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Heterosis and Inbreeding Depression in F_2 Populations of Upland Cotton (*Gossypium hirsutum* L.)

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Abstract

Hybrid cotton production through exploitation of heterosis is the only way for having vertical improvement and betterment in seed cotton yield which has been stagnated in the recent years. The current study was conducted to evaluate the performance of F_2 population for studying mean performance, heterotic effects and inbreeding depression in upland cotton for polygenic traits. Parental genotypes and their F_2s were sown at Khyber Pakhtunkhwa Agricultural University, Peshawar during 2010, manually. All the traits revealed highly significant ($p \leq 0.01$) variations for both parents and their F_2 hybrids. Mean performance for parents and their F_2 hybrids is: (5.26 to 7.12 & 4.43 to 6.60) seeds locule^{-1}, (21.10 to 28.03 & 20.40 to 28.50) seed boll^{-1}, (32.20 to 34.80 & 32.22 to 35.05) lint% and (62.87 to 85.47 & 45.94 to 92.04) seed cotton yield plant^{-1}, respectively. Heterotic effects found over mid parent and better parent were: 66.66% & 46.66% (seeds locule^{-1}), 60% & 30% (seed boll^{-1}), 43.33% & 30% (lint %) and 36.66% & 16.66% (seed cotton yield plant^{-1}), respectively. For the parameters: seeds locule^{-1} (11 & 10), seeds boll^{-1} (2 & 1) and seed cotton yield plant^{-1} (3 & 1) showed positive highly significant heterosis for both mid and better parent, respectively while lint% did not reveal any positive significant heterosis. F_2 populations *i.e.* CIM-499 × CIM-554 and CIM-554 × CIM-499 revealed highly significant heterotic effects over mid and better parent for all the traits except lint % while CIM-554 × CIM-707 showed highly significant heterotic effects for seeds locule^{-1} and seed cotton yield palnt^{-1}. Positive economic heterotic effects were also exhibited by more than 50% of the F_2 population *i.e.*, 76.66% for seed locule^{-1}, 50% for seeds boll^{-1}, 3.33% for lint% and 20% for seed cotton yield plant^{-1}, respectively. By comparing F_2 mean values with F_1s, only lint % showed (0.00% to 15.55%) maximum inbreeding depression while negligible amount of inbreeding depression was observed for the remaining traits. However, negative inbreeding depression was revealed by majority of the F_2 population like 96.66% (seeds locule^{-1} & seeds boll^{-1}), 60% (lint%) and 90% (seed cotton yield^{-1}), respectively meant F_2 population has shown more stability even after segregation and have exceeded the check cultivars and better parents in performance.

Keywords

Heterosis, Inbreeding Depression, Lint, F_2

1. Introduction

Cotton (*Gossypium hirsutum* L.) is a major cash crop, often cross-pollinated, long day plant belonging to the family *Malvacae*. It is a sixth largest source of vegetable oil in the world and can boost up the economy of any country by producing edible oil for human consumption, feed (seed cake) for animals and local consumption in textile industries. Worldwide, most common cultivated species of cotton is *Gossypium hirsutum* L., a tetraploid, also called as upland cotton and provides 90% fiber production while *Gossypium barbadense* called as Egyptian cotton produces only 3% fiber. These both species are also known as new world cotton [1].

Heterosis (over better parent) is a best source for improvement of F_1 and F_2 hybrids for production. It has ability which can lead breeders for commercial utilization of valuable hybrid combinations in breeding program. It can also play a vital role for selection of potential parents with desired vigor, maternal effects and genetic variance. Hybrid cotton has successfully attracted the concentration of cotton breeders for commercial utilization of hybrid progenies [2]. However, hybrid cotton has been produced successfully on primary basis since 1960s in countries like China and India due to availability of cheaper labor.

Inbreeding depression is also related to high heterosis in F_1 hybrids and has to search for moderate type of heterosis which has some stability to have less inbreeding depression at F_2 level [3]. Allelic and non-allelic interactions of genes in presence of specific environmental effects will lead us to successful heterosis results. Superiority of hybrids over commercial cultivars and genotypes is known as useful heterosis [4]. It is a well-known fact that without proper combination of parents, heterosis does not occur. Heterosis can be used for enhancement of cotton production by exploitation of heterozygosity and to get such cotton hybrids which are superior to best parents. The comparison of performance of the best hybrids with standard cultivars will result in determination of economic heterosis.

