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RESEARCH ARTICLE

# Investigating the Combining Ability of Yield and Fiber Quality in Upland Cotton (*Gossypium hirsutum* L.)

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**ABSTRACT**

Cotton is an essential fiber crop across the world that has a vital role in the GDP of Pakistan as a source of fiber, vegetable oil, and livestock feed. Cotton crop is adversely affected by climate change due to which a significant decrease in yield has been observed over the last few years. The production of improved cotton cultivars is essential as the demand for crop yield and quality of fiber has increased with the increase in population. Combining ability helps to select parents with specific traits that interact favorably in hybrids, ensuring more controlled and targeted improvement. The primary goal of the present investigation is to assess the combining ability for yield and associated character of 8 parents (3 lines and 5 testers) and 15 crosses developed by the line × tester analysis. Significant variations in yield and fiber properties were found by analysis of variance, indicating considerable genetic variability among parents. The GCA and SCA were computed for the yield and its related characters. All the studied traits were primarily governed by non-additive types of gene action. The parents viz., S-9, Bahar-2017, MSDK, and AA-933 were identified as good general combiners. The hybrids, Bahar-2017 × AA-933, FH-172 × AA-933, MSDK × FH-154 and MNH-992 × NIAB-777 were identified as best hybrids. The parents and their hybrids having high values of GCA and SCA respectively will provide a route for research programs to increase cotton yield.

**Key words:** Combining ability, Variance, Gene action, Seed cotton yield.

## INTRODUCTION

Cotton is referred to as the "King of fiber" and is cultivated all around the globe (Chandel et al., 2017; Kamal et al., 2024). The genus *Gossypium* comprises approximately 50 species, making it a diverse group of plants within the family *Malvaceae* (Tutushkina et al., 2023; Zafar et al., 2024a). There are fifty species in the genus *Gossypium*. Forty-five of these species are diploid with only two cultivated species: *Gossypium herbaceum* and *Gossypium arboreum*, which are known as old-world cotton. Five species are naturally tetraploid, among which there are only two cultivated species known as *Gossypiun hirsutum* (Upland cotton) and *Gossypium barbadense* (Egyptian cotton). *Gossypium hirsutum* L. is an allotetraploid species that produces about 90% of the world's cotton (Viot and Wendel, 2023; Zafar et al., 2023; Zafar et al., 2024b).

Cotton has prime importance in providing fiber and oilseed worldwide (Kabir et al., 2022). Besides fiber, cotton also offers fuel and food to humans and animals. Cotton seed oil is an edible vegetable oil that contributes significantly to the national oil industry (Shuli et al., 2018). There is continually fluctuation in seed cotton yield in Pakistan and there are many reasons for this change. During 2022-23, it was severely damaged due to climatic changes such as shortage of irrigation water and heat wave. This year, cotton contributed 0.3 percent to GDP and 1.4 percent to value added in agriculture. Area under cotton cultivation increased to 2,144 thousand hectares against last year, but floods and insect pests such as pink bollworm, whitefly and thrips damaged the crop (Government of Pakistan, 2022-2023; Zafar et al., 2020).

A yearly drop in cotton production has been observed as the current varieties are not adapting to the continuously changing climatic conditions. So, the development of high-yielding parental combinations is

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required (Shahzad et al., 2022). High yielding and better fiber quality traits have been effectively integrated into cotton cultivars through conventional hybridization and mutation breeding (Esmail et al., 2008). The yield can be increased by enhancing parameters that have a beneficial impact on output, such as the no. of sympodia per plant, the no. of seed per locule, and the no. of bolls per plant (Constable et al. 2015).

Choosing the right parent is crucial for any breeding effort. Combining ability helps identify parents and hybrids with high general combining ability (GCA) and specific combining ability (SCA) impacts, respectively. It is used in crop breeding to study heterosis and to combine desirable and stable genes (Sawarkar et al., 2014). It is very important to identify the gene action that governs yield, earliness, and fiber quality parameters. GCA variance is an indicator of additive gene action while SCA variance indicate non-additive gene action (Zafar et al., 2022a; Madugula et al., 2023). If GCA effects are high, selection is most suitable for development of a variety. While hybrid development is best when SCA effects are high (Munir et al., 2018).

