



## Effects of cytoplasm on heterosis for agronomic traits in upland cotton (*Gossypium hirsutum*)

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### ABSTRACT

The effects of cytoplasm on productivity and heterosis for seed cotton (*Gossypium hirsutum* L.) yield and its component was studied in 64 hybrids. Four male sterile (A) lines CMS F 505, CMS CSH 2379, CMS LRA 5166 and CMS Jhorar and their corresponding maintainer (B) lines were crossed with eight restorer lines in a line  $\times$  tester design. The 64 crosses and a standard check, CSHH 198, were grown in a randomized block design with three replications during 2008–09. Analysis of variance revealed significant differences among genotypes. Cytoplasmic effects were estimated by comparing A  $\times$  R and B  $\times$  R hybrids combinations. Both positive and negative cytoplasmic effects were observed for all the characters studied. On the basis of mean of two groups of hybrids, it was revealed that cytoplasm significantly decreased number of bolls/plant, 2.5% span length, maturity coefficient, micronaire value and fibre strength as compared to normal cytoplasm. The estimation of standard heterosis of individual crosses showed that *Gossypium G. harknessii* cytoplasm imparting sterility also influenced heterosis in most of the crosses. Among CMS-based hybrids, CMS Jhorar  $\times$  CIR 920 P<sub>1-3</sub> (1 574 kg/ha), and among conventional hybrids F 505  $\times$  CIR 526 P<sub>2</sub> (1 944 kg/ha) were found to be highest yielding. The range of heterosis varied from –8.8 to 29.9 % in conventional hybrids while heterosis range of CMS cross combinations varied from –5.2 to 5.2 % for seed cotton yield. The combination, CMS F 505  $\times$  CIR 126 P<sub>2-1</sub> recorded the highest number of bolls (60.9), and was heterotic by a magnitude of 25.0%, while the highest heterotic effect was observed in F 505  $\times$  CIR 97 P<sub>3-4</sub> (37.9%) in conventional crosses. Similar effect of *G. harknessii* cytoplasm has been observed for other characters studied. It is thus the interaction of particular cytoplasm with the nuclear genes that affects performance. It would be more appropriate to test the CMS lines in different combinations rather than converting the female parent of released hybrids into male sterile lines.

**Key words:** Cotton, Cytoplasm, Heterosis, Restorer lines

Cotton (*Gossypium hirsutum* L.) is a bisexual often cross-pollinated crop. Cytoplasmic male sterility (CMS) is a maternally inherited phenotype, characterized by an inability to produce viable pollen because of interaction between cytoplasm and nuclear genes, while female fertility is unaffected. Cytoplasmic-nuclear male-sterility is an important biological tool, which has been used by plant breeders to increase yields in cross-pollinated crops by commercial exploitation of the phenomenon of hybrid vigour. CMS and utilization of fertility restorer system have made a breakthrough in conquering breeding bottleneck by artificial emasculation and unfolded a bright outlook for promoting commercial production of hybrid seed. Fertility of CMS plants can be recovered by nuclear fertility restorer genes. Reduction in cost of hybrid seed production is possible by using male sterility in comparison to conventional method of hand emasculation and pollination (Mehetre and Patil 2004).

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The best-known sterile cytoplasmic source available for heterosis breeding in cotton is from *G. harknessii* (Meyer 1965 and Meyer 1975). It was also reported that sterile cytoplasm has detrimental effect on yield traits in hybrid cotton but this detrimental effect could be overcome by using better CMS lines and restorers with high restorability (Dutt *et al.* 2004). In cotton, the CMS system could not be exploited commercially because of complex system of restoration and a suspected penalty on seed cotton yield and contributing traits as reported by several workers (Tuteja *et al.* 2005 and 2008). But the course of evolution can overcome this incompatibility. Keeping this in view, a breeding programme was started to develop alloplasmic restorer lines using pedigree method of breeding. These new restorer lines were used to synthesize hybrids based on normal cytoplasm and their male sterile counterparts. The effect of cytoplasm on mean performance and magnitude of heterosis in yield and fibre quality characters could then be studied using these hybrids.