The F_2 lines revealed larger range of adaptation regarding to their parents and F_1 hybrids due to presence of genetic variation and larger heterogenity [5] [6].

F_2s can produce better combinations of fiber quality and yield than their parents and F_2s yield was highly correlated with F_1s and parental lines. It is expected that F_2 populations express only 50% of the economic heterosis shown by F_1 hybrids, and even less when heterosis is defined in terms of the higher yielding parent. Nonetheless, F_2 lines with lower inbreeding depression in yield and superior performance than well-adapted cultivars have been found. The existence of such lines lends credibility to the use of F_2s in hybrid cotton production. Previous findings are also of view about the F_2 hybrids heterosis in cotton [7]. On the other hand, a group of physical properties can play a vital role in determination of textile use and economic value of cotton. The cotton hybrid can be produced through heterobeltiosis by crossing two cotton cultivars to enhance seed production in combination with better fiber quality [8].

A successful cotton breeding program depends upon the choice and use of best parental lines for crossing and selection of favorable gene combinations. Improvements in cotton yields can be made by applying dependable tools to cotton breeders regarding to heterotic studies and inbreeding depression. For enhancement of production per unit area by proper availability of environment, identification and selection of genotypes with best genetic potential is a regular requirement. In view of economic importance of hybrid cotton cultivation and importance of selected hybrids in segregating generations, the current research was undertaken to study the genetic potential, heterotic effects and inbreeding depression for yield related traits in 6 × 6 F_2 diallel populations of upland cotton.

2. Materials and Methods

Genetic material: Breeding material used during the study of genetic potential, heterotic effects and inbreeding depression for yield related traits in 6 × 6 F_2 populations of upland cotton were consisted of six different *Gossypium hirsutum* L. genotypes *i.e.* CIM-446, CIM-496, CIM-499, CIM-506, CIM-554 and CIM-707 (having broad genetic base and varied by pedigree, date of release, seed cotton yield and fiber quality traits) and their 30 F_2 cross combinations in a complete diallel fashion. Some of the characteristics of used varieties/genotypes during the study have been mentioned below.

Experimental design and field procedures: The mean performance, heterosis

S.No	Variety	Year of Release	Ginning Out-Turn (%)	Staple Length		Micronaire	Fibre Strength (tppsi)
				Inch	Mm		
1	CIM-446	1998	36.2	1-1/16	27.0	4.7	97.4
2	CIM-496	2005	41.1	1-5/32	29.7	4.6	93.5
3	CIM-499	2003	40.2	1-5/32	29.6	4.4	97.3
4	CIM-506	2004	38.5	1-1/8	28.7	4.5	98.9
5	CIM-554	2009	41.5	1-1/8	28.5	4.7	96.8
6	CIM-707	2004	38.1	1-1/4	32.5	4.2	97.5

and inbreeding depression in parental genotypes and their F_2 populations of upland cotton for polygenic traits were conducted at Khyber Pakhtunkhwa Agricultural University, Peshawar during 2010. The hand sown method was used for parental genotypes and their F_2s in a randomized complete block (RCB) design with three replications. Each treatment was consisted of two rows having four meter length with 30 cm plant to plant and 75 cm row to row distance. All the recommended cultural practices and inputs were applied for all the entries from time of sowing till the harvesting including fertilizer, hoeing, irrigation and pest control and the crop was grown in uniform conditions to reduce the environmental variability. Boll picking was done for two times on single plant basis and ginning was made with eight saw-gins.

Statistical analysis: Data for all the variables were analyzed through analysis of variance (ANOVA) [9]. After getting the significant differences, the means were further compared and separated with least significant difference (LSD) test.

