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A Study of Heterosis in Upland Cotton (*Gossypium hirsutum* L.)

R.S. Pathak and Parkash Kumar
Haryana Agricultural University, Hissar (India)

Summary. Heterosis (over mid parent) and "useful" heterosis (over commercial variety H14) estimates were obtained from a line x tester analysis of crosses involving thirteen diverse female parents with two locally adapted varieties H14 (local standard) and J34. Marked heterosis was observed for seed cotton yield, boll number and halo length. The values of positive heterosis and "useful" heterosis for seed cotton yield ranged from 28.1 to 87.0% and 20.1 to 45.5%, respectively. The overall study of heterosis revealed that female parents PRS-72 (USSR), 5904F (USSR) and MCU-5 (Madras Cambodian Uganda Selection, Coimbatore) were among the top three females, showing considerable heterosis in crosses with H14 and J34 for seed cotton yield and fibre properties. The practical difficulties in exploiting the phenomenon of heterosis and possible experimental approaches in upland cotton are discussed.

Introduction

Heterosis has often been obtained in cotton but to be of potential value a hybrid should be more profitable than the best available commercial variety. This means that hybrids should be higher yielding and probably possess superior fibre properties as well. Spectacularly high-yielding hybrids with superior fibre properties have been recently developed in India. The pace has been set by the development of an intra-*hirsutum* hybrid, named 'Hybrid-4', which has the parentage of Gujarat-67 (Local standard) and American Nectariless. This hybrid has recorded very high yields of seed cotton and has shown adaptability to varied soils and climatic conditions in the central state of Gujarat and parts of Mysore and Maharastra (Patel, 1971). It is the first hybrid cotton variety in the world to be grown on such a large scale. Another equally promising hybrd, Varalaxmi, has been developed in the state of Mysore (Katarki, 1972). This hybrid was developed from an interspecific cross of the locally adapted variety Laxmi *(G. hirsutum)* with SB289E *(G.barbadense)* from the U.S.S.R. In large scale trials conducted in the Mysore State, this hybrid has outyielded Hybrid-4 and possesses superior fibre properties as well. The yield potential of these hybrids, when grown in the northern part of India, has not been realized because of the differing agroclimatic conditions prevailing. There is no such high-yielding hybrid or variety available for cultivation in the north where, nertheless, there is great potential for increasing cotton production. In this study we investigated the potential value of heterosis in the northern environment, using two of the better varieties as common parents in each cross studied.

Materials and Methods

We crossed thirteen inbred lines with two locally adapted parents, H14 (Local standard) and J34. These varieties were selected, primarily on the basis of their diversity for yield components and fibre properties, from a large collection of genetic stocks obtained from the U.S.A., the U.S.S.R., Africa and from within India. The general and genetic background and designation for each parent is as follows:

- H14 - The locally adapted commercial variety with average yield potential but poor in fibre properties.
- J34 - An improved variety, slightly later than H14 and possessing a high degree of resistance to jassids.
- TH37 - A variety synthesized from an interspecific cross of *G. thurberi* × *G. hirsutum* (TH) at Indore and improved for lint qualities and jassid resistance.
- LLPool - A selection from local material collected at Hissar for long lint.
- PRS-72 - Pirrcom Russian Strain is an introduction from the U.S.S.R. It is characterized by short fruiting sympodial branches and cluster boll bearing, complete suppression of monopodial branches, early maturity, but high susceptibility to jassids under northern Indian conditions.
- K4005 - An introduction from the U.S.S.R. with high yield potential, early maturity and high ginning percentage.
- 5904F - Another early maturing type from the U.S.S.R. with good fibre quality characters.
- Reba B-50 - A strain from East Africa, reported to be immune to all races of *Xanthomonas malvacearum* prevalent in India. It is also early in maturity and drought resistant but highly susceptible to jassids.
- SA267 - An early maturing strain from South America.
- Stoneville - A strain from the U.S.A., which bears bold bolls and has a high ginning percentage.
- Type 6-6-4R - Another strain from the U.S.A. with many monopodial branches and medium maturity.
- Bobdel - An introduction from West Africa, having a high ginning percentage and long fibres.
- 5143C - A strain from Ceylon having high yields and a high ginning percentage.