Table 1 Analysis of variance for difference between CMS-based hybrids and conventional-based hybrids, i e [CMS–conventional hybrids] for yield and quality characters

Source	D F	Seed cotton yield (kg/ha)	No. of bolls/plant	Boll weight (g)	GOT (%)	2.5% span length (mm)	Maturity coefficient	Micronaire value	Strength (g/tex)
Replications	2	280 184.9	2.78	−0.36	4.79	0.01	−0.28	0.01	0.01
Differences	32	104 623.7**	159.30**	0.60**	80.88**	−0.49**	−0.87**	0.013	−0.29**
Error	64	17 800.9	3.49	0.04	0.089	0.01	−0.003	−0.013	−0.02

\* $P=0.05$ , \*\* $P=0.01$ 

## MATERIALS AND METHODS

The material for the present study comprised four male sterile (A) lines, viz CMS F 505, CMS CSH 2379, CMS LRA 5166 and CMS Jhorar and their corresponding maintainer (B) lines F 505, CSH 2379, LRA 5166 and Jhorar and eight fertility restorer @ lines, viz CIR 97 P<sub>3-4</sub>, CIR119 P<sub>2-1</sub>, CIR 126 P<sub>2-1</sub>, CIR 526 P<sub>2</sub>, CIR 920 P<sub>1-2</sub>, CIR 920 P<sub>1-3</sub>, CIR 926 P<sub>2-3</sub>, and CIR 1169P<sub>2</sub>.

Four male sterile lines and their corresponding maintainer lines were crossed with as paired crosses with eight restorer lines in a line × tester design to produce 64 crosses during 2007–08. The A × R and B × R crosses and a standard check CSHH 198, were grown in paired rows in a randomized block design (RBD) with a spacing of 100 cm × 45 cm between rows and plants respectively at the Regional Station, Central Institute for Cotton Research, Sirsa during 2008–09. Five random plants were selected to record the data on number of bolls/ plant and boll weight. The data on seed cotton yield was recorded on per plot basis and then converted into hectare basis. All the seed cotton samples were cleaned and ginned carefully in the laboratory for estimation of ginning percentage and analyzed for fibre quality parameters, viz 2.5% span length, micronaire value, fibre strength and maturity coefficient. The difference of two types of hybrids, i e CMS-based hybrids (A × R) and hybrids developed by (B × R) for each of the cross in each replication was taken in the same direction [(A × R)-(B × R)]. The analysis of variance for these differences was performed to assess the existence as well as variation for magnitude of differences among the 32 sets of crosses. A paired t- test was also performed to determine the overall effect of male sterile cytoplasm on different characters. The heterosis was calculated over best check CSHH 198 and was expressed in percentage (Rai 1978).

## RESULTS AND DISCUSSION

The analysis of variance (Table 1) indicated that the mean squares for differences between CMS and conventional hybrids were highly significant for all the characters except micronaire value, thereby suggesting that the magnitude of difference was not the same among 32 pairs of crosses for these characters and for micronaire value the non-significant mean squares do not rule out the possibility of existence of

differences between crosses. The means of hybrids of the two sets based on the A and B parents were, thus, further compared to examine the size and direction of difference. A comparison of overall mean of these two groups of hybrids (through t- test) revealed that on the whole male sterile cytoplasm significantly decreased number of bolls/plant, 2.5% span length, fibre maturity coefficient, micronaire value and fibre strength (Table 2).

The heterosis of CMS and conventional hybrids for different characters is given in Table 3 which indicates that among the male sterility-based hybrids the highest yield of 1 574 kg/ha was recorded by CMS Jhorar × CIR 920 P<sub>1-3</sub> followed by CMS F505 × CIR 126 P<sub>2-1</sub> (1543 kg/ha), whereas among conventional hybrids the highest seed cotton yield of 1 944 kg/ha was recorded by the hybrid F 505 × CIR 526 P<sub>2</sub>, followed by CSH 2379 × CIR 526 P<sub>2</sub> (1 736 kg/ha). The range of heterosis of conventional based hybrids over CSHH 198 (1 497 kg/ha) for seed cotton yield was from −8.8 to 29.9%, while heterosis range of CMS crosses varied from −5.2 to 5.2 % for seed cotton yield. Only one single cross among conventional hybrids, F 505 × CIR 526 P<sub>2</sub> recorded the significant positive heterosis of 29.9 %, whereas CMS F505 × CIR 526 P<sub>2</sub> was non-significant for seed cotton yield. However, none of the CMS crosses over CSHH 198 showed significant positive heterosis for this trait. This implies that cytoplasmic effects were result the interaction between the cytoplasm and nuclear genome as reported by Young and Virmani (1990).