Heterosis: The F_2 heterosis over mid parents was calculated in terms of percent increase (+) or decrease (−) of F_2 hybrids against its mid parent values according to the following formula [10].

$$\text{Heterosis }\% = \frac{\overline{F}_2 - \overline{MP}}{\overline{MP}} \times 100 \quad (1)$$

The F_2 heterobeltiosis (heterosis over better parents) was formulated in terms of percent increase/decrease of F_2 hybrid over its better parent according to [11] by using following formula.

$$\text{Heterobeltiosis }\% = \frac{\overline{F}_2 - \overline{BP}}{\overline{BP}} \times 100 \quad (2)$$

The "*t*" test was used to determine whether the mid and better parents F_2 heterosis was significant or not. The "*t*" values were computed by using the following formula according to [12].

$$t = \frac{\overline{F}_{2ij} - \overline{MP}_{ij} / \overline{BP}_{ij}}{\sqrt{\frac{3}{8}(EMS)}} \quad (3)$$

where;

$\overline{F}_{2ij}$ = Mean of the ij^{th} $\overline{F}$ cross.

$\overline{MP}_{ij}$ = Mid parent value for the ij^{th} cross.

$\overline{BP}_{ij}$ = Better parent value for the ij^{th} cross.

EMS = Error mean square.

For assessment of economic heterosis, the cultivar CIM-473 was used as check cultivar and was also grown with other cultivars but was not included in 6 × 6 diallel hybrids. The check cultivar was compared with mean values of other parental cultivars and F_2 hybrids and economic heterosis was formulated.

Inbreeding depression: Inbreeding depression in F_2 hybrids was calculated as percent decrease of F_2 hybrids when compared with F_1 hybrid means as outlined by [13].

$$\text{Inbreeding Depression } \% = \frac{F_2 - F_1}{F_1} \times 100 \quad (4)$$

3. Results and Discussion

Regarding analysis of variance, the mean values for thirty six cotton genotypes including six parents and their 30 F_2 hybrids revealed highly significant differences ($p \leq 0.01$) for seeds per locule, seeds per bolls, lint % and seed cotton yield per plant, respectively (**Table 1**). The traits wise results about genetic potential, heterosis over mid and better parents and inbreeding depression in F_2 populations in light of previous review are discussed as follows.

Seeds per locule: Seeds per locule varied from 5.26 (CIM-554) to 7.12 (CIM-446) among parents and 4.43 (CIM-506 × CIM-496) to 6.60 (CIM-496 × CIM-499 & CIM-554 × CIM-707) in F_2 population (**Table 2**). Seeds per locule play a vital role in determining of seed cotton yield and is highly associated with production of boll number means high boll number will lead to more number of locules and ultimately produce more seed cotton yield, before ginning. Out of 30 F_2 cross combinations, 20 showed positive value of mid parents heterosis ranged from 0.00% (CIM-446 × CIM-554) to 22.22% (CIM-554 × CIM-707), while 14 F_2 hybrids revealed superior performances over their parents ranged from 0.17% (CIM-496 × CIM-707) to 19.13% (CIM-554 × CIM-707). Remaining, F_2 population showed negative heterotic performance for mid parent and better parent. Collectively, 22 F_2 hybrids showed significant heterosis for mid parent and better parent, respectively [14] [15] [16] [17]. Moreover, 23 F_2 hybrids revealed 76.66% economic heterosis ranged from 1.99% (CIM-554 × CIM-506) to 19.13% (CIM-554 × CIM-707). It is expected that F_2 populations express 50% of the economic heterosis shown by F_1 hybrids, and even less when heterosis is defined in terms of the higher yielding parent. Overall, 66.66%, 46.66% and 76.66% heterotic performance was recorded for mid parent, better parent and for economic heterosis, respectively (**Table 3**). In case of inbreeding depression, F_2 population performed better and showed negative inbreeding depression except the cross CIM-554 × CIM-499 which only performed (0.00%) positively means F_2 population have increased the number of seeds per locule which is desirable

Table 1. Mean squares and CV% of various Morpho-yield traits of upland cotton.

Parameters	Mean squares	CV %
Seeds locule^{-1}	0.84**	4.12
Seeds boll^{-1}	4.99**	10.82
Lint %	1.79**	2.81
Seed cotton yield plant^{-1}	352.52**	8.83

**, Significant at $p \leq 0.01$.

Table 2. Mean performance of parental cultivars and F_2s for Morpho-yield traits of upland cotton.

