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Effect of alien cytoplasmic and nuclear genes on seed cotton yield and fibre quality traits in cotton (*Gossypium hirsutum*)

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ABSTRACT

A study was conducted during 2005–06 to find out the effect of alien cytoplasm in 'alloplasmic×euplasmic' hybrids in first experiment, and the effect of alien cytoplasm as well as of alien nuclear genes in the 'alloplasmic×euplasmic' and 'euplasmic×euplasmic' hybrids, respectively, in the second experiment. The hybrids for both the experiments were produced using line×tester mating system. Yield and contributing traits exhibited superiority of conventional 'euplasmic×euplasmic' hybrids over cytoplasmic male sterility based 'alloplasmic×euplasmic' hybrids in both the experiments and over the genetic male sterility-based 'euplasmic×euplasmic' hybrids in second experiment. Cytoplasmic male sterility-based 'alloplasmic×euplasmic' hybrids were superior over the genetic male sterility-based 'euplasmic×euplasmic' hybrids in the second experiment for yield and boll weight, however, for fibre quality traits the trend of performance was variable. Alien cytoplasmic and nuclear genes did not exhibit severe deleterious effects for fibre quality related traits, even though a gain was reported in cytoplasmic male sterility based 'alloplasmic×euplasmic' hybrids for 2.5% span length and uniformity ratio over the 'euplasmic×euplasmic' hybrids in first experiment. In the second experiment, cytoplasmic male sterility-based 'alloplasmic×euplasmic' hybrids expressed their superiority over the genetic male sterility-based 'euplasmic×euplasmic' hybrids for most of the fibre quality traits. The average performance of conventional euplasmic×euplasmic' hybrids were unambiguously superior over the two types of hybrids for yield and contributing traits and most of the quality traits.

Key words: Alloplasmic, Cytoplasm, Economic heterosis, Euplasmic, Nuclear genes

Cotton (*Gossypium hirsutum* L.) is one of the most important cash crops of the world. It is globally cultivated for its fibre as well as for seed oil yield. It is an often cross pollinated crop and possesses a considerable amount of heterosis as reported by several workers (Tuteja *et al.* 2004b and Nirania *et al.* 2004). Larger flower size of the crop, highly skilled labour force and dedicated effort of scientific personnel made possible to develop world's first conventional hybrid in diploid as well as in tetraploid species of cotton in India. But in other cotton producing countries, like USA, Australia and China, hybrid seed production on a large scale is not possible by using conventional method of hand emasculation and pollination as it is labour, time and capital oriented. Several alternate methods for emasculation are available, eg use of chemical hybridizing agents, alcohol treatment, cold water treatment, use of genetic male sterility and cytoplasmic male sterility systems. Out of these only genetic male sterility and cytoplasmic male sterility systems are quite effective, because in rest of the methods there is always a chance of pistil damage and secondly the anthers are not always completely eliminated, so there remains a chance of self-pollination. In case of genetic male sterility and cytoplasmic male sterility systems, only cytoplasmic male sterility system may be more effective, because in genetic male sterility system 50% of the plants of 'A' line have to be rouged out at flowering as they produce pollen. So use of cytoplasmic male sterility line approach may prove the best method of hybrid seed production in cotton as it can reduce the cost of seed production. But the success in development of cytoplasmic male sterility-based hybrid largely depend on availability of stable male sterile cytoplasm and the effective restorer for fertility restoration in the resultant hybrids. Although there are several sources of sterile cytoplasm, viz *Gossypium arboreum*, *G. harknessii*, *G. anomalum* and *G. aridium* but the best-known sterile cytoplasmic source available for heterosis breeding in cotton is from *G. harknessii*. The cytoplasmic male sterility system could not be exploited commercially because of detrimental/ hazardous effect of the cytoplasm on the seed cotton yield

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and contributing traits as reported by several workers (Tuteja *et al.* 2004a, Dutt *et al.* 2004). So there is a need to find out such a cytoplasmic male sterility line×restorer combination which can overcome the ill effects of the alien cytoplasm. We initiated our research programme to find out the effect of alien cytoplasm of male sterile lines in cytoplasmic male sterility-based 'alloplasmic×euplasmic' hybrids in first experiment, and the effect of alien cytoplasmic as well as alien nuclear genes for male sterility in cytoplasmic male sterility based 'alloplasmic×euplasmic' and genetic male sterility based 'euplasmic×euplasmic' hybrids, respectively in the second experiment.