Genetic studies in *Gossypium hirsutum* L. can be made through various biometrical methods including line × tester method (Munir et al., 2016; Zafar et al., 2022b). This mating design can be used by plant breeders to identify superior parents and hybrids for attributes being investigated and it is commonly utilized for selection in early generations (Kempthorne, 1957). Moreover, this approach offers valuable insights into the genetic mechanisms that govern yield and yield components (Yehia and El-Hashash, 2019).

The primary aim of this study was to assess the combining ability and gene activity for yield and fiber quality traits in both parents and hybrids. Moreover, this study will be helpful in developing better-performing varieties with better genetic makeup, ultimately contributing to sustainable growth and the economic importance of cotton globally and in Pakistan.

## MATERIALS AND METHODS

The study was conducted in the experimental area of the PBG Department at the University of Agriculture, Faisalabad in 2022. The breeding material was provided by the cotton lab of the Plant Breeding and Genetics department. The experimental material consisting of 5 lines (Bahar-2017, FH-172, S-9, MNH-992, and MSDK) and 3 testers (FH-154, AA-933, and MSDK) was sown in earthen pots in the glasshouse. Suitable conditions of light, humidity and temperature were maintained in greenhouse for the seedling emergence and appropriate growth. At the time of flowering five lines were crossed with three testers to produce $F_0$ hybrid seed.

Seeds from eight parents and their crosses were planted in the field with three replications using a Randomized Complete Block Design. The rows were spaced 75 cm apart and the plants were spaced 30 cm apart. All the precautions were taken to ensure the purity of the genetic material. Proper agronomic practices were taken from planting to picking. From each replication, five plants of each genotype were marked for data collection. At maturity, data were collected for various yield characteristics including plant height (PH), number of bolls per plant (No. B/P), sympodial branches per plant (SB/P), boll weight (BW/P), seed cotton yield per plant (SCY/P), lint weight per plant (LW/P), and ginning outturn percentage (GOT %). Fiber characteristics such as fiber length (FL), fiber strength (FS), and fiber fineness (FF) were assessed using a High-Volume Instrument at the Department of Textile Technology, University of Agriculture, Faisalabad.

Data for all the traits were statistically evaluated using the analysis of variance approach to determine the differences between genotypes for all traits (Steel et al., 1997). The parameters with significant differences were then evaluated for specific combining ability (SCA) and general combining ability (GCA) using Kempthorne's (1957) method.

## RESULTS

Table 1 displays the analysis of mean squares for yield and fiber characteristics in the line × tester experiment. ANOVA revealed significant results for fiber strength and fineness and very significant results for all other parameters. The mean square for replication was not significant for all tested features, however, GOT and lint output per plant exhibited highly significant values. The variations resulting from crossings showed highly significant results for all yield traits.

Among fiber-related parameters, fiber length showed a highly significant mean square and the other two showed non-significant values. All investigated traits exhibited considerable genetic variability among parents except fiber fineness. The results for mean squares of parent(p) vs cross(c) were highly significant for most investigated characters. The variance analysis showed that the mean squares of lines, testers, and their interaction were statistically significant for all metrics except fiber strength and fineness. The lines, testers, and lines × testers showed significantly significant mean squares for most analyzed characters.

Graph 1 illustrates the contribution of the lines, tests, and their interactions. The lines had a greater proportional contribution for plant height, boll weight, sympodial branches per plant, and fiber strength. On the other hand, the line × tester interaction showed a greater contribution for the number of bolls per plant, seed cotton yield per plant, lint weight per plant, GOT%, fiber length, and fiber fineness. The testers had the smallest relative contribution for all the qualities examined.