Parents and F_2 Populations	Seeds locule^{-1}	Seeds boll^{-1}	Lint %	Seed cotton yield plant^{-1} (g)
CIM-446	7.12	28.03	32.27	62.87
CIM-496	6.04	25.97	33.70	85.47
CIM-499	5.46	22.13	34.07	75.86
CIM-506	5.49	22.20	34.80	84.26
CIM-554	5.26	21.10	33.12	55.74
CIM-707	5.54	24.03	32.20	73.09
CIM-446 × CIM-496	5.82	23.07	32.10	74.56
CIM-446 × CIM-499	5.71	23.43	32.77	45.94
CIM-446 × CIM-506	6.37	27.23	32.52	70.11
CIM-446 × CIM-554	6.19	25.27	33.05	72.56
CIM-446 × CIM-707	5.35	22.97	32.72	72.95
CIM-496 × CIM-446	6.20	26.53	35.05	80.99
CIM-496 × CIM-499	6.60	27.20	33.75	70.90
CIM-496 × CIM-506	4.89	20.40	34.08	61.57
CIM-496 × CIM-554	5.81	25.73	33.96	76.89
CIM-496 × CIM-707	6.05	24.20	32.71	52.97
CIM-499 × CIM-446	5.30	23.93	33.54	60.32
CIM-499 × CIM-496	5.37	24.07	33.54	59.89
CIM-499 × CIM-506	6.50	25.07	33.55	70.29
CIM-499 × CIM-554	6.19	26.07	34.59	73.79
CIM-499 × CIM-707	6.52	25.33	34.54	73.75
CIM-506 × CIM-446	6.53	25.53	32.22	61.76
CIM-506 × CIM-496	4.43	20.80	34.36	92.04
CIM-506 × CIM-499	5.48	21.77	33.12	73.13
CIM-506 × CIM-554	5.85	22.47	34.30	59.50
CIM-506 × CIM-707	6.52	28.50	33.85	75.25
CIM-554 × CIM-446	6.42	22.10	34.52	53.77
CIM-554 × CIM-496	5.52	21.67	34.13	60.91
CIM-554 × CIM-499	6.17	25.83	33.69	86.01
CIM-554 × CIM-506	5.65	24.80	33.59	74.17
CIM-554 × CIM-707	6.60	23.60	34.13	77.27
CIM-707 × CIM-446	6.15	22.23	33.35	59.89
CIM-707 × CIM-496	6.06	25.00	32.86	67.94
CIM-707 × CIM-499	5.98	25.23	33.44	77.55
CIM-707 × CIM-506	6.35	23.33	33.44	70.81
CIM-707 × CIM-554	6.09	23.53	33.24	53.55
$LSD_{0.05}$	**0.3985**	**4.356**	**1.210**	**7.437**

Table 3. Heterosis (MP, BP & Eco.) and Inbreeding Depression for Seeds locule^{-1} and Seeds boll $^{-1}$ in F_2s of upland cotton.

