No.	Parents	Seed cotton yield (g)	Upper half mean length (mm)	Fibre strength (g/tex)	Fibre fineness (ug/inch)	Uniformity ratio (%)
	Lines (Female)					
1	AKH-09-5	-2.968	1.215**	1.158**	0.168**	0.417
2	AKH-081	12.162**	-0.298**	-0.155**	-0.048	-0.208
3	Phule-688	-0.194	-0.668**	0.141**	0.014	0.375
4	NH-615	-3.824*	0.761**	-0.143**	-0.215**	0.042
5	RHC-1651	-5.176**	-1.010**	-1.001**	0.081	-0.625*
	Tester (Male)					
1	Suchitra	8.350**	-0.933**	-0.636**	0.148**	-0.475
2	Subhiksha	0.854	-0.367**	-0.816**	0.302**	0.125
3	Sunata	0.224	0.327**	0.818**	0.182**	0.525
4	Suraksha	-4.840	0.660**	0.498**	0.002	0.392
5	Nano	-7.895**	-0.827**	-0.456**	-0.265**	-0.208
6	Surabhi	5.116*	0.987**	0.591**	-0.092**	-0.342
7	MCU-5VT	-3.090	0.393**	0.091**	-0.098**	-0.142
8	Suraj	1.283	-0.240**	-0.089**	-0.178**	0.125

* Significant at 5% level of significance ** Significant at 1% level of significance

Among male parents, Surabhi (0.987) showed maximum significant positive gca effect and was good general combiner for upper half mean length. The tester Sunata showed highest gca effect for fibre strength (0.818) and uniformity ratio (0.525) and found as best general combiner whereas Nano (-0.265) exhibited significant and negative gca effects which is desirable for fibre fineness.

Among the crosses, Phule-688 X Surabhi (25.724) showed highest significant positive sca effect for seed cotton yield per plant. The crosses RHC-1651 X Suraj (2.057) and AKH-081 X Sunata (2.762) showed highest significant positive sca effects for upper half mean length and fibre strength respectively. None of the cross exhibited highest significant positive sca effects for uniformity ratio. Cross RHC-1651 X Suchitra (-0.861) exhibited highest significant negative sca effect for fibre fineness.

Similar type of result reported by Sakhare *et al.* (2005) [16], Khosla *et al.* (2007) [7], Preetha and Raveendran (2008) [13], Saravanan *et al.* (2010) [17], Patel *et al.* (2012) [11], Jaiwar *et al.* (2012) [4], Sawarkar *et al.* (2015) [18], Usharani *et al.* (2016) [21] and Khokhar *et al.* (2018) [6], Mangi *et al.* (2024) [8], Riaz *et al.* (2023) [5] and Bagyalakshmi *et al.* (2023) [1] for evaluated traits.

Table 2: Estimation of specific combining ability effects of crosses.

