Indian J. Genet., 50(1): 37–44 (1990)

INVESTIGATIONS ON EXPLOITATION OF HETEROSIS IN COTTON (*GOSSYPIUM HIRSUTUM* L.) USING MALE STERILITY

N. L. BHALE AND M. G. BHAT*

Central Institute for Cotton Research, Post Bag No. 125, G.P.O. Nagpur 440001

(Received: December 29, 1987; accepted: February 6, 1989)

ABSTRACT

Study of cytoplasmic-genic and genetic male sterility (CMS and GMS) for exploitation of heterosis in cotton led to the identification of five suitable exotic *Gossypium hirsutum* restorers of cytoplasmic-genic male sterility. The 29 CMS hybrids obtained by using 6 male sterile lines (A lines) and 5 restorer lines (R lines), as well as 172 GMS hybrids involving 9 genetic male sterile lines were compared with several cotton genotypes for their seed cotton yield and economic characters. The GMS hybrids were superior to CMS hybrids, significantly surpassing the yield of the commercial Hybrid-4. The CMS hybrids did not show significant improvement in yield over the commercial cotton hybrid. The genetic background, local adaptability, and diversity of parents appeared to be responsible for the superiority of GMS hybrids over CMS hybrids. The presence of strong sterile cytoplasm may also be a probable reason for the poor performance of CMS hybrids, besides the limited number of hybrids based on cytoplasmic-genic male sterility system in contrast with genetic male sterility system, where large number of hybrid combinations were possible and thus produced and tested. The study also revealed that 4 out of 172 GMS hybrids with high economic heterosis for yield and also superior to Hybrid-4 in four other economic characters can be commercially exploited. Since the female parents of these hybrids are male sterile, the cost of hybrid seed production can be substantially reduced.

Key words: *Gossypium hirsutum* L., cotton, male sterility, restorer, heterosis.

Although several varieties of cotton were developed and released for commercial cultivation in India, the first hybrid, Hybrid-4, was released in 1970 in Gujarat, followed by Varalaxmi in 1972 in Karnataka. Since then many cotton hybrids have been released for commercial cultivation in the country. Hybrid cotton seed production by hand emasculation and pollination made these hybrids a commercially successful and viable proposition in India, primarily due to cheap labour in comparison to the advanced countries. However, the cost of such hybrid cotton seed is 20-25 times higher than that of pure varieties.

Stable and dependable male sterility systems are now available in cotton also. Meyer [1] developed stable cytoplasmic male sterile cotton with the cytoplasm of *Gossypium harknessii* Brandagee and the genome of *G. hirsutum*. A single dominant gene Rf from *G. harknessii* is

* Addressee for correspondence.

essential for fertility restoration and a gene, the Enhancer factor, from *G. barbadense* increases fertility [1–3]. Among various sources of genetic male sterility, the double recessive male sterile type with ms_5ms_5 ms_6ms_6 genes is most promising [4]. Genetic male sterility of Gregg source having these double recessive genes has been transferred to promising Indian strains of *hirsutum* cotton [5]. The performance of hybrids produced by utilizing both cytoplasmic-genic sterile (CMS) and genetic male sterile (GMS) lines in crosses with several cotton genotypes was studied in 1985 and 1986. In addition, stable restorer lines of CMS were also identified.

MATERIALS AND METHODS

Six CMS lines (A-lines), JCMSBN, JCMSK2, S278CMS, DESHAMS-16, DESHAMS-277 and Laxmi CMS; and nine GMS lines, G-67 GMS, Laxmi GMS, IAN 579 GMS, B59-1684 GMS, B-1007 GMS, MCU-4 GMS, MCU-5 GMS, K34007 GMS and Gregg GMS, were used as female parents in crosses, in which 12 genotypes were used as male parents with both CMS and GMS lines for the 1985 hybrid trials (crosses made in 1984). For the 1986 hybrid trials, four restorers and another genotype, DES 146C, were used as male parents in crosses with CMS lines (A-lines), and 29 genotypes in the crosses with GMS lines made in 1985.

The 55 CMS-based F_1 (47 F_1 in replicated and 8 F_1 in unreplicated trials) and 36 F_1 using GMS (12 F_1 in replicated and 24 F_1 in unreplicated trials) were tested with Hybrid-4 (H-4) in 1985 for yield and other economic characters. In the replicated trial, hybrids were grown in plots of 4.32 m^2 with 90 x 60 cm spacing, each hybrid having one row of 8 plants. The CMS and GMS hybrids were grown in separate trials in randomised blocks design with three replications. The hybrids with limited seeds were compared in unreplicated trials.