F_2 Populations	Seeds per Locules				Seeds per boll			
	MP (%)	BP (%)	Ec. Het (%)	Inb. Dep. (%)	MP (%)	BP (%)	Ec. Het (%)	Inb. Dep. (%)
CIM-446 × CIM-496	−11.55	−18.26	5.05	−16.74	−14.56	−17.70	−4.27	−24.73
CIM-446 × CIM-499	−9.22	−19.80	3.07	−20.91	−6.58	−16.41	−2.78	−24.39
CIM-446 × CIM-506	1.11	−10.53	14.98	−11.65	8.44	−2.85	12.99	−14.53
CIM-446 × CIM-554	0.00	−13.06	11.73	−21.74	2.89	−9.85	4.85	−22.60
CIM-446 × CIM-707	−15.48	−24.86	−3.43	−23.46	−11.76	−18.05	−4.69	−22.24
CIM-496 × CIM-446	−5.78	−12.92	11.91	−16.55	−1.74	−5.31	10.08	−23.74
CIM-496 × CIM-499	14.78**	9.27**	19.12	−6.12	13.10	4.74	12.86	−5.91
CIM-496 × CIM-506	−15.10	−19.04	−11.73	−33.11	−15.28	−21.45	−15.35	−36.78
CIM-496 × CIM-554	2.83	−3.81	4.87	−21.38	9.33	−0.92	6.76	−12.30
CIM-496 × CIM-707	4.49	0.17	9.21	−9.57	−3.20	−6.82	0.41	−18.93
CIM-499 × CIM-446	−15.74	−25.56	−4.33	−34.65	−4.59	−14.63	−0.71	−5.71
CIM-499 × CIM-496	−6.61	−11.09	−3.07	−15.57	0.08	−7.32	−0.12	−25.66
CIM-499 × CIM-506	18.82**	18.40**	17.33	−14.59	13.13	12.93	4.02	−15.73
CIM-499 × CIM-554	15.49**	13.37**	11.73	−9.90	20.63**	17.80*	8.17	−11.90
CIM-499 × CIM-707	18.55**	17.69**	17.69	−9.70	9.75	5.41	5.10	−15.93
CIM-506 × CIM-446	3.65	−8.29	17.87	−11.76	1.67	−8.92	5.93	−20.49
CIM-506 × CIM-496	−23.09	−26.66	−20.04	−41.86	−13.62	−19.91	−13.69	−35.54
CIM-506 × CIM-499	0.18	−0.18	−1.08	−23.78	−1.75	−1.93	−9.67	−21.72
CIM-506 × CIM-554	8.93**	6.56*	5.60	−26.97	3.79	1.22	−6.76	−37.15
CIM-506 × CIM-707	18.33**	17.69**	17.69	−12.13	23.32**	18.60**	18.26	2.41
CIM-554 × CIM-446	3.72	−9.83	15.88	−15.86	−10.01	−21. 16	−8.30	−32.77
CIM-554 × CIM-496	−2.30	−8.61	−0.36	−10.39	−7.90	−16.56.	−10.08	−15.84
CIM-554 × CIM-499	5.11**	13.00**	11.37	0.00	19.52*	16.72*	7.18	−10.87
CIM-554 × CIM-506	5.21	2.91	1.99	−6.15	14.55	11.71	2.90	−13.53
CIM-554 × CIM-707	22.22**	19.13**	19.13	−6.78	4.60	−1.79	−2.07	−19.04
CIM-707 × CIM-446	−2.84	−13.62	11.01	−10.61	−14.60	−20.69	−7.76	−34.11
CIM-707 × CIM-496	4.66	0.33	9.39	−23.77	0.00	−3.74	3.73	−22.84
CIM-707 × CIM-499	8.73**	7.94**	7.94	−18.75	9.32	4.99	4.69	−21.28
CIM-707 × CIM-506	15.24**	14.62**	14.62	−3.64	0.95	−2.91	−3.20	−21.95
CIM-707 × CIM-554	12.78**	9.93**	9.93	−13.49	4.29	−2.08	−2.37	−21.01

Check: CIM-473 = 5.54 Check: CIM-473 = 24.10. *: Significant.

to enhance the seed cotton yield at end. Highest negative inbreeding depression was noted in CIM-506 × CIM-496 while lowest negative inbreeding depression was observed in CIM-707 × CIM-506 having values −41.86% and −3.64%, respectively (**Table 3**). It has also been suggested that little inbreeding depression exists for F_2 and F_3 generations and it is possible to screen and select high yielding F_2 hybrids [18]. Indication of high inbreeding depression even by having superior heterotic performances was also revealed that high performing hybrids had showed high inbreeding depression. It has elaborated that F_2 populations can be used as hybrid cotton if have better performance over their superior parents because F_2 crop can easily be managed with increased amount of seed produced by F_1 plants [19]. Therefore, in cotton the F_2 populations could be used for hybrid cotton production.

