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HETEROSIS STUDIES FOR MORPHOLOGICAL AND WITHIN BOLL YIELD RELATED TRAITS IN GOSSYPIUM HIRSUTUM

Akasha Ashraf[1], Muhammad Yasir Saleem[1], Sara Raza[1] and Jazib Javed[*1]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan

**Corresponding author*: jazibjaved.uaf@gmail.com

ABSTRACT

Cotton is the most important fibre crop. Cotton production in Pakistan is declining every year so there is need to develop new high yielding varieties of cotton to boost country's economy. This research study was directed to assess heterotic potential of nine F_1 hybrids for different morphological and within boll yield components. For this purpose, the nine F_1 hybrids along with their parent were sown in two replications in the field area of Department of Plant Breeding and Genetics, University of Agriculture Faisalabad during the normal growing season. The analysis of variance showed highly significant difference among genotypes for all the traits except seed index and fiber length which showed significant difference. The cross VH-329×CRS-2 showed maximum significant heterosis (80.05%) and heterobeltiosis (65.18%) for seed cotton yield with positive heterosis in bolls per plant (45.68%), seed volume (22.58%), fiber length (9.20%) and negative heterosis in node number of first fruiting branch (-23.64%), number of monopodial branches (-0.73%) and fiber fineness (-15.74%) followed by the cross VH-329×CIM-595 which showed 41.06% heterosis and 15.72% heterobeltiosis with positive heterosis in sympodial branches (23.76%), bolls per plant (56.83%), seeds per boll (7.76%), lint index (12.56%), lint percentage (13.39%) and negative heterosis in node number for first fruiting branch (-23.64%), monopodial branches (-20.0%) and fiber fineness (-19.07%). The cross combinations i.e., VH-329×CRS-2 and VH-329×CIM-595 may be used for commercial exploitation of heterosis in cotton.

Keywords: Heterobeltiosis, Within Boll Yield Components, Lint Percentage, Morphological Traits, Hybrids.

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1. INTRODUCTION

Cotton is the main fibre crop utilized in the textile industry, as well as a source of edible oil, is grown in over 80 countries throughout the world (Shahzad et al. 2019).

The requirement for fiber in textile industry is rising. To meet this problem, hybridization can be used to boost the production potential of modern cotton genotypes. In this aspect, hybrids are produced by the use of heterosis. Heterosis is the phenomenon in which the offspring of two genetically distinct parents outperform the mid-parent (relative heterosis) or better parent (heterobeltiosis) for different traits. Primary aim is to make varieties or hybrids that are resistant to major pests, diseases and abiotic stresses in addition to higher yield and fibre quality. The heterosis research is useful in crop breeding programmes to generate a significant degree of heterotic response by parents with desirable traits (Adsare et al. 2017).

Heterosis is the essential genetic tool for improving the yield in both self-pollinated and cross-pollinated crops (Chakholoma et al. 2021). Due to the ease of manual emasculation and pollination, commercial exploitation of heterosis in cotton has become possible and cost-effective. Using heterosis in crops has provided major economic benefits during the last century. Various workers have observed heterosis and heterobeltiosis in cotton. Cotton heterosis has proven to be a successful technique to boost yields, enhance fibre quality, and improve disease resistance in cotton (Zhou et al. 2021). Within-boll yield components have a significant impact on yield estimation. Within-boll yield components have received minimal selection pressure due to the difficulties of measuring them (Tang and Xiao, 2013).

Cotton experts have long aimed to use heterosis breeding to increase production and fibre quality attributes. Several studies have found considerable heterosis for a variety of features, such as favorable heterotic effects on fibre elongation (Solongi et al. 2019). Depending on the characters involved, both positive and negative heterosis can be beneficial. Basal et al. (2011) proposed that the best new F_1 hybrids may be identified and selected based on their specific combining ability and heterotic estimations.

The demand for natural fibre products with superior quality features necessitates the improvement of superior and high yielding hybrids in cotton. The purpose of this study is to determine the extent of heterosis and heterobeltiosis of cotton germplasm for several morphological and within boll yield traits. Breeders can utilize this information to select the top performing crosses for their future breeding programme based on these traits.

2. MATERIALS AND METHODS

The experiment was carried out in the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. The plant material studied in this genetic study was generated by crossing three cotton lines, Tarzan-05, FH-342, and VH-329, as well as three testers, CRS-2, CIM-595, and BS-80. In October 2020, the parent genotypes were grown in pots in a glasshouse to produce F_1 seeds. The temperature in the glasshouse was kept at 35 degrees Celsius. Crosses were made at the time of flowering, and all preventive precautions were taken to avoid genetic contamination. On May 2021, hybrids and their parents were planted in a field. The experiment was designed in a randomized complete block design with two replications, with randomization of parents and hybrids. Maximum ten plants were planted in each row. The space between rows and plants was fixed at 75cm and 30cm, respectively. Every genotype received all of recommended agronomic cultural practices. The following parents and hybrids were used in the experiment.

2.1. Parents

I. Tarzan-05
II. FH-342
III. VH-329
IV. CRS-2
V. CIM-595
VI. BS-80

2.2. Hybrids

I. Tarzan-05 × CRS-2
II. Tarzan-05 × CIM-595
III. Tarzan-05 × BS-80
IV. FH-342 × CRS-2
V. FH-342 × CIM-595
VI. FH-342 × BS-80
VII. VH-329 × CRS-2
VIII. VH-329 × CIM-595
IX. VH-329 × BS-80

Five plants from each genotype and replication were randomly selected and data for the following traits were recorded.

2.3. Number of Sympodial Branches

Direct fruit bearing branches are sympodial branches. Sympodial branches were counted from five plants in a row and then average was calculated for analysis.

2.4. Mature Bolls per Plant

For each cultivar in every replication, the total number of bolls from both picking was counted, and the average was calculated.

2.5. Node Number of 1st Fruiting Branch

The number of nodes above the cotyledonary node along the main stem until the one that gave rise to the first fruiting branch on the plants was used to calculate the node number for the first fruiting branch. In each replication, the data were averaged for each family.

2.6. Plant Height (cm)

The height of the plant was measured after it had stopped growing. Then average was calculated for further investigation.

2.7. Number of Monopodial Branches

The average number of monopodial branches was estimated for analysis after counting monopodial branches from selected five plants in a row.