In 1986, 55 CMS-based F_1 (19 F_1 in replicated and 36 F_1 in unreplicated trials) and 195 F_1 using GMS (172 F_1 replicated and 23 F_1 in unreplicated trials) were evaluated with Hybrid-4 with 90 x 60 cm spacing, in 3-row plots of 16.2 m^2 with 10 plants per row for CMS hybrids and 2-row plots of 10.8 m^2 for GMS hybrids. The CMS and GMS hybrids were grown in separate trials in randomised block design with three replications. As in 1985, hybrids with limited seeds were compared in unreplicated trials. Data for yield and other economic characters from unreplicated trials are not reported, except their utilization for identification of restorers in the CMS hybrids. Yield data from the replicated trials were statistically analysed. Economic heterosis of seed cotton yield in hybrids over H-4 was worked out.

RESULTS AND DISCUSSION

IDENTIFICATION OF RESTORERS

Four cotton genotypes, namely, MEX 685-3, Dixie king ne restorer, Demeter III [1] and Demeter III [2] from cotton germplasm of CICR were identified as stable restorers in 1985 based on the study of a large number of crosses made between A-lines and different cotton genotypes. Based on the study of 1986, another genotype, DES 146 C, was also found to be a restorer. All these five *G. hirsutum* genotypes restore fertility in CMS hybrids.

Patel and Mehta [6] found that none of the 1008 cotton genotypes (911 *hirsutum* and 97 *barbadense*) used for crossing with CMS nectariless line (A-line) carried the fertility restorer gene. They also reported that the original line 8-1029, possessing restorer gene(s), received from Dr. Weaver, segregated into male sterile, weak male fertile, and strong male fertile, and evolved a procedure to transfer restorer genes to another genotype by special backcrossing method.

Table 1. Performance of CMS hybrids for yield, economic heterosis for yield and other characters (1985)

Hybrid	Seed cotton yield (kg/ha)	Heterosis for yield over H-4 (%)	Boll wt. (g)	Boll No.	Halo length (mm)	Ginning (%)
NICMSH-1	2227	+6.9	6.2	31.1	24.8	36.3
NICMSH-2	2477	+18.9	5.4	36.0	26.4	35.6
NICMSH-3	1581	−24.1	4.5	29.6	25.3	36.4
NICMSH-4	1963	−5.8	5.2	32.2	27.6	38.2
NICMSH-5	1685	−19.1	4.8	30.3	25.0	34.4
NICMSH-6	1921	−7.8	5.5	38.1	26.7	36.6
NICMSH-7	1199	−42.4	3.6	45.1	29.7	33.9
NICMSH-8	840	−59.7	5.3	20.3	27.1	35.4
NICMSH-9	1025	−50.8	4.8	23.8	25.8	36.0
NICMSH-10	1933	−7.2	5.6	30.0	29.2	36.8
NICMSH-11	1741	−16.4	5.0	27.7	23.8	36.5
NICMSH-12	1940	−6.9	3.3	37.0	33.0	33.9
NICMSH-13	1910	−8.3	5.1	29.8	26.3	36.3
NICMSH-14	1498	−28.1	5.6	31.7	26.8	34.9
NICMSH-15	1523	−26.9	5.3	31.1	28.6	37.1
HYBRID-14	2083	—	5.4	34.3	26.3	32.6
CD 5%	625					

Shroff [7] reported that the *G. barbadense* restorers (eg. JPR-1 and JPR-6) were superior for restoration of fertility as compared to other restorers. He reported three *G. barbadense* restorers (JPR-1, JPR-6, and UCA1B-1), and three *G. hirsutum* restorers (JBW1g-221-36, JBW1g-221-43 and JDESHAF-16/3, the last being a poor fertility restorer).

EVALUATION OF HYBRIDS

CMS hybrids. In 1985, only 15 out of 47 CMS hybrids tested could be evaluated for seed cotton yield and other economic characters, as the remaining 32 hybrids had problems in fertility restoration. The performance of these 15 CMS hybrids from replicated trial for seed cotton yield, economic heterosis and other important characters in 1985 is presented in Table 1.