Seeds per boll: Seeds per boll varied from 21.10 (CIM-554) to 28.03 (CIM-446) among parental cultivars and 20.40 (CIM-496 × CIM-506) to 28.50 (CIM-506 × CIM-707) among F_2 population (**Table 2**). Seeds per boll play a vital role in contributing seed cotton yield. Path coefficient analysis showed that seeds per boll had positive effect on yield. Out of 30 F_2 hybrids, 18 showed positive mid parent heterosis ranged from 0.00% (CIM-707 × CIM-496) to 23.32% (CIM-506 × CIM-707), while 09 F_2 hybrids performed superior over their parents and showed positive heterobeltiosis ranged from 1.22% (CIM-506 × CIM-554) to 18.60% (CIM-506 × CIM-707). Rest of F_2 population revealed negative heterotic performances for the respective trait. Collectively, 06 F_2 hybrids showed significant heterosis for both mid and better parent, respectively. F_2 hybrid heterosis in cotton has been reported by several workers and F_2s can express at least 50% of the economic heterosis shown by F_1 hybrids, which can lead to cultivar improvement [20] [21] [22]. Moreover, half number of F_2 hybrids showed 50% positive economic heterosis ranged from 0.41% (CIM-496 × CIM-707) to 18.26% (CIM-506 × CIM-707). Overall, 60%, 30% and 50% of mid parent, better parent and economic heterosis has been recorded for the said trait (**Table 3**). It was suggested that little inbreeding depression exists for F_2 and F_3 generations and it is possible to screen and select high yielding F_2 hybrids as already mentioned above. In case of inbreeding depression, only one F_2 hybrid (CIM-506 × CIM-707) performed positively and showed (2.41%) positive inbreeding depression while rest of F_2 population performed well by showing stability even after segregation and revealed negative inbreeding depression ranged from −5.71% (CIM-499 × CIM-446) to −37.15% (CIM-506 × CIM-554) (**Table 3**). It was also showed that high performing hybrids showed high inbreeding depression. High inbreeding depression was performed by high performing hybrids. The existence of superior lines in F_2 reveals that superior alleles for the trait may have accumulated in the same line. The seeds per ball is a quantitative trait so additive gene action may be involved and those have contributed in the better performance. Results supported the idea that F_2 populations could work as a hybrid crop if properly managed and if parents selected on basis of F_2 performance, because F_1 hybrids cannot clarify the stability of F_2 populations [23]. Therefore, such F_2 populations would be desirable to use as hybrid cotton to enhance the boll number and eventually seed cotton yield.

Lint% (GOT): The lint % (GOT) varied from 32.20 (CIM-707) to 34.80 (CIM-506) among parents and 32.10 (CIM-446 × CIM-496) to 35.05 (CIM-496 × CIM-446) among F_2 population (**Table 2**). Lint% after ginning of seed cotton becomes a chief output for cotton breeders because cotton is basically grown for purpose of obtaining fibers. We extract edible oil from cotton seed which serves as a byproduct for people used. Out of 30 F_2 cross combinations, 13 cross combinations showed positive mid parent heterosis ranged from 0.32% (CIM-506 × CIM-496) to 6.27% (CIM-496 × CIM-446). Further, 09 F_2 hybrids revealed positive heterobeltiosis ranged from 0.36% (CIM-707 × CIM-554) to 4.23% (CIM-554 × CIM-446), while remaining all F_2 population performed heterotically negative for both mid and better parent. Moreover, only 01 F_2 hybrid (CIM-496 × CIM-446) revealed (0.68%) positive economic heterosis while rest of F_2 population showed negative economic heterosis. Overall, 43.33%, 30% and 3.33% of the F_2 population showed positive mid parent, better parent and economic heterosis, respectively for lint% (**Table 4**). The current findings are accorded with the findings that revealed low lint% values for heterosis after staple length [24]. In case of inbreeding depression, more than half number of F_2 hybrids revealed negative inbreeding depression ranged from −1.90% (CIM-499 × CIM-707) to −12.07% (CIM-554 × CIM-707) means F_2 population has shown stability and performed well after segregation in comparison with the F_1 generation. The F_2 hybrids including CIM-446 × CIM-506, CIM-506 × CIM-707 and CIM-496 × CIM-446 performed positively by having values of 15.55%, 9.76% and 8.54%, respectively and revealed positive inbreeding depression for the said trait (**Table 4**). Lower magnitude of inbreeding depression for lint % and staple length indicated that additive genes were responsible for the expression of these traits [25].

