Study of Heterosis, Combining Ability and Parental Diversity for Seed Cotton Yield and Contributing Traits using Diallel Data in Cotton (G. hirsutum L.)

R.K. Giri, S.K. Verma1, J.P. Yadav

ABSTRACT

Background: Combining ability and parental diversity contributes directly to improve the heterotic potential. The experiment was aimed to study the parental diversity and its contribution to heterosis and to get an idea if parental diversity has any influence on the combining ability of the parental lines.

Methods: The field testing was carried out during 2017-18 at three locations comprises, Sirsa, Bathinda and Abohar. Total eight parents were crossed in diallel manner to produce 56 combination excluding eight parental genotypes using full diallel. All the hybrids and parental lines were tested using RBD at the selected locations and the mean of these three locations data was used to study the relationship. Genetic relatedness of the parents was studied using 20 SSR markers and the distance/similarity matrix was developed using Jaccard coefficient method.

Result: Genotypes showed significant (p ≤ 0.01) differences for mean squares values for all the traits under study. F-2228, F-2164 and LH-2108 were the parents with best general combining abilities. Parental lines RS-2013 and RST were found to be the most divergent lines. The best F₁ hybrids such as RST-9 x F-2164, LH-2076 x RST-9 and LH-2076 x RS-2013 comprised of diverse parents produced high heterosis for seed cotton yield. Among all the traits under study the maximum heterosis was received for seed cotton yield with a max gain of 126.8% over the mid parent.

Key words: Combining ability, Genetic distance, Gossypium hirsutum L., Heterosis, SSR, Seed cotton yield.

INTRODUCTION

Cotton is the foremost natural fibre crop of global importance grown commercially in around 75 countries with 2.9 million household engaged in its production, accounting for 25.9 million bales (170 kg) of lint production (DNFI, 2020). Cotton plays a key role in the national economy by way of its contribution in trade, industry, employment and foreign exchange earnings. India has largest area under cotton cultivation i.e. 11.6 mha, which is one third of the total world acreage (33.98 mha). India occupies first position in production followed by USA and China (Statista, 2019). The average productivity of cotton in India is very low compare to the other cotton-growing nations of the world so the knowledge of parental divergence and its impact on impact on yield and contributing traits can enhance the genetic improvement efforts for yield enhancement. The genetic improvement efforts limited by the low germplasm diversity in the upland cotton.

Upland cotton (Gossypium hirsutum L.) has a narrow genetic base due to genetic bottlenecks associated with polyploidy, domestication and modern plant breeding practices (Bowman et al., 1996; Iqbal et al., 2001). The low genetic base cotton has been validated by using molecular marker studies. Tyagi et al. (2014) have shown over 90% similarity based on a wide selection of several hundred cultivars and germplasm lines using simple sequence repeat (SSR) marker-based genotyping. Several other workers Lewis (2001) and May et al. (1995) suggested that narrow genetic diversity in cotton to impact the improvements in lint yield and fiber quality.

Looking into the challenge of narrow genetic base it is very much desirable to select germplasm from different geographical areas which exhibit maximum diversity. To improve productivity, one of the most important steps in a breeding programme is the detection of suitable parents which can produce heterosis. For the selected parents it is crucial be good combiner, which is required to gets its potential represented in hybrid. In combining ability, the entire genetic variability of each trait can be partitioned into GCA and SCA as defined by Sprague and Tatum (1942) and reciprocal effects as sketched by Griffing’s (1956). They stated that GCA
effects administer the additive type of gene action whereas the SCA effects are shown due to genes which are non-additive (dominant or epistatic) in nature. Sayal et al., (1997) and Hassan et al., (1999) reported the importance of non-additive type of gene action for different cotton traits.

**MATERIALS AND METHODS**

The parental material multiplication and crossing program for the research was undertaken at ICAR-CICR, Regional Research Station, Sirsa. The experimental material was comprised of eight G. hirsutum lines viz., RS-2013, RST-9, RS-810, F-1378, F-2164, F-2228, LH-2076 and LH-2108. These eight parents were crossed in a diallel manner with reciprocals to produce 56 F₁ hybrids at ICAR-CICR, Regional Research Station, Sirsa during kharif-2016. All the 56 F₁ crosses along with eight parents were planted at three farmer field locations at Sirsa, Bathinda and Abhor. The entries were tested in Randomized Block Design with a spacing of 105x60 cm row to row and plant to plant spacing respectively during the 2017-18 season. Data for different traits under study was randomly collected from five plants from each plot.

