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Full Length Research Paper

Cottonseed oil and yield assessment via economic heterosis and heritability in intraspecific cotton populations

Naqib Ullah Khan[1]*, Huseyin Basal[2] and Gul Hassan[3]

[1]Department of Plant Breeding and Genetics, Khyber Pakhtunkhwa Agricultural University Peshawar 25130, Pakistan.
[2]Department of Crop Science, Faculty of Agriculture, Adnan Menderes University, 09100 Aydin, Turkey.
[3]Department of Weed Science, Khyber Pakhtunkhwa Agricultural University, Peshawar 25130, Pakistan.

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Due to the difficulty in producing cotton F_1 hybrid seed through hand emasculation and pollination, the capture of heterosis in cotton production is limited. The purpose of this study was to evaluate the potential of 6 × 6 F_1 and F_2 intra-*hirsutum* diallel hybrids relative to heterosis, inbreeding depression, heritability and correlation. Average F_1 hybrids mean values were higher than those of F_2s, while F_2s exceeded the parents. However, in F_1s and F_2s, the average mean values were 22.30 and 19.48 for seeds boll^{-1}, 8.87 and 8.56 g for seed index, 112.36 and 87.51 g for seedcotton yield and 30.07 and 28.30% for cottonseed oil. Heterosis over better parents was more pronounced in F_1s as compared to F_2s. However, in F_1s and F_2s, the average positive heterosis was 11.54 and 4.50%; 3.40 and 2.41%; 46.30 and 28.96% and 6.04 and 1.52%, respectively, for the above traits. Even after segregation and inbreeding depression, the F_2s expressed about 50% of F_1s heterosis. The inbreeding depression in F_2s was -6.51 to -16.92 with low to high heritability, and significant positive correlation of cottonseed oil with other traits. The cultivar CIM-1100 derivatives performed better and exceeded all other hybrids in both generations.

Key words: Hybrid vigor, inbreeding depression, cottonseed traits, cottonseed oil, *Gossypium hirsutum.*

INTRODUCTION

Development and utilization of high yielding and stress tolerant cultivars have a fundamental position in crop production technology package, which could be facilitated through introgressive hybridization (Khan, 2003; Khan et al., 2007a). The success of transgressive segregation depends upon the identification of genotypes with the ability to transmit high production potential into specific genotypic combinations. Heterosis is a performance of F_1/F_2 genotypic combinations and is useful in determining the most appropriate parents for specific traits. It is an established tool for breeders to assess and understands the gene action and the magnitude of genetic variance involved in the breeding material.

Economic heterosis in the F_1 hybrids is a function of heterozygosity and can result in improved performance and production. The potential use of heterosis for increasing cotton yields has been an important objective of breeders in only a few regions of the world. Except in countries where a vast and cheap labor force is available to make emasculations and crosses by hand, essentially, no commercial use of heterosis currently exists in cotton (Chaudhry, 1997; Khan et al., 2007a). Hybrid seed produced through hand emasculation and pollination techniques is expanding in China and India because of cheaper labor (Zhang and Pan, 1999), and in China following the commercial exploitation of transgenic *Bacillus thuringiensis* (BT) cotton (Wang and Li, 2000). In

*Corresponding author. E-mail: nukmarwat@yahoo.com. Tel: +92-346-901-9112. Fax: +92-91-921-6520.

India, at least 40% of the cotton produced is derived from intra-specific hybrids of *Gossypium hirsutum*, and 8% from inter-specific hybrids of *G. hirsutum* × *Gossypium barbadense* (Chaudhry, 1997). The yield increase through intra- and inter-specific heterosis over the better parent or best commercial cultivar (useful heterosis) has been documented in numerous reviews (Galanopoulou and Roupakias, 1999; Wei et al., 2002; Yuan et al., 2002; Zhang et al., 2002; Khan et al. 2007a). The average increase in yield and yield components of F_1 hybrids are found to be mostly greater than heterosis in fibre quality traits. The availability of male sterile parents has opened the way for additional commercial exploitation of hybridization in cotton; hence, work continues in the study of hybrid performance by breeders (Khan et al., 1999, 2000). Basal and Turgut (2003) concluded that yield and fiber quality traits can be improved through applying 3 way crosses, or modified backcross and recurrent selection to genotypes having remarkable heterosis and combining ability.

The F_2 hybrids having greater heterogeneity and genetic variation might result in a vast range of adaptation relative to their parents and F_1 hybrids (Meredith and Brown, 1998; Wu et al., 2004). The F_2s exhibited superiority over their better parents when grown under stress conditions and lower yielding sites. Meredith (1990) demonstrated that F_2s can produce better combinations of yield and fiber quality than their parents. Results also indicated that F_2s performance was highly correlated with F_1s yield performance, and in some cases the F_2s heterosis has been found equivalent to F_1s heterosis. The F_2s heterosis in cotton has also been mentioned in previous studies (Wang and Pan, 1991; Tang et al., 1993; Li et al., 2000; Xing et al., 2000; Han and Liu, 2002; Khan, 2003; Khan et al., 2007a). It is expected that F_2s may even 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 hybrids with lower inbreeding depression in yield and superior performance than well-adapted cultivars have been found (Meredith, 1990). The existence of such hybrids lends credence to the use of F_2 hybrids in cotton production. Khan et al. (2007b) noticed moderate to high heritability for cotton seed traits and oil content in intra-*hirsutum* F_2 hybrids. The higher the heritability, the simpler the selection process and greater the response to selection (Larik et al., 2000; Khan, 2003).

Numerous studies have been reported on seeds traits (seed number and index), but little work has been reported on the genetics and heterosis of cottonseed oil percentage in cotton breeding. A few reports in the literature (Kohel, 1980; Dani and Kohel, 1989; Dani, 1991; Khan, 2003; Khan et al., 2007b) have determined that cotton genotypes differ in oil percentage. The estimates of heterosis provided useful information with regard to the possibilities and extent of improvement in the characters of breeding material through selection. The present work provides useful information about economic heterosis of F_1 and F_2 hybrids over better parents, inbreeding depression and heritability (broad sense) in F_2s, and correlation of cottonseed oil with seeds per boll, seed index and seed cotton yield. Though the inferences drawn here, in a strict sense, apply to the genotypes involved, the findings will provide insights into these issues in a broader sense.

MATERIALS AND METHODS

Genetic material

Breeding material comprised of six different *G. hirsutum* genotypes and their 30 F_1 and F_2 hybrids (including reciprocal) generated through 6 × 6 complete diallel crossing. The parental cultivars of *G. hirsutum* were CIM-109, CIM-240, CIM-1100, FH-682, BH-36 and CRIS-9 having broad genetic base and were varied by date of release, pedigree, seedcotton and fiber yield as well as fiber quality traits.

Experimental design and field procedures

Experiments comprised of crossing block; F_1 and F_2 populations of upland cotton were conducted during 2007 - 2009 at Khyber Pakhtunkhwa Agricultural University, Peshawar, Pakistan. Peshawar lies between 34°, 02′ North latitude and 71°, 37′ East longitude. Six diverse genotypes of upland cotton were hand sown during May 2007, in a non-replicated crossing block. Each cultivar having five rows, 27 m in length, with plants and rows spacing of 60 and 100 cm to facilitate hand emasculation and crossing. Cultivars were crossed in a complete diallel fashion. The half of the F_1 populations was planted in 2008 for F_2 seed production, produced through crossing in the previous season. During 2009, the experiments having 30 F_1 and F_2 hybrids with six parents were hand-sown in a randomized complete block (RCB) design. Each F_1 was planted in a single row measuring 3.30 m with three replications, while in F_2s the plant population was increased and were planted in four rows, 6.30 m in length, with four replications. The plants and rows spacing were 30 and 75 cm, respectively in all the populations. All the recommended cultural practices and inputs including fertilizer, hoeing, irrigation and pest control were applied same for all the entries from sowing till the harvesting and the crop was grown under uniform conditions to minimize environmental variations to the maximum possible extent. Picking was made in the months of November - December every year on single plant basis and ginning was done with eight saw-gins.