MATERIALS AND METHODS

Two experiments were conducted at the Regional Station Sirsa during crop season 2005–06. In the first experiment, the materials for study comprised 69 hybrids (34 alloplasmic×euplasmic hybrids, 34 euplasmic×euplasmic hybrids and 1 Zonal check hybrid 'CSHH 198').

Six cytoplasmic genetic male sterile (CGMS) lines, 'CMS K 34007', 'CMS LRA 5166', 'CMS F 505', 'CMS Jhurar', 'CMS H 777' and 'CMS SH 2379' were developed by substitution genome of standard varieties/germplasm lines into the cytoplasm of G. *harknessii*. Genotype 'IH 76' carrying *G. harknessii* cytoplasm was used as donor parent in the development of cytoplasmic male sterility lines by back cross breeding.

Two type of hybrids, i e cytoplasmic male sterility-based 'alloplasmic×euplasmic' (female lines with diversified cytoplasm for male sterility and restorer lines with diversified nuclear gene for fertility restoration from *G. harknessii*) and conventional 'euplasmic×euplasmic' (maintainer lines of cytoplasmic male sterility lines were crossed by restorer lines) were produced using line×tester mating approach during the *kharif* 2004–05 crop season.

The experimental material was grown in a randomized block design with three replications by keeping row-to-row and plant-to-plant distance of 1.0 m and 0.45 m, respectively during crop season 2005–06. Observations were taken for the following yield-related traits, viz seed cotton yield/plant, boll weight and ginning out turn (%) and fibre quality traits, viz 2.5% span length (mm), uniformity ratio (%), micronaire value and tenacity (g/tex). The observations recorded on five randomly selected plants and their mean values were used for further analysis. The mean value of all the replications for all the traits under study was calculated and using these figures the economic heterosis over the zonal hybrid check 'CSHH 198' was calculated (Meredith and Bridge 1972).

The experimental material for the second experiment consisted three type of hybrids six cytoplasmic male sterility-based 'alloplasmic×euplasmic' (female with diversified cytoplasm and male with nuclear gene/s for sterility and fertility respectively), six genetic male sterility-based 'euplasmic×euplasmic' (female and males with alien nuclear genes for male sterility and fertility respectively) and six conventional 'euplasmic×euplasmic' (male with diversified gene/s from *G. harknessii*) hybrids. Three type of hybrids were developed. The cytoplasmic male sterility and genetic male sterility version of breeding line 'K 34007' was crossed by alloplasmic restorer lines 'CIR 23A', 'CIR 26', 'CIR 28A', 'CIR 36', 'CIR 70' and 'CIR 72' to produce the first two type of hybrids while the maintainer line 'K 34007' was crossed with the above said euplasmic restorer lines to produce the third type of hybrids. All the 18 hybrids along with zonal hybrid check 'CSHH 198' were grown by following the same sowing plan, observations were recorded for the same traits, analysis was done using same procedures and results were interpreted for the same parameters as in experiment 1.

RESULTS AND DISCUSSION

Experiment 1

The economic heterosis for seed cotton yield over the zonal hybrid check 'CSHH 198' ranged from –49.45 to 72.41% in hybrids resulting from conventional 'euplasmic×euplasmic' combinations (Table 1). Out of total 34 euplasmic×euplasmic crosses the average economic heterosis (average of every euplasmic lines×all the six euplasmic restorer line) of euplasmic lines 'LRA 5166', 'F 505' and 'Jhurar' expressed positive values 20.34, 6.90 and 6.90% respectively. The range of heterosis changed with the introduction of alien cytoplasm (cytoplasm of *G. harknessii* in alloplasmic×euplasmic lines). So in hybrids with cytoplasmic male sterility-based 'alloplasmic×euplasmic' combination, the economic heterosis ranged from –48.28 to 11.52. None of the 'alloplasmic × euplasmic' hybrids could produce positive value for average economic heterosis.

The rate of heterosis loss in the hybrids resulted due to alloplasmic effect was also examined. Except few, most of the cytoplasmic male sterility-based 'alloplasmic×euplasmic' hybrids expressed a reduction in economic heterosis, the maximum loss was noticed to be 72.41% in 'LRA 5166'×'CIR 32' cross combination. Each of the six alloplasmic male sterile×euplasmic restorer lines combination depicted the average loss in heterosis, but it was maximum (47.72%) in 'LRA 5166'×restorers hybrids and minimum (7.45%) in 'SH 2379'×restorers hybrids.