Seed cotton yield per plant: Seed cotton yield varied from 55.74 (CIM-554) to 85.47 (CIM-496) among parental cultivars and 45.94 (CIM-446 × CIM-499) to 92.04 (CIM-506 × CIM-496) among F_2 population (**Table 2**). Seed cotton yield per plant is a major and very important trait in growing cotton besides lint yield. As seed cotton yield was highly depended on boll plant^{-1} due to presence of close relationship between them [26]. Out of 30 cross combinations, 11 showed positive mid parent heterosis ranged from 0.53% (CIM-446 × CIM-496) to 30.71% (CIM-554 × CIM-499) while only 05 F_2 hybrids showed positive heterobeltiosis ranged from 2.23% (CIM-707 × CIM-499) to 15.41% (CIM-446 × CIM-554). Collectively, 06 F_2 hybrids showed significant heterosis for both mid and better parent, respectively. It was observed that significant mid parent heterosis in 13 hybrids and heterobeltiosis in 11 hybrids for seed cotton yield in upland cotton. Seed cotton yield was found with greater variation mostly affected by different yield contributing traits in different previous studies [18]. Moreover, 06 F_2 hybrids revealed positive economic heterosis ranged from 0.22% (CIM-496 ×

Table 4. Heterosis (MP, BP & Eco.) and Inbreeding Depression for lint% and Seed cotton yield plant $^{-1}$ in F_2s of upland cotton.

F_2 Populations	Lint % (GOT)				Seed cotton yield per plant (%)			
	MP (%)	BP (%)	Ec. Het (%)	Inb. Dep. (%)	MP (%)	BP (%)	Ec. Het (%)	Inb. Dep. (%)
CIM-446 × CIM-496	−2.66	−4.75	−7.79	−7.52	0.53	−12.76	−2.82	−54.86
CIM-446 × CIM-499	−1.20	−3.81	−5.86	−1.97	−33.77	−39.44	−40.12	−45.66
CIM-446 × CIM-506	−3.01	−6.56	−6.57	15.55	−4.70	−16.79	−8.62	−49.95
CIM-446 × CIM-554	1.10	−0.21	−5.06	−4.73	22.35**	15.41*	−5.42	−58.98
CIM-446 × CIM-707	1.52	1.39	−6.00	0.43	7.31	−0.23	−4.91	−50.18
CIM-496 × CIM-446	6.27	4.04	0.68	8.54	9.2	−5.24	5.57	−52.91
CIM-496 × CIM-499	−0.38	−0.94	−3.04	−2.68	−12.11	−17.05	−7.59	7.04
CIM-496 × CIM-506	−0.50	−2.07	−2.10	3.15	−27.45	−27.96	−19.75	−27.92
CIM-496 × CIM-554	1.65	0.77	−2.44	−10.13	8.90	−10.04	0.22	−31.85
CIM-496 × CIM-707	−0.73	−2.94	−6.03	−7.89	−33.19	−38.03	−30.96	−31.87
CIM-499 × CIM-446	1.12	−1.56	−3.65	−4.01	−13.04	−20.49	−21.38	−19.74
CIM-499 × CIM-496	−1.00	−1.56	−3.65	−10.13	−25.75	−29.93	−21.94	−49.33
CIM-499 × CIM-506	−2.55	−1.52	−3.61	−4.77	−12.20	−16.58	−8.38	−23.56
CIM-499 × CIM-554	−2.97	1.53	−0.60	3.19	12.14*	−2.73	−3.82	−27.43
CIM-499 × CIM-707	−4.25	−0.74	−0.83	−1.90	−0.97	−2.78	−3.87	37.36
CIM-506 × CIM-446	−3.90	−7.41	−7.44	4.01	−16.05	−26.70	−19.50	−65.40
CIM-506 × CIM-496	0.32	−1.26	−1.29	−4.95	8.46	7.69	19.97	−11.82
CIM-506 × CIM-499	−3.80	−4.83	−4.85	−5.34	−8.66	−13.21	−4.68	−40.00
CIM-506 × CIM-554	1.00	−1.44	−1.47	3.06	−15.00	−29.39	−22.45	−68.83
CIM-506 × CIM-707	1.04	−2.73	−2.76	9.76	−4.35	−10.69	−1.92	−0.48
CIM-554 × CIM-446	5.59	4.23	−0.83	3.11	−9.33	−14.47	−29.91	−68.89
CIM-554 × CIM-496	−2.15	1.27	−1.95	1.70	−13.73	−28.74	−20.61	−32.30
CIM-554 × CIM-499	0.29	−1.12	−3.22	−10.87	30.71**	13.38**	12.11	−23.99
CIM-554 × CIM-506	−1.08	−3.47	−3.50	−2.47	5.96	−11.97	−3.32	−50.97
CIM-554 × CIM-707	4.50	3.05	−1.95	−12.07	19.96**	5.72	0.72	−40.58
CIM-707 × CIM-446	−3.47	3.35	−4.19	−2.66	−11.90	−18.06	−21.94	−50.65
CIM-707 × CIM-496	−0.27	−2.49	−5.60	3.69	−14.30	−20.51	−11.44	−54.44
CIM-707 × CIM-499	0.93	−1.85	−3.94	−2.11	4.13	2.23	1.08	−1.71
CIM-707 × CIM-506	−0.17	−3.91	−3.94	−4.59	−10.00	−15.96	−7.70	1.97
CIM-707 × CIM-554	1.77	0.36	−4.51	0.00	−16.87	−26.73	−30.20	−58.89