Sr. No.	Hybrids	Seed cotton yield (g)	Upper half mean length (mm)	Fibre strength (g/tex)	Fibre fineness (ug/inch)	Uniformity ratio (%)
1	AKH-09-5 X Suchitra	11.288	0.025	1.203**	0.252**	-0.150
2	AKH-09-5 X Subhiksha	-6.573	0.858**	1.349**	0.532**	0.917
3	AKH-09-5 X Sunata	-16.899**	-0.602**	-0.451**	-0.615**	-1.150
4	AKH-09-5 X Suraksha	11.455*	0.832	0.902**	0.198**	1.317
5	AKH-09-5 X Nano	2.476	-1.082**	-0.478**	0.065	0.583
6	AKH-09-5 X Surabhi	-0.834	0.205*	0.309**	-0.042	0.717
7	AKH-09-5 X MCU-5VT	-6.672	0.332**	-1.124**	-0.068	-1.483
8	AKH-09-5 X Suraj	5.758	-0.568**	-1.711**	-0.322**	-0.750
9	AKH-081 X Suchitra	-21.362**	0.037	-1.118**	-0.165*	-0.192
10	AKH-081 X Subhiksha	-7.093	-0.596**	-0.038	0.282**	0.208
11	AKH-081 X Sunata	6.594	1.511**	2.762**	0.268**	0.808
12	AKH-081 X Suraksha	-9.295*	0.811**	-0.218**	-0.085	0.942
13	AKH-081 X Nano	6.989	0.831**	0.435**	-0.218**	-0.458
14	AKH-081 X Surabhi	-20.908**	-1.416**	-2.245**	-0.492**	-1.658*
15	AKH-081 X MCU-5VT	20.208**	0.044	0.988**	0.115	0.142
16	AKH-081 X Suraj	24.868**	-1.223**	-0.565**	0.295**	0.208
17	Phule-688 X Suchitra	-10.420*	0.108	0.319**	0.073	0.558
18	Phule-688 X Subhiksha	10.102*	-1.525**	-0.634**	0.053	-0.375
19	Phule-688 X Sunata	-12.234**	-1.152**	-2.368**	0.373**	-1.775*
20	Phule-688 X Suraksha	7.524	1.182**	1.453**	0.019	-0.308
21	Phule-688 X Nano	-10.525*	1.135**	1.506**	-0.081	0.958
22	Phule-688 X Surabhi	25.724**	0.155	-0.041	0.079	0.092
23	Phule-688 X MCU-5VT	-2.403	0.282**	0.059	-0.414**	0.225
24	Phule-688 X Suraj	-7.770	-0.185*	-0.294**	-0.101	0.625
25	NH-615 X Suchitra	13.970**	-1.021**	-0.031	0.702**	-0.108
26	NH-615 X Subhiksha	4.399	1.446*	-0.351**	-0.552**	-0.375
27	NH-615 X Sunata	14.513**	-0.281**	0.049	0.002	0.892
28	NH-615 X Suraksha	6.657	-0.081	0.469**	-0.352**	-0.975
29	NH-615 X Nano	-19.072**	-0.527**	-1.078**	-0.052	-1.708*
30	NH-615 X Surabhi	2.978	0.292**	0.676**	0.308**	1.092
31	NH-615 X MCU-5VT	-7.883	0.252**	-0.524**	-0.018	1.225
32	NH-615 X Suraj	-15.563**	-0.081	0.789**	-0.038	-0.042
33	RHC-1651 X Suchitra	6.523	0.850**	-0.375**	-0.861**	-0.108
34	RHC-1651 X Subhiksha	-0.835	-0.183*	-0.326**	-0.314**	-0.375
35	RHC-1651 X Sunata	8.026	0.523**	0.007	-0.027	1.225
36	RHC-1651 X Suraksha	-16.340**	-2.743**	-2.606*	0.219**	-0.975
37	RHC-1651 X Nano	20.131**	-0.357**	-0.386**	0.286**	0.625
38	RHC-1651 X Surabhi	-6.960	0.763**	1.301**	0.146*	-0.242
39	RHC-1651 X MCU-5VT	-3.250	-0.910**	0.601**	0.386**	-0.108
40	RHC-1651 X Suraj	-7.294	2.057**	1.781**	0.166**	-0.042

* Significant at 5% level of significance ** Significant at 1% level of significance

Conclusion

The present investigation revealed significant genetic variability among the genotypes for all traits studied, as confirmed by ANOVA. This genetic diversity provides a strong foundation for breeding programs aimed at improving cotton yield and fibre quality. Several hybrids exhibited notable standard heterosis for seed cotton yield, with AKH-081 X Suraj, Phule-688 X Surabhi, and AKH-081 X MCU-5VT emerging as particularly promising crosses. These combinations consistently outperformed the standard checks, indicating their potential for commercial cultivation.

In terms of fibre traits, AKH-09-5 X Suraksha showed superior performance in upper half mean length, fibre strength, and uniformity ratio, while RHC-1651 X Suchitra recorded the most desirable negative heterosis for fibre fineness. The combining ability analysis identified AKH-081, AKH-09-5, and Suchitra as strong general combiners for yield and quality attributes. Additionally, crosses such as Phule-688 × Surabhi and AKH-081 X Sunata exhibited significant specific combining ability, suggesting their suitability for hybrid development.

Acknowledgement

I am grateful to the Head of Department of Agricultural Botany, and Senior Research Scientist, Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola for providing all the necessary facilities for conducting the research work.

References

1. Baghyalakshmi K, Priyanka AR, Aravind K, Manickam S. Genetic analysis for estimating combining ability in *Gossypium hirsutum* L. × *Gossypium barbadense* L. hybrids. Electronic Journal of Plant Breeding. 2023;15(1):21-30.