2.8. Boll Weight (g)

Boll weight is measured in grams. It is calculated by dividing the seed cotton yield by total number of picked bolls on that plant. Mean values were calculated for each genotype and replication.

$$\text{Boll weight} = \frac{\text{Total weight of Seed cotton}}{\text{Total number of bolls}}$$

2.9. Seed Index (g)

Seed index is the weight of 100 seeds in grams. After ginning, the weight of hundred seeds was measured in grams using an electric balance for each plant. These 100 seeds were taken randomly. Mean values were calculated.

2.10. Number of Seeds Per Boll

After the ginning of cotton bolls from each plant, the seedsfrom five selected bolls were counted separately for each plant and then divided by the number of bolls. For each genotype, the average data was computed.

2.11. Seed Volume Per 100 Seeds (cm3)

Ethanol was used to determine seed volume. Firstly, ethanol was poured into a flask and the volume was measured. Then, pour 100 cotton seeds into the ethanol-filled flask and measured the increased volume of ethanol.

2.12. Seed Density (g/cm3)

Seed density is the ratio of seed weight and seed volume. Seed density was calculated by using following formula:

$$\text{Seed density}=\frac{\text{Seed index}}{\text{Seed volume per 100 seeds}}$$

2.13. Lint Index (g)

Lint index is calculated as the weight of lint generated by 100 seeds in grams. The following formula was used to compute it:

$$\text{Lint Index} =\frac{\text{Seed index} \times \text{lint percentage}}{100 - \text{Lint percentage}}$$

2.14. Lint Percentage

After weighing the seed cotton, a single rolling electrical ginner was used to gin it. The weight of the lint was measured using an electronic balance. The following formula was used to compute the lint percentage:

$$\text{Lint percentage} =\frac{\text{Sample lint weight}}{\text{Seed cotton weight in sample}} \text{x } 100$$

2.15. Seed Cotton Yield (g)

From each plant, mature bolls were picked. The picking was done twice to obtain total seed cotton. The electrical balance was used to weigh the harvest in grams. The average seed cotton yield of each genotype was obtained.

2.16. Fibre Fineness (µg/inch)

The HVI system was used to measure fibre fineness by placing a 10 g sample of lint in a micronaire compartment. When the sample weight was within the range, the Micronaire test began immediately and was shown on the testing screen. By opening the chamber's cover, a compilation sample was released. For statistical analysis, average fibre fineness was recorded in this manner for all samples of each genotype.

2.17. Fibre Length (mm)

Uster HVI-900 is used to measure fibre length in millimeters. The mean values were computed for each of the genotype.

2.18. Fibre Strength (g/tex)

Uster HVI-900 is also used to measure fibre strength in g/tex. The mean values were computed for each of the genotype.

2.19. Statistical Analysis

The data of the research was analyzed for genotypic variations at the genetic level of each trait under study. Significant traits were further investigated to estimate the heterosis and heterobeltiosis by following Falconer and Mackay (1996).

$$\text{Heterosis}=\frac{F_1 - MP}{MP}\times 100$$

$$\text{Heterobeltiosis}= \frac{F_1 - BP}{BP}\times 100$$

T-test was used to test the significance of heterosis and heterobeltiosis. T-value was calculated by the formula explained by Wynne et al. (1970).

t-test for heterosis

$$t= \left[\frac{F_1 - MP}{\frac{3}{2r} EMS}\right]^{0.5}$$

t-test for heterobeltiosis

$$t= \left[\frac{F_1 - MP}{\frac{2}{r} EMS}\right]^{0.5}$$

Where, F_1= mean of F_1 cross; MP= mid parent value; EMS= error mean square.

3. RESULTS

To check the genotypic difference for traits the data was subjected to analysis of variance. Heterosis and heterobeltiosis were determined by calculating the percent increase or decrease in F_1 hybrids and their significance was determined using the T-test.

3.1. Number of Sympodial Branches

Analysis of variance showed highly significant genotypic differences for number of sympodial branches among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 2. Among hybrids, maximum value fornumber of sympodial branches (33.54) was observed in crossVH-329×BS-80 while minimum value for number of sympodial branches (16.33) was observed in the cross Tarzan-05×BS-80. Among parents, VH-329 exhibited maximum value for number of sympodial branches (22.60) and BS-80 showed minimum value (18.70).

Table 1: Mean square values for different traits in cotton

Sources of variation	Replication	Genotype	Error
Degree of freedom	1	14	14
Number of sympodial branches	0.1	35.06**	3
Number of bolls per plant	14.93	68.57**	5.55
Number of 1st fruiting branch	2.43	4.48**	0.45
plant height	16.9	205.8**	10.83
Number of monopodial branches	0.01	0.37**	0.03
Boll weight	0.002	0.22**	0.01
Seed index	0.03	0.74*	0.26
Seeds per boll	0.52	8.7**	0.86
seed volume	0.53	1.87**	0.53
Seed density	0.0006	0.036**	0.0043
Lint index	0.02	0.2**	0.04
Lint percentage	3.6	7.92**	0.85
Seed cotton yield	512.33	822.19**	30.85
fiber fineness	0.02	0.36**	0.04
Fiber length	0.0003	1.33**	0.47
Fiber strength	0.03	6.8**	2.07

Table 2: Heterosis and heterobeltiosis (%) of nine crosses for number of sympodial branches in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-4.62	-5.91
Tarzan-05×CIM-595	15.26	14.82
Tarzan-05×BS-80	-15.06	-17.32
FH-342×CRS-2	-0.13	-1.72
FH-342×CIM-595	-3.92	-4.52
FH-342×BS-80	13.17	10.43
VH-329×CRS-2	7.69	2.21
VH-329×CIM-595	23.76**	16.37
VH-329×BS-80	64.89**	50.66**

The heterosis and heterobeltiosis (%) for number of sympodial branchesis shown in Table 1.2. Five crosses showed positive heterosis and four crosses showed negative heterosis. The heterosis ranged from -15.06% (Tarzan-05×BS-80) to 64.89% (VH-329×BS-80). Only two crosses VH-329×CIM-595 and VH-329×BS-80 showed highly significant positive heterosis.

Five crosses showed positive heterobeltiosis and four crosses showed negative heterobeltiosis. Theheterobeltiosis ranged from -17.32% (Tarzan-05×BS-80) to 50.66% (VH-329×BS-80). One cross VH-329×BS-80 showed highly significant positive heterobeltiosis for number of sympodial branches.