Likewise, for boll weight all the cytoplasmic male sterility based 'alloplasmic×euplasmic' and most of the conventional 'euplasmic×euplasmic' hybrids expressed negative economic heterosis but this time again the value was much towards negative side in cytoplasmic male sterility-based 'alloplasmic×euplasmic' hybrids. Similar to yield, boll weight (g) also exhibited losses in economic heterosis in CMS-based 'alloplasmic×euplasmic' hybrids, which was maximum (45.52%) in 'K 34007'×'CIR 26' cross combination. This again depicted the detrimental effect of alien cytoplasm. For character ginning out turn (%) most of the hybrids,

Table 1 Hybrids showing economic heterosis for seed cotton yield/plant, boll weight (g) and ginning out turn (%) over zonal hybrid check 'CSHH 198' and loss/gain in heterosis due to alien cytoplasm in alloplasmic×euplasmic hybrids

Hybrid	Seed cotton yield (g/plant)			Boll weight (g)			Ginning out turn (%)		
	Alloplasmic× euplasmic	Euplasmic× euplasmic	Loss/gain in heterosis	Alloplasmic× euplasmic	Euplasmic× euplasmic	Loss/gain in heterosis	Alloplasmic× euplasmic	Euplasmic× euplasmic	Loss/gain in heterosis
'K34007'×'CIR 23A'	–17.24	–3.45	13.79	–21.74	1.79*	23.53	7.14*	11.43*	4.29
'K34007'×'CIR 26'	–19.52	–12.62	6.90	–25.83	19.69*	45.52	–1.14	–3.43	–2.29
'K34007'×'CIR 28A'	–22.41	–24.14	–1.72	–23.27	–9.46	13.81	10.29*	9.14*	–1.14
'K34007'×'CIR 32'	–31.03	14.97	46.00	–13.55	–16.88	–3.32	–4.00	3.43*	7.43
'K34007'×'CIR 70'	–13.79	–21.86	–8.07	–11.51	–8.44	3.07	6.57*	2.29*	–4.29
'K34007'×'CIR 72'	–11.52	3.45	14.97	–3.58	–24.81	–21.23	3.14*	10.86*	7.71
Mean	–19.24	–7.24	12.00	–15.60	–5.37	10.23	3.14*	5.71*	2.57
'LRA5166'×'CIR 23A'	–28.76	26.41*	55.17	–10.23	–5.12	5.12	0.29	15.43*	15.14
'LRA5166'×'CIR 26'	–36.76	–17.24	19.52	–29.41	0.77	30.18	–8.00	8.57*	16.57
'LRA5166'×'CIR 28A'	–40.21	–19.52	20.69	–7.42	–1.79*	5.63	1.71*	6.29*	4.57
'LRA5166'×'CIR 32'	–40.21	72.41*	112.62	–21.48	–7.42	14.07	–4.29	–1.14	3.14
'LRA5166'×'CIR 70'	–4.62	–12.62	–8.00	–18.67	–15.09	3.58	6.86*	15.43*	8.57
'LRA5166'×'CIR 72'	–13.79	3.45*	17.24	–17.39	–19.69	–2.30	6.86*	14.86*	8.00
Mean	–27.38	20.34*	47.72	–18.16	–7.93	10.23	0.57	10.00*	9.43
'F505'×'CIR 23A'	3.45*	33.31*	29.86	–23.53	–12.02	11.51	4.57*	13.71*	9.14
'F505'×'CIR 26'	–25.31	–3.45	21.86	–17.65	–8.95	8.70	3.14*	8.57*	5.43
'F505'×'CIR 28A'	–22.41	–14.97	7.45	–22.25	–12.28*	9.97	10.57*	2.86*	–7.71
'F505'×'CIR 32'	–5.72	–31.03	–25.31	–1.02	1.53	2.56	0.00	0.57	0.57
'F505'×'CIR 70'	–31.03	31.03*	62.07	–19.95	–11.00	8.95	14.86*	9.14*	–5.71
'F505'x 'CIR 72'	–13.79	26.41*	40.21	–9.21	–6.91	2.30	9.14*	2.29*	–6.86
Mean	–21.52	6.90	28.41	–15.60	–7.93	7.67	7.14*	6.29*	–0.86
'Jhurar'×'CIR 23A'	11.52*	8.07	–3.45	–6.65	–7.16	–0.51	4.00*	14.29*	10.29
'Jhurar'×'CIR 26'	–31.03	–8.07	22.97	–12.53	14.83	27.37	–11.14	1.14*	12.29
' Jhurar'x 'CIR 28A'	–25.31	–26.41	–1.10	–7.42	0.51	7.93	–3.43	0.57	4.00
'Jhurar'x 'CIR 32'	–19.52	–31.03	–11.52	–2.56	4.86*	7.42	–4.57	1.71*	6.29
'Jhurar'×'CIR 70'	–42.55	–1.17	41.38	–11.25	0.00	11.25	12.00*	9.71*	–2.29
'Jhurar'×'CIR 72'	–19.59	8.07*	27.66	–16.62	–2.05	14.58	2.29*	14.86*	12.57
Mean	–28.76	6.90*	35.66	–8.18	–7.93	0.26	–0.57	6.29*	6.86
'H–777'×'CIR 23A'	–28.76	–8.07	20.69	–22.25	–21.48	0.77	9.43*	14.29*	4.86
'H–777'×'CIR 26'	–31.03	–8.07	22.97	–29.41	–7.93	21.48	0.57	2.29*	1.71
'H–777'x 'CIR 28A'	–28.76	–12.62	16.14	–15.09	–17.90	–2.81	8.29*	4.00*	–4.29
'H–777'×'CIR 32'	–44.83	–31.03	13.79	–22.25	–16.62	5.63	–0.57	1.71*	2.29
Mean	–33.34	–14.97	18.38	–22.25	–15.60	6.65	4.43*	5.71*	1.29
'SH2379'×'CIR 23A'	–40.21	–49.45	–9.24	–30.43	–15.86	14.58	8.57*	15.43*	6.86
'SH2379 '×'CIR 26'	–28.76	–47.10	–18.34	–23.79	–20.46	3.32	0.86*	10.29*	9.43
'SH2379'×'CIR 28A'	–36.76	–26.41	10.34	–22.76	–21.74	1.02	12.86*	–1.14	–14.00
'SH2379'×'CIR 32'	–25.31	–19.52	5.79	–23.79	–27.11	–3.32	4.29*	–1.14	–5.43
'SH 2379'×'CIR 70'	–48.28	–26.41	21.86	–19.18	–13.30	5.88	10.00*	14.29*	4.29
'SH 2379'×'CIR 72'	–31.03	3.45*	34.48	–4.35	–17.65	–13.30	9.71*	9.14*	–0.57
Mean	–35.03	–27.59	7.45	–20.72	–18.16	2.56	7.71*	7.71*	0.00