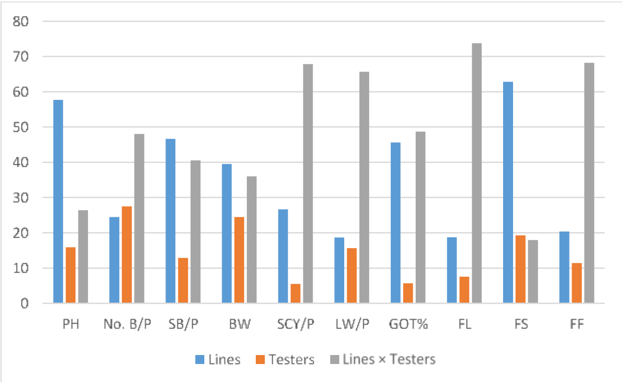
Table 2 shows that higher Specific Combining Ability (SCA) variants compared to General Combining Ability (GCA) variances for all traits indicate the primary impact of non-additive gene action.

**Table 1:** Analysis of mean squares for yield and fiber quality characters

| SOV | DF | PH | No. B/P | SB/P | BW | SCY/P | LW/P | GOT% | FL | FS | FF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Replication | 2 | 0.82 ns | 3.02 ns | 4.61 ns | 0.07 ns | 15.86 ns | 15.36** | 24.30** | 0.67 ns | 17.85 ns | 0.49 ns |
| Genotype | 22 | 104.89** | 64.42** | 7.78** | 1.93** | 207.77** | 36.70** | 73.19** | 3.93 ** | 26.85 * | 0.59 * |
| Crosses | 14 | 131.19** | 75.65** | 7.78** | 1.41** | 109.54** | 49.89** | 86.18** | 4.29 ** | 13.47 ns | 0.49 ns |
| LINE(c) | 4 | 264.86** | 64.86** | 12.70** | 1.96** | 102.26** | 32.64** | 137.63** | 2.81 ** | 29.60 ns | 0.35 ns |
| TEST(c) | 2 | 146.10** | 145.43** | 7.01 | 2.42** | 42.14** | 54.56** | 34.43** | 2.27 * | 18.16 ns | 0.39 ns |
| LXT (c) | 8 | 60.63** | 63.60** | 5.52* | 0.89** | 130.03** | 57.35** | 73.40** | 5.54 ** | 4.22 ns | 0.58 ns |
| Parents | 7 | 66.23** | 28.02** | 8.76** | 2.16** | 381.09** | 13.77** | 52.44** | 2.16 * | 49.75 ** | 0.63 ns |
| Line (p) | 4 | 103.41** | 30.96** | 7.21* | 2.81** | 383.68** | 20.90** | 73.88** | 1.56 ns | 76.40 ** | 0.57 ns |
| Tester (p) | 2 | 24.42** | 33.42** | 14.53** | 0.20 | 197.74** | 0.57 | 32.86** | 3.82 ** | 9.75 ns | 0.22 ns |
| L × T | 1 | 1.14 | 5.43 | 3.40 | 3.50** | 737.42** | 11.66* | 5.87 | 1.24 ns | 23.15 ns | 1.69 * |
| Cross vs Parent | 1 | 7.34 | 161.90** | 0.87 | 7.54** | 369.68** | 12.48* | 36.55** | 11.17 ** | 53.97 ns | 1.68 * |
| Error | 44 | 3.56 | 3.48 | 2.25 | 0.14 | 6.74 | 1.89 | 3.76 | 0.70 | 14.33 | 0.29 |

**Table 2:** Combining ability variances for yield and fibre characters

| | PH | No. B/P | SB/P | BW | SCY/P | LW/P | GOT% | FL | FS | FF |
|---|---|---|---|---|---|---|---|---|---|---|
| GCA variance | 2.49 | 0.42 | 0.08 | 0.01 | -0.72 | -0.26 | 0.45 | -0.04 | 0.32 | -0.00 |
| SCA variance | 19.23 | 20.02 | 1.12 | 0.25 | 41.51 | 18.44 | 23.20 | 1.62 | -4.29 | 0.10 |
| GCA var / SCA var | 0.12 | 0.02 | 0.07 | 0.07 | -0.01 | -0.01 | 0.01 | -0.02 | -0.07 | -0.03 |