Table 2 Values of 'paired t'- test for difference between CMS hybrids (A × R)– conventional Hybrids (B × R) for yield and its component characters

Character	t-value
Seed cotton yield (kg/ha)	−2.00
Number of bolls/plant	−2.02*
Boll weight (g)	−1.53
Ginning out turn (%)	−0.03
2.5% span length (mm)	−5.62**
Maturity coefficient	−5.61**
Micronaire value	−5.60**
Strength (g/tex)	−5.61**

\* $P=0.05$ , \*\* $P=0.01$

Table 3 Per cent heterosis of CMS-based hybrids (A × R) over conventional check hybrid CSHH 198 for different characters

Hybrid	Seed cotton yield (kg/ha)						Number of bolls/plant						Boll weight (g)						Ginning out turn (%)						
	Conventional hybrids			Male sterile-based hybrids			Conventional hybrids			Male sterile-based hybrids			Conventional Hybrids			Male sterile-based hybrids			Conventional hybrids			Male sterile-based hybrids			
	Mean values	Per cent heterosis	Per cent heterosis	Mean values	Per cent heterosis	Per cent heterosis	Mean values	Per cent heterosis	Per cent heterosis	Mean values	Per cent heterosis	Per cent heterosis	Mean values	Per cent heterosis	Per cent heterosis	Mean values	Per cent heterosis	Per cent heterosis	Mean values	Per cent heterosis	Per cent heterosis	Mean values	Per cent heterosis	Per cent heterosis	
F 505 × CIR 97 P <sub>3-4</sub>	1 134	-24.2	972	-35.1	67.1	37.9*	51.2	5.1	2.41	-39.2	2.70	-32.2	35.0	2.19	36.5	6.4*									
F 505 × CIR 119 P <sub>2-1</sub>	1 690	12.9	1 389	-7.2	55.4	13.9	53.5	9.9	2.67	-32.7	2.64	-33.7	36.7	7.30*	35.2	2.5									
F 505 × CIR 126 P <sub>2-1</sub>	1 574	5.1	1 543	3.1	54.6	12.3	60.9	25.0*	3.02	-23.9	3.65	-8.2	34.2	0.00	35.2	2.5									
F 505 × CIR 526 P <sub>2</sub>	1 944	29.9*	1 358	-9.3	61	25.3*	51.5	5.8	3.23	-18.7	2.96	-25.6	37.7	10.2*	36.3	5.9*									
F 505 × CIR 920 P <sub>1-2</sub>	1 574	5.1	1 142	-23.7	58.1	19.5*	50.6	4.0	3.35	-15.7	2.87	-27.8	34.5	0.73	36.0	5.0*									
F 505 × CIR 920 P <sub>1-3</sub>	1 250	-16.5	1 373	-8.2	59.3	21.8*	53.6	10.1	3.12	-21.4	3.36	-15.7	34.2	0.00	36.5	6.4*									
F 505 × CIR 926 P <sub>2-3</sub>	1 524	1.8	1 034	-30.9	57.1	17.4	49.9	2.4	3.24	-18.4	3.07	-22.9	34.7	1.31	32.5	-5.2									
F 505 × CIR 1169 P <sub>2</sub>	1 204	-19.6	1 343	-10.3	47.4	-2.4	56.9	16.8*	2.52	-36.6	2.92	-26.7	34.5	0.73	34.0	-0.9									
LRA 5166 × CIR 97 P <sub>3-4</sub>	1 250	-16.5	772	-48.5	62.8	29.0*	48.4	-0.5	2.56	-35.5	2.23	-43.9	34.5	0.73	36.7	6.9*									
LRA 5166 × CIR 119 P <sub>2-1</sub>	1 134	-24.2	1 296	-13.4	57.3	17.7	48.3	-0.8	2.79	-29.7	2.83	-28.9	35.2	2.92	34.2	-0.4									
LRA 5166 × CIR 126 P <sub>2-1</sub>	1 620	8.2	1 420	-5.2	56.6	16.4	58.0	19.0*	3.84	-3.4	3.21	-19.3	35.5	3.65	34.5	0.6									
LRA 5166 × CIR 526 P <sub>2</sub>	1 296	-13.4	1 111	-25.8	59.6	22.5*	50.0	2.6	3.57	-10.1	2.90	-27.1	38.2	11.6*	34.5	0.6									
LRA 5166 × CIR 920 P <sub>1-2</sub>	995	-33.5	1 173	-21.6	52.1	7.1	51.8	6.3	3.96	-0.4	3.50	-12.1	34.7	1.46	35.0	2.0									
LRA 5166 × CIR 920 P <sub>1-3</sub>	1 597	6.7	1 312	-12.4	57.6	18.5*	41.7	-14.3	3.52	-11.3	3.10	-22.0	35.5	3.65	36.2	5.4*									
LRA 5166 × CIR 926 P <sub>2-3</sub>	718	-52.1	972	-35.1	50.1	3.0	41.9	-14.0	3.3	-17.0	3.41	-14.2	35.0	2.19	33.3	-2.8									
LRA 5166 × CIR 1169 P <sub>2</sub>	1 366	-8.8	1 096	-26.8	52.8	8.5	45.5	-6.5	3.79	-4.7	2.96	-25.6	34.5	0.73	35.7	4.0*									
CSH 2379 × CIR 97 P <sub>3-4</sub>	856	-42.8	725	-51.5	43.6	-10.2	51.8	6.3	2.09	-47.4	2.67	-33.0	38.5	12.4*	37.8	10.3*									