*P = 0.05

irrespective of their nature (euplasmic×euplasmic or alloplasmic × euplasmic) had positive economic heterosis and it was maximum (7.70%) in alloplasmic male sterile line 'SH 2379' based hybrids in cytoplasmic male sterility-based 'alloplasmic×euplasmic' system and euplasmic line 'LRA 5166' based hybrids (10%) in conventional 'euplasmic × euplasmic' system.

In contrary to yield and contributing traits, some fibre quality traits, viz 2.5% span length (mm) and uniformity ratio (%), expressed a gain in economic heterosis in cytoplasmic male sterility-based 'alloplasmic×euplasmic' as well as in conventional 'euplasmic×euplasmic' hybrids (Table 2). The gain in 'alloplasmic×euplasmic' hybrids confirms the findings of researchers (Bhale 1999 and Shroff 2004) and contrary to the findings of Tuteja *et al.* (2004a) and Dutt *et al.* (2004). Like seed cotton yield, boll weight also showed reduction/losses in cytoplasmic male sterility-based 'alloplasmic×euplasmic' hybrids as compared to

Table 2 Hybrids showing economic heterosis for fibre quality traits over zonal hybrid check 'CSHH198' and loss/gain in heterosis due to alien cytoplasm in alloplasmic×euplasmic lines