Traits measurement and statistical analyses

The data were recorded for seeds per boll, seed index seed cotton yield and cottonseed oil percentage. For seeds per boll in each genotype, 50 bolls were separated and after counting the number of seeds in each boll, the average number of seeds per boll was calculated. For seed index in each genotype, one hundred fuzzy cottonseeds free from lint, disease or any other insect pest were weighed on electronic balance. For cottonseed oil content %, the seed samples were acid-delinted and oven dried at 40°C for 24 h and oil analysis was carried out by Wide Line Nuclear Magnetic Resonance (NMR, 4000). All the data were subjected to analysis of variance and was carried out according to Gomez and Gomez (1984). Heterosis was calculated in F_1 and F_2 hybrids against its better

Table 1. Mean squares for F_1, F_2 hybrids and parents and correlation of cottonseed oil % with other traits in a 6 × 6 diallel cross of upland cotton.

Component of variation	Seed per boll		Seed index		Seed cotton yield		Cottonseed oil %	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Blocks	6.028	6.502	0.252	0.544	13.191	39.719	0.062	6.404
Genotypes	15.131**	7.478**	1.199**	0.978**	4472.994**	1343.963**	4.985**	2.126**
Error	2.152	2.598	0.133	0.097	25.337	28.560	0.346	0.818

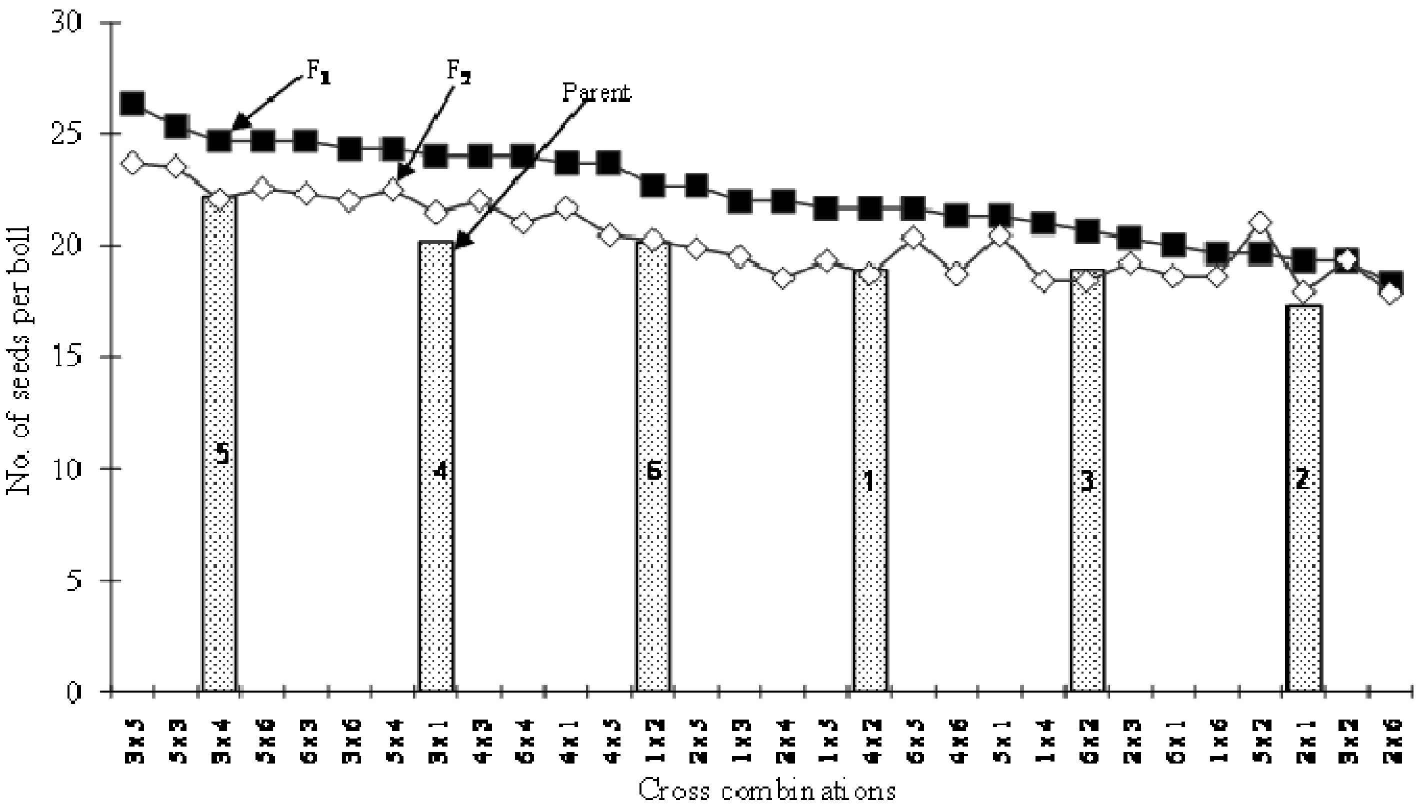

Figure 1. Mean performance of F_1, F_2 hybrids and parents for seeds per boll in a 6 × 6 diallel cross of upland cotton. (1, CIM-109; 2, CIM-240; 3, CIM-1100; 4, FH-682; 5, BH-36; 6, CRIS-9; 3 × 5, CIM-1100 × BH-36; 5 × 3, BH-36 × CIM-1100; 3 × 4, CIM-1100 × FH-682 etc.).

parent value as suggested by Fehr (1987) and Khan et al. (2007a). The inbreeding depression in F_2 hybrids was formulated as percentage decrease of F_2 hybrids when compared with F_1 hybrid means as outlined by Hallaner and Miranda (1986), Baloch et al. (1993) and Khan (2003).

RESULTS

Genetic variability in F_1 and F_2 hybrids and their parents

According to analysis of variance (ANOVA), highly significant differences ($P \leq 0.01$) were recorded for seeds per boll, seed index, seed cotton yield and cottonseed oil percentage among the 30 F_1s and F_2s including their parents (Table 1). The average F_1s seeds per boll, seed index, seed cotton yield and cottonseed oil % were higher than those of F_2s, while F_2s values for the said traits were higher than parents. Seeds per boll varied from 17.31 (CIM-240) to 22.16 (BH-36) among the parents and 18.33 (CIM-240 × CRIS-9) to 26.33 (CIM-1100 × BH-36) among the F_1s and 17.90 (CIM-240 × CIM-109) to 23.68 (CIM-1100 × BH-36) among the F_2s (Figure 1). Maximum F_1 seeds per boll were produced by hybrid CIM-1100 × BH-36 (26.33) and were also at par with nine other crosses that ranged from 24.00 to 25.33 seeds per boll. Six of the