**Graph 1:** Contribution of lines, testers and their interactions for yield and fiber traits to total variance

Table 2 displays the general combining ability effects of various attributes of all parental individuals from the line × tester analysis. The line S-9 was identified as the top general combiner due to its considerable general combining ability effects on several traits such as plant height (3.73), GOT % (2.81), number of bolls per plant (2.15), fiber length (0.58), and boll weight (0.32). Bahar-2017 shown strong general combining ability impacts for boll weight (0.39), number of bolls per plant (1.55), and fiber length (0.62). An MSDK exhibited a substantial effect on sympodial branches per plant, seed cotton output per plant, and lint weight per plant. Meanwhile, FH-172 was identified as the best suited general combiner for the number of bolls per plant and GOT%. AA-933 showed a high general combining ability effect for five traits: plant height (3.16), number of bolls per plant (3.02), boll weight (0.38), seed cotton yield per plant (1.92), and lint weight per plant (1.19). Tester FH-154 had considerable general combining ability for lint weight per plant and ginning out turn %, but NIAB-777 shown good general combining ability for sympodial branches per plant.

The hybrid Bahar-2017 × AA-933 showed significant effects for several characteristics, including number of bolls per plant, boll weight, lint weight per plant, and ginning out turn percentage. On the other hand, FH-172 × AA-933 was the most effective combiner for plant height, seed cotton yield per plant, lint weight per plant, and fiber length. The hybrid MSDK × FH-154 shown high performance in terms of number of bolls per plant (3.22), seed cotton yield per plant (5.57), and fiber length (1.44). On the other hand, MNH-992 × NIAB-777 was the most effective combination for number of bolls per plant (4.15), boll weight (0.58), and seed cotton yield per plant (5.89). The hybrids S-9 × FH-154, S-9 × NIAB-777, MNH-992 × FH-154, MNH-992 × AA-933, and MSDK × NIAB-777 exhibited significant positive specific combining ability effects for two characteristics each as shown in Table 3.

## DISCUSSION

Genetic variation plays a vital role in enhancing plant productivity and fiber characteristics. Therefore, understanding the genetic basis of variation in a specific trait is important for plant breeders. Genetic components indicate an appropriate amount of diversity with a pattern of inheritance, assisting cotton breeders in selection for breeding population.

The mean squares obtained from the line × tester analysis showed significant differences ($P < 0.01$) in factors such as genotypes, parents, crosses, parent versus cross, lines, testers, and their interactions for various plant traits including plant height (PH), number of bolls per plant (No. B/P), sympodial branches per plant (SB/P), boll weight (BW/P), seed cotton yield per plant (SCY/P), lint weight per plant (LW/P), GOT %, fiber length (FL), fiber strength (FS), and fiber fineness (FF). Arain et al. (2015), Rizwan (2015), and Al-Guboory (2016) presented similar results.

Combining ability effects provides an adequate overview of the genetic control of various plant traits. Results revealed that non-additive genetic variances were higher than additive because of higher SCA in

**Table 3:** GCA effects of parents for yield and fiber traits in upland cotton

| Lines | PH | No. B/P | SB/P | BW | SCY/P | LW/P | GOT% | FL | FS | FF |
|---|---|---|---|---|---|---|---|---|---|---|
| Bahar-2017 | -9.52 ** | 1.55 * | 0.72 ns | 0.39 ** | -1.46 ns | 0.52 ns | -3.53 ** | 0.62 * | -2.00 ns | -0.22 ns |
| FH-172 | 3.03 ** | 1.90 ** | -0.83 ns | -0.73 ** | -3.77 ** | -0.68 ns | 4.35 ** | -0.27 ns | 0.41 ns | 0.13 ns |
| S-9 | 3.73 ** | 2.15 ** | -1.56 ** | 0.32 * | -1.69 * | 0.70 ns | 2.81 ** | 0.58 * | 0.72 ns | 0.08 ns |
| MNH-992 | 1.61 ** | -3.91 ** | 0.28 ns | -0.20 ns | 2.40 ** | -2.84 ** | -4.58 ** | -0.34 ns | 2.44 ns | 0.21 ns |
| MSDK | 1.14 ns | -1.69 * | 1.39 ** | 0.22 ns | 4.52 ** | 2.29 ** | 0.95 ns | -0.58 * | -1.58 ns | -0.20 ns |
| Testers | | | | | | | | | | |
| FH-154 | -3.08 ** | 0.18 ns | -0.41 ns | 0.04 ns | -0.72 ns | 1.01 * | 1.58 ** | -0.41 ns | -1.08 ns | 0.06 ns |
| AA-933 | 3.16 ** | 3.02 ** | -0.38 ns | 0.38 ** | 1.92 ** | 1.19 ** | -0.14 ns | 0.36 ns | 1.12 ns | 0.12 ns |
| NIAB-777 | -0.09 ns | -3.20 ** | 0.79 * | -0.42 ** | -1.20 ns | -2.20 ** | -1.44 ** | 0.05 ns | -0.04 ns | -0.18 ns |