Hybrid	2.5% span length (mm)			Uniformity ratio (%)			Micronaire Value			Tenacity (g/tex)		
	Alloplasmic× euplasmic	Euplasmic× euplasmic	Loss/gain in heterosis	Alloplasmic× euplasmic	Euplasmic× euplasmic	Loss/gain in heterosis	Alloplasmic× euplasmic	Euplasmic× euplasmic	Loss/gain in heterosis	Alloplasmic× euplasmic	Euplasmic× euplasmic	Loss/gain in heterosis
'K34007'×'CIR 23A'	6.79*	5.28*	–1.51	0.00	4.17*	4.17	4.35*	4.35*	0.00	–5.12	0.47	5.58
'K34007'×'CIR 26'	2.64*	7.17*	4.53	2.08*	4.17*	2.08	–13.04	–8.70	4.35	–6.51	0.47	6.98
'K34007'×'CIR 28A'	–1.89	2.64*	4.53	4.17*	4.17*	0.00	0.00	4.35*	4.35	–9.77	–9.30	0.47
'K34007'×'CIR 32'	4.15*	7.55*	3.40	4.17*	0.00	–4.17	–2.17	2.17*	4.35	–1.40	–3.72	–2.33
'K34007'×'CIR 70'	–3.02	5.66*	8.68	4.17*	4.17*	0.00	–4.35	–17.39	–13.04	–6.51	–5.12	1.40
'K34007'×'CIR 72'	3.77*	4.15*	0.38	4.17*	4.17*	0.00	–8.70	–10.87	–2.17	–6.98	–5.12	1.86
Mean	2.26*	5.28*	3.02	3.13*	3.54*	0.42	–4.35	–4.35	0.00	–6.05	–3.72	2.33
'LRA5166'x 'CIR 23A'	8.30*	5.28*	–3.02	6.25*	4.17*	–2.08	17.39*	–2.17	–19.57	–3.72	0.00	3.72
'LRA5166'x 'CIR 26'	3.02*	1.89*	–1.13	0.00	4.17*	4.17	–13.04	4.35*	17.39	0.93	–2.79	–3.72
'LRA5166'x 'CIR 28A'	7.92*	6.79*	–1.13	–2.08	4.17*	6.25	–6.52	8.70*	15.22	2.79	–0.93	–3.72
'LRA5166'x 'CIR 32'	2.26*	4.15*	1.89	4.17*	0.00	–4.17	–2.17	6.52*	8.70	–3.26	–2.79	0.47
'LRA5166'x 'CIR 70'	9.81*	1.51*	–8.30	–2.08*	–2.08	0.00	–2.17	0.00	2.17	6.51	–4.19	–10.70
'LRA5166'x 'CIR 72'	6.79*	4.15*	–2.64	4.17*	0.00	–4.17	–4.35	–4.35	0.00	0.47	–3.72	–4.19
Mean	6.42*	3.77*	–2.64	1.67*	1.25*	–0.42	–2.17	2.17*	4.35	0.47	–2.33	–2.79
'F505'×'CIR 23A'	3.02*	3.77*	0.75	0.00	–2.08	–2.08	6.52*	–2.17	–8.70	–2.79	–9.30	–6.51
'F505'×'CIR 26'	1.89*	9.81*	7.92	0.00	4.17*	4.17	–10.87	2.17*	13.04	–9.77	–1.86	7.91
'F505'×'CIR 28A'	1.89*	3.02*	1.13	4.17*	0.00	–4.17	8.70*	6.52*	–2.17	–5.12	–1.40	3.72
'F505'×'CIR 32'	6.04*	3.77*	–2.26	0.00	4.17*	4.17	2.17*	0.00	–2.17	–6.51	–3.72	2.79
'F505'×'CIR 70'	5.66*	8.30*	2.64	4.17*	0.00	–4.17	4.35*	–6.52	–10.87	–1.86	–2.79	–0.93
'F505'x 'CIR 72'	4.53*	10.19*	5.66	2.08*	–4.17	–6.25	–4.35	2.17*	6.52	–3.72	–6.98	–3.26
Mean	3.77*	6.42*	2.64	1.67*	0.42*	–1.25	2.17*	0.00	–2.17	–5.12	–4.19	0.93
'Jhurar'×'CIR 23A'	2.64*	5.66*	3.02	0.00	8.33*	8.33	8.70*	17.39*	8.70	–10.23	–1.86	8.37
'Jhurar'×'CIR 26'	4.53*	5.28*	0.75	0.00	8.33*	8.33	–6.52	6.52*	13.04	–6.98	–8.84	–1.86
' Jhurar'×'CIR 28A'	1.13*	–0.75	–1.89	4.17*	8.33*	4.17	8.70*	2.17*	–6.52	–3.72	3.72	7.44
'Jhurar'×'CIR 32'	–2.26	0.75*	3.02	2.08*	10.42*	8.33	2.17*	8.70*	6.52	–6.05	–5.58	0.47
'Jhurar'×'CIR 70'	1.13*	6.79*	5.66	6.25*	6.25*	0.00	–4.35	4.35*	8.70	–3.26	–2.33	0.93
'Jhurar'×'CIR 72'	3.02*	4.53*	1.51	6.25*	8.33*	2.08	–8.70	4.35*	13.04	2.79	–2.79	–5.58
Mean	6.04*	6.42*	0.38	4.17*	0.42*	–3.75	4.35*	0.00	–4.35	–3.72	–4.19	–0.47
'H–777'×'CIR 23A'	6.04*	11.32*	5.28	4.17*	8.33*	4.17	13.04	0.00	–13.04	–3.72	1.86	5.58
'H–777'×'CIR 26'	4.91*	8.30*	3.40	6.25*	8.33*	2.08	–13.04	–8.70	4.35	–1.86	–1.86	0.00
'H–777'×'CIR 28A'	–0.38	0.38	0.75	4.17*	6.25*	2.08	8.70	0.00	–8.70	–3.72	–2.33	1.40
'H–777'×'CIR 32'	5.28*	–0.75*	–6.04	6.25*	8.33*	2.08	–13.04	–6.52	6.52	–2.79	–5.12	–2.33
Mean	3.96*	4.91*	0.94	5.21*	7.92*	2.71	–1.09	–4.35	–3.26	–3.02	–1.86	1.16
'SH2379'×'CIR 23A'	18.11*	1.89*	–16.23	–2.08*	2.08*	4.17	–6.52	–4.35	2.17	–1.40	–10.23	–8.84
'SH2379 '×'CIR 26'	9.43*	11.70*	2.26	2.08*	2.08*	0.00	–13.04	2.17*	15.22	–2.79	–3.72	–0.93
'SH2379'×'CIR 28A'	7.92*	13.96*	6.04	0.00	4.17*	4.17	–10.87	–15.22	–4.35	–2.79	–0.47	2.33
'SH2379'×'CIR 32'	6.04*	5.28*	–0.75	2.08*	8.33*	6.25	–6.52	2.17*	8.70	–2.79	–3.72	–0.93
'SH 2379'×'CIR 70'	7.17*	11.70*	4.53	4.17*	6.25*	2.08	–4.35	–13.04	–8.70	–8.84	5.58	14.42
'SH 2379'×'CIR 72'	11.32*	11.32*	0.00	2.08*	4.17*	2.08	–6.52	–23.91	–17.39	–3.72	12.56	16.28
Mean	10.19*	9.43*	–0.75	1.46*	4.58*	3.13	–8.70	–8.70	0.00	–3.72	0.00	3.72