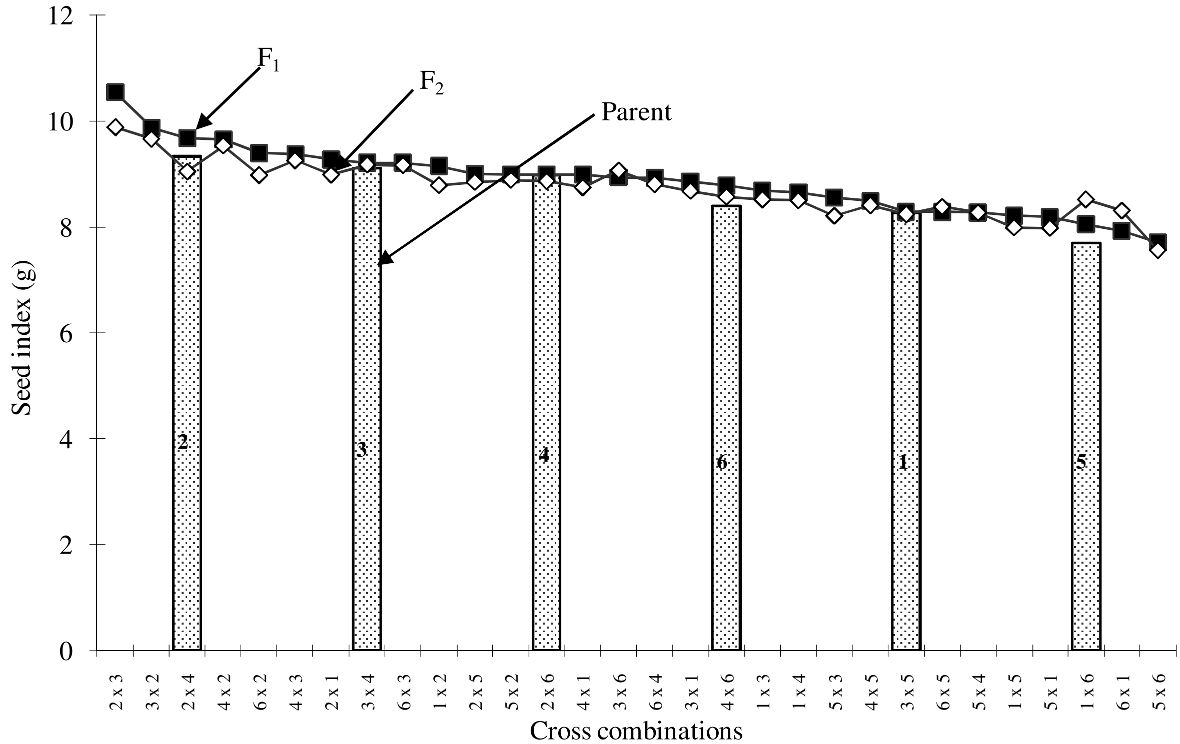

Figure 2. Mean performance of F_1, F_2 hybrids and parents for seed index in a 6 × 6 diallel cross of upland cotton. (1, CIM-109; 2, CIM-240; 3, CIM-1100; 4, FH-682; 5, BH-36; 6, CRIS-9; 2 × 3, CIM-240 × CIM-1100; 3 × 2, CIM-1100 × CIM-240; 2 × 4, CIM-240 × FH-682 etc.).

nine were CIM-1100 derivatives. Generally more than 2/3 of the F_1 hybrids surpassed their respective better parental values. The lowest number of seeds per boll was exhibited by parent cultivars CIM-240 (17.31), CIM-109 and CIM-1100 (18.91) and the F_1 hybrid CIM-240×CRIS-9 (18.33). In F_2s, highest seeds per boll (20.23 to 23.68) were found in 16 hybrids, with six being deriva-tives of cultivar CIM-1100 as also mentioned in F_1 generation. So these F_2 hybrids were found very valuable and could be used in producing hybrid cultivars with greater number of seeds per boll.

Seed index varied from 7.70 (BH-36) to 9.33 g (CIM-240) among parents, 7.71 (BH-36 × CRIS-9) to 10.55 g (CIM-240 × CIM-1100) among the F_1s and 7.56 (BH-36 × CRIS-9) to 9.89 g (CIM-240 × CIM-1100) among the F_2 hybrids (Figure 2). Eleven of the F_1 hybrids had maximum seed index that ranged from 9.00 - 9.88 g. In the F_2 generation, seven hybrids had remarkable seed index (9.05 - 9.67 g) and these hybrids can be further utilized to produce bold and higher numbers of seeds per boll. The hybrid CIM-240 × CIM-1100 has shown best performance for seed index in F_1s (10.55 g) as well as in F_2s (9.89 g) having more stability with less inbreeding depression. The lowest seed index was possessed by cultivar BH-36 (7.70 g) and its cross with CRIS-9 (7.56 g).

In F_1 generation, the seed cotton yield per plant varied from 54.31 - 94.77 g among the parents and 59.12 - 188.81 g among the hybrids (Figure 3). The highest and statistically at par seed cotton yield was recorded in F_1 hybrids CRIS-9 × CIM-1100 (188.81 g), BH-36 × CIM-1100 (183.58 g) and CIM-1100 × CIM-109 (180.92 g). These were followed by at par second top scoring hybrids i.e. CIM-1100 × CRIS-9 (169.98 g), CIM-1100 × FH-682 (164.16 g), CIM-109 × CIM-1100 (162.68 g), CIM-240 × CIM-1100 (160.56 g) and FH-682 × CIM-1100 (155.19 g). In F_2 generation, the seed cotton varied from 63.63 (CIM-240 × FH-682) to 138.10 g (CIM-1100 × FH-682) among the hybrids. Highest seed cotton yield of 138.10 g was obtained in F_2 hybrid CIM-1100 × FH-682 and was followed by three other derivatives of CIM-1100 i.e. FH-682 × CIM-1100 (122.60 g), CIM-1100 × CRIS-9 (121.84 g) and CRIS-9 × CIM-1100 (119.96 g). The lowest seed cotton yield was recorded in hybrid CIM-240 × FH-682 (63.63 g). The hybrids of CIM-1100 have the maximum yield which may be utilized in the segregating generations to evolve the cultivars with good yield potential.

Cottonseed oil percentage varied from 27.55 (BH-36) to 29.32% (CIM-240) among the parents, 27.49 (CRIS-9 × BH-36) to 32.34% (CIM-1100 × FH-682) among the F_1s and F_2s manifested 27.30 (CIM-240 × CRIS-9) to 30.17% (CIM-1100 × FH-682) (Figure 4). In F_1 hybrids, maximum oil percentage was obtained in the cross combination CIM-1100 × FH-682 (32.34%) and was found statistically