3.2. Mature Bolls Per Plant

Analysis of variance showed highly significant genotypic differences for mature boll per plant among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 3. Among hybrids, maximum value for mature boll per plant (42.50) was observed incross VH-329×CIM-595 while minimum value (21.40) was observed incross Tarzan-05×CRS-2. Among parents, CIM-595 showed maximum valuefor mature boll per plant (29.10) whilst Tarzan-05 exhibited minimum value (20.88). The results showed positive heterosis in six crosses and other three crosses exhibited negative heterosis. The heterosis ranged from -10.17% (FH-342×CIM-595) to 56.83% (VH-329×CIM-595). Tarzan-05×BS-80 and FH-342×CRS-2 showed significant positive heterosis whilst the crossesTarzan-05×CIM-595, VH-329×CRS-2 and VH-329×CIM-595 showed highly significant positive heterosis.

The results showed that six crosses revealed positive heterobeltiosis and three crosses showed negative heterobeltiosis. Theheterobeltiosis ranged from -19.59% (FH-342×CIM-595) to 46.05% (VH-342×CIM-595). FH-

342×CIM-595 showed significant negative heterobeltiosis. Two crossesVH-329×CRS-2 and VH-329×CIM-595 exhibited highly significant positive heterobeltiosis for number of bolls per plant.

3.3. Node Number of 1st Fruiting Branch

Analysis of variance showed highly significant genotypic differences for node number for first fruiting branch among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 4. Among hybrids, maximum valuefor node number for first fruiting branch (9.00) was observed incross FH-342×CIM-595while minimum value (4.90) was observed incross VH-329×CRS-2. Among parents, FH-342 exhibited maximum valuefor node number for first fruiting branch (10.40) and CRS-2 showed minimum value (7.70).

The heterosis and heterobeltiosis (%) for node number for first fruiting branch is shown in Table 3.2. Negative heterosis had been observed in all the crosses expect the cross Tarzan-05×CRS-2. The heterosis ranged from -41.14% (Tarzan-05×CIM-595) to 2.35% (Tarzan-05×CRS-2). Only one cross combinationTarzan-05×BS-80 showed significant negative heterosis. The cross Tarzan-05×CIM-595 revealed maximum negative heterosis (-41.14%) followed by VH-329×CRS-2 (-38.75%) and VH-329×CIM-595 (-23.64%).

The results showed negative heterobeltiosis in all crosses for node number of first fruiting branch. The heterobeltiosis ranged from -44.62% (Tarzan-05×CIM-595) to -6.45% (Tarzan-05×CRS-2). Two crossesTarzan-05×BS-80 and FH-342×BS-80 showed significant negative heterobeltiosis. The cross combination Tarzan-05×CIM-595 exhibited maximum significant negative heterobeltiosis (-44.62%) followed byVH-329×CRS-2 (-40.96%), VH-329×CIM-595 (-24.01%) and FH-342×CRS-2 (-19.23%) for node number of first fruiting branch.

3.4. Plant Height (cm)

Analysis of variance showed highly significant genotypic differences for plant height among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 5. Among hybrids, maximum value for plant height (125.73) was observed incross VH-329×CIM-595while minimum value (83.40) was observed inthe cross Tarzan-05×BS-80. Among parents, CIM-595 showed maximum value for plant height (123.44) whilstCRS-2 exhibited minimum value (100.33).

The heterosis and heterobeltiosis (%) for plant height is shown in Table 5. The results revealed positive heterosis in two crosses and all other crosses showed negative heterosis. The heterosis ranged from -21.96% (Tarzan-05×BS-80) to 6.76% (FH-342×BS-80). Only two cross combinations Tarzan-05×CIM-595 and FH-342×CIM-595 showed significant negative heterosis and two crosses FH-342×BS-80 and VH-329×CIM-595 showed significant positive heterosis. Only one cross Tarzan-05×BS-80 showed highly significant negative heterosis.

Only two crosses showed positive heterobeltiosis and all other crosses exhibited negative heterobeltiosis. Theheterobeltiosis ranged from -24.00% (Tarzan-05×BS-80) to 6.02% (FH-342×BS-80). One hybrid (FH-342×BS-80) showed significant positive heterobeltiosis. The cross Tarzan-05×BS-80 showed maximum highly significant negative heterobeltiosis (-24.00%)followed by the cross Tarzan-05×CIM-595 (-14.31%), FH-342×CIM-595 (-11.73%) and VH-329×CRS-2(-7.70%) for plant height.

3.5. Number of Monopodial Branches

Analysis of variance showed highly significant genotypic differences for number of monopodial branches among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 6. Among hybrids, maximum value for number of monopodial branches (2.20) was observed in the cross FH-342×CRS-2while minimum value (0.80) was observed in cross FH-342×BS-80. Among parents, CRS-2 showed maximum value for number of monopodial branches (1.70) and BS-80 exhibited minimum value (0.70).

The heterosis and heterobeltiosis (%) for number of monopodial branches is shown in Table 5.2. The results revealed positive heterosis in six crosses and three crosses showed negative heterosis. The heterosis ranged from -20.0% (VH-329×CIM-595) to 122.22% (Tarzan-05×BS-80). Only one crossFH-342×CIM-595 showed significant positive heterosis. The crossTarzan-05×BS-80 showed highly significant positive heterosis (122.22%) followed by the crosses VH-329×BS-80 (82.35%), FH-342×CRS-2 (66.04%) and FH-342×BS-80 (62.50%) for number of monopodial branches.

The results showed positive heterobeltiosis in six crosses and three crosses exhibited negative heterobeltiosis. The heterobeltiosis ranged from -34.29% (Tarzan-05×CRS-2) to 81.82% (Tarzan-05×BS-80). One crossTarzan-05×CRS-2 showed highly significant negative heterobeltiosis, two crosses FH-342×CRS-2 and FH-342×BS-80 showed significant positive heterobeltiosis and two crosses Tarzan-05×BS-80 and VH-329×BS-80 showed highly significant positive heterobeltiosis for monopodial branches.

3.6. Boll Weight (g)

Analysis of variance showed highly significant genotypic differences for boll weight among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 7. Among hybrids, maximum value for boll weight (3.82) was observed inFH-342×CRS-2followed by the crosses FH-342×BS-80 (3.79), VH-329×CRS-2 (3.72) and FH-342×CIM-595 (3.71) while minimum value (2.93) was observed inVH-329×CIM-595. Among parents, CIM-595 exhibited maximum value for boll weight (4.06) whilstVH-329 showed minimum value (3.13).