**Table 4:** SCA effects of crosses for yield and fiber characters in upland cotton

| Crosses | PH | No. B/P | SB/P | BW | SCY/P | LW/P | GOT% | FL | FS | FF |
|---|---|---|---|---|---|---|---|---|---|---|
| Bahar-2017 × FH-154 | -2.86 ** | -5.95 ** | 0.58 ns | -0.62 ** | 2.57 ns | -0.31 ns | -6.05 ** | 0.58 ns | 1.43 ns | 0.31 ns |
| Bahar-2017 × AA-933 | 4.74 ** | 7.93 ** | 0.38 ns | 0.62 ** | -3.93 ** | 5.19 ** | 8.19 ** | -0.63 ns | -0.61 ns | 0.04 ns |
| Bahar-2017 × NIAB-777 | -1.88 ns | -1.98 ns | -0.96 ns | -0.00 ns | 1.36 ns | -4.88 ** | -2.14 ns | 0.05 ns | -0.82 ns | -0.35 ns |
| FH-172 × FH-154 | 0.59 ns | 3.50 ** | 0.47 ns | 0.03 ns | -5.24 ** | -1.41 ns | -1.66 ns | -1.73 ** | -1.32 ns | -0.10 ns |
| FH-172 × AA-933 | -4.99 ** | -2.31 * | -1.57 ns | -0.32 ns | 4.84 ** | 3.66 ** | 0.58 ns | 2.16 ** | 0.22 ns | -0.30 ns |
| FH-172 × NIAB-777 | 4.40 ** | -1.19 ns | 1.10 ns | 0.30 ns | 0.39 ns | -2.25 * | 1.08 ns | -0.43 ns | 1.10 ns | 0.40 ns |
| S-9 × FH-154 | -3.35 ** | 1.65 ns | -1.31 ns | 0.39 ns | 7.02 ** | -2.56 ** | 1.47 ns | -0.42 ns | -1.33 ns | -0.12 ns |
| S-9× AA-933 | 2.88 ** | -1.87 ns | 0.99 ns | -0.09 ns | -2.60 ns | -3.13 ** | -4.89 ** | -0.46 ns | 0.64 ns | -0.19 ns |
| S-9 × NIAB-777 | 0.47 ns | 0.22 ns | 0.32 ns | -0.31 ns | -4.42 ** | 5.70 ** | 3.43 ** | 0.88 ns | 0.69 ns | 0.32 ns |
| MNH-992 × FH-154 | 0.71 ns | -2.42 * | -0.98 ns | -0.01 ns | -9.92 ** | 2.96 ** | 5.13 ** | 0.13 ns | 0.28 ns | 0.12 ns |
| MNH-992 × AA-933 | -2.83 ** | -1.73 ns | -0.18 ns | -0.57 ** | 4.04 ** | -2.25 * | -3.86 ** | 0.46 ns | -0.45 ns | 0.55 ns |
| MNH-992 × NIAB-777 | 2.12 * | 4.15 ** | 1.16 ns | 0.58 ** | 5.89 ** | -0.71 ns | -1.27 ns | -0.59 ns | 0.17 ns | -0.67 * |
| MSDK × FH-154 | 4.91 ** | 3.22 ** | 1.24 ns | 0.21 ns | 5.57 ** | 1.32 ns | 1.12 ns | 1.44 ** | 0.94 ns | -0.20 ns |
| MSDK × AA-933 | 0.20 ns | -2.02 ns | 0.38 ns | 0.36 ns | -2.35 ns | -3.47 ** | -0.02 ns | -1.53 ** | 0.20 ns | -0.10 ns |
| MSDK × NIAB-777 | -5.11 ** | -1.20 ns | -1.62 ns | -0.57 ** | -3.22 * | 2.15 * | -1.10 ns | 0.08 ns | -1.14 ns | 0.30 ns |