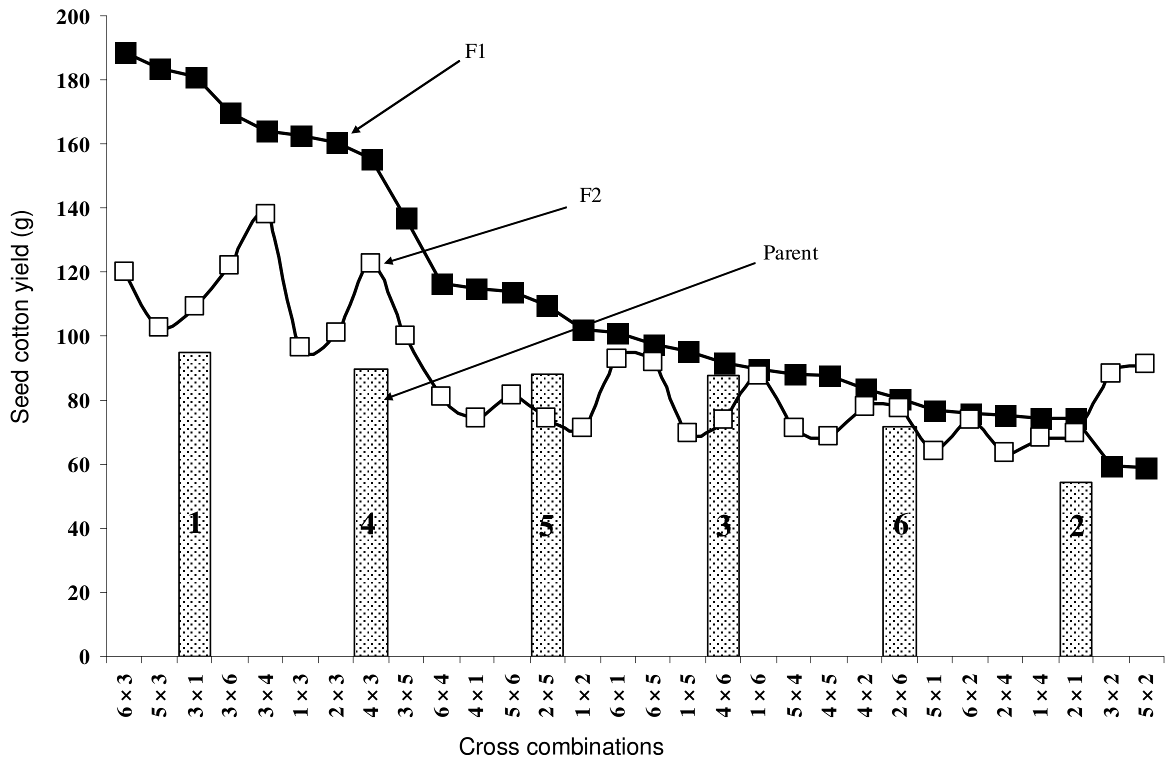

Figure 3. Mean performance of F_1, F_2 hybrids and parents for seed cotton yield in a 6 × 6 diallel cross of upland cotton. (1, CIM-109; 2, CIM-240; 3, CIM-1100; 4, FH-682; 5, BH-36; 6, CRIS-9; 6 × 3, CRIS-9 × CIM-1100; 5 × 3, BH-36 × CIM-1100; 3 × 1, CIM-1100 × CIM-109 etc.).

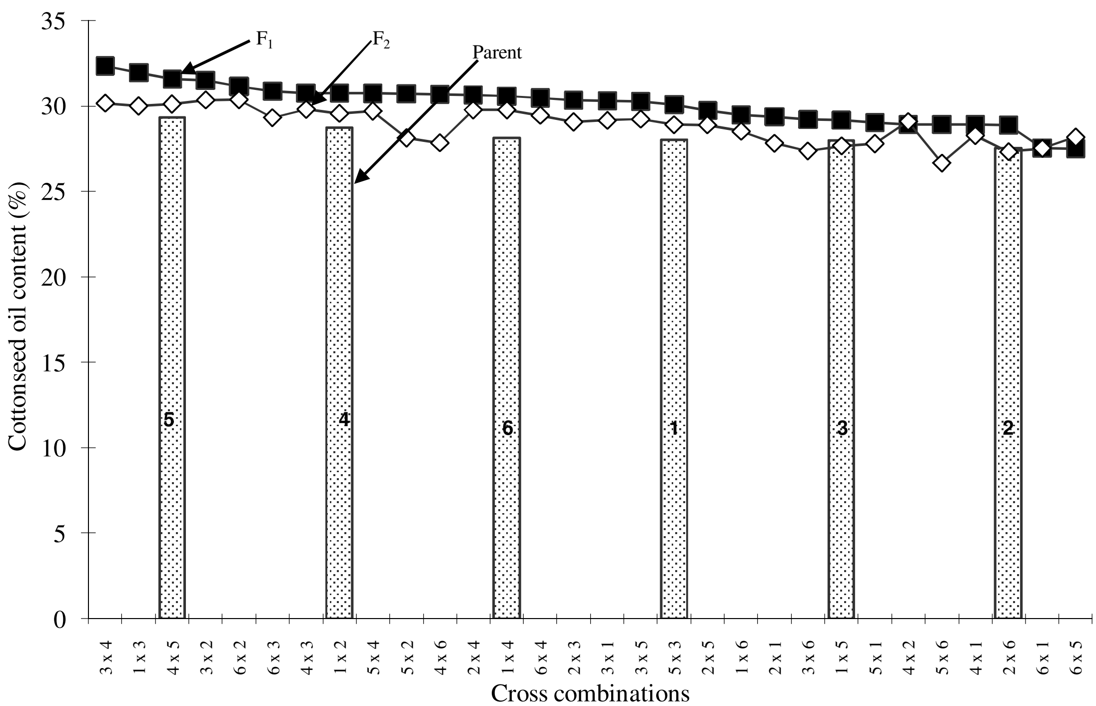

Figure 4. Mean performance of F_1, F_2 hybrids and parents for cottonseed oil in a 6 × 6 diallel cross of upland cotton. (1, CIM-109; 2, CIM-240; 3, CIM-1100; 4, FH-682; 5, BH-36; 6, CRIS-9; 3 × 4, CIM-1100 × FH-682; 1 × 3, CIM-109 × CIM-1100; 4 × 5, FH-682 × BH-36 etc.).

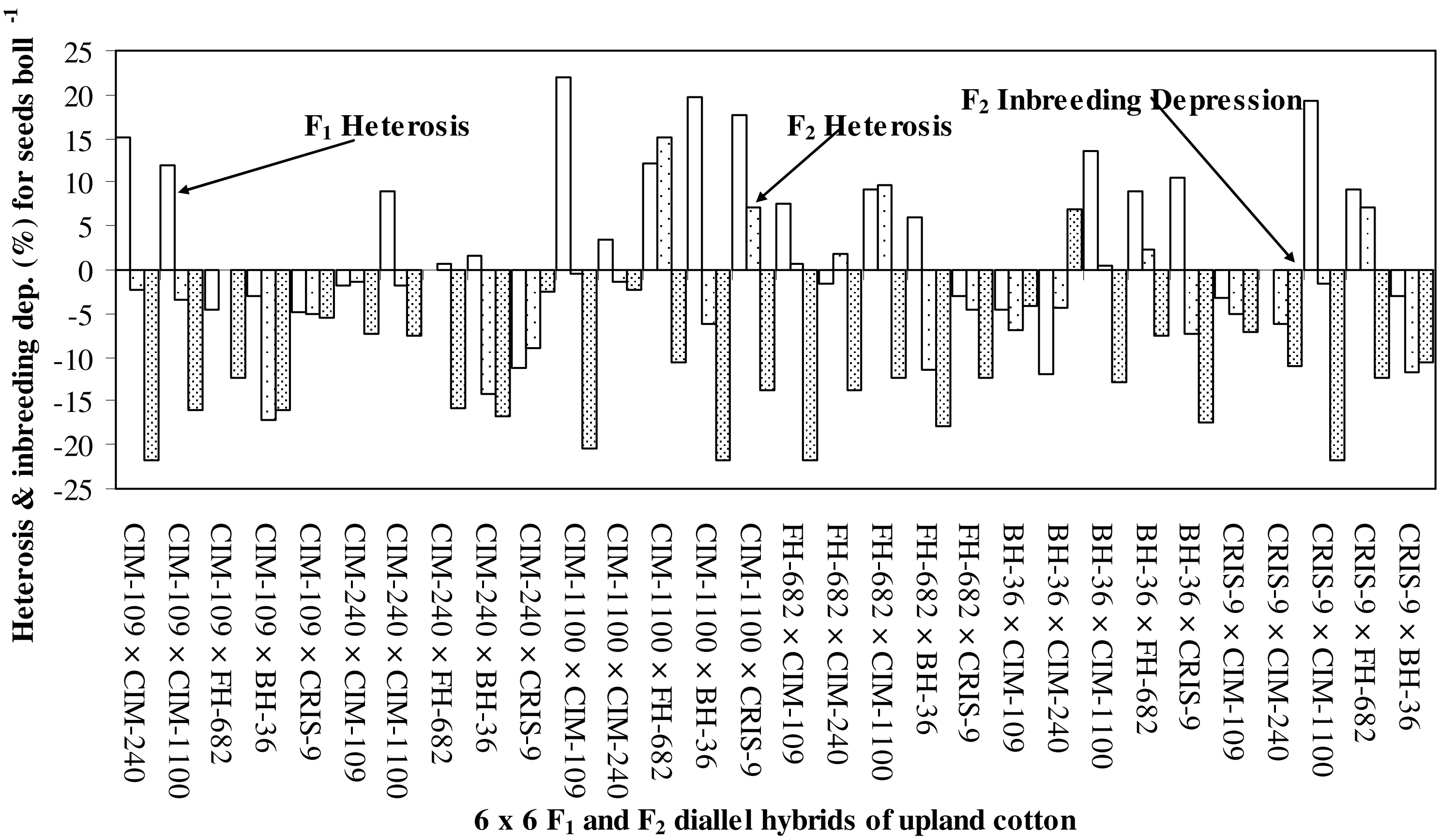

Figure 5. Heterosis in F_1s and F_2s, and inbreeding depression in F_2s for seeds per boll in a 6 × 6 diallel cross of upland cotton.