Table 3: Heterosis and heterobeltiosis (%) of nine crosses for number of bolls per plant in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-1.38	-6.96
Tarzan-05×CIM-595	32.73**	12.89
Tarzan-05×BS-80	23.31*	10.98
FH-342×CRS-2	19.13*	19.13
FH-342×CIM-595	-10.17	-19.59*
FH-342×BS-80	5.57	0.39
VH-329×CRS-2	45.68**	39.58**
VH-329×CIM-595	56.83**	46.05**
VH-329×BS-80	-3.66	-4.41

Table 4: Heterosis and heterobeltiosis (%) of nine crosses fornode number of 1st fruiting branchin cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	2.35	-6.45
Tarzan-05×CIM-595	-41.14**	-44.62**
Tarzan-05×BS-80	-14.44*	-17.20*
FH-342×CRS-2	-7.18	-19.23**
FH-342×CIM-595	-3.23	-13.46
FH-342×BS-80	-6.81	-14.42*
VH-329×CRS-2	-38.75**	-40.96**
VH-329×CIM-595	-23.64**	-24.01**
VH-329×BS-80	-4.88	-7.07

Table 5: Heterosis and heterobeltiosis (%) of nine crosses for plant height in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-3.28	-4.76
Tarzan-05×CIM-595	-6.99**	-14.31**
Tarzan-05×BS-80	-21.96**	-24.00**
FH-342×CRS-2	-0.63	-4.02
FH-342×CIM-595	-5.92*	-11.73**
FH-342×BS-80	6.76*	6.02*
VH-329×CRS-2	-2.33	-7.70**
VH-329×CIM-595	6.22*	1.85
VH-329×BS-80	-2.24	-3.78

Table 6: Heterosis and heterobeltiosis (%) of nine crosses for number of monopodial branches in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-19.30	-34.29**
Tarzan-05×CIM-595	30.00	24.09
Tarzan-05×BS-80	122.22**	81.82**
FH-342×CRS-2	66.04**	25.71*
FH-342×CIM-595	36.84*	30.00
FH-342×BS-80	62.50**	44.44*
VH-329×CRS-2	-0.73	-22.00
VH-329×CIM-595	-20.00	-20.00
VH-329×BS-80	82.35**	55.00**

The heterosis and heterobeltiosis (%) for boll weight is shown in Table 6.2. Only four crosses exhibited positive heterosis and five crosses showed negative heterosis. The heterosis ranged from -18.34% (VH-329×CIM-595) to 8.26% (VH-329×CRS-2). Only one crossVH-329×CRS-2 showed significant positive heterosis and three crossesVH-329×CIM-595, Tarzan-05×CIM-595 and VH-329×BS-80 showed highly significant negative heterosis.

Only two crosses showed positive heterobeltiosis and six crosses exhibited negative heterobeltiosis. The heterobeltiosis ranged from -28.03% (VH-329×CIM-595) to 2.49% (FH-342×BS-80). The cross Tarzan-05×CRS-2 showed significant negative heterobeltiosis. Four cross combinations VH-329×CIM-595, Tarzan-05×CIM-595, and VH-329 × BS-80 and FH-342 × CIM-595 showed highly significant negative heterobeltiosis for boll weight.

3.7. Seed Index (g)

Analysis of variance showed significant genotypic differences for seed index among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 8. Among hybrids, maximum value for seed index (8.30) was observed in the cross Tarzan-05×BS-80 followed by the crosses FH-342×BS-80 (8.1), Tarzan-05×CRS-2 (8.0) and FH-342×CRS-2 (7.9) while minimum value (6.66) was observed inVH-329×CRS-2. Among parents, CIM-595 exhibited maximum value for seed index (8.60) and VH-329 showed minimum value (6.85).

The heterosis and heterobeltiosis (%) for seed index is shown in Table 6. Only three crosses exhibited positive heterosis and six crosses showed negative heterosis. The heterosis ranged from -10.70% (Tarzan-05×CIM-595) to

8.01% (Tarzan-05×CRS-2). The cross Tarzan-05×CIM-595exhibited significant negative heterosis (-10.70%) followed by the cross FH-342×CIM-595 (-10.59%) for seed index.

Two crosses showed positive heterobeltiosis and other cross combinations showed negative heterobeltiosis. The heterobeltiosis ranged from -17.44% (VH-329×CIM-595) to 4.80% (Tarzan-05×BS-80). Two cross combinationsVH-329×BS-80 andFH-342×CIM-595 exhibited significant negative heterobeltiosis. Two crosses Tarzan-05×CIM-595 and VH-329×CIM-595 showed highly significant negative heterobeltiosis for seed index.

3.8. Number of Seeds Per Boll

Analysis of variance showed highly significant genotypic differences for number of seeds per boll among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 9. Among hybrids, maximum value for number of seeds per boll (35.40) was observed incross FH-342×CRS-2 while minimum value (30.90) was observed in the cross Tarzan-05×CRS-2. Among parents, CRS-2 exhibited maximum value for number of seeds per boll (35.10) and FH-342 showed minimum value (28.85).

The heterosis and heterobeltiosis (%) for number of seeds per boll is shown in Table 8.2. Only one cross showed negative heterosis and all other crosses showed positive heterosis. The heterosis ranged from -4.11% (Tarzan-05×CRS-2) to 13.88% (FH-342×CIM-595). All the hybrids showed highly significant positive heterosis expect two cross combinations Tarzan-05×CRS-2 and VH-329×CRS-2.

Two cross combinations showed negative heterobeltiosis and seven crosses showed positive heterobeltiosis. The heterobeltiosis ranged from -11.97% (Tarzan-05×CRS-2) to 11.47% (Tarzan-05×BS-80). Three crossesTarzan-05×CIM-595, FH-342×BS-80 and VH-329×CIM-595 displayed significant positive heterobeltiosis and three crosses Tarzan-05×BS-80, FH-342×CIM-595 and VH-329×BS-80 showed highly significant positive heterobeltiosis. One cross Tarzan-05×CRS-2 showed highly significant negative heterobeltiosis for number of seeds.

3.9. Seed Volume Per 100 Seeds (cm^3)

Analysis of variance showed highly significant genotypic differences for seed volume among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 10. Among hybrids, maximum value for seed volume (10.0) was observed in cross Tarzan-05×BS-80 and FH-342×BS-80while minimum value (7.0) was observed inTarzan-05×CIM-595. Among parents, BS-80 exhibited maximum value for seed volume (10.0) and CRS-2 showed minimum value (7.5).