Check: CIM-473 = 34.81 Check: CIM-473 = 76.72. *: Significant.

CIM-554) to 19.97% (CIM-506 × CIM-496). In case of inbreeding depression, all F_2 populations showed negative inbreeding depression except three F_2 hybrids. Overall, 36.66%, 16.66% and 20% heterosis was noted for mid parent, better parent and for economic heterosis (**Table 4**). Out of 30 cross combinations, 27 cross combination revealed negative inbreeding depression means F_2 has more stability to perform well after segregation and have great potential to explore it in future to come out with a fruitful results. Maximum inbreeding depression was observed in the cross CIM-554 × CIM-446 (−68.89%) while minimum inbreeding depression were recorded in CIM-506 × CIM-707 (−0.48%). High inbreeding depression has also been observed for the seed cotton yield. Moreover, only three F_2 hybrids *i.e.*, CIM-499 × CIM-707, CIM-496 × CIM-499 and CIM-707 × CIM-506 performed positively by having values of 37.36%, 7.04% and 1.97%, respectively (**Table 4**). F_2 hybrids with lower inbreeding depression in yield expressed superior performance over well-adapted cultivars as already mentioned by Meredith. Even after inbreeding depression in F_2s, presence of some promising population can reveal better performance hence positive selection can provide better opportunity for further improvement.

4. Conclusions

The F_2 hybrids manifested a remarkable percentage and ranges of mid parent, better parent and economic heterosis having negligible effects of inbreeding depression for majority of the characters of upland cotton. The remarkable heterotic performance for mid parent and better parent was revealed by the F_2 population including, CIM-554 × CIM-707, CIM-499 × CIM-506, CIM-499 × CIM-707, CIM-506 × CIM-707, CIM-499 × CIM-554, CIM-554 × CIM-499, CIM-496 × CIM-446 and CIM-446 × CIM-554, respectively while CIM-496 × CIM-499, CIM-506 × CIM-707, CIM-496 × CIM-446, CIM-506 × CIM-496 and CIM-554 × CIM-499 were the F_2 hybrids which showed the highest positive economic heterosis. Collectively, CIM-499 × CIM-554, CIM-554 × CIM-499, CIM-554 × CIM-707 and CIM-506 × CIM-707 showed superiorly with significant heterosis for yield and yield contributing traits for all parameters except lint%. Majority of the F_2 population did not reveal inbreeding depression meant having superiority over F_1s even after segregation which is more desirable for selection of best hybrid cotton. Overall, these parental cultivars and F_2 hybrids can be used and studied for further betterment in advanced generations for improvement of seed cotton as they have the capabilities to produce excess yield and production of cotton in future breeding program.

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