at par with 16 other hybrids having 30.09 - 31.96% oil and in which eight were CIM-1100 hybrids. In the F_2 generation, maximum oil percentage was obtained in the combination FH-682 × CIM-1100 (30.17%) which was derived from the reciprocal of top F_1 for oil percentage, and was equivalent with 15 other F_2 hybrids (eight were derivatives of CIM-1100) ranging from 28.89 - 29.80% oil. Overall, the lowest cottonseed oil percentage was found in cultivars BH-36 and CRIS-9 and two hybrids of CRIS-9 with CIM-109 and BH-36.

Heterosis over high parent and inbreeding depression

Overall, the average positive heterosis was 11.56 and 4.50%, 3.40 and 2.41%, 46.30 and 28.96%, 6.04 and 1.52%, respectively, in F_1 and F_2 hybrids for seeds per boll, seed index, seed cotton yield and cottonseed oil percentage. It seems that the mean F_2s heterosis was low as compared to F_1s but it still acceptable as exceeding even better parents in performance. In case of seeds per boll, the positive heterosis over the better parents was found in 23 F_1 hybrids (Figure 5) and ranged from +2.22 (CIM-240 × CIM-109 and CIM-1100 × CIM-240) to +26.92% (CIM-1100 × CIM-109). The 15 F_2 hybrids were found superior over their better parents and the heterosis varied from +1.44 (BH-36 × FH-682) to +13.48% (CIM-1100 × CIM-109) for seeds per boll. The top 10 F_1 and F_2 hybrids having maximum heterosis were also derivatives of cv. CIM-1100. The F_2 hybrids manifested inbreeding depression (-2.62 to -15.82%) for seed per boll (Figure 4). Two F_2 hybrids (BH-36 × CIM-240 and CIM-1100 × CIM-240) showed increases in seeds per boll as compared to their F_1s and manifested even positive values for inbreeding depression due to transgressive recombination. More than 75% of the F_1 hybrids showed heterosis for seeds per boll, while in F_2, half of the hybrids showed positive values for heterosis over better parents. Selection in these desirable F_2 hybrids can also lead to development of the best genotypes through segregating generations.

In case of seed index (Figure 6), nine F_1 hybrids attained positive heterotic effects over better parent values which ranged from +0.11 (FH-682 × CIM-109) to +13.08% (CIM-240 × CIM-1100). In F_2 generation, seven hybrids displayed heterosis over their better parent ranging from +0.55 (CRIS-9 × CIM-1100) to +6.00% (CIM-240 × CIM-1100). All

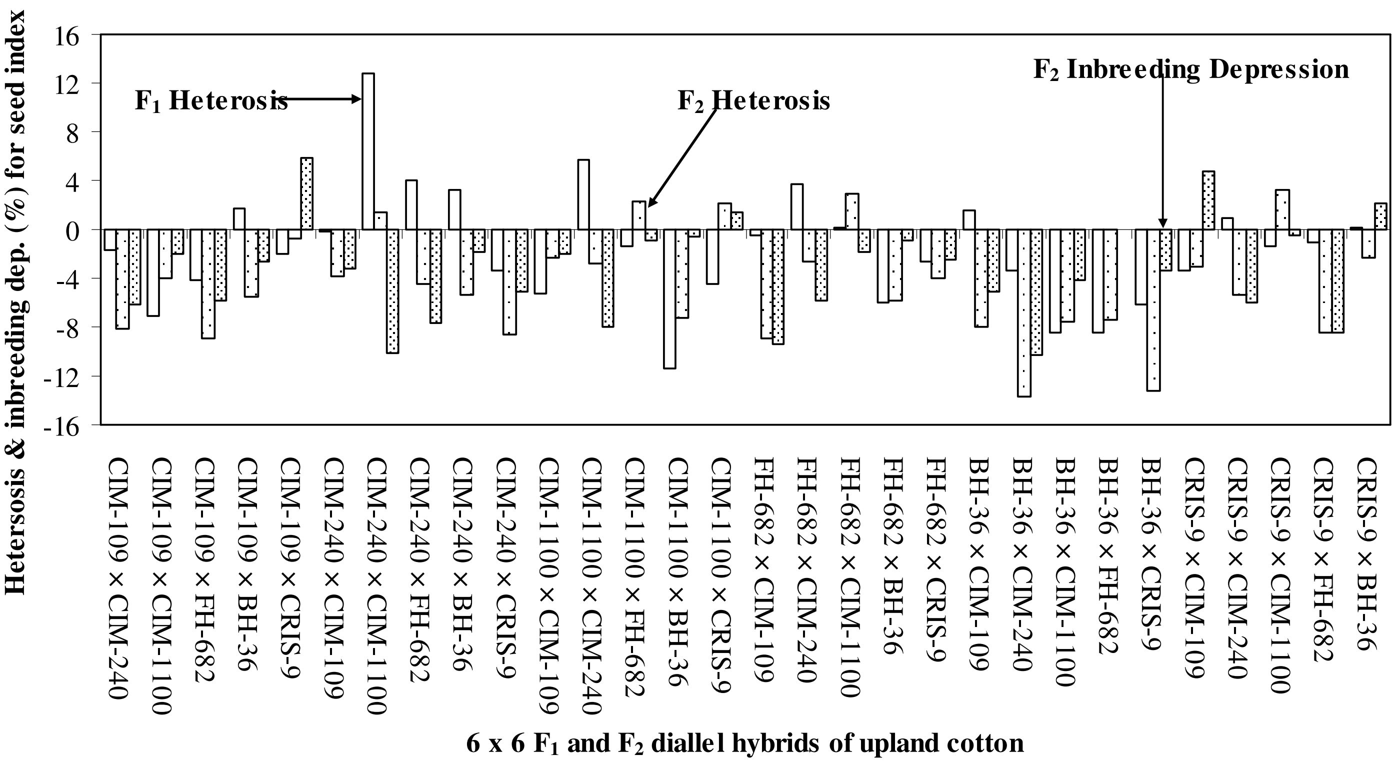

Figure 6. Heterosis in F_1s and F_2s, and inbreeding depression in F_2s for seed index in a 6 × 6 diallel cross of upland cotton.

the F_2 hybrids displayed inbreeding depression with range of -0.43 to -6.51. As compared to F_1s, the F_2 hybrid seed index values were decreased because of smaller seeds due to inbreeding. However, five F_2 hybrids showed increase in their mean values of seed index as compared to their F_1 hybrid means. As compared to parents, the F_2s having bigger seeds had higher mean values. The selection in these desirable genotypes can also provide a base for further improvement in the seed index.