Continued

Hybrid	Seed cotton yield (kg/ha)				Number of bolls/plant				Boll weight (g)				Ginning out turn (%)			
	Conventional hybrids		Male sterile-based hybrids		Conventional hybrids		Male sterile-based hybrids		Conventional Hybrids		Male sterile-based hybrids		Conventional hybrids		Male sterile-based hybrids	
	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis
CSH 2379 × CIR	1 319	-11.9	664	-55.7	60.8	24.9*	49.0	0.5	2.23	-43.8	2.51	-36.9	35.0	2.19	37.3	8.8*
119 P <sub>2-1</sub>																
CSH 2379 × CIR	1 134	-24.2	1 358	-9.3	54.6	12.3	54.1	11.0	2.8	-29.6	3.37	-15.3	35.5	3.65	34.8	1.6
126 P <sub>2-1</sub>																
CSH 2379 × CIR	1 736	16.0	1 065	-28.9	45.9	-5.5	48.7	-0.1	3.25	-18.1	2.79	-29.9	36.7	7.3*	36.5	6.4*
526 P <sub>2</sub>																
CSH 2379 × CIR	926	-38.1	849	-43.3	44.1	-9.2	42.3	-13.1	3.13	-21.3	2.64	-33.7	36.5	6.5*	35.5	3.5*
920 P <sub>1-2</sub>																
CSH 2379 × CIR	1 296	-13.4	1 173	-21.6	43.9	-9.6	45.5	-6.6	2.84	-28.6	3.49	-12.2	38.2	11.6*	35.8	4.5*
920 P <sub>1-3</sub>																
CSH 2379 × CIR	1 620	8.2	679	-54.6	56.8	16.7	46.2	-5.1	3.32	-16.4	2.42	-39.2	36.5	6.5*	34.0	-0.9
926 P <sub>2-3</sub>																
CSH 2379 × CIR	1 065	-28.9	772	-48.5	60.9	25.2*	44.8	-8.1	3.04	-23.4	2.72	-31.7	36.5	6.5*	37.5	9.3*
1169 P <sub>2</sub>																
CMS Jhorar × CIR	602	-59.8	741	-50.5	45.6	-6.1	50.7	4.2	3.31	-16.6	2.71	-31.9	33.7	-1.46	36.5	6.4*
97 P <sub>3-4</sub>																
CMS Jhorar × CIR	1 181	-21.1	926	-38.1	40.6	-16.4	54.0	10.8	3.63	-8.6	3.33	-16.4	35.5	3.65	35.8	4.5*
119 P <sub>2-1</sub>																
CMS Jhorar × CIR	1 250	-16.5	1 157	-22.7	52.4	7.8	52.5	7.9	3.75	-5.5	3.06	-23.0	32.7	-4.38	35.5	3.5*
126 P <sub>2-1</sub>																
CMS Jhorar × CIR	880	-41.2	1 389	-7.2	52.8	8.5	49.7	2.1	3.25	-18.1	3.22	-19.1	34.5	0.73	36.0	5.0*
526 P <sub>2</sub>																
CMS Jhorar × CIR	880	-41.2	910	-39.2	45.9	-5.5	50.4	3.5	3.66	-7.9	3.43	-13.7	36.2	5.8*	34.8	1.6
920 P <sub>1-2</sub>																
CMS Jhorar × CIR	995	-33.5	1 574	5.2	58.8	20.8*	45.1	-7.5	3.14	-21.0	3.45	-13.3	37	8.0*	36.5	6.4*
920 P <sub>1-3</sub>																
CMS Jhorar × CIR	694	-53.6	802	-46.4	43.9	-9.6	54.2	11.2	2.95	-25.8	3.03	-23.8	33.5	-2.19	35.0	2.0
926 P <sub>2-3</sub>																
CMS Jhorar × CIR	1 157	-22.7	1 281	-14.4	52.1	7.1	58.2	19.5*	3.59	-9.7	3.81	-4.4	36.2	5.8*	36.0	5.0*
1169 P <sub>2</sub>																
CSHH 198 (Check)	1 497		1 497		48.7		48.7		3.98		3.98		34.3		34.3	