The Trial data was subjected to analysis of variance (ANOVA) using OP STAT computer software (Sheoran et al. 1998) to test the null hypothesis of no difference between various F₁ crosses and their parental lines. Estimates of GCA were computed according to (Griffing, 1956). The diallel analysis was used to evaluate traits that had a significant variation among parents. Simple additive-dominance model approach (Hayman, 1954, 1958) modified by Mather and Jinks (1982) was followed for genetic analysis and for estimation of the components of genetic variation.

The parental diversity was taken out using 20 Simple Sequence Repeats (SSR) markers. The DNA of the cotton samples were extracted from the tender leaves (collected from the testing plots during kharif/2017) using CTAB method (Zhang and Stewart, 2000). The purity and concentration of DNA were determined by agarose gel electrophoresis and spectrophotometric analysis. All DNA samples were diluted to a working concentration (50 ng/μL). Stock DNA samples were stored at -40°C and working DNA samples at 4°C until PCR amplification. This DNA sample was used to hybridize with the SSR markets. The similarity study was done using Jaccard coefficient. The Jaccard coefficient values were compared to calculate the similarity of dissimilarity between parents. A dendrogram based on these similarity coefficients was constructed by using unweighted pair group method of arithmetic means (UPGMA).

**RESULTS AND DISCUSSION**

Analysis of variance indicated highly significant differences due to treatments fulfilling the basic requirement to take the study forward (Table 1). The result suggests that there is

**Table 1**: Analysis of Variance for Diallel.

| Source of Variation | DF | Mono | Sym | Boll Weight | Plant Height | Seed Cotton Yield | GOT | Seed Index | Fiber Length | Fiber Strength | MIC |
|---------------------|----|------|-----|-------------|--------------|-------------------|-----|------------|--------------|---------------|-----|
| Replications        | 1  | 0.045| 0.009| 0.132*      | 0.241        | 0.047             | 4.13| 0.186      | 1.92*        | 0.001         | 0.604|
| Treatments          | 63 | 0.28**| 2.319**| 0.116**     | 876.43**     | 0.21**            | 4.127**| 1.359**    | 3.93**       | 7.23**        | 0.181**|
| Error               | 63 | 0.037| 1.197| 0.032       | 10.59        | 0.022             | 1.232| 0.224      | 0.041        | 0.051         | 0.03 |
| Total               | 127|      |      |             |              |                   |     |            |              |               |     |

Note: *"** gives the significance at 0.05 and 0.01 percent level.

**Table 2**: ANOVA for Combining Ability.

| Source of Variation | DF | Mono | Sym | Boll Weight | Plant Height | Seed Cotton Yield | GOT | Seed Index | Fiber Length | Fiber Strength | MIC |
|---------------------|----|------|-----|-------------|--------------|-------------------|-----|------------|--------------|---------------|-----|
| Due to GCA          | 7  | 0.506**| 6.369**| 0.497**     | 442.63**     | 0.17**            | 2.514| 6.357**    | 13.07**      | 24.35**       | 0.272**|
| Due to SCA          | 28 | 0.246**| 1.538| 0.094**     | 1744.02**    | 0.333**           | 6.266**| 0.639**    | 3.142**      | 4.494**       | 0.157**|
| Due to Reciprocals  | 28 | 0.258**| 2.087*| 0.042       | 117.31**     | 0.098**           | 2.39* | 0.83**     | 2.451**      | 5.687**       | 0.183**|
| Maternal Effect     | 7  | 0.335| 3.216| 0.16        | 2.109        | 0.16              | 2.045| 2.959      | 3.719        | 0.19          |     |
| Mater. Interaction  | 21 | 0.233**| 1.711| 125.97**    | 0.077**      | 2.483*            | 0.955**| 2.282**    | 6.343**      | 0.181**       |     |
| Error               | 63 | 0.037| 1.197| 0.032       | 10.59        | 0.022             | 1.232| 0.224      | 0.041        | 0.051         | 0.03 |
| GCA:SCA             | 2.057| 4.141| 5.287| 0.254       | 0.511        | 0.401             | 9.948| 4.159      | 5.418        | 1.732         |     |

Note: *"** gives the significance at 0.05 and 0.01 percent level.
enough variability in genetic material. The ANOVA for combining ability effects (Table 2) indicated that the mean square values of GCA were highly significant ($p \leq 0.01$) for all the traits except for GOT. The mean square values for SCA were also significant for all the traits except for the number of sympods. Though the maternal effects are non-significant for all the traits under study, but maternal interaction were seen significant for all the traits except for the number of sympods. Mean square values due to reciprocals were also found significant for all the traits except for boll weight.