For seed cotton yield per plant (Figure 7), 20 F_1 hybrids had positive heterosis over better parents and the increase ranged from +0.82 (CIM-109 × BH-36) to +115.22% (CRIS-9 × CIM-1100). The 16 F_1 hybrids exhibited significant heterosis over the best parent. All the CIM-1100 hybrids (except as a maternal parent with CIM-240) manifested maximum and highly significant heterosis over the better parent (+55.75 to +115.22%). In F_2 generation (Figure 6), the positive heterosis for seed cotton yield was recorded in 13 hybrids. The range of high parent heterosis was +0.73 (CRIS-9 × BH-36) to +77.03% (CIM-1100 × FH-682). The 11 hybrids were found superior as compared to better parents and had significant heterosis at $P \leq 0.01$ and $P \leq 0.05$. The F_2 genotypes also showed inbreeding depression ranged from -1.87 to -44.15%.

For cottonseed oil percentage, all the F_1 hybrids (except four) were found superior as compared to better parental lines for cottonseed oil (Fig. 8) and the range of heterosis was +0.20 (CIM-240 × CIM-109) to +13.62% (CIM-109 × CIM-1100). However in F_2 hybrids, 17 hybrids were found superior than better parent for cottonseed oil and the heterosis ranged from +0.75 (CRIS-9 × BH-36) to +6.65% (CIM-109 × CIM-1100). All the F_2 hybrids also displayed inbreeding depression (-2.50 to -9.29%). The eight out of these 17 F_2 populations were from CIM-1100 which manifested the possibility of improvement in cottonseed oil through simple selection.

Heritability and correlation

In F_2 hybrids, the broad sense heritability (H^2) for seeds per boll was low to high (0.40 - 0.90) (Figure 9). In CIM-1100 hybrids, the H^2 was moderate to high ranging from 0.78 - 0.90. For seed index, H^2 was similar and ranged from 0.44 - 0.93 (Figure 9), while in CIM-1100 derivatives the H^2 was moderate to high (0.66 to 0.93). For seed cotton yield (Fig. 10) the H^2 in F_2 hybrids was ranged from 0.55 - 0.92, while in promising hybrids of CIM-1100 the H^2 range was 0.78 - 0.92. For cottonseed oil content (Figure 10), H^2 was low to high (0.46 - 0.91), while in F_2 progenies of CIM-1100 the H^2 was high (0.80 - 0.91). The hybrid wise high ratio of broad sense heritability for each trait was also confirmed by desirable heterosis in the said

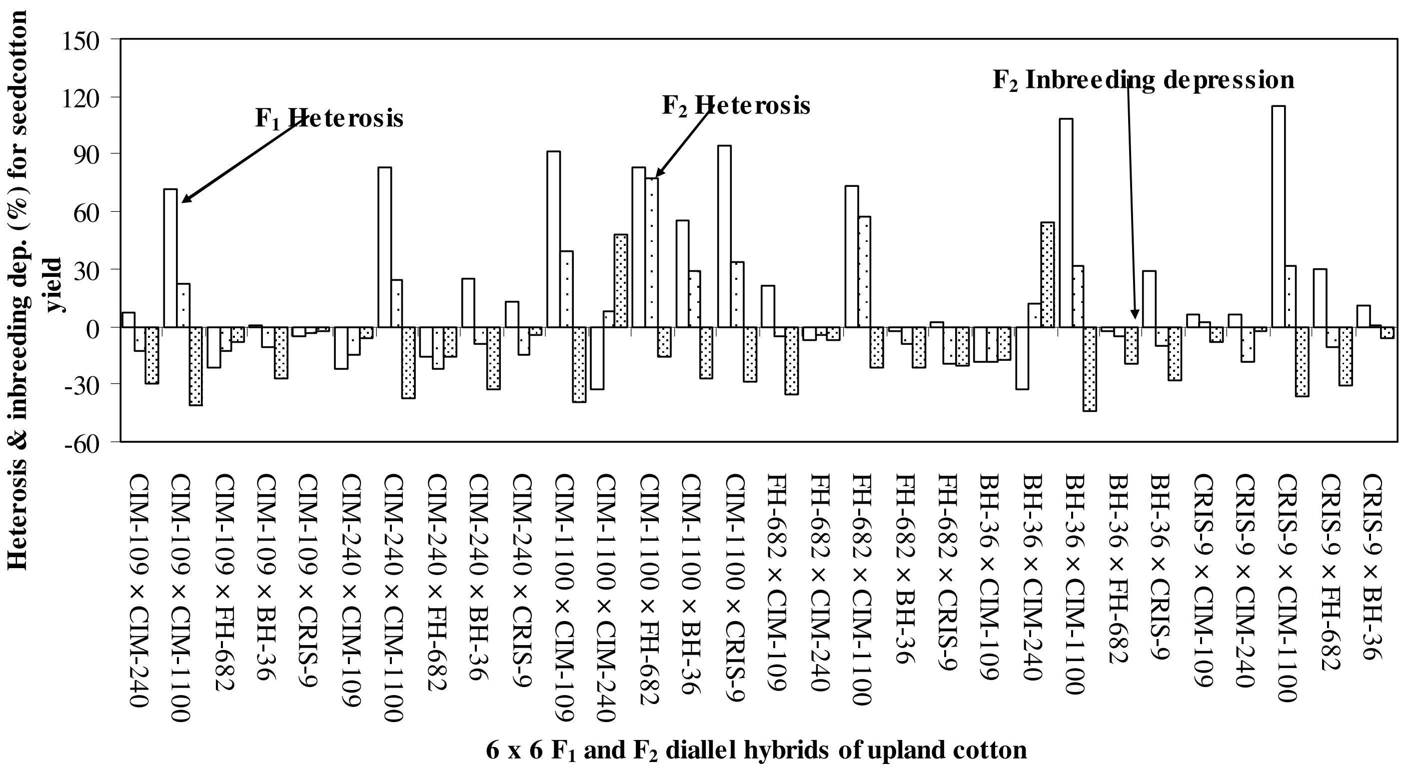

Figure 7. Heterosis in F_1s and F_2s, and inbreeding depression in F_2s for seed cotton yield in a 6 × 6 diallel cross of upland cotton.