Table 7: Heterosis and heterobeltiosis (%) of nine crosses for boll weight in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-3.22	-7.04*
Tarzan-05×CIM-595	-13.47**	-19.69**
Tarzan-05×BS-80	1.69	0.00
FH-342×CRS-2	2.22	1.16
FH-342×CIM-595	-4.44	-8.72**
FH-342×BS-80	3.90	2.49
VH-329×CRS-2	8.26*	-1.46
VH-329×CIM-595	-18.34**	-28.03**
VH-329×BS-80	-11.76**	-17.89**

Table 8: Heterosis and heterobeltiosis (%) of nine crosses for seed index in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	8.01	3.48
Tarzan-05×CIM-595	-10.70*	-15.12**
Tarzan-05×BS-80	5.93	4.80
FH-342×CRS-2	1.29	-6.55
FH-342×CIM-595	-10.59*	-11.63*
FH-342×BS-80	-0.43	-3.27
VH-329×CRS-2	-4.52	-6.20
VH-329×CIM-595	-8.09	-17.44**
VH-329×BS-80	-5.42	-11.81*

Table 9: Heterosis and heterobeltiosis (%) of nine crosses for number of seeds per boll in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-4.11	-11.97 **
Tarzan-05×CIM-595	10.43**	8.17 *
Tarzan-05×BS-80	11.66**	11.47 **
FH-342×CRS-2	10.71**	0.85
FH-342×CIM-595	13.88**	10.62 **
FH-342×BS-80	9.12**	8.38 *
VH-329×CRS-2	2.30	-5.13
VH-329×CIM-595	7.76*	6.70 *
VH-329×BS-80	10.89**	9.50 **

The heterosis and heterobeltiosis (%) for seed volume is shown in Table 9.2. Three crosses showed negative heterosis and six crosses exhibited positive heterosis. The heterosis ranged from -24.32% (Tarzan-05×CIM-595) to 22.58% (VH-329×CRS-2). VH-329×CRS-2showed highly significant positive heterosis and Tarzan-05×CIM-595 showed highly significant negative heterosis.

Four crosses showed negative heterobeltiosis and two crosses exhibited positive heterobeltiosis. The heterobeltiosis ranged from -26.32% (Tarzan-05×CIM-595) to 18.75% (VH-329×CRS-2). The cross VH-329×CRS-2showed highly significant positive heterobeltiosis. One cross Tarzan-05×CRS-2showed significant negative andTarzan-05×CIM-595 exhibited highly significant negative heterobeltiosis for seed volume.

3.10. Seed Density (g/cm3)

Analysis of variance showed highly significant genotypic differences for seed density among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 11. Among hybrids, maximum value for seed density (1.19) was observed inTarzan-05×CRS-2while minimum value (0.74) was observed inVH-329×BS-80. Among parents, CRS-2 showed maximum value for seed density (0.98) and BS-80 showed minimum value (0.79).

The heterosis and heterobeltiosis (%) for seed density is shown in Table 10.2. Only four crosses showed positive heterosis and all other crosses exhibited negative heterosis. The heterosis ranged from -15.01% (VH-329×CIM-595) to 32.92% (Tarzan-05×CRS-2). Only one cross VH-329×CIM-595 showed significant negative heterosisand two crosses FH-342×CIM-595 and Tarzan-05×CIM-595 exhibited significant positive heterosis. One cross Tarzan-05×CRS-2 showed highly significant positive heterosis.

Only four crosses revealed positive heterobeltiosis and all other crosses showed negative heterobeltiosis. Theheterobeltiosis ranged from -21.47% (VH-329×CIM-595) to 22.05% (Tarzan-05×CRS-2). The cross FH-342×CIM-595 displayed significant positive heterobeltiosis.One cross VH-329×CIM-595 exhibited highly significant negative heterobeltiosis and Tarzan-05×CRS-2 showed highly significant positive heterobeltiosis for seed density.

Table 10: Heterosis and heterobeltiosis (%) of nine crosses for seed volume in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-5.88	-15.79*
Tarzan-05×CIM-595	-24.32**	-26.32**
Tarzan-05×BS-80	2.56	0.00
FH-342×CRS-2	9.09	0.00
FH-342×CIM-595	-11.11	-11.11
FH-342×BS-80	5.26	0.00
VH-329×CRS-2	22.58**	18.75*
VH-329×CIM-595	11.76	5.56
VH-329×BS-80	5.56	-5.00

Table 11: Heterosis and heterobeltiosis (%) of nine crosses for seed density in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	32.92**	22.05**
Tarzan-05×CIM-595	18.08*	9.42
Tarzan-05×BS-80	3.43	1.84
FH-342×CRS-2	-6.25	-7.69
FH-342×CIM-595	17.89*	17.28*
FH-342×BS-80	-5.48	-13.23
VH-329×CRS-2	-0.84	-9.23
VH-329×CIM-595	-15.01*	-21.47**
VH-329×BS-80	-7.50	-8.64

Table 12: Heterosis and heterobeltiosis (%) of nine crosses for Lint index in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-0.85	-0.90
Tarzan-05×CIM-595	-2.58	-3.51
Tarzan-05×BS-80	-4.26	-7.65
FH-342×CRS-2	-14.80**	-17.22**
FH-342×CIM-595	-10.52**	-13.91**
FH-342×BS-80	-13.76**	-14.37**
VH-329×CRS-2	-9.89*	-14.54**
VH-329×CIM-595	12.56**	7.78
VH-329×BS-80	-2.95	-11.01*

3.11. Lint Index (g)

Analysis of variance showed highly significant genotypic differences for lint index among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 12. Among hybrids, maximum value for lint index (5.28) was observed inVH-329×CIM-595while minimum value (2.16) was observed inVH-

329×CRS-2. Among parents, BS-80 showed maximum value for lint index (5.36) and VH-329 showed minimum value (4.47).

The heterosis and heterobeltiosis (%) for lint index is shown in Table 12. Only one cross showed positive heterosis and eight crosses showed negative heterosis. The heterosis ranged from -14.80% (FH-342×CRS-2) to 12.56% (VH-329×CIM-595). VH-329×CRS-2 showed significant negative heterosis. VH-329×CIM-595 showed highly significant positive heterosis. Three crosses FH-342×CRS-2, FH-342×CIM-595 and FH-342×BS-80 showed highly significant negative heterosis.