### Mean Performance

Mean performance acts as the main criterion in selecting better hybrids as it reveals their real value. Shimna and Ravikesavan (2008) suggested that the per se performance of hybrids appeared to be a useful index in judging them. Gilbert (1958) reported that parents with good per se performance would result in good hybrids. Table 3 gives the trait means for the straight cross combinations as well as for reciprocal cross combinations. For number of monopods per plant straight and reciprocal crosses shared common mean whereas the trait range for reciprocal crosses was broader than straight crosses range. Number of sympods trait mean for straight and reciprocals was 12.6 and 12.2 respectively with straight crosses sharing a broader range than reciprocals. Boll weight trait mean and range was similar for straight and reciprocal crosses. For plant height the trait mean range was found highest among all the traits.

### Average and Standard Heterosis

Heterotic effects were observed for all the ten given traits over mid and standard check but the extent of heterosis varied from trait to trait. Heterotic effects of straight as well as for reciprocal cross combination was computed over mid parent was termed as Average Heterosis and over the standard check was termed as Standard Heterosis. For the straight and reciprocal cross combinations, the mean heterotic effects are presented in Table 4. Average heterosis was found positive for all the traits in both straight and reciprocal cross combinations except for number of sympods for which mean for reciprocal effects was found to be negative. Several workers have reported similar type of results for economic traits in cotton (Choudhary et al. 2014, Solanki et al. 2014, Srinivas and Bhadru 2015).

Average heterosis mean for Number of Monopods for straight and reciprocal combinations crosses was found to

### Table 3: Trait Mean and Range for Straight and Reciprocal Crosses.

| Trait           | Straight Crosses | Reciprocal Crosses |
|-----------------|------------------|--------------------|
|                 | Trait Mean       | Range              | Trait Mean       | Range              |
| No. of Monopods | 2.5              | 2.0 - 3.1          | 2.5              | 1.4 - 3.3          |
| No. of Sympods  | 12.6             | 10.5 - 14.9        | 12.2             | 10.7 - 14.1        |
| Boll Weight     | 2.8              | 2.2 - 3.1          | 2.8              | 2.2 - 3.2          |
| Plant Height    | 123.2            | 107.0 - 137.7      | 125.9            | 110.1 - 137.8      |
| Seed Cotton Yield | 1.500          | 1.135 - 1.894      | 1.613            | 1.168 - 1.997      |
| Ginning Out-turn | 33.8            | 31.6 - 36.2        | 33.4             | 31.4 - 35.6        |
| Seed Index      | 8.0              | 6.7 - 9.8          | 8.2              | 6.5 - 10.6         |
| Fiber Length    | 27.1             | 24.3 - 29.3        | 27.2             | 24.3 - 30.0        |
| Fiber Strength  | 28.5             | 25.4 - 32.3        | 28.7             | 24.5 - 32.2        |
| Micronaire value| 5.0              | 4.5 - 5.4          | 4.9              | 4.4 - 5.5          |

### Table 4: Mean Heterotic effects for Straight and reciprocals.

| Trait           | Average Heterosis Mean | Standard Heterosis Mean |
|-----------------|------------------------|-------------------------|
|                 | Straight Crosses        | Reciprocal Crosses      | Reciprocal Crosses    | Straight Crosses   |
| No. of Monopods | 2.2                    | 2.2                     | -6.0                  | -6.0               |
| No. of Sympods  | 0.6                    | -2.0                    | -1.9                  | -4.5               |
| Boll Weight     | 8.8                    | 9.8                     | -2.7                  | -1.8               |
| Plant Height    | 75.2                   | 79.0                    | -9.3                  | -7.3               |
| Seed Cotton Yield | 70.9              | 83.2                    | -0.3                  | 6.9                |
| Ginning Out-turn | 10.0                 | 8.7                     | 1.0                   | -0.1               |
| Seed Index      | 0.6                    | 3.7                     | -4.7                  | -1.8               |
| Fiber Length    | 6.3                    | 6.9                     | -1.1                  | -0.6               |
| Fiber Strength  | 5.0                    | 5.6                     | 4.2                   | 4.8                |
| Micronaire value| 6.7                    | 5.2                     | -1.8                  | -3.3               |
be equal (2.2% in each case). For number of sympods mean heterotic effects were positive for straight crosses (0.6%) but it was found negative for reciprocal crosses (-2.0%). Maximum average heterosis was observed for seed cotton yield (70.9%, 83.2%) for straight and reciprocal crosses. Plant height followed seed cotton yield for leveraging wide range of heterosis (75.2%, 79.0%) for straight and reciprocal crosses. Positive average heterotic effects were obtained for both straight and reciprocal crosses.