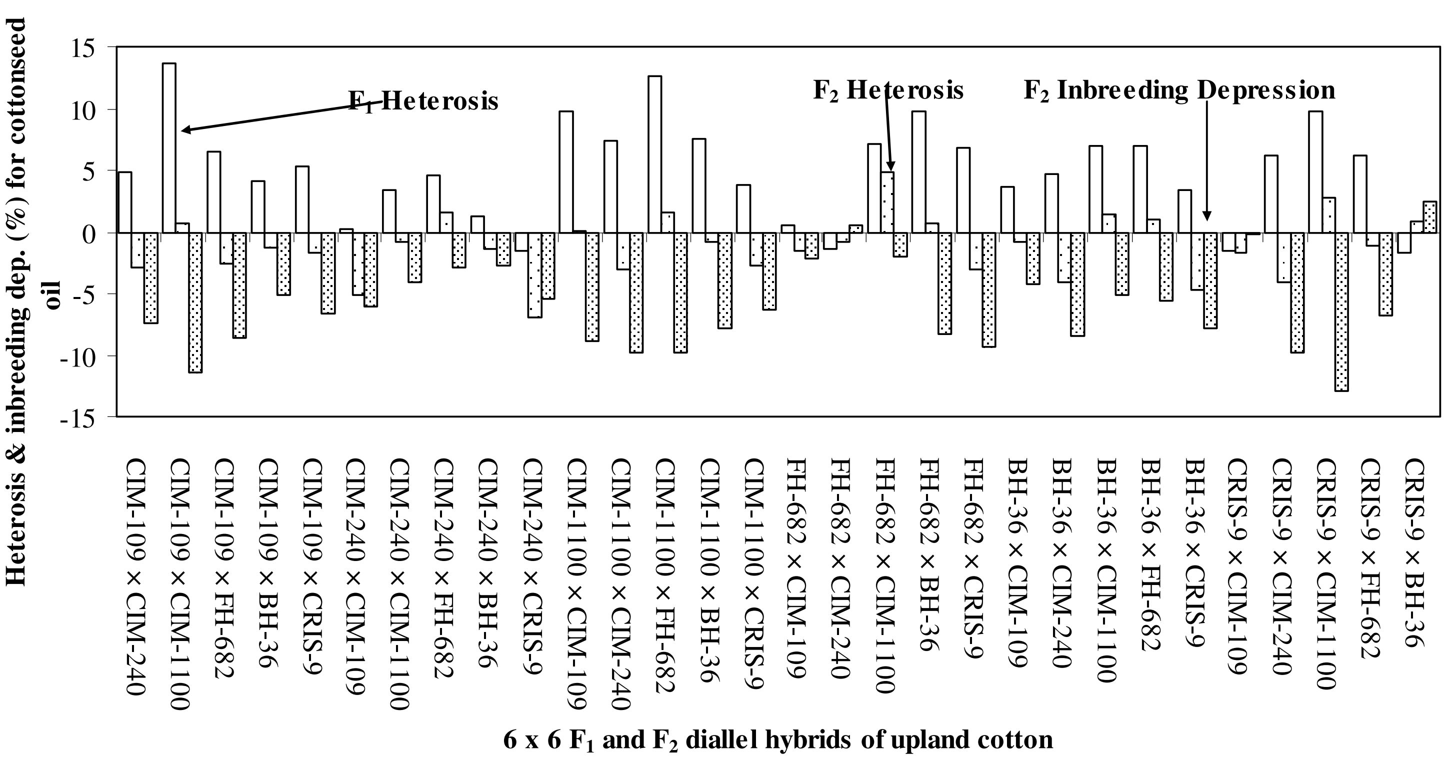

Figure 8. Heterosis in F_1s and F_2s, and inbreeding depression in F_2s for cottonseed oil in a 6 × 6 diallel cross of upland cotton.

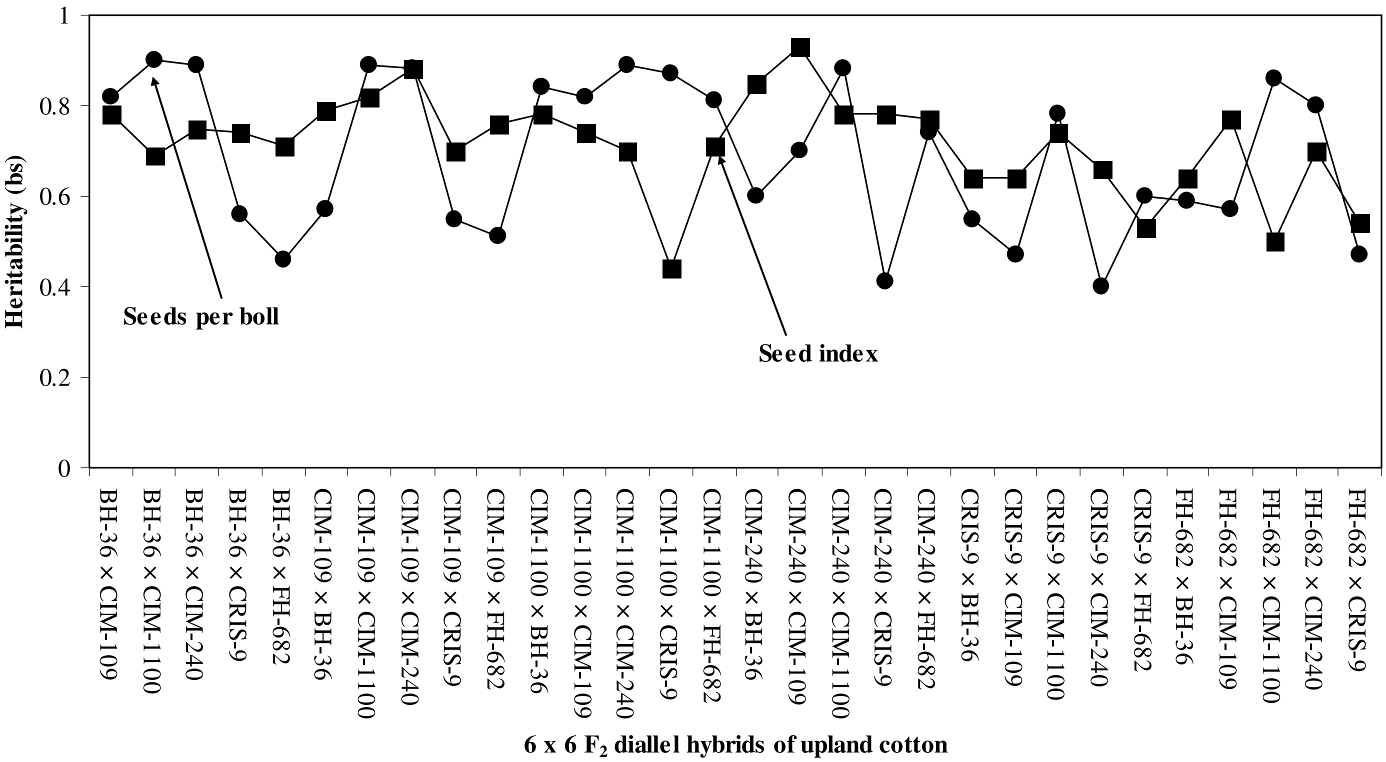

Figure 9. Heritability in F_2 hybrids for seed per boll and seed index in a 6×6 diallel cross of upland cotton.

traits. The correlation coefficient of cottonseed oil with seed cotton yield and oil contributing traits i.e., seeds per boll, seed index and seed cotton yield was also determined (Table 2). It was also encouraging to observe that the correlation of cottonseed oil percentage was found positive with seeds per boll (r = 0.223 and 0.023), seed index (r = 0.366 and 0.376) and seed cotton yield (r = 0.272 and 0.130), respectively in both generations.

DISCUSSION

Functional heterosis was observed for seeds per boll, seed index, seed cotton yield and cottonseed oil percentage in both F_1 and F_2 generations hybrids and especially in the top 10 hybrids which also indicated remarkable heterosis in F_2s also for all the traits. CIM-1100 hybrids showed high heritability and thus reduced environmental impact on these traits. The said results supports the idea that F_2 hybrids could work as a hybrid crop if properly managed and if the parents were selected on the basis of F_2 performance, because the F_1 hybrids cannot clarify the position of the level of stability at the F_2 level (Galanopoulou and Roupakias, 1999). It is also well known that F_2 heterosis exists in cotton and F_2 hybrids with lower inbreeding depression in yield related traits and promised superior performance than well-adapted cultivars (Dani and Kohel, 1989; Khan et al. 2007a). F_2 hybrids have being extensively grown in China demonstrating that their yields were significantly higher than commercial cultivars (Jing et al., 1995; Li et al., 1997). Results revealed that average F_1 mean values for all the traits were found greater than those of F_2s due to inbreeding depression, while F_2 values were higher than parents which confirm the findings of Wu et al. (2004). Our conclusions are also in corroboration with those of Baloch et al. (1993); Hassan et al. (1999); Azhar and Ahmad (2000); Khan et al. (2000) and Khan (2003).