* $P = 0.05$

conventional 'euplasmic×euplasmic' hybrids. Similar to our findings, Weaver (1986) also reported that hybrids using cultivars as the female parent (not sterile cytoplasm) produced the high yield, but hybrids produced by using restorers with *G. harknessii* cytoplasm as the female parent showed about 8% reduction on yield. Similarly, Zhu *et al*. (1998) also observed detrimental effect of sterile cytoplasm on yield and contributing traits. The average performance for ginning out turn (%) was fairly well expressed in cytoplasmic male sterility-based 'alloplasmic×euplasmic' as well as in conventional 'euplasmic×euplasmic' hybrids. The per cent loss for ginning out turn in 'alloplasmic×euplasmic' hybrids over 'euplasmic×euplasmic' hybrids was found minimum or even a slight gain (0.86) was recorded in alloplasmic line 'F 505' based hybrids. This indicates that the genetic background of specific line may overcome the hazardous effect of alien cytoplasm.

Experiment 2

The economic heterosis for seed cotton yield (Table 3) over the zonal hybrid check 'CSHH 198' was negative in all the hybrids, irrespective of there nature except conventional euplasmic×euplasmic hybrids 'K 34007'×'CIR 32' and 'K 34007'×'CIR 70'. The mean economic heterosis value (negative) was maximum (–29.72) in genetic male sterility based 'euplasmic×euplasmic' hybrid (female and male parents have alien nuclear gene/s for male sterility and fertility restoration, respectively), while it was minimum (–7.24) in conventional 'euplasmic×euplasmic' (with diversified nuclear gene for fertility restoration) hybrids. The mean average heterosis value of cytoplasmic male sterility based 'alloplasmic×euplasmic' hybrids was also negative but it was in between (–19.24) the conventional and genetic male sterility-based 'euplasmic×euplasmic' hybrids. This clearly depicts the detrimental effect of alien cytoplasm as well as of nuclear genes on yield. Similar results were also observed for boll weight, where the mean economic heterosis was negative for all the three type of the crosses. This time again the mean economic heterosis value was minimum (–6.39) for conventional 'euplasmic×euplasmic' hybrids, maximum (–22.76) for genetic male sterility based 'euplasmic × euplasmic' hybrids and in between (–16.62) for cytoplasmic male sterility-based 'alloplasmic×euplasmic' hybrids. The reduction in heterosis was probably either due to the pleiotropic effect of alien cytoplasm and nuclear gene/s of *G. harknessii* origin or due to the tight linkage between the gene/s for desired trait (here in this case male sterility and fertility restoration are the desired traits) and other unknown but deleterious genes of *G. harknessii* origin which pose a critic hindrance in the fuller potential expression of the native gene/s of *G. hirsutum* for yield and contributing traits.