For standard heterosis study, out of ten traits under study positive heterotic effects were found for fiber strength for both straight and reciprocals whereas for seed cotton yield positive effects were found for reciprocal combinations and GOT positive effects were exhibited by straight crosses only. Trait number of monopods per plant exhibited same extent for heterotic effects for straight and reciprocal crosses. Maximum standard heterosis was observed for seed cotton yield (-0.3%, 6.9%) followed by fiber strength (4.2%, 4.8%). Similar types of trends for standard heterosis were also found by earlier researchers (Ashok et al. 2013, Patel et al. 2014 and Usharani et al. 2015, Sawarkar et al. 2015, Hussain et. al. 2020).

Table 5: Parental lines, their origin and Characteristics.

| Line Code | Origin                  | Characteristics                                           |
|-----------|-------------------------|-----------------------------------------------------------|
| RS 2013   | Sri Ganganagar, Rajasthan | Average yielder, open plant type with average fiber       |
| RST 9     | Sri Ganganagar, Rajasthan | Average yielder, spreading type plant, high GOT, poor fiber |
| RS 810    | Sri Ganganagar, Rajasthan | Poor yielder, Short and Erect Plant type, below average fiber |
| F 1378    | Faridkot, Punjab         | Good yield potential, Erect Plant Type, Good fiber        |
| F 2164    | Faridkot, Punjab         | High yields, Tall plant type and good fiber               |
| F 2228    | Faridkot, Punjab         | Good yields, open and tall plant type with superior fiber |
| LH 2076   | Ludhiana, Punjab         | Poor yielder, open plant type and superior fiber          |
| LH 2108   | Ludhiana, Punjab         | Good yielder, high GOT, medium tall with average fiber    |

Table 6: Best Heterotic Effects for Straight Crosses.

| Trait                  | Rank | Pedigree          | Cross code | Average Heterosis | Standard Heterosis |
|------------------------|------|-------------------|------------|-------------------|--------------------|
| No. of Monopods        | 1st  | RST-9 x F-2164    | 2 x 5      | 35.4              | 24.6               |
|                        | 2nd  | RS-810 x LH-2108  | 3 x 8      | 23.2              | 13.4               |
|                        | 3rd  | RST-9 x LH-2108   | 2 x 8      | 17.2              | 7.9                |
| No. of Sympods         | 1st  | RS-2013 x LH-2108 | 1 x 8      | 19.4              | 16.4               |
|                        | 2nd  | F-1378 x F-2228   | 4 x 6      | 17.0              | 14.1               |
|                        | 3rd  | RS-2013 x F-2228  | 1 x 6      | 15.4              | 12.5               |
| Boll Weight            | 1st  | F-2228 x LH-2076  | 6 x 7      | 22.5              | 9.5                |
|                        | 2nd  | F-2164 x F-2228   | 5 x 6      | 18.5              | 6.0                |
|                        | 3rd  | RS-2013 x F-2228  | 1 x 6      | 16.5              | 4.2                |
| Plant Height           | 1st  | F-2164 x F-2228   | 5 x 6      | 95.9              | 1.4                |
|                        | 2nd  | RS-2013 x RST-9   | 1 x 2      | 95.7              | 1.3                |
|                        | 3rd  | RST-9 x LH-2108   | 2 x 7      | 95.7              | 1.3                |
| Seed Cotton Yield      | 1st  | F-1378 x LH-2108  | 4 x 8      | 115.1             | 25.5               |
|                        | 2nd  | RST-9 x LH-2108   | 2 x 8      | 112.8             | 24.1               |
|                        | 3rd  | F-2164 x F-2228   | 5 x 6      | 112.3             | 23.9               |
| GOT                    | 1st  | RST-9 x LH-2108   | 2 x 8      | 17.7              | 8.1                |
|                        | 2nd  | F-1378 x LH-2108  | 4 x 8      | 16.5              | 7.0                |
|                        | 3rd  | RST-9 x LH-2076   | 2 x 7      | 15.2              | 5.8                |
| Seed Index             | 1st  | F-2228 x LH-2076  | 6 x 7      | 20.1              | 13.8               |
|                        | 2nd  | F-2228 x LH-2108  | 6 x 8      | 18.9              | 12.6               |
|                        | 3rd  | RST-9 x LH-2108   | 2 x 6      | 15.1              | 9.0                |
| Fiber Length           | 1st  | F-1378 x F-2164   | 4 x 5      | 15.0              | 6.9                |
|                        | 2nd  | RST-9 x F-2228    | 2 x 6      | 14.2              | 6.2                |
|                        | 3rd  | F-1378 x F-2228   | 4 x 6      | 13.0              | 5.1                |
| Fiber Strength         | 1st  | F-2164 x LH-2108  | 5 x 8      | 19.0              | 18.1               |
|                        | 2nd  | RS-2013 x F-2228  | 1 x 6      | 12.2              | 11.3               |
|                        | 3rd  | F-1378 x F-2228   | 4 x 6      | 11.4              | 10.6               |
| Micronaire             | 1st  | RS-2013 x LH-2108 | 1 x 8      | 16.3              | 6.9                |
|                        | 2nd  | RS-2013 x LH-2076 | 1 x 7      | 15.2              | 5.9                |
|                        | 3rd  | RS-810 x F-1378   | 3 x 4      | 14.1              | 5.0                |
Table 7: Best Heterotic Effects for Reciprocal Crosses.