2. Bano M, Shakeel A, Haq W, Khalid MN, Ahmad NH, Sharif S, Kanwal MA, Bhutta A, Bibi, Amjad I. Estimation of combining ability for within-boll yield components in upland cotton (*Gossypium hirsutum*). Sarhad Journal of Agriculture. 2023;39(1):174-181.
3. Isong A, Balu A, Isong C, Bamishaiye E. Estimation of heterosis and combining ability in interspecific cotton hybrids. Electronic Journal of Plant Breeding. 2019;10(2):827-837.
4. Jaiwar SS, Avinashe HA, Patel BN. Heterosis for seed cotton yield and its contributing traits in upland cotton (*Gossypium hirsutum* L.). Journal of Soils and Crops. 2012;22(2):314-320.
5. Kempthorne O. An Introduction to Genetical Statistics. New York: John Wiley & Sons, Inc.; London: Chapman & Hall Ltd.; 1957.
6. Khokhar ES, Shakeel A, Maqbool MA, Abuzar MK, Zareen S, Syeda SA, Asadullah M. Studying combining ability and heterosis in different cotton (*Gossypium hirsutum* L.) genotypes for yield and yield contributing traits. Pakistan Journal of Agricultural Research. 2018;31(1):55-68.
7. Khosla G, Gill BS, Sohu RS. Heterosis and combining ability analysis for plant and seed characters in upland cotton. Journal of Cotton Research and Development. 2007;21(1):12-15.
8. Mangi GS, Soomro AZ, Jatoi WA, Chachar Q, Mari SN. Breeding for enhanced fibre quality traits in upland cotton (*Gossypium hirsutum* L.) through line × tester analysis. Pakistan Journal of Biotechnology. 2024;21(1):101-113.
9. Meredith WR, Bridge RR. Heterosis and gene action in cotton (*Gossypium hirsutum* L.). Crop Science. 1972;12(3):304-310.
10. Panse VG, Sukhatme PV. Statistical Methods for Research Workers. New Delhi: Indian Council of Agricultural Research; 1954.
11. Patel NA, Patel BN, Bhatt JP, Patel JA. Heterosis and combining ability for seed cotton yield and component traits in interspecific cotton hybrids (*Gossypium hirsutum* × *Gossypium barbadense* L.). Madras Agricultural Journal. 2012;99(10-12):649-656.
12. Pavitra MJ, Kajjidoni ST, Venkatesh. Heterosis for productivity and fibre quality traits among hybrids derived from diverse lines of *Gossypium hirsutum* L. International Journal of Current Microbiology and Applied Sciences. 2019;8(2):1379-1384.
13. Preetha S, Raveendran TS. Combining ability and heterosis for yield and fibre quality traits in line × tester crosses of upland cotton (*Gossypium hirsutum* L.). International Journal of Plant Breeding and Genetics. 2008;2(2):64-74.
14. Rauf S, Shah KN, Afzal I. A genetic study of some earliness related characters in cotton (*Gossypium hirsutum* L.). Caderno de Pesquisa, Série Biologia, Santa Cruz do Sul. 2005;17(1):81-93.
15. Riaz A, Ullah F, Chohan SM, Saeed A, Aqeel M, Sher A, Nadeem A, Akram M, Shahid M, Hussnain H, Khalid MN. Estimation of heterosis and combining ability effects for yield and fiber quality traits in cotton (*Gossypium hirsutum* L.). Biological and Clinical Sciences Research Journal. 2023;2023:261.
16. Sakhare BA, Wandhare MR, Ladole MY, Wakode MM. Combining ability studies in diploid cotton. Journal of Cotton Research and Development. 2005;19(1):52-54.
17. Saravanan NA, Ravikesavan R, Raveendran TS. Combining ability analysis for yield and fibre quality parameters in intraspecific hybrids of *Gossypium hirsutum* L. Electronic Journal of Plant Breeding. 2010;1(4):856-863.
18. Sawarkar M, Solanke A, Mhasal GS, Deshmukh SB. Combining ability and heterosis for seed cotton yield, its components and fiber quality traits in *Gossypium hirsutum* L. Indian Journal of Agricultural Research. 2015;49(2):154-159.
19. Tuteja OP. Studies on suitability of CGMS based heterosis breeding and its causes in upland cotton. Cotton Research Journal. 2014;6(1):1-6.
20. Tuteja OP, Kumar S, Singh M, Luthra P. Heterosis for seed cotton yield and quality characters in cotton single cross hybrids of *Gossypium hirsutum* L. Journal of Cotton Research and Development. 2006;20(1):48-50.
21. Usharani CV, Manjula SM, Patil SS. Estimating combining ability through line × tester analysis in upland cotton. Research in Environment and Life Sciences. 2016;9(5):628-633.