Only one cross showed positive heterobeltiosis and other eight crosses exhibited negative heterobeltiosis. The heterobeltiosis ranged from -17.22% (FH-342×CRS-2) to 7.78% (VH-329×CIM-595). One hybrid (VH-329×BS-80) showed significant negative heterobeltiosis and four crossesFH-342×CRS-2, FH-342×CIM-595, FH-342×BS-80 and VH-329×CRS-2 showed highly significant negative heterobeltiosis for lint index.

3.12. Lint Percentage

Analysis of variance showed highly significant genotypic differences for lint percentage among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 13. Among hybrids, maximum value for lint percentage (42.43) was observed inVH-329×CIM-595followed by the crosses VH-329×BS-80 (40.5), VH-329×CRS-2 (40.0) and Tarzan-05×CIM-595 (39.2) while minimum value (35.70) was observed inFH-342×CRS-2. Among parents, CRS-2 exhibited maximum value for lint percentage (40.38) whilstCIM-595 showed minimum value (35.27).

The heterosis and heterobeltiosis (%) for lint percentage is shown in Table 12.2. Five crosses showed positive heterosis and all other crosses showed negative heterosis. The heterosis ranged from -8.97% (FH-342×CRS-2) to 13.39% (VH-329×CIM-595). Only two crosses Tarzan-05×CIM-595 and VH-329×CIM-595 showed highly significant positive heterosis. Tarzan-05×BS-80 showed significant negative heterosis and two crosses FH-342×CRS-2 and FH-342×BS-80 showed highly significant negative heterosis.

Three crosses showed positive heterobeltiosis and other crosses showed negative heterobeltiosis.The heterobeltiosis ranged from -11.59% (FH-342×CRS-2) to 7.38% (VH-329×CIM-595).Two cross combinations Tarzan-05×CRS-2 andTarzan-05×BS-80exhibited significant negative heterobeltiosis and two crosses FH-342×CRS-2 and FH-342×BS-80 showed highly significant negative heterobeltiosis.VH-329×CIM-595 showed highly significant positive heterobeltiosis for lint percentage.

3.13. Seed Cotton Yield (g)

Analysis of variance showed highly significant genotypic differences for seed cotton yield among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 14. Among hybrids, maximum seed cotton yield (129.99) was observed in the cross VH-329×CRS-2 followed by the crosses VH-329×CIM-595 (118.8), Tarzan-05×CIM-595 (95.9) and FH-342×BS-80 (92.6) while minimum seed cotton yield (65.33) was observed inTarzan-05×CRS-2. Among parents, CIM-595 exhibited maximum seed cotton yield (102.53) whilstTarzan-05 showed minimum yield (63.59).

The heterosis and heterobeltiosis (%) for seed cotton yield is shown in Table 14. Six crosses showed positive heterosis and three crosses showed negative heterosis. The heterosis ranged from -8.15% (Tarzan-05×CRS-2) to 80.05% (VH-329×CRS-2). Tarzan-05×CIM-595 andFH-342×CRS-2 showed significant positive heterosis. Four cross combinations Tarzan-05×BS-80, VH-329×CRS-2, FH-342×BS-80, and VH-329×CIM-595 showed highly significant positive heterosis.

Five crosses showed positive heterobeltiosis and other crosses showed negative heterobeltiosis. The heterobeltiosis ranged from -23.60% (FH-342×CIM-595) to 65.18% (VH-329×CRS-2). Tarzan-05×CRS-2 showed significant negative heterobeltiosis. Three cross combinations Tarzan-05×BS-80, FH-342×BS-80 and VH-329×CIM-595 showed significant positive heterobeltiosis. FH-342×CIM-595 showed highly significant negative and VH-329×CRS-2 showed highly significant positive heterobeltiosis for seed cotton yield.

3.14. Fiber Fineness

Analysis of variance showed highly significant genotypic differences for fiber fineness among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 15. Among hybrids, maximum value for fiber fineness (5.8) was observed in cross Tarzan-05×CRS-2 followed by the cross FH-342×CIM-595 (5.55), Tarzan-05×BS-80 (5.2) and Tarzan-05×CIM-595 (5.1) while minimum value for (4.35) was observed in cross VH-329×CIM-595. Among parents, VH-329 showed maximum value for (5.5) whilst FH-342 exhibited minimum value (4.55).

The heterosis and heterobeltiosis (%) for fiber fineness is shown in Table 15. Three crosses showed positive heterosis and six crosses exhibited negative heterosis. The heterosis ranged from -19.07% (VH-329×CIM-595) to 13.27% (FH-342×CIM-595). The cross combination VH-329×CIM-595exhibited maximum significant negative heterosis (-19.07) followed by VH-329×CRS-2 (-15.74) and FH-342×BS-80 (-8.63). FH-342×CIM-595 showed highly significant positive heterosis.

Only two crosses showed positive heterobeltiosis and seven crosses exhibited negative heterobeltiosis. The heterobeltiosis ranged from -20.91% (VH-329×CIM-595) to 9.43% (FH-342×CIM-595). FH-342×CIM-595 showed highly significant positive heterosis. The cross combination VH-329×CIM-595 exhibited maximum significant negative heterobeltiosis (-20.91%) followed by crosses VH-329×CRS-2 (-17.27%) and FH-342×BS-80 (-15.09%). FH-342×CIM-595showed significant positive heterobeltiosis for fiber fineness.

3.15. Fiber Length

Analysis of variance showed significant genotypic differences for fiber length among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 16. Among hybrids, maximum value for fiber length (26.4) was observed incrossVH-329×CRS-2followed by the cross FH-342×CIM-595 (26.15), Tarzan-05×CIM-595 (25.5) and Tarzan-05×CRS-2 (25.4) while minimum value (23.5) was observed in cross VH-329×BS-80. Among parents, Tarzan-05 showed maximum value for fiber length (26.2) whilst VH-329 showed minimum value (24.1).

The heterosis and heterobeltiosis (%) for fiber length is shown in Table 16. Four cross combinations showed positive heterosis and five crosses showed negative heterosis. The heterosis ranged from -3.89% (VH-329×BS-80) to 9.20% (VH-329×CRS-2). One cross VH-329×CRS-2 showed highly significant positive heterosis.

Two crosses showed positive heterobeltiosis and sixcrosses showed negative heterobeltiosis. The heterobeltiosis ranged from -5.24% (VH-329×BS-80) to 8.87% (VH-329×CRS-2). One cross VH-329×CRS-2 showed highly significant positive and VH-329×BS-80exhibited significant negative heterobeltiosis for fiber length.