| Trait                  | Rank | Pedigree         | Cross code | Average Heterosis | Standard Heterosis |
|------------------------|------|------------------|------------|-------------------|-------------------|
| No. of Monopods        | 1st  | LH-2076 x F-2228 | 7 x 6      | 31.3              | 20.9              |
|                        | 2nd  | LH-2076 x RS-2013| 7 x 1      | 27.3              | 17.1              |
|                        | 3rd  | F-2228 x RST-9   | 6 x 2      | 15.2              | 6.0               |
| No. of Sympods         | 1st  | F-2228 x F-2164  | 6 x 5      | 12.6              | 9.8               |
|                        | 2nd  | LH-2108 x F-2228 | 8 x 6      | 11.4              | 8.6               |
|                        | 3rd  | F-2164 x F-1378  | 5 x 4      | 9.8               | 7.0               |
| Boll Weight            | 1st  | LH-2108 x F-1378 | 8 x 4      | 24.4              | 11.3              |
|                        | 2nd  | LH-2076 x F-2228 | 7 x 6      | 24.4              | 11.3              |
|                        | 3rd  | LH-2108 x F-2228 | 8 x 6      | 22.5              | 9.5               |
| Plant Height           | 1st  | F-2164 x RST-9   | 5 x 2      | 95.9              | 1.4               |
|                        | 2nd  | LH-2108 x F-2164 | 8 x 5      | 95.0              | 1.0               |
|                        | 3rd  | LH-2108 x RS-2013| 8 x 1      | 95.0              | 0.9               |
| Seed Cotton Yield      | 1st  | LH-2076 x RS-2013| 7 x 1      | 126.8             | 32.3              |
|                        | 2nd  | F-2164 x RST-9   | 5 x 2      | 117.7             | 27.0              |
|                        | 3rd  | F-2228 x F-1378  | 6 x 4      | 117.0             | 28.6              |
| Ginning Out-turn       | 1st  | F-2164 x RS-810  | 5 x 3      | 15.7              | 6.3               |
|                        | 2nd  | F-1378 x RST-9   | 4 x 2      | 13.6              | 4.4               |
|                        | 3rd  | LH-2076 x RS-2013| 7 x 1      | 13.1              | 3.9               |
| Seed Index             | 1st  | F-2228 x F-2164  | 6 x 5      | 33.3              | 26.3              |
|                        | 2nd  | LH-2108 x F-2228 | 8 x 6      | 22.6              | 16.1              |
|                        | 3rd  | LH-2076 x F-2228 | 7 x 6      | 20.8              | 14.4              |
| Fiber Length           | 1st  | LH-2076 x F-1378 | 7 x 4      | 17.7              | 9.5               |
|                        | 2nd  | LH-2076 x F-2228 | 7 x 6      | 14.8              | 6.8               |
|                        | 3rd  | F-2228 x F-1378  | 6 x 4      | 14.2              | 6.2               |
| Fiber Strength         | 1st  | F-2228 x F-2164  | 6 x 5      | 18.6              | 17.7              |
|                        | 2nd  | LH-2076 x F-1378 | 7 x 4      | 17.7              | 16.8              |
|                        | 3rd  | F-2228 x F-1378  | 6 x 4      | 17.7              | 16.8              |
| Micronaire             | 1st  | LH-2076 x RS-810 | 7 x 3      | 17.4              | 7.9               |
|                        | 2nd  | LH-2108 x LH-2076| 8 x 7      | 15.2              | 5.9               |
|                        | 3rd  | LH-2108 x F-2228 | 8 x 6      | 14.1              | 5.0               |