The best CMS hybrid (NICMSH-2) registered 2477 kg/ha yield of seed cotton. Although two CMS hybrids (NICMSH-2 and 1) were numerically superior to H-4, none of the CMS hybrids gave significantly higher seed cotton yield. These two CMS hybrids were at par with H-4 for other economic characters.

In 1986, 12 out of 19 CMS hybrids in replicated trial produced fertile pollen, and hence only these could be evaluated for yield and other economic characters (Table 2). None of these hybrids was superior to H-4.

Table 2. Performance of CMS hybrids for yield, economic heterosis for yield and other characters (1986)

Hybrid*	Seed cotton yield (kg/ha)	Heterosis for yield over H-4 (%)	Boll wt. (g)	Boll No.	Halo length (mm)	Ginning (%)
NICMSH-5-206	1086	−25.5	3.8	27.3	23.6	37.3
NICMSH-6-205	1188	−18.5	4.1	25.0	24.3	34.3
NICMSH-9-222	458	−68.6	5.0	15.1	26.0	38.5
NICMSH-13-211	1346	−7.6	4.3	29.7	26.4	34.5
NICMSH-14-213	594	−59.2	4.4	20.8	26.3	35.8
NICMSH-15-214	755	−48.2	4.4	23.7	23.7	37.2
NICMSH-0-207	1117	−23.3	4.0	28.0	24.6	35.0
NICMSH-UR-208	1085	−25.5	4.2	26.0	24.6	34.0
NICMSH-UR-215	704	−51.7	3.8	24.8	25.8	37.2
NICMSH-0-216	512	−64.9	3.8	21.7	26.0	35.0
NICMSH-0-218	804	−44.8	4.1	25.8	25.1	36.4
NICMSH-UR-223	388	−73.4	4.5	14.1	26.0	34.8
HYBRID-4	1457	—	4.4	28.8	27.7	34.3
CD 5%	310					

* First numeral ¤ code No. of 1985; second numeral ¤ code No. of 1986; 0 — not tested in 1985, UR — unreplicated trial of 1985.

In contrast to the present findings, Shroff et al. [8] and Shroff [7] reported better performance of the CMS hybrids. Shroff et al. [8] evaluated a few inter- and intraspecific hybrids developed by utilization of the CMS restorer system and found that JCMSRB-50 (the CMS line), in general, performed well in combination with the Egyptian restorer parent, particularly in the hybrid JCMSRB-50 x JPR-6. Shroff [7] also reported that a single-cross interspecific hybrid, JCHB-12, developed on CMS background gave very encouraging results on cultivators fields also. He also found that single-cross hybrids outyielded 3-way hybrids, while the latter were more stable in performance over environments.

GMS hybrids. The 12 GMS hybrids evaluated in replicated trial in 1985 for seed cotton yield, economic heterosis and other economic characters differed significantly for seed cotton yield (Table 3). The best GMS hybrid, NIGMSH-11, recorded seed cotton yield of 3512 kg/ha. Eight GMS hybrids were nonsignificantly and six were significantly superior to H-4 for seed cotton yield. The range of economic heterosis for yield in 8 superior GMS hybrids over H-4 was 23.1%– 68.6%. NIGMSH-11 and NIGMSH-6 were highly promising with their economic heterosis over H-4 68.6% and 66.7%, respectively.

Table 3. Performance of GMS hybrids for yield, economic heterosis for yield and other characters (1985)

Hybrid	Seed cotton yield (kg/ha)	Heterosis for yield over H-4 (%)	Boll wt. (g)	Boll No.	Halo length (mm)	Ginning (%)
NIGMSH-1	3044	+46.1	4.5	53.6	30.1	35.0
NIGMSH-2	1486	− 28.7	4.3	33.3	23.7	34.2
NIGMSH-3	1852	− 11.1	4.6	33.4	33.3	36.3
NIGMSH-4	2669	+28.1	4.6	46.0	29.2	34.1
NIGMSH-5	2836	+36.1	6.0	33.1	27.6	37.4
NIGMSH-6	3472	+66.7	4.4	47.2	26.8	34.8
NIGMSH-7	2840	+36.3	5.3	37.9	29.4	35.3
NIGMSH-8	1789	− 14.1	4.4	30.1	29.3	36.4
NIGMSH-9	2565	+23.1	5.3	42.8	32.2	35.8
NIGMSH-10	2789	+33.9	5.6	43.1	31.4	34.8
NIGMSH-11	3512	+68.6	5.9	53.4	30.4	37.5
NIGMSH-12	1602	− 23.1	4.7	30.1	26.7	35.4
HYBRID -4	2083	—	5.4	34.3	26.3	32.6
CD 5%	694					