comparison to GCA for majority of the traits. The findings indicated that heterosis breeding is well-suited for the traits under investigation. This may lead to high performance of cross combination. Pushpam and Raveendran (2015), Sawarkar et al. (2015) and Manonmani et al. (2020) also observed prevalence of non-additive type of gene action for yield parameters. Contrary to this, Khan et al. (2015) and Soomro (2015) observed additive gene effects while Max et al. (2021) found the existence of both additive and non-additive genetic interactions in their research.

The Line × tester interaction was observed to exhibit a more pronounced influence on the overall variances across all the examined traits, surpassing the contributions of both the individual lines and testers. In contrast, the testers exhibited minimum contributions for all examined traits. The outcomes from the present study were supported by Khokhar et al. (2018).

It was expected that lines with more pronounced GCA effects for a trait in cross combination with various testers can produce superior hybrids for that specific trait. The breeders confirmed that if there is at least one of the parental line having high GCA effects then it can be used to develop a new hybrid through line × tester analysis. The assessment of combining ability effects (GCA and SCA) gives detailed information that may be used to classify parental lines, tester, and their crosses. The line S-9 recorded as best general combiner for number of sympodia, GOT %, number of bolls, fiber length and boll weight. However, among testers, AA-933 exhibited high GCA effect for characters such as number of bolls, boll weight, seed cotton yield per plant and lint weight per plant. The line Bahar-2017 and S-9 were good general combiner while MSDK was the poor general combiner for fiber length. All other lines and testers had the non-significant GCA effects for all the fiber quality parameters i.e., staple length, staple strength and staple fineness.

It was clear that both lines and testers exhibited varying positive or negative response of GCA to the variable. The positive effects of GCA suggested that further improvements are expected in breeding for yield, its various components and fiber quality parameters. Similar findings were also made by Rizwan (2015), Soomro (2015) and Chen et al. (2022)

The hybrid Bahar-2017 × AA-933 exhibited substantial specific combining ability effects for five traits: plant height, number of bolls per plant, boll weight, lint weight per plant, and GOT%. The results align with the studies conducted by Premalatha et al. (2020), Abro et al. (2021), Chakholoma et al. (2022), and Arif et al. (2022). The results of specific combining ability effects showed that the best pairings did not always come from parents with strong general combining ability impacts. The parents Bahar-2017 and AA-933 had low general combining ability, however their cross combination Bahar-2017 × AA-933 showed the highest significant specific combining ability for oil content percentage. The findings align with the studies conducted by Khan et al. (1991), Coyle and Smith (1997), Shakeel et al. (2001), and Basal and Turgut (2003). Parents with high General Combining Ability (GCA) for a specific trait are anticipated to result in enhanced yield in hybrid combinations. Parents MNH-992 and AA-933 showed substantial general combining ability impacts, and their cross MNH-992 × AA-933 displayed the highest specific combining ability for seed cotton production per plant. The results were consistent with the findings of Khan et al. (2017).

## Conclusion

The GCA and SCA mean squares were both significant, but the extent of variations related to SCA was greater for all parents than GCA, indicating a prevalence of non-additive gene expression. S-9 and AA-933 proved to be the most outstanding general combiners for most of the parameters investigated across lines and testers, and hence may be employed reliably in hybridization programs to select desirable plants from segregating populations. Among the F1 hybrids, cross Bahar-2017 × AA-933 was best specific combiners for plant height, no. of bolls per plant, boll weight, lint weight per plant and ginning out turn %. Therefore, this cross-show potential to be used for hybrid development for a variety of traits.

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