Genetic Diversity of Parents

Parents for this study were collected from 1) PAU Ludhiana, 2) RAU Regional Cotton Station Sri Ganganagar and 3) Regional Cotton Research Station Faridkot. The selection of parents was done based on their diversity for different agronomic and phenotypic traits. The origin and phenotypic traits of the parental lines are proved in Table 5. Based on SSR markers the distance matrix of eight parents (Table 8) revealed that the two parental lines P2 (RST-9) and P7 (LH-2076) had a genetic distance (GD) of 0.500, the highest among the eight genotypes used in this study. RST-9 also had higher GD (ranging from 0.462 to 0.500) with other lines. The second largest genetic distance was observed for P1 (RS-2013) with a range of 0.333 to 0.429 with all the other parental line used in the study. Parent P3 (RS 810), P4 (F 1378), P5 (F 2164) and P6 (F-2228) were most closely related or were found to be sister lines as the genetic distance between all the four were zero. Three of the four lines were originated from Faridkot (Punjab) while parent P3 has origin from Sri Ganganagar (Rajasthan). Parent P7 (LH 2076) was closely related with P3, P4, P5 P6 and P8 with GD of 0.071 whereas P8 (LH 2108) also depicted close relation with P3, P4, P5 and P6 with GD of 0.143. The close relatedness of Parents was understandable as they were all derived from Punjab except for P2. Parent P1 (RS 2013) and P2 (RST-9) highest GD from parental originated from Ludhiana (Punjab) followed by parental lines originated from Faridkot (Punjab). Tyagi et al. (2014), Lewis (2001) and May et al. (1995) also suggested narrow genetic diversity in cotton. The results of hybrid performance per se shows a positive correlation between GD of parents and the performance of their hybrids for Seed cotton yield, Plant height, GOT and number of Monopods per plant. For these traits top 40 - 60% of the top hybrids involved distant parents (DP) i.e. RST-9 and RS-2013 as one of the parents. For number of monopods the distant parents contributed 6 hybrids in top 10 hybrids among straight crosses and 5 hybrids in reciprocal crosses. For plant height DP contributed 4 and 6 crosses among top 10 crosses. For seed cotton yield 4 and 5 crosses among top 10 hybrids constituted DP for straight and reciprocal crosses respectively whereas for GOT 4 and 6 cross combinations of DP were part of top ten best heterotic crosses for straight and reciprocal crosses. Further it was found that among the list of Top three best heterotic crosses...
for all the ten traits for straight crosses, out of total 30, 26 crosses have top four most diverse lines as one or both parents (Table 6). For Reciprocal crosses among the top three crosses for all the traits, top four diverse parents contributed towards 22 crosses out of total 30 (Table 7). Apart from these results it was also found that there were crosses in the top performer where the closely related parents were involved in hybrid production. This was in line with the earlier studies of Altaher and Singh (2003) and Kulkarni and Nanda (2006) where they found that moderate divergence can also produce good heterosis. Zhang et. al. (2017) also found that the additive effects of parents contribute hybrid performance.

Parental data for GCA indicates that Parent 6 (F 2228) is the best general combiner followed by Parent 8 (LH 2108) and Parent 5 (F 2164) But as per the distance matrix (Table 8) the best combiner parent (F 2228) is least diverse (0 to 0.462) from other parents involved whereas second best GCA parent (LH 2108) has medium divergence ranging from 0.071 to 0.462. Further the combining ability status of two most divergent parents i.e. P1 (RS 2013) and P2 (RST 9) was the lowest combining abilities, having positive combining ability effects for only one and three traits respectively. These results show that there is no correlation between the genetic diversity and combining ability of lines. Kamra et. al (2020) also found no correlation between combining ability and parental diversity in maize. The combining ability of the parents was reflected in better positive heterosis than the poor general combiner parents.