Table 1. Heterosis and "useful" heterosis (in parentheses) expressed as percentage in upland cotton

Hybrid	Days to first flowering	No. of bolls per plant	Boll weight (gm)	No. of seeds per boll
SA267 × J34	- 1.1(-0.3)	-26.2*	- 3.2	- 7.6
Reba-B-50 × J34	12.9	-14.8	5.8(2.5)	-10.1
ISC76 × J34	2.1(-1.7)	8.1(37.4**)	14.7(1.6)	- 1.5
Stoneville × J34	- 8.7(-8.2)	30.9**(36.4**)	- 7.2	1.5(11.3)
5904F × J34	13.7	38.1**(47.3**)	3.1(1.3)	4.8
K4005 × J34	16.9	-36.9**	13.4	-23.9*
LLPool × J34	- 7.0(-1.9)	28.2*(17.7)	- 9.2	7.8(2.3)
TH37 × J34	- 2.1(-3.4)	35.6**(36.6**)	8.9	12.2(2.9)
Type 6-6-4R × J34	7.6	- 0.8	5.9	12.1(0.5)
5143C × J34	- 1.0(1.8)	-41.8**	-19.5	- 6.7
Bobdel × J34	4.1	-19.9	-22.2*	4.9(8.5)
MCU-5 × J34	-32.0**(5.6)	-42.7**(37.1**)	- 2.3	-10.1
PRS-72 × J34	0.1	59.2**(44.8**)	2.7	2.4(2.7)
SA267 × H14	9.0	-38.6**	- 2.7	- 7.4
Reba-B-50 × H14	- 5.8(- 6.2)	-21.6*	- 3.9	- 0.1(1.3)
ISC76 × H14	- 5.6(-3.6)	-31.9*	- 4.3	- 9.7
Stoneville × H14	- 2.5(-1.9)	2.6(6.4)	-14.9	- 8.2(0.1)
5904F × H14	- 3.4(-6.3)	-30.8**	- 8.2	14.2(7.7)
K4005 × H14	4.5	-32.1**	-25.7**	-23.2**
LLPool × H14	- 9.1(-1.8)	-18.1	-36.2	- 7.9
TH37 × H14	- 8.9(-7.8)	-47.8**	- 2.2	-15.5
Type-6-6-4-R × H14	5.9	-28.6*	-36.0	-12.9
5143C × H14	1.8	-21.8*	-19.6	7.1(9.9)
Bobdel × H14	12.2	32.3*(19.7*)	-29.4	5.6(8.5)
MCU-5 × H14	- 6.8(-31.8**)	-37.3**	- 2.6	-21.5*
PRS-72 × H14	- 1.2(15.9)	64.6**(49.1**)	4.9	4.3(5.8)

* Significant at $P = 0.05$; ** significant at $P = 0.01$

ISC76 - An improved strain with extra-long fibres developed in Gujarat.

MCU-5 - A Cambodian type extra long staple variety with high yield potential. It is the best *hirsutum* cotton variety adapted to southern states of India, but fails miserably in northern Indian conditions.

The 41 treatments ($26F_1$ hybrids and 15 parents) were grown in a randomized block design with three replications at the Research Farm of Haryana Agricultural University, Hissar, during the year 1972. Individual plots were single rows each of ten plants, spaced at 60 cm between rows and 30 cm between the plants. Five plants in each entry were selected randomly in each replication for observations on: (1) days to first flowering; (2) number of bolls per plant; (3) boll weight (gm) - average of five bolls from each plant; (4) number of seeds per boll - average of seeds from 5 bolls from each plant; (5) ginning percentage - average of 5 samples from each entry, with the help of ginning percentage balance; (6) seed index (gm); (7) lint index (gm) - calculated as the ratio of seed index × ginning percentage/100 - ginning percentage; (8) yield of seed cotton (gm) per plant - average of five selected plants in each entry; (9) halo length (mm) - average of five halos from each plant using a halo length measuring disc provided by the Cotton Technological Laboratory, Bombay.