Continued

Hybrid	2.5% span length (mm)				Micronaire value				Bundle Strength (g/tex)				Maturity coefficient			
	Conventional hybrids		Male sterile-based hybrids		Conventional hybrids		Male sterile-based hybrids		Conventional Hybrids		Male sterile-based hybrids		Conventional hybrids		Male sterile-based hybrids	
	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis
F 505 × CIR 97 P <sub>3-4</sub>	27.1	5.0*	25.5	-1.2	3.9	-2.5	3.8	-5.0	22.5	12.5*	19.7	-1.5	51	10.9*	50	8.7*
F 505 × CIR 119 P <sub>2-1</sub>	27.8	7.8*	26.7	3.5*	3.9	-2.5	3.8	-5.0	22.2	11.0*	21.4	7.0*	50	8.7*	48	4.3*
F 505 × CIR 126 P <sub>2-1</sub>	27.8	7.8*	26.4	2.3*	3.8	-5.0	4.0	0.0	22.7	13.5*	20.1	0.5	51	10.9*	49	6.5*
F 505 × CIR 526 P <sub>2</sub>	27.5	6.6*	26.4	2.3*	3.8	-5.0	3.4	-15.0	21.1	5.5*	20.8	4.0*	52	13.0*	48	4.3*
F 505 × CIR 920 P <sub>1-2</sub>	29.4	14.0*	26.5	2.7*	3.5	-12.5	3.4	-15.0	25	25.0*	21.1	5.5*	50	8.7*	48	4.3*
F 505 × CIR 920 P <sub>1-3</sub>	27.6	7.0*	26.6	3.1*	3.8	-5.0	3.9	-2.5	22.8	14.0*	19.3	-3.5	49	6.5*	47	2.2*
F 505 × CIR 926 P <sub>2-3</sub>	27.7	7.4*	26.9	4.3*	3.8	-5.0	3.3	-17.5	21.9	9.5*	21.6	8.0*	50	8.7*	47	2.2*
F 505 × CIR 1169 P <sub>2</sub>	27.2	5.4*	27.3	5.8*	3.9	-2.5	3.6	-10.0	21.9	9.5*	20.6	3.0*	51	10.9*	48	4.3*
LRA 5166 × CIR 97 P <sub>3-4</sub>	27.7	7.4*	26.9	4.3*	4.1	2.5	4.6	15.0*	21.9	9.5*	19.8	-1.0	50	8.7*	50	8.7*
LRA 5166 × CIR 119 P <sub>2-1</sub>	27.8	7.8*	28.6	10.9*	4.1	2.5	4.6	15.0*	21.4	7.0*	21.0	5.0*	51	10.9*	46	0.0
LRA 5166 × CIR 126 P <sub>2-1</sub>	27.9	8.1*	26.8	3.9*	4.1	2.5	4.3	7.5*	22.5	12.5*	20.8	4.0*	51	10.9*	48	4.3*
LRA 5166 × CIR 526 P <sub>2</sub>	26.8	3.9*	26.6	3.1*	4.2	5.0	4.2	5.0*	22.1	10.5*	21.0	5.0*	51	10.9*	47	2.2*
LRA 5166 × CIR 920 P <sub>1-2</sub>	27.6	7.0*	25.9	0.4	4.2	5.0	4.3	7.5*	23.8	19.0*	20.6	3.0*	51	10.9*	49	6.5*
LRA 5166 × CIR 920 P <sub>1-3</sub>	28	8.5*	27.1	5.0*	4.0	0.0	4.1	2.5	21.1	5.5*	19.7	-1.5	51	10.9*	48	4.3*
LRA 5166 × CIR 926 P <sub>2-3</sub>	27.8	7.8*	27.2	5.4*	4.1	2.5	4.0	0.0	21.4	7.0*	20.3	1.5*	48	4.3*	46	0.0
LRA 5166 × CIR 1169 P <sub>2</sub>	28.6	10.9*	27.4	6.2*	3.7	-7.5	3.9	-2.5	21.8	9.0*	20.6	3.0*	50	8.7*	45	-2.2
CSH 2379 × CIR 97 P <sub>3-4</sub>	28.1	8.9*	27.3	5.8*	4.0	0.0	4.0	0.0	22.4	12.0*	19.5	-2.5	52	13.0*	48	4.3*