**CONCLUSION**

It was found that the diversity among the parents involved in the study was less and it was very visible that parents from different institutes/geography were distant from each other. Parents with good general combiner produce better positive heterosis compare to poor general combiner. The best combiners for different traits also contributed around 40-50% of the top ten most heterotic hybrids. RS 2013 and RST 9 were most diverse among all the eight parental lines. The genetic diversity is correlated positively with heterosis for Seed cotton yield, Plant height, GOT and number of Monopods per plant. Genetically diverse lines produced significant crosses among the top three best heterotic crosses for all the ten traits under study. The genetically diverse lines were not found to be good general combiner which indicated towards no correlation between divergence and combining abilities. It was also visible from the study that the heterotic effects of reciprocal cross combinations were similar in extent indicating absence of maternal effects.

### Table 8: Distance matrix of Parental Lines.

|     | RS-2013 (P1) | RST-9 (P2) | RS-810 (P3) | F-1378 (P4) | F-2164 (P5) | F-2228 (P6) | LH-2076 (P7) | LH-2108 (P8) |
|-----|--------------|------------|-------------|-------------|-------------|-------------|--------------|--------------|
| RS-2013 (P1) | 0 | 0.333 | 0.385 | 0.385 | 0.385 | 0.385 | 0.429 | 0.385 |
| RST-9 (P2) | 0.333 | 0 | 0.462 | 0.462 | 0.462 | 0.462 | 0.5 | 0.462 |
| RS-810 (P3) | 0 | 0 | 0 | 0 | 0 | 0.071 | 0.143 | 0.143 |
| F-1378 (P4) | 0 | 0 | 0 | 0 | 0 | 0.071 | 0.143 | 0.143 |
| F-2164 (P5) | 0 | 0 | 0 | 0 | 0 | 0.071 | 0.143 | 0.143 |
| F-2228 (P6) | 0 | 0 | 0 | 0 | 0 | 0.071 | 0.143 | 0.143 |
| LH-2076 (P7) | 0 | 0 | 0 | 0 | 0 | 0.071 | 0.143 | 0.143 |
| LH-2108 (P8) | 0 | 0 | 0 | 0 | 0 | 0.071 | 0.143 | 0.143 |

**REFERENCES**

Altaher, A.F. and Singh, R.P. (2003). Genetic diversity studies in upland cotton (Gossypium hirsutum L) using two methods of clustering. Journal Indian Society Cotton Improvement. 28(3): 158-163.

Ashokkumar, K., Senthilkumar, K. and Ravikesavan, R. (2013). Heterosis studies for fibre quality of upland cotton in line x tester design. African Journal Agriculture Research. 8(48): 6359-6365.

Bowman, D.T., May, O.L. and Calhoun, D.S. (1996). Genetic base of upland cotton cultivars released between 1970 and 1990. Crop Science. 36: 577-581.

Choudhary, R., Solanki, B.G., Choudhary, R., Singh, A.K. and Khandelwal, V. (2014). Heterosis in single cross inter and intra-specific hybrids of desi cotton in relation to seed cotton yield and its contributing characters. The Bioscan. 9(2): 839-843.

Discover Natural Fiber Initiative, (2020). Forty million households produce natural fibres. Press Release, 20 April 2020.

Gilbert, N.E. (1958). Diallel cross in plant breeding. Heredity. 15: 563-568.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Australian Journal of Biological Science. 9: 463-493.

Hassan, G., Mahmood G., Khan, N.U. and Razzaq, A. (1999). Combining ability and heterobeltiotic estimates in a diallel cross of cotton (G. hirsutum). Sarhad Journal of Agriculture. 15: 563-568.

Hayman, B.I. (1954a). The theory and analysis of diallel crosses. Genetics. 39: 789-809.

Hayman, B.I. (1954b). The analysis of variance of diallel cross. Biometrics. 10: 235-245.

Hayman, B.I. (1958). The theory and analysis of diallel crosses II. Genetics. 43: 63-85.

Hussain, M., Tahir, A., Saif, R., Tahir, S., Tahir, Z., Sultana, R., Qadir, M. and Nawaz B. (2020). Combining ability analysis for seed cotton yield related traits in upland cotton. Life Science Journal. 17(5): 81-84.
Iqbal, M.J., Reddy, O.U.K., El-Zik, K.M. and Pepper, A.E. (2001). A genetic bottleneck in the ‘evolution under domestication’ of upland cotton Gossypium hirsutum L. examined using DNA fingerprinting. Theoretical and Applied Genetics. 103: 547-554.