Statistical analysis was carried out on the mean values of five plants obtained in each entry. Tests of significance for heterosis (F_1-MP) and "useful" heterosis (F_1-H14) were made on the computed differences. The differences were expressed as percentage of the mid-parent (MP) and commercial H14 as heterosis $p = 100 \times (F_1\text{-MP})/\text{MP}$ and "useful" heterosis $p = 100 \times (F_1\text{-H14})/\text{H14}$, respectively.

Results

Table 1 gives percent heterosis measured as increase (positive) or decrease (negative) over the mid-parent value and "useful" heterosis measured as increase over the commercial variety H14, for each trait.

Fourteen out of twenty-six crosses studied showed negative heterosis for number of days taken from sowing to first flowering, which was desirable. Both crosses involving MCU-5 with J34 and H14 showed negative heterosis indicating desirable early flowering combinations. The "useful" heterosis for this character was observed only in one cross MCU × H14.

Only seven crosses showed significant positive heterosis values for number of bolls per plant. Maximum heterotic increase in boll number was recorded in crosses involving the female parent PRS-72 with H14 and J34: 64.6 percent heterosis was recorded in cross PRS-72 × H14, closely followed by the cross PRS-72 × J34 (59.2%). These crosses also recorded significant values of "useful" heterosis, next in value being the crosses 5904F × J34 (47.3%) and PRS-72×J34 (44.8%). It is interesting to note that the parent PRS-72, which bears few bolls on its plants due to its high susceptibility to jassids, has contributed a high number of bolls in

Seed index	Lint index	Ginning p	Yield of seed cotton	Halo length
- 0.9	17.8(11.9)	12.1**(6.0**)	-50.8**	4.8(12.0)
2.7(2.6)	9.3(9.9)	4.3(1.8)	-15.5	0.6(4.0)
- 3.7(4.2)	- 8.3	- 1.9	- 0.9(6.9)	5.5(12.4*)
- 3.8	0.7	3.1(0.6)	40.1**(20.1*)	- 1.6
-12.1*	16.5	- 3.4	64.7**(45.5**)	2.7
-15.7**	- 1.8	10.2(0.9)	-52.8**	12.2*(16.5**)
- 6.4	- 2.4	- 3.3	28.1*	- 3.1(12.0*)
0.1	- 0.8	- 0.3	38.7**	- 0.7(12.0*)
3.8	5.2	9.7	-44.9**	8.9(8.0)
- 3.9	- 1.7	1.9	-38.8**	- 2.4(12.8*)
- 9.3	-22.1*	-10.5**	-29.1*	- 3.2(2.0)
- 5.1	- 4.1	2.2	64.5**(16.1)	3.3(13.2*)
5.9	-15.3	5.5	87.0**(34.1**)	- 5.9
- 8.6	- 6.1	2.8	-51.3**	20.8**(23.7**)
1.9(4.6)	1.4(7.5)	- 0.3	-14.3	7.8(10.4)
6.7(4.7)	-10.2	.01	-46.2**	3.8(10.0)
- 5.1	- 6.2	.01	-21.9*	13.8*(14.0*)
- 9.4	- 4.8(1.9)	1.2(1.5)	-43.2**	-14.3*(9.2)
-10.8*	- 1.2	3.9	-67.1**	9.3(12.8*)
- 2.5	- 7.9	- 2.9	-46.3**	- 0.2(14.9*)
- 3.5	3.9(1.4)	6.0(0.9)	-36.6**	3.9(16.5**)
- 7.7	- 7.5	6.5	-61.2**	3.9(2.4)
- 2.3	1.3(0.3)	2.8	-21.7*	- 7.7(1.2)
3.1(0.6)	- 1.4	- 2.5	-24.7*	4.2(9.2)
3.3	4.8	2.5	-15.9**	- 3.2(5.6)
- 5.4	0.5	5.1	64.1**(36.6**)	7.4(8.0)

cross combinations. The other female parents which showed high values of "useful" heterosis for boll number were ISC76, MCU-5, TH37, and Stoneville when crossed with J34.