Table 3 Concluded

Hybrid	2.5% span length (mm)			Micronaire value			Bundle Strength (g/tex)			Maturity coefficient						
	Conventional hybrids		Male sterile-based hybrids	Conventional hybrids		Male sterile-based hybrids	Conventional Hybrids		Male sterile-based hybrids	Conventional hybrids		Male sterile-based hybrids				
	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis	Mean values	Per cent heterosis				
CSH 2379 × CIR 119 P <sub>2-1</sub>	29.8	15.5*	26.3	1.9*	3.7	-7.5	3.5	-12.5	22.1	10.5*	20.0	0.0	48	4.3*	45	-2.2
CSH 2379 × CIR 126 P <sub>2-1</sub>	29.1	12.8*	27.3	5.8*	3.8	-5.0	3.7	-7.5	21.4	7.0*	20.6	3.0*	50	8.7*	47	2.2*
CSH 2379 × CIR 526 P <sub>2</sub>	28.8	11.6*	28	8.5*	3.6	-10.0	3.4	-15.0	21.7	8.5*	21.4	7.0*	50	8.7*	49	6.5*
CSH 2379 × CIR 920 P <sub>1-2</sub>	28.4	10.1*	27.4	6.2*	3.9	-2.5	4.2	5.0*	21.2	6.0*	20.0	0.0	48	4.3*	48	4.3*
CSH 2379 × CIR 920 P <sub>1-3</sub>	29.4	14.0*	27.8	7.8*	3.8	-5.0	3.9	-2.5	21.1	5.5*	20.0	0.0	51	10.9*	47	2.2*
CSH 2379 × CIR 926 P <sub>2-3</sub>	30.3	17.4*	28.1	8.9*	4.0	0.0	3.7	-7.5	22.2	11.0*	20.8	4.0*	49	6.5*	48	4.3*
CSH 2379 × CIR 1169 P <sub>2</sub>	28.6	10.9*	28.2	9.3*	3.6	-10.0	4.2	5.0*	22.5	12.5*	20.1	0.5	46	0.0	49	6.5*
CMS Jhorar × CIR 97 P <sub>3-4</sub>	25.9	0.4	25.5	-1.2	3.7	-7.5	3.8	-5.0	22.8	14.0*	20.7	3.5*	49	6.5*	49	6.5*
CMS Jhorar × CIR 119 P <sub>2-1</sub>	24.8	-3.9	25.7	-0.4	4.0	0.0	4.0	0.0	21.8	9.0*	20.9	4.5*	50	8.7*	48	4.3*
CMS Jhorar × CIR 126 P <sub>2-1</sub>	27	4.7*	26.3	1.9*	4.1	2.5	3.9	-2.5	20.9	4.5*	21.1	5.5*	49	6.5*	49	6.5*
CMS Jhorar × CIR 526 P <sub>2</sub>	26.2	1.6*	25.6	-0.8	3.8	-5.0	3.9	-2.5	20	0.0	19.4	-3.0	47	2.2*	51	10.9*
CMS Jhorar × CIR 920 P <sub>1-2</sub>	26.2	1.6*	26.2	1.6*	4.0	0.0	3.9	-2.5	21.4	7.0*	20.0	0.0	47	2.2*	48	4.3*
CMS Jhorar × CIR 920 P <sub>1-3</sub>	25.9	0.4	25.9	0.4	4.1	2.5	4.0	0.0	22	10.0*	19.1	-4.5	47	2.2*	49	6.5*
CMS Jhorar × CIR 926 P <sub>2-3</sub>	25.7	-0.4	24.7	-4.3	4.0	0.0	4.0	0.0	22.5	12.5*	18.9	-5.5	46	0.0	47	2.2*
CMS Jhorar × CIR 1169 P <sub>2</sub>	27.5	6.6*	25.3	-1.9	3.9	-2.5	4.1	2.5	21	5.0*	19.8	-1.0	50	8.7*	50	8.7*
CSHH 198 (Check)	25.8		25.8		4.0		4.0		20.0		20.0		46		46	