The results indicated that the best performing F_1s also performed well in the F_2 generation with less inbreeding depression. Wu et al. (2004) noted that the performance of the F_1 and F_2 hybrids can be mostly predicted by the average performance of the parents. However, Galanopoulou and Roupakias (1999) reported that the performance of the F_2 cannot be adequately predicted by the performance of the F_1. In general, there is a substantial reduction of heterosis from F_1 - F_2 (Zhang and Pan, 1999). In the studies reported herein, it was noted that the higher F_1 heterosis had more inbreeding depression and show abrupt decline as compared to the F_1 hybrids having moderate heterosis. The results of same pattern have also been reported by Li et al. (2000) and Wei et al. (2002). The combined performance of the hybrids in the F_1 and F_2 generations may be a good indicator of the

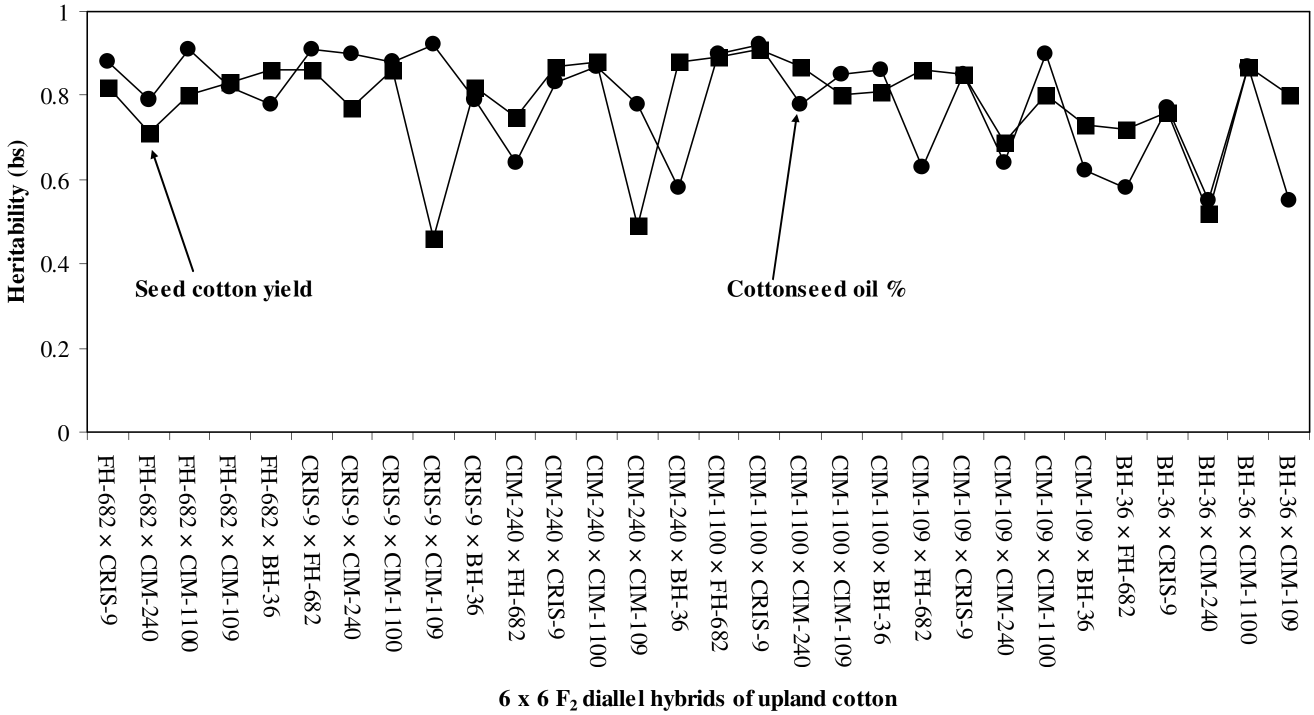

Figure 10. Heritability in F_2 hybrids for seed cotton yield and cottonseed oil in a 6 × 6 diallel cross of upland cotton.

Table 2. Correlation of cottonseed oil percentage with other traits in a 6 × 6 diallel crosses of upland cotton.

Traits	Correlation (r) of cottonseed oil % with other traits	
	F_1	F_2
Seeds per boll	0.223	0.023
Seed index	0.366	0.376
Seed cotton yield	0.272	0.130

most promising populations to be utilized as F_2 hybrids in cotton production (Galanopoulou and Roupakias, 1999). The same confirmation was also observed in cv. CIM-1100 F_1 and F_2 hybrids and was noted as the high performers for all the traits studied.

The results also revealed that in F_2s even after inbreeding depression, some promising population (e.g., CIM-1100 derivatives) revealed better performance for all the traits and positive selection can provide better base for further improvement. The abrupt drop in traits performance at F_2 level was due to inbreeding depression and segregation. Meredith (1990) also reported that the F_2 hybrids with lower inbreeding depression in yield had superior performance than well adapted cultivars. Khan et al. (2000), Basal and Turgut (2003) and Khan et al. (2007) also mentioned that F_1 hybrids with high heterosis were also associated with higher inbreeding depression. Average heterosis of F_2 over mid parent, based on population mean, 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 for further use (Yuan et al., 2002). F_2 hybrids having extra ordinary performance could also be used as such for seed of F_2 crop to increase the seed cotton yield on per unit area as suggested by Baloch et al. (1993) and Khan et al. (2000) and (2009). F_2 hybrids have greater genetic variation and might result in a greater range of adaptation relative to their parents and F_1 hybrids (Meredith and Brown, 1998; Wang and Li, 2000; Wei et al. 2002; Wu et al., 2004). F_2 hybrid heterosis in cotton has been reported (Wang and Pan, 1991; Tang et al., 1993; Li et al., 2000; Xing et al., 2000; Han and Liu, 2002; Khan, 2003) and F_2s can express at least 50% of the economic heterosis shown by F_1 hybrids, which can lead to cultivar improvement.

The cv. CIM-1100 hybrids can also be used in intensive selection for further exploitation in segregating generaions to produce new strains with better yield, oil content and seed related traits. Overall, the highest heterosis was expressed in this group of parents and hybrids for seed cotton yield, cottonseed oil followed by seeds per boll and seed index, suggesting a slight increase in cottonseed oil, seeds per boll and especially seed size and eventually the seed cotton yield will be a great achievement. Selection in these F_2 hybrids will produce better families of hybrids having higher oil percentage. CIM-1100 hybrids showed moderate to high heritability and were found more responsive for selection on the basis of phenotypic performance and heritability, while other hybrids presented low to medium heritability. Khan et al. (2007b) noticed moderate to high heritability for seed cotton yield, cotton seed traits and oil content in intra-*hirsutum* F_2 hybrids of CIM-1100. The higher the heritability, the simpler the selection process and the greater the response to selection (Larik et al., 2000; Khan, 2003). Positive and significant correlation between cottonseed oil, and seed cotton yield and seed traits was also encouraging and the genetic gain in yield, seed index and seeds per boll will have a direct positive impact on cottonseed oil percentage. Khan (2003) also noted positive correlation for cottonseed oil with yield and oil contributing traits. The genotypes derived from such type of F_2 hybrids will met the edible oil demand of the developing countries like Pakistan and will have a positive impact on their foreign exchange.

Conclusion

Overall, F_1 hybrid mean values for seeds per boll, seed index, seed cotton yield and cottonseed oil were higher than F_2 hybrids, while F_2 hybrids supersede their parental mean values. High parent heterosis was more pronounced in the F_1 as compared to the F_2 due to inbreeding depression. But it was encouraging to note that F_2 hybrids, even after segregation and inbreeding depression, manifested 50% or even more heterosis. The greatest heterosis was observed for seed cotton yield and cottonseed oil followed by other seed traits. An increase in cottonseed oil percentage, seed cotton yield and cottonseed traits will be a valuable addition to cotton cultivars.

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