Table 13: Heterosis and heterobeltiosis (%) of nine crosses for lint percentage in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-4.22	-5.50*
Tarzan-05×CIM-595	6.46**	1.04
Tarzan-05×BS-80	-4.74*	-5.28*
FH-342×CRS-2	-8.97**	-11.59**
FH-342×CIM-595	1.93	-1.76
FH-342×BS-80	-7.19**	-9.17**
VH-329×CRS-2	0.13	-0.98
VH-329×CIM-595	13.39**	7.38**
VH-329×BS-80	2.23	1.89

Table 14: Heterosis and heterobeltiosis (%) of nine crosses for seed cotton yield in cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	-8.15	-16.98*
Tarzan-05×CIM-595	15.61*	-6.37
Tarzan-05×BS-80	30.14**	19.16*
FH-342×CRS-2	18.28*	8.93
FH-342×CIM-595	-7.18	-23.60**
FH-342×BS-80	29.73**	21.08*
VH-329×CRS-2	80.05**	65.18**
VH-329×CIM-595	41.06**	15.72*
VH-329×BS-80	-6.63	-13.19

Table 15: Heterosis and heterobeltiosis (%) of nine crosses for fiber finenessin cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	9.95	9.43*
Tarzan-05×CIM-595	-2.86	-2.86
Tarzan-05×BS-80	-1.42	-1.89
FH-342×CRS-2	1.52	-5.66
FH-342×CIM-595	13.27**	5.71
FH-342×BS-80	-8.63*	-15.09**
VH-329×CRS-2	-15.74**	-17.27**
VH-329×CIM-595	-19.07**	-20.91**
VH-329×BS-80	-3.70	-5.45

Table 16: Heterosis and heterobeltiosis (%) of nine crosses for fiber lengthin cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	0.69	-3.05
Tarzan-05×CIM-595	-1.16	-2.67
Tarzan-05×BS-80	-1.76	-4.39
FH-342×CRS-2	-1.61	-4.11
FH-342×CIM-595	2.65	2.35
FH-342×BS-80	-0.10	-1.57
VH-329×CRS-2	9.20**	8.87**
VH-329×CIM-595	2.63	0.00
VH-329×BS-80	-3.89	-5.24*

3.16. Fiber Strength

Analysis of variance revealed highly significant genotypic differences for fiber strength among genotypes (Table 1). Mean performance of parents and crosses as well as heterosis are given in Table 17. Among hybrids, maximum value for fiber strength (27.7) was observed incrossTarzan-05×BS-80 followed by FH-342×CIM-595

(27.15), VH-329×CRS-2 (26.75) and FH-342×CRS-2 (26.25) whilst minimum value for fiber strength (22.7) was exhibited by the cross Tarzan-05×CIM-595. Among parents, VH-329 showed maximum value for fiber strength (28.35) whilst CIM-595 showed minimum value (21.8).

The heterosis and heterobeltiosis (%) for fiber strength is shown in Table 17. Six crosses exhibited positive heterosis and three crosses showed negative heterosis. The heterosis ranged from -11.84% (VH-329×CIM-595) to 15.30% (Tarzan-05×BS-80). The cross combination Tarzan-05×BS-80 exhibited maximum positive heterosis (15.30) followed by the crossFH-342×CRS-2 (11.58). VH-329×CIM-595 showed significant negative heterosis.

The results revealed that four crosses showed positive heterobeltiosis while four crosses showed negative heterobeltiosis. The heterobeltiosis ranged from -16.58% (VH-329×CIM-595) to 14.94% (Tarzan-05×BS-80). Tarzan-05×BS-80showed significant positive heterobeltiosis and two crosses VH-329×CIM-595 and VH-329×BS-80 exhibited highly significant negative heterobeltiosis for fiber strength. The graphical representation of heterosis and heterobeltiosis (%) for fiber strength is shown in Fig. 16.2 and 16.3 respectively.

Table 17: Heterosis and heterobeltiosis (%) of nine crosses for fiber strengthin cotton

Hybrids	Heterosis (%)	Heterobeltiosis (%)
Tarzan-05×CRS-2	6.23	1.46
Tarzan-05×CIM-595	-7.82	-10.28
Tarzan-05×BS-80	15.30**	14.94*
FH-342×CRS-2	11.58*	9.60
FH-342×CIM-595	7.42	7.31
FH-342×BS-80	2.33	0.00
VH-329×CRS-2	6.68	-5.64
VH-329×CIM-595	-11.84*	-16.58**
VH-329×BS-80	-6.58	-13.58**

4. DISCUSSION

Cotton demand is rising higher than the growth rate of global population, thus we have to improve yield per unit area. One of the key causes for poor yield per acre in Pakistan is the usage of poor quality seed. To increase productivity, new high-yielding cultivars must be developed. Cotton is an often cross pollinated crop that lends itself to both heterosis breeding and hybridization followed by selection in later generations. The phenomenon of heterosis has been the most important genetic instrument in increasing the production of self and cross pollinated crops and is regarded as the great innovation in crop development.

Heterosis has the ability to increase yield by 10 to 30% while improving fibre characteristics (Dhamayanthi and Rathinael, 2017). China and India, two cotton-producing countries, have adopted heterosis breeding to produce hybrids of cotton and enhanced yield (Basal et al. 2011). Cotton hybrids has almost 50% higher yield than cotton varieties (Monicashree et al. 2017). Cotton hybrids have covered around 20% of the total global acreage (Munir et al. 2016). In India, hybrid cotton is cultivated in about 90% of total cotton area (Rani et al. 2020). In Vietnam about 70% of total cotton area is covered by hybrids. In china, hybrid cotton is cultivated on 40% area (Memon et al. 2015). Field trials on hybrid cotton in China have resulted in a 20-30% increase in yield (Memon et al. 2015). In Pakistan, hybrid cotton is not successful due to the costly labor-intensive production system. There is a continuous need to produce viable hybrids and use innovative techniques to improve hybrid performance.

Present study indicated significant differences for all attributes, revealing that the experimental materials exhibited high variability. This reveals the choice to use these characteristics for heterosis. Solanki et al. (2014) and Kencharaddi et al. (2015) found substantial variations in seed cotton yield and associated variables among cotton genotypes. Heterosis and heterobeltiosis were measured in this study by employing method of Falconer and Mackay (1996). For all of the traits studied, heterosis was observed. For various features, all hybrids showed a range of heterosis and heterobeltiosis values.Both positive and negative values were observed for heterosis and heterobeltiosis.