Kamara, M.M., Rehan, M., Ibrahim, K.M., Alsohim, A.S., Elsharkawy, M.M., Kheir, A.M.S., Hafez, E.M. and El-Esawi, M.A. (2020). Genetic Diversity and Combining Ability of White Maize Inbred Lines under Different Plant Densities. Plants. 9: 1140.

Kulkarni, A.A. and Nanda, H.C., (2006). Genetic diversity in upland cotton (Gossypium hirsutum L.). Indian Journal Plant Genetic Resources. 19(2): 226-230.

Lewis, H. (2001). A review of yield and quality trends and components in American upland cotton. P. 1447-1453. In Proc. Beltwide Cotton Conf., Anaheim, CA 10-13. Jan. 2001. National Cotton Council of America, Memphis, TN.

Mather, K. and Jinks, J.L. (1971). Biometrical Genetics Ed. Chapman and Hall Ltd, London 2nd, p. 38.

Mather, K. and Jinks, J.L. (1982). Introduction to Biometrical Genet. Ed. Chapman and Hall Ltd., London.

May, O.L., Bowman, D.T. and Calhoun, D.S. (1995). Genetic diversity of U.S. Upland cotton cultivars released between 1980 and 1990. Crop Science. 35: 1570-1574.

Patel, D.H., Patel, D.U. and Kumar, V. (2014). Heterosis and combining ability analysis in tetraploid cotton (G. hirsutum L. and G. barbadense L.). Electronic Journal Plant Breeding. 5(3): 408-414.

Sawarkar M., Solanke A., Mshasal G.S. and Deshmukh S.B. (2015). Combining ability and heterosis for seed cotton yield and fiber quality traits in cotton Gossypium hirsutum L. Indian Journal of Agricultural Research. 49(2): 154-159.

Sayal, O.U., Jatoi, S.A., Baloch, M.S. and Hussain, I. (1997). Estimation of combining ability for quantitative traits in G. hirsutum using Griffings technique of diallel. Science Khyber. 10(2): 13-21.

Sheoran, O.P., Tonk, D.S., Kaushik, L.S., Hasija, R.C. and Pannu, R.S. (1998). Statistical Software Package for Agricultural Research Workers. Recent Advances in information theory, Statistics and Computer Applications by D.S. Hoodaand R.C. Hasija Department of Mathematics Statistics, CCS HAU, Hisar. p139-143.

Shimna, B. and Ravikesavan, R. (2008). Combining ability analysis of yield related traits and fibre quality traits in cotton (Gossypium spp.). Journal of Cotton Research and Development. 22(1): 23-27.

Solanki, H.V., Mehta, D.R., Rathod,V.B. and Valu, M.G. (2014). Heterosis for seed cotton yield and its contributing characters in cotton (Gossypium hirsutum L.). Electronic Journal of Plant Breeding. 5(1): 124-130.

Sprague, G.F. and Tatum, L.A. (1942). General and specific combining ability in single crosses of corn. Journal of American Society of Agronomy. 35: 283-295.

Srinivas B. and Bhadru D. (2015). Heterosis studies for yield and fiber quality traits in intra hirsutum hybrids of cotton Gossypium hirsutum L. Agricultural Science Digest. 35(4): 295-299.

Statista. (2019). Cotton production by country worldwide. Cotton Survey, Press Release, statista.com, September 2019.

Tyagi, P., Gore, M.A., Bowman, D.T., Campbell, T.B., Udall, J.A. and Kuraparthy, V. (2014). Genetic diversity and population structure in the US Upland cotton (Gossypium hirsutum L.). Theoretical Applied Genetics. 127: 283-295.

Usharani, K.S., Vindhiyavaran, P., Amala Balu, P. and Boopathi, N.M. (2015). Heterosis studies for fibre quality traits in diallel crosses of upland cotton (Gossypium hirsutum L.). The Bioscan. 10(2): 793-799.

Zhang, J. and Stewart, J.M. (2000). Economical and rapid method for extracting cotton genomic DNA. Journal of Cotton Science. 4: 193-201.

Zhang, J.F., Abdelraheem, A. and Wu, J.X. (2017). Heterosis, combining ability and genetic effect and relationship with genetic distance based on a diallel of hybrids from five diverse Gossypium barbadense cotton genotypes. Euphytica. 213: 208.