The mean economic heterosis value for ginning out turn per cent was positive for all the three type of hybrids and

Table 3 Hybrids showing economic heterosis for seed cotton yield/plant, boll weight (g) and ginning out turn (%) over zonal hybrid check 'CSHH198' and loss/gain in heterosis due to alien cytoplasm/nuclear gene in CMS-based alloplasmic×euplasmic and GMS-based euplasmic×euplasmic (alien nuclear gene) hybrids

Hybrid	Seed cotton yield (g/plant)					Boll weight (g)					Ginning out turn (%)				
	A	B	C	Per cent loss+	Per cent loss++	A	B	C	Per cent loss+	Per cent loss ++	A	B	C	Per cent loss+	Per cent loss++
'K34007'×'CIR 23A'	–3.45	–27.59	–17.24	–24.14	–13.79	1.79	–24.30	–21.74	–26.09	–23.53	11.43*	9.71*	7.14*	–1.71	–4.29
'K34007'×'CIR 26'	–12.62	–13.79	–19.52	–1.17	–6.90	19.69*	–27.37	–25.83	–47.06	–45.52	–3.43	5.14*	–1.14*	8.57	2.29
'K34007'x 'CIR 28A'	–24.14	–40.21	–22.41	–16.07	1.72	–9.46	–30.43	–23.27	–20.97	–13.81	9.14*	2.57*	10.29*	–6.57	1.14
'K34007'×'CIR 32'	14.97*	–31.03	–31.03	–46.00	–46.00	–16.88	–9.72	–13.55	7.16	3.32	3.43*	–3.71	–4.00	–7.14	–7.43
'K34007'×'CIR 70'	–21.86	–32.21	–13.79	–10.34	8.07	–8.44	–20.97	–11.51	–12.53	–3.07	2.29*	11.43*	6.57*	9.14	4.29
'K34007'×'CIR 72'	3.45*	–33.31	–11.52	–36.76	–14.97	–24.81	–23.79	–3.58	1.02	21.23	10.86*	5.71*	3.14*	–5.14	–7.71
Mean	–7.24	–29.72	–19.24	–22.48	–12.00	–6.39	–22.76	–16.62	–16.37	–10.23	5.71*	5.14*	3.71*	–0.57	–2.00

Where A,B and C are conventional 'euplasmic×euplasmic', genetic male sterility based 'euplasmic×euplasmic' and cytoplasmic male sterility based 'alloplasmic×euplasmic' hybrids respectively.

+ & ++ indicate per cent loss/gain in economic heterosis over conventional 'euplasmic × euplasmic' hybrids of genetic male sterility-based 'euplasmic×euplasmic' hybrids and cytoplasmic male sterility-based 'alloplasmic × euplasmic' hybrids, respectively

*P = 0.05 level of probability.

conventional hybrids again depicted their superiority over genetic male sterility and cytoplasmic male sterility system-based ‘alloplasmic×euplasmic’ and ‘euplasmic×euplasmic’ hybrids, respectively. But here contrary to the earlier traits the performance of genetic male sterility-based ‘euplasmic×euplasmic’ hybrids were superior (5.14%) over the cytoplasmic male sterility-based ‘alloplasmic×euplasmic’ hybrids (3.71%). This clearly indicates that the fuller expression of this trait in cytoplasmic male sterility-based ‘alloplasmic×euplasmic’ hybrids is lower down by the cytoplasmic genes of *G. harknessii* origin.

The per cent losses in economic heterosis over conventional ‘euplasmic×euplasmic’ hybrids for seed cotton yield (–22.48% in genetic male sterility and –12.0% in cytoplasmic male sterility) and boll weight (–16.37% in genetic male sterility and –10.23% in cytoplasmic male sterility) was higher in genetic male sterility-based ‘euplasmic×euplasmic’ hybrids as compared to cytoplasmic male-sterility based ‘alloplasmic×euplasmic’ hybrids. This indicates that the alien nuclear genes have more detrimental effect as compared to alien cytoplasmic genes. But this was not true for the trait ginning out turn, where reverse was true, ie alien cytoplasm has more deleterious effect as compare to alien nuclear genes.