In 1986, 172 GMS hybrids were evaluated in two sets: 81 hybrids in replicated hybrid trial and 91 hybrids in replicated trial in line x tester mating design. Out of 172 GMS hybrids, 109 were superior to H-4 and 38 hybrids among them had more than 50% economic heterosis over H-4. Table 4 shows the performance of some very promising GMS hybrids, some of which also performed better in 1985. Economic heterosis exceeding 100% over H-4 was exhibited by five GMS hybrids (NIGMSH-0-13, 0-159, 0-65, 0-26 and 0-91), the maximum being 133.8% in NIGMSH-0-13. Out of the 109 high yielding GMS hybrids identified, 26 had higher boll weight, 62 higher boll number, 36 longer fibres, and 56 higher ginning percentage as compared to H-4. Out of these 109 hybrids, 17 were superior in three economic characters over H-4 and four in all the four economic characters studied besides yield.

Weaver [4] found that genetic male sterility in Gregg genotype was governed by two pairs of homozygous recessive alleles, ms_5 and ms_6. Srinivasan et al. [9] studied the inheritance of genetic male sterility of some Indian *hirsutum* cotton genotypes by crossing with Gregg and found that some genotypes carried homozygous dominant alleles at two loci while others had homozygous dominant alleles at one locus. They also demonstrated maintenance of genetic male sterility by sib-mating among the sterile and fertile sibs. Srinivasan and Gururajan [10, 11] outlined the procedure of producing hybrid cotton utilizing genetic male sterility and concluded that the cost of hybrid seed so produced was substantially reduced in comparison with the conventional method. Evaluation of several hybrids involving GMS cotton strains [12–15] confirmed yield superiority of some of the hybrids over the best varieties under cultivation and suitability of two hybrids, viz., CPH-2 and CPH-4, for commercial cultivation.

Table 4. Performance of promising GMS hybrids for yield, economic heterosis for yield and other characters (1986)

Hybrid*	Seed cotton yield (kg/ha)	Heterosis for yield over H-4 (%)	Boll wt. (g)	Boll No.	Halo length (mm)	Ginning (%)
Line x tester expt.:						
NIGMSH-1-84	1554	+74.8	3.8	22.7	27.2	36.8
NIGMSH-4-32	1117	+25.7	3.8	24.8	28.9	36.1
NIGMSH-6-19	1603	+80.3	4.5	24.0	26.6	35.8
NIGMSH-7-71	1337	+50.4	3.8	28.6	26.9	35.9
NIGMSH-10-45	1636	+84.0	4.4	21.9	29.7	37.1
NIGMSH-UR-6	1766	+98.7	3.6	24.0	28.3	39.1
NIGMSH-0-13	2078	+133.8	4.8	30.8	27.8	39.3
NIGMSH-0-23	1564	+75.9	4.7	21.1	25.3	37.3
NIGMSH-0-26	1886	+112.2	5.0	25.5	28.7	36.8
NIGMSH-0-36	1586	+78.4	4.6	24.7	25.8	38.0
NIGMSH-0-39	1706	+91.9	4.3	20.8	28.3	34.9
NIGMSH-UR-58	1604	+80.4	3.3	25.2	28.1	39.1
NIGMSH-0-65	1906	+114.4	4.7	21.3	25.1	38.0
NIGMSH-0-91	1811	+103.7	4.5	21.0	27.2	38.0
HYBRID-4	889	—	3.6	21.9	25.8	34.6
CD 5%	407					
Regular hybrid trial:						
NIGMSH-0-120	1512	+87.6	3.7	23.5	25.8	36.9
NIGMSH-0-140	1421	+76.3	3.2	23.9	26.2	36.4
NIGMSH-0-155	1510	+87.3	4.6	21.4	25.6	39.9
NIGMSH-0-159	1788	+121.8	5.2	24.9	25.6	40.2
NIGMSH-0-163	1434	+77.9	4.8	29.8	25.6	39.2
NIGMSH-0-172	1526	+89.3	4.5	31.7	24.6	41.8
HYBRID-4	806	—	3.3	18.3	26.8	36.0
CD 5%	578					

* First numeral —code No. of 1985; second numeral —code No. of 1986; 0—not tested in 1985; UR—unreplicated trial of 1985.