Sympodial branches per plant tend to have direct relationship with seed cotton yield. Bilwal et al. (2018) also observed higher number of sympodia in cotton. Two hybrids revealed significant positive mid parent heterosis and one hybrid showed significant positive heterobeltiosis for sympodial branches. Significant positive heterosis was also reported by Chakholoma et al. (2021) for number of sympodial branches per plant in desirable direction.

Number of bolls per plant has direct relation with yield as bolls per plant increases yields also increases (Sahito et al. 2016). Five crosses exhibited significant positive heterosis for bolls per plant in desirable direction whereas, one hybrid recorded significant negative heterobeltiosis. Arain et al. (2015) also reported variable amount of heterotic effect for this character in their studies. Choudhary et al. (2014) also found negative heterobeltiosis for bolls per plant.

When the first sympodia branch emerges at an early node, the number of sympodia increases, therefore, negative heterosis is more desirable in node number of first fruiting branch. Four hybrids showed negative heterosis and six hybrids revealed negative heterobeltiosis for this trait in this study. The findings are according to result of Munir et al. (2016).

Cotton plants that are medium in height are considered good for two reasons. First, medium-sized plants can grow a large number of sympodial branches, resulting in a greater number of fruiting branches. Second, compared to taller plants, medium tall plants may be more resistant to lodging and early maturity (Baloch et al. 2014). Three hybrids showed significant negative heterosis and heterobeltiosis for plant height. These hybrids showed heterosis and heterobeltiosis for plant height in desirable direction. Two crosses exhibited significant positive heterosis. Chaudhary et al. (2019) also observed positive significant heterosis in two hybrids for plant height. Dhamayanthi and Rathinael, (2017) and Chakholoma et al. (2021) also reported positive non-desirable heterosis for plant height.

Lesser monopodial branches were considered because monopodial branches are vegetative branches, and a large number of monopodia cause the plant to become bushy, take up more area, and produce fewer fruits (Rani et al. 2020). For monopodial branches per plant, five hybrids demonstrated substantial positive heterosis. Dhamayanthi and Tarzan-05×CRS-2 hybrid depicted significant negative relative heterobeltiosis. Chakholoma et al. (2021) reported significant negative heterosis in desirable direction for this trait.

Because seed cotton yield is directly related to boll weight, this feature is significant for contribution of seed cotton yield. So, positive heterosis is desirable for boll weight. In case of boll weight, only one hybrid showed significant positive mid parent heterosis and none of the hybrid showed positive heterobeltiosis. Negative heterosis is desirable for seed index since the hybrids produce more lint (Munir et al.2016). In case of seed index, two hybrids showed negative heterosis and four hybrids showed negative heterobeltiosis.

Number of seeds per boll has direct relation with the seed cotton yield as the number of seeds increases the lint yield also increases. So, positive heterosis in seeds per boll is desirable (Ali et al. 2016). Seven out of nine hybrids showed positive heterosis in desired direction for number of seeds per boll.

Positive heterosis for seed volume and seed density is desirable. Negative and positive heterosis was observed for seed volume and seed density. One cross combination exhibited positive heterosis and Tarzan-05×CIM-595 displayed significant negative heterosis for seed volume. Three crosses showed significant positive heterosis and one cross VH-329×CIM-596 showed significant negative heterosis and heterobeltiosis for seed density. Ali et al. (2016) also reported similar results for seed volume and seed density.

Positive heterosis is desired for lint index. Four hybrids showed negative and only one hybrid showed positive heterosis for lint index. Five hybrids showed negative heterobeltiosis for lint index.The cross VH-329×CIM-596 exhibited positive heterosis for lint index. Munir et al. (2016) observed similar results for lint index in their research.

Lint percentage had direct positive correlation with lint yield (Imran et al. 2012). Two hybrids showed positive and three hybrids showed negative heterosis for lint percentage. Only one hybrid displayed significant positive heterobeltiosis for this trait. Arain et al. (2015) and Chakholoma et al. (2021) reported positive heterosis sand heterobeltiosis for lint percentage.

Among various plant traits, seed cotton yield has a special significance since it is essential in strengthen the economy of the country. The parent CIM-595 gave the highest seed cotton yield per plant (102.5 g) and the cross combinationVH-329×CRS-2 gave the highest seed cotton yield per plant (130.0 g). Significant positive heterosis and heterobeltiosis for seed cotton yield per plant was observed in six hybrids. VH-329×CRS-2 exhibited maximum significant positive heterosis and heterobeltosis for seed cotton yield. Significant and positive heterosis and heterobeltiosis for seed cotton yield was reported by Udaya et al. (2020).

Fibre fineness or micronaire is a significant feature of cotton fibre quality and is highly valuable in the textile industry. Negative heterosis is preferred for this character since higher micronaire values imply roughness of the fibre. The finer the fibre, the lower the micronaire value is (Chakholoma et al. 2021). Three hybrids showed significant negative heterosis and heterobeltosis for fiber fineness but FH-342×CIM-595 showed significant positive heterosis. The length of the fibre is crucial for textile manufacturing and varies substantially among cotton species because to genetic differences. Cotton fibre with long staple length generates smoother and stronger fabrics because they are finer, stronger, and more flexible than short staple length fibre (Chakholoma et al. 2021). In case of fiber length, the cross VH-329×CRS-2 exhibited significant positive heterosis and heterobeltosis. The cross combination VH-329×BS-80 displayed significant negative heterobeltosis. Chaudhary et al. (2019) also found significant positive heterosis in one hybrid for fiber strength.

One of the most significant fibre qualities is fibre strength (g/tex), which is quantitatively inherited. Cotton fibre that is stronger, longer, finer, and more consistent are demanded by modern textile industries (Chakholoma et al. 2021). For fiber strength, two hybrids displayed significant positive heterosis in desired direction. One hybrid exhibited significant negative heterosis. Chakholoma et al. (2021) also found significant positive heterosis for all the hybrids for fiber strength. Two crosses VH-329×CRS-2 and VH-329×CIM-595 were found to have desirable heterosis and heterobeltosis for most of the traits and these hybrids could be used for commercial exploitation of heterosis in cotton.

Conclusion

The current study observed significant degree of heterosis for seed cotton yield per plant and associated features, indicating that heterosis has a greater economic potential in cotton hybrid breeding. The F_1 hybrids showing desirable heterosis and heterobeltiosis can be advanced for the development of hybrid variety. Based on the above results, the hybrid VH-329×CRS-2 and VH-329×CIM-595 could be used for commercial exploitation of heterosis in cotton.

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