Negative heterosis was observed in most of the crosses studied for boll weight. Eight crosses showed positive heterosis, whereas only three crosses exhibited "useful" heterosis. The crosses showing "useful" heterosis, were Reba B-50 × J34 (2.5%), ISC67 × J34 (1.6%) and 5904F × J34 (1.3%). For number of seeds per boll, eleven hybrids showed positive heterosis, though it was not significant in any case. The cross 5904F × H14 showed the maximum increase of 14.2% in number of seeds over its midparent value. Maximum value of "useful" heterosis of 11.3% was recorded in the cross between Stoneville and J34 for number of seeds per boll.

Though most of the hybrids showed negative heterosis for seed index, it was positive in eight crosses. The cross combination ISC76 × H14 recorded the maximum value of both heterosis and "useful" heterosis. For lint produced from 100 seeds, maximum heterosis increase to the order of 17.8% was found in the cross SA267 × J34. This cross also recorded the maximum value of 11.9% of "useful" heterosis.

Contrary to the negative heterosis observed for seed index and lint index, the heterosis values for ginning percentage were positive in most of the cases. However, it was only one cross (SA267 × J34) which showed significant values of heterosis (12.1%) as well as "useful" heterosis (6.0%). The other crosses which gave a fairly high positive heterosis involved the female parents K4005, Type 6-6-4 R and PRS-72, when crossed with male parents J34 and H14, and TH37 with H14.

When heterosis was calculated for yield of seed cotton most of the crosses showed negative values. Only seven out of twenty-six crosses showed a heterosis increase over their midparent values. The maximum heterosis increase of 87% was observed in the cross PRS-72 × J34, followed by two crosses, PRS-72 × H14 and 5904F × J34, both showing 64% heterosis. The same three crosses showed higher values of "useful" heterosis than did the others. As much as 45.5% of "useful" heterosis was found in cross 5904F × J34, while the other two crosses PRS72 × J34 and PRS-72 × H14 gave nearly 35% of "useful" heterosis for seed cotton yield.

An encouraging result was obtained for halo length. Sixteen out of twenty-six crosses showed heterosis for halo length over H14. A maximum of 23.7% of heterosis (positive) was found in the cross SA267 × H14 for this character. The other crosses which showed considerable increases in fibre length over H14 involved the female parents K4005, TH37, LLPool, MCU-5 and ISC-76, crossed with J34 and H14.

Discussion

Numerous studies in cotton have shown significant heterosis for yield where heterosis was defined as F_1-MP, MP denoting the mid-parent value. Though several workers have suggested the feasibility of exploiting heterosis in intervarietal crosses, this has not been exploited commercially, mainly because of the low magnitude of heterosis in most intervarietal crosses. The F_1 increases have no practical use unless the heterosis increase over the commercial variety is large. Good cross combinations have been very few in most studies. This may be explained by examining the cytogenetic make-up of upland cotton. In cross-pollinated crops such as maize the homozygous inbreds, when crossed, exhibit heterosis of high order. The hybrid populations, as a rule, are heterozygous and homogeneous. In cotton, however, both parental and hybrid populations are heterozygous and heterogeneous and they differ only in degree. Cotton is readily self-fertilized, but it does not approach obligate self-fertilization. *G.hirsutum* is an amphidiploid and it maintains a form of heterozygosity between homoelogous loci. Strains already carrying the favourable dominant growth genes would not be expected to express much heterosis. The influence of the duplicated genetic information of the allotetraploid was demonstrated experimentally when Young et al. (1966) showed that cultivated allotetraploid cotton *(G.hirsutum)* displayed less inbreeding depression and heterosis than cultivated diploid cotton *(G.arboreum)*. In fact the material selfed for many generations maintains a high degree of heterozygosity at many loci. Therefore, the magnitude of heterosis in upland cotton is much less than that generally expected.