In 1986, as in the previous year, GMS hybrids performed better than CMS hybrids. The GMS system has an advantage over CMS in that a large number of males can be tested in crosses with the GMS male sterile lines, since almost all the *hirsutum* genotypes of cotton germplasm when used as males give fertile F_1 in case of GMS, whereas only a limited number of crosses can be made in CMS due to very few restorers available at present. Further, conversion of male genotypes is not required in the GMS system, whereas for CMS the male genotypes must be converted into restorers, which is a tedious process. The genetic background, local adaptability, and genetic diversity of both the parents in a cross may also be responsible for the superiority of GMS hybrids over the CMS ones. The presence of strong sterile cytoplasm in CMS may be an additional reason for the poor performance of CMS hybrids. Strong sterile cytoplasms have a tendency to reduce heterosis, since in such cases restorers can only restore fertility but cannot neutralise completely the adverse effect of strong sterile cytoplasm on heterosis.

ACKNOWLEDGEMENTS

The authors thank Dr. V. V. Singh of this Institute for help in the initial crossing programme. Authors are also thankful to Dr. J. B. Weaver, Jr., Dr. V. N. Shroff, Dr. K. Srinivasan, Dr. N. P. Mehta, and Sr. Cotton Breeder, MPKV, Rahuri, for supplying male sterile lines for the study.

REFERENCES

1. V. G. Meyer. 1975. Male sterility from *Gossypium harknessii*. J. Hered., **66** (1): 23–27.
2. D. B. Weaver and J. B. Weaver, Jr. 1977. Inheritance of pollen fertility restoration in cytoplasmic male sterile upland cotton. Crop Sci., **17**: 497–499.
3. D. D. Davis. 1978. Hybrid cotton: specific problems and potentials. Adv. Agron., **30**: 129–157.
4. J. B. Weaver, Jr. 1968. Analysis of a genetic double recessive completely male sterile cotton. Crop Sci., **8**: 597–600.
5. K. Srinivasan and K. N. Gururajan. 1978. Transference of male sterility to some improved cotton varieties. ISCI J., 3(1): 17–20.
6. J. C. Patel and N. P. Mehta. 1985. Identification and transfer of restorer gene(s) to cotton strains for use as pollinator. Cotton Dev., 14(4): 49–50.
7. V. N. Shroff. 1985. Research review on work done at Indore on cytoplasmic male sterility in cotton. Proc. National Seminar on Rainfed Cotton Production Technology, Parbhani, 24 May 1985. Central Institute for Cotton Research, Nagpur: 31–36.

8. V. N. Shroff, S. Dubey, R. Julka, S. C. Pandey, S. B. Jadhav and K. C. Mandloi. 1983. Evaluation of commercial hybrids from cytoplasmic male sterility in cotton. ISCI J., 3(1): 5–14.

9. K. Srinivasan, V. Santhanam and S. Rajasekaran. 1972. Inheritance of male sterility in *G. hirsutum* crosses. Madras Agric. J., **59**(8): 438–439.

10. K. Srinivasan and K. N. Gururajan. 1973. Boll setting in intra- *hirsutum* hybrids utilizing male sterile line. Madras Agric. J., **60**(9–12): 1885–1886.

11. K. Srinivasan and K. N. Gururajan. 1974. Economics of production of hybrid cotton seed utilizing male sterile line. Cotton Dev., **4**(3): 3–5.

12. V. Santhanam, K. Srinivasan and S. Rajasekaran. 1972. Performance of hybrid cotton involving male sterile line. Curr. Sci., **41**: 423–424.

13. K. Srinivasan, V. Santhanam and S. Rajasekaran. 1972. Development of hybrid cotton utilizing male sterile line. Cotton Dev., **2**(3): 37–39.

14. K. Srinivasan and K. N. Gururajan. 1976. Hybrid performance of additional combination of crosses involving male sterile cottons. Sci. Cult., **42**(8): 426–428.

15. K. Srinivasan and K. N. Gururajan. 1978. Role of male sterile line in the development of hybrid cotton. ISCI J., 3(2): 79–85.