\*P=0.05, \*\*P=0.01

Among male sterility-based hybrids, only one single cross CMS F505 × CIR 126 P<sub>2-1</sub> produced the highest number of bolls (60.9) and was heterotic by a magnitude of 25.0% over CSHH 198 (48.7) while their maintainer line counterpart did not show any significant heterosis. The number of bolls/plant in the CMS hybrids ranged from 41.7 to 60.9, whereas for conventional hybrids it ranged from 40.6 to 67.1 bolls/plant. Among conventional hybrids, the highest heterotic effect was observed in F 505 × CIR 97 P<sub>3-4</sub> (37.9%), followed by LRA 5166 × CIR 97 P<sub>3-4</sub> (29.0 %), while the CMS-based counterparts were non-heterotic for number of bolls/plant. For boll weight, none of the CMS and conventional hybrids showed significant heterosis.

Among male sterility hybrids, the highest ginning out-turn was recorded by CMS CSH 2379 × CIR 97 P<sub>3-4</sub> (37.8%), which showed 10.3% heterosis over CSHH 198 (34.3%). The conventional hybrid CSH 2379 × CIR 97 P<sub>3-4</sub> recorded highest ginning out turn (38.5%), which showed 12.4 % heterosis over CSHH 198 (34.3%). The hybrids LRA 5166 × CIR 526 P<sub>2</sub> and CSH 2379 × CIR 920 P<sub>1,3</sub> were both heterotic by a same magnitude of 11.6% while its male sterile counterpart CMS LRA 5166 × CIR 526 P<sub>2</sub> were non-heterotic and CMS CSH 2379 × CIR 920 P<sub>1,3</sub> was heterotic by a magnitude of 4.5% over CSHH 198 for ginning out turn.

The highest 2.5% span length among male sterility hybrids was recorded by CMS LRA 5166 × CIR 119 P<sub>2-1</sub> which showed 10.9% heterosis, followed by the hybrid CMS CSH 2379 × CIR 1169 P<sub>2</sub> which exhibited heterosis of 9.3%. The CMS-based crosses exhibited heterosis the range of -0.4-10.9% (Table 3) while this range for conventional crosses was from -0.4 to 17.4%. The hybrid CSH 2379 × CIR 926 P<sub>2-3</sub> showed the highest heterosis for 2.5% span length with a magnitude of 17.4%, followed by the hybrid CSH 2379 × CIR 119 P<sub>2-1</sub> (15.5%) while their CMS counterparts also showed significant heterosis of 8.9 and 1.9%, respectively.