In the present study heterosis increase for yield of seed cotton was not appreciably high. Of twenty-six crosses, only seven showed positive heterosis, ranging from 28.1 to 87.0%. The "useful" heterosis, that is, the heterosis increase over H14, for seed cotton yield ranged from 20.1 to 45.5%. These results were very close to the maximum "useful" heterosis observed by other workers (Hawkins et al. 1965; Jones and Loden, 1951; Lee et al. 1967; Miller and Lee, 1964). It is evident that "useful" heterosis for yield exists in very few cross combinations. This means that many more crosses should be studied to find a really good cross combination with high heterosis. Among the yield components, increase in boll number was a major contributing factor in heterosis and "useful" heterosis for seed cotton yield in these populations. The results of individual traits in this study are comparable with those of earlier reports by Pathak (1968), Hooda (1969), Singh et al. (1969) and Singh and Murty (1971). However, a breeder does not make decisions solely in terms of individual traits. When the combined results for yield and lint quality factors are observed the superiority of hybrids is even more pronounced. Four hybrids, namely PRS-72 × H14, PRS-72 × J34, 5904F × × J34 and MCU-5 × J34, were superior in yield of seed cotton to the local commercial variety H14 and also had longer fibre than H14. These hybrids could be considered a favourable cross combination. There can be little doubt that the small favourable increase in both yield and fibre properties can combine to produce hybrids with much superior performance to an accepted variety like H14.

The degree of heterosis depends primarily on dominance and genetic diversity. Loci without dominance can show neither inbreeding depression nor heterosis. Because of the allotetraploid nature of *G.hirsutum*, the intervarietal crosses do not show pronounced inbreeding depression and heterosis. The alternative breeding procedure would be to exploit heterosis in crosses between parents with greater genetic diversity. The degree of heterosis following a cross between two particular lines or populations depends on the square of the difference of gene frequency between populations (Falconer, 1960). As expected, the maximum amount of positive heterosis for seed cotton yield was obtained in crosses of genetically diverse parents, i.e. between PRS-72 (U.S.S.R.), 5904F (U.S.S.R.), MCU-5 (Cambodian type strain from Coimbatore) and the locally adapted male parents J34 and H14. It is also expected that the crosses between adapted × exotic parents would show a higher magnitude of heterosis than those between adapted × adapted or exotic × exotic parents. Such favourable cross combinations were few in the present material, as most of the crosses showed negative heterosis. The magnitude of heterosis reported by some workers is even lower than the results obtained here. Meredith et al. (1972), for example, obtained heterosis ranging from 7.1 to 47.0% and "useful" heterosis from 8.0 to 15.0%. This was probably due to the lack of genetic diversity in their material.

Breeding Methodology

Considering the results reported so far, it appears that the magnitude of heterosis increases obtained in most studies in upland cotton, including the present one, has been rather low and so not of practical use. It is only rarely that favourable cross combinations have been obtained. Under these circumstances the application of a new breeding procedure, named the "Comprehensive Breeding System", outlined by Eberhart et al. (1967), appears a promising experimental approach to developing superior cotton hybrids. In contrast to the conventional procedure, the comprehensive breeding system utilizes two improved populations to develop superior hybrids. The system has four main phases:

1. Evaluation of local and exotic varieties so that the breeding material is the best available. Since general combining ability is most important in the preliminary screening, the comparison of all collections as test crosses to the locally adapted variety would often be the most satisfactory method. One season result would usually provide adequate information from which to select the best entries if enough locations are used.

2. Compositing the selected breeding material into two or more populations in such a manner that each population has considerable genetic variation for the traits like yield, its components and fibre properties, so that crosses of these populations will show heterosis.

3. Recurrent selection in each population to increase the frequency of favourable genes so that the populations and population crosses are improved with each selection cycle. Selection of plants in each selection cycle could be based on certain norms fixed for yield of seed cotton, ginning percentage and fibre properties. Intermating between selected plants of a population could be increased by placing honey bee hives in the field, isolated from another such population. Increased intermating would permit greater recombination and more chances of recombining desirable characters. Genetic and cytoplasmic male sterile lines, where available, could be utilized effectively.

4. Release of a commercial variety as a single cross hybrid from inbred lines developed from elite material after each cycle of selection.

The application of the comprehensive breeding system has been very successful in developing superior hybrids in maize (Eberhart et al. 1967 and Suwantaradon and Eberhart 1974) and sorghum (Doggett and Eberhart, 1968). However, the superiority of this procedure over the conventional procedure in the case of cotton needs to be experimentally verified.

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Dr. R.S. Pathak,
Department of Crop Science
University of Nairobi
P.O. Box 30197
Nairobi (Kenya)

Parkash Kumar
Department of Plant Breeding
Haryana Agricultural University
Hissar (India)