The superiority of cytoplasmic male sterility-based ‘alloplasmic×euplasmic’ hybrids over the genetic male sterility-based ‘euplasmic×euplasmic’ hybrids indicated that it is the nuclear gene/s instead of the cytoplasmic genes of *G. harknessii* origin which make a ceiling on the fuller expression of the fibre quality traits, namely 2.5% span length and uniformity ratio. But the superiority of conventional ‘euplasmic×euplasmic’ hybrids over the cytoplasmic male sterility-based ‘alloplasmic×euplasmic’ hybrids indicated that the cytoplasmic genes also have detrimental effect on the expression of quality characters. So, both *G. harknessii* origin-based cytoplasmic male sterility as well as nuclear genes have negative effects on most of the fibre quality as well as for yield and contributing traits with few exceptions (Table 4). This is the reason for not exploiting commercially the cytoplasmic male sterility and genetic male sterility-based hybrid seed production systems by researchers and the hybrid seed producers. But it does not mean to end up the breeding efforts. The search for better restorer lines and high performer cytoplasmic male sterility lines should be uninterruptedly carried on.

The ill effect of the alien nuclear genes can be overcome by breeding efforts, which may take time. But it is difficult task to overcome the ill effect of the alien cytoplasm because the cytoplasm is transmitted to the next generation only by female parent. Here only opportunity remains for breeders is to choose best performing breeding lines for yield and related traits in which *G. harknessii* cytoplasm has to be transferred for converting them into male sterile lines. Precise breeding involving newer biotechnological approaches of

Table 4 Hybrids showing economic heterosis for fibre quality traits over zonal hybrid check ‘CSHH198’ and loss/gain in heterosis due to alien cytoplasm/nuclear gene in CMS-based alloplasmic×euplasmic and GMS-based euplasmic×euplasmic (alien nuclear gene) hybrids

Hybrid	2.5% span length (mm)					Uniformity ratio (%)					Micronaire Value					Tenacity (g/tex)				
	A	B	C	Per cent loss+	Per cent loss++	A	B	C	Per cent loss+	Per cent loss ++	A	B	C	Per cent loss+	Per cent loss++	A	B	C	Per cent loss+	Per cent loss++
‘K34007’×‘CIR 23A’	2.2*	–1.8	3.7*	–4.0	1.5	8.7*	–2.2*	4.4*	–10.9	–4.3	–5.9	–5.9	–5.9	0.0	0.0	3.9*	3.4*	–1.9	–0.5	–5.8
‘K34007’×‘CIR 26’	4.0*	0.4	–0.4	–3.7	–4.4	8.7*	0.0*	6.5*	–8.7	–2.2	–17.7	–25.5	–21.6	–7.8	–3.9	3.9*	9.6*	–3.4	5.8	–7.2
‘K34007’×‘CIR 28A’	–0.4	–7.3	–4.8	–7.0	–4.4	8.7*	10.9*	8.7*	2.2	0.0	–5.9	–7.8	–9.8	–2.0	–3.9	–6.3	–1.9	–6.7	4.3	–0.5
K34007×CIR 32	4.4*	–3.3	1.1*	–7.7	–3.3	4.4*	2.2*	8.7*	–2.2	4.3	–7.8	–11.8	–11.8	–3.9	–3.9	–0.5	5.8*	1.9*	6.3	2.4
‘K34007’×‘CIR 70’	2.6*	1.5*	–5.9	–1.1	–8.4	8.7*	6.5*	8.7*	–2.2	0.0	–25.5	–11.8	–13.7	13.7	11.8	–1.9	–1.9	–3.4	0.0	–1.4
‘K34007’×‘CIR 72’	1.1*	1.1*	0.7	0.0	–0.4	8.7*	4.4*	8.7*	–4.3	0.0	–19.6	–15.7	–17.7	3.9	2.0	–1.9	6.3*	–3.9	8.2	–1.9
Mean	2.2*	–1.5	–0.7	–3.7	–2.9	8.0*	3.7*	7.6*	–4.3	–0.4	–13.7	–13.7	–13.7	0.0	0.0	–0.5	3.4*	–2.9	3.8	–2.4

Where A,B and C are conventional ‘euplasmic×euplasmic’, genetic male sterility based ‘euplasmic×euplasmic’ and cytoplasmic male sterility based ‘alloplasmic×euplasmic’ hybrids, respectively.

+ & ++ indicate per cent loss/gain in economic heterosis over conventional ‘euplasmic×euplasmic’ hybrids of genetic male sterility-based ‘euplasmic×euplasmic’ hybrids and cytoplasmic male sterility-based ‘alloplasmic×euplasmic’ hybrids, respectively.

P = 0.05 level of probability.

gene transfer can be used for the transfer of only desired gene/s for male sterility in *G. hirsutum* breeding to avoid any deleterious effect. Besides this there is a need to develop better and stable performing restorer lines with high restoration ability.

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