Among CMS-based hybrids, the highest Micronaire value was exhibited by the two hybrids, i e CMS LRA 5166 × CIR 97 P<sub>3-4</sub> and CMS LRA5166 × CIR 119 P<sub>2-1</sub> which was heterotic by a magnitude of 15% while their maintainer line counterparts did not show any heterosis. Likewise, among male sterility hybrids, the strongest fibre was produced by CMS F 505 × CIR 926 P<sub>2-3</sub> (21.6 g/tex), followed by CMS F505 × CIR 119 P<sub>2-1</sub> and CMS CSH 2379 × CIR 526 P<sub>2</sub> (21.4 g/tex), which show 8.0 and 7.0% heterosis, respectively. For conventional crosses, the hybrids F 505 × CIR 920 P<sub>1,2</sub> (25.0 g/tex), followed by LRA 5166 × CIR 920 P<sub>1,2</sub> (23.8 g/tex) produced strongest fiber which showed 25.0 and 19.0 % heterosis respectively. It was also observed that almost all the conventional crosses except Jhorar × CIR 526 P<sub>2</sub> showed heterosis for this character. Results of the present study were consistent with previous studies (Gill *et al.* 2009).

For fibre maturity coefficient, CMS-based hybrid Jhorar × CIR 526 P<sub>2</sub> exhibited the highest heterotic effect of 10.9 per cent and for conventional crosses, two hybrids, F 505 × CIR 526 P<sub>2</sub> and CSH 2379 × CIR 97 P<sub>3-4</sub> showed the same heterotic magnitude of 13.0%. It is also evident from Table 3 that mostly CMS crosses are heterotic with a lower magnitude while conventional crosses are heterotic with a higher magnitude.

It is thus evident that exotic cytoplasm inducing male sterility does not exhibit consistent effect as compared to normal cytoplasm on various traits studied. The *Gossypium harknessii* cytoplasm had unfavourable effect on number of bolls, boll weight, yield and fibre quality traits in some of the cross combinations but some crosses have been identified which are at par with the maintainer lines having normal cytoplasm. Therefore the performance of male sterility-based hybrids in cotton is governed by the compatibility of nuclear genes with the sterility-inducing cytoplasm. It would be more appropriate to test the CMS lines in newer combinations rather than converting the female parents of released hybrids into male sterile lines.

#### REFERENCES

- Dutt Yagya, Wang Xue De and Nirania K S. 2004. Effect of sterile cytoplasm on lint yield and contributing traits of F1 hybrids in cotton (*Gossypium hirsutum* L.). *International Symposium on Strategies for Sustainable Cotton Production- A Global Vision 1*, pp 216-9. 23-25 November 2004, University of Agricultural Sciences, Dharwad, Karnataka.
- Gill, B S, Sohu, R S, Dhaliwal Inderpreet and Gill, M S. 2009. Effect of *Gossypium harknessii* cytoplasm on heterosis of economic characters in upland cotton (*Gossypium hirsutum* L.). *Journal of Cotton Research and Development* **23** (2): 204-8.
- Mehetre, S S and Patil, V R. 2004. Genetics and morphological studies of new genetic male sterile lines of cotton (*Gossypium arboreum* L.). *Indian Journal of Genetics* **64**: 161-2.
- Meyer V G. 1965. Cytoplasm effects on anther numbers in interspecific hybrids. *Journal of Heredity* **56**: 292-4.
- Meyer V G. 1975. Male sterility from *Gossypium harknessii*. *Journal of Heredity* **66**: 23-7.
- Rai. B. 1978. *Heterosis Breeding*. Agro Biological Publications. New Delhi.
- Tuteja O P, Singh P, Kumar Sunil and Singh Mahendar 2005. Identification of fertility restorers for *G. harknessii* based cytoplasmic male sterility system in cotton (*G. hirsutum* L.). *Indian Journal of Genetics* **65** (2):143-4.
- Tuteja O P, verma S K. and Singh Mahendar 2008. Effect of *G. harknessii* based cytoplasmic male sterility on seed cotton yield and fibre quality traits in upland cotton (*Gossypium hirsutum* L.). *Indian Journal of Genetics* **68** (3): 288-95.
- Young J B. and Virmani, S S. (1990). Effects of cytoplasm on heterosis and combing ability for agronomic traits in rice (*Oryza sativa* L.). *Euphytica* **48**: 177-88.