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Heterosis studies using thermo-sensitive genetic male sterile lines in rice

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ABSTRACT

Two-line breeding using thermo-sensitive genic male sterile lines (TGMS) is a better alternative for three-line breeding in rice in tropical region. Six elite TGMS line were crossed with eight diverse male parents. The resultant 48 hybrids were evaluated along with their parents and a standard check PA 6444 at three locations. Pooled analysis for heterosis revealed that grain yield was mostly due to simultaneous heterosis for different yield components. The crosses DRR 7S x EPLT 109R, DRR 22S x KMR 3R, DRR 17S x BCW 56R, DRR 6S x BCW 56R, DRR 20S x KMR 3R and DRR 1S x IR 58025B were found to be good based on their over all performance across the traits.

Key words: *rice, thermo-sensitive genetic male sterile, heterosis lines*

Hybrid rice technology one of the practically feasible and readily adoptable genetic options has been amply demonstrated in China. Cytoplasmic genetic male sterility (cms) is by far the most widely used system for developing rice hybrids in China and elsewhere. CMS system, although stable, is cumbersome to use for developing hybrids (Virmani, 1996). It restricts the use of varieties/elite lines as parental lines for want of specific maintainer and restorer genes.

The thermo-sensitive genetic male sterility system (TGMS) is considered to be a more efficient alternative to the CMS system for hybrid seed production, in which sterility/fertility expression is controlled by temperature at a particular stage of panicle development. Deploying TGMS system for developing two line hybrids has several advantages over conventional CMS system, as it requires neither maintainer for seed multiplication nor the restorers for hybrid seed production. Any line can be converted into a TGMS line and any line can be used as a pollen parent thus paving the way for widening the genetic base of hybrids. Besides, this system is most suitable for developing hybrids in *Japonica* and Basmati rice in which restorers are hard to find (Virmani and Ilyas-Ahmed, 2001). In the present investigation efforts were made to know the nature and magnitude of heterosis in the form of average heterosis, heterobeltiosis and standard heterosis for grain yield and its components in TGMS lines.

MATERIALS AND METHODS

Six elite TGMS lines (DRR 1S, DRR 6S, DRR 7S, DRR 18S, DRR 20S, DRR 22S) were crossed with eight diverse male parents (APMS 6B, PMS 17B, CRMS 32B, IR 58025B, KMR 3R, EPLT 109R, C 20R, BCW 56R) during wet season (WS) 2005 at Directorate of Rice Research (DRR), Rajendranagar, Hyderabad. The resultant hybrids were evaluated along with their parents and a standard check PA 6444 in a randomized block design, replicated thrice at three diverse locations viz., DRR, Hyderabad; Regional Agricultural Research Station (RARS), Warangal; and RARS, Jagtial during dry season 2005-06. A standard package of practices was followed for raising the crop. Data were recorded on plant height, number of productive tillers plant^{-1}, panicle length, number of spikelets panicle^{-1}, spikelet fertility, 100 grain weight and grain yield plant^{-1} on ten random plants per each replication per each treatment. Days to 50% flowering was recorded on plot basis. Heterosis (Liang *et al*., 1972) was estimated as the superiority of F_1 over mid parent (average heterosis), better parent (heterobeltiosis) and standard check (standard heterosis) for eight characters in 48 hybrids.

RESULTS AND DISCUSSION

The pooled analysis for variance over three locations revealed significant differences for locations for all the characters except number of spikelets panicle^{-1} and spikelet fertility. Significant differences for replications x locations were not recorded (Table 1). The differences among the parents, parents vs. hybrids and hybrids were observed to be significant for all the characters studied.

Early maturing hybrids are desirable as they produce more yield per day and fit well in multiple cropping system. In pooled analysis, average heterosis ranged from -16.24 (DRR 1S x BCW 56R) to 15.57 per cent (DRR 20S x IR 58025B). Eleven hybrids took significantly less number of days. The crosses of DRR 1S were most promising for early flowering than the other hybrids. Twenty one hybrids exhibited significant negative heterobeltiosis and matured earlier than their corresponding better parents. The hybrids DRR 1S x BCW 56R, DRR 1S x KMR 3R, DRR 1S x CRMS 32B and DRR 1S x IR 58025B flowered early and recorded significant and negative standard heterosis (Table 2). Presence of both negative and positive heterosis was reported earlier by Verma *et al.* (2004), Shanthala *et al.* (2006) and Chaudhary *et al.* (2007). Shorter plant type is an important character of a hybrid to withstand lodging. In this study, the hybrids showed both positive and negative nature of heterosis with regard to plant height. The hybrids were in the range from -21.64 to 10.96 per cent of heterosis and from -31.18 to 10.31 per cent of heterobeltiosis. The highest significant and negative heterosis was observed in DRR 1S x EPLT 109R (-24.83%) followed by DRR 17S x CRMS 32B (-23.05%). Several workers *viz.*, Lokaprakash *et al.* (1992), Verma *et al.* (2004) and Shanthala *et al.* (2006) reported the both positive and negative heterosis.

The average heterosis for number of productive tillers plant^{-1} ranged from -7.62 (DRR 1S x CRMS 32B) to 73.26 per cent (DRR 7S x APMS 6B). Only five hybrids viz., DRR 7S x APMS 6B, DRR 7S x IR 58025B, DRR 6S x CRMS 32B, DRR 20S x CRMS 32B and DRR 20S x IR 58025B showed significant positive standard heterosis over PA 6444 (Table 2). Significant positive heterosis for this character was also reported by Lokaprakash *et al.* (1992), Panwar *et al.* (2002) and Shanthala *et al.* (2006). Hybrids are generally characterized by having larger panicles indicating their efficiency in partitioning of assimilates to reproductive parts. This is one of the attributes of higher yields in hybrids. Twenty three hybrids registered significant positive heterosis (-12.08 to 26.69 per cent) but no hybrid registered significant and positive heterosis for panicle length over the check PA 6444.

Number of spikelets panicle^{-1} is the main yield contributing character in the hybrids. Significant positive heterosis is desirable for this trait. The relative heterosis and heterobeltiosis ranged from -29.51 (DRR 1S x CRMS 32B) to 64.17 per cent (DRR 1S x PMS 17B) and from -37.76 (DRR 1S x CRMS 32B) to 53.83 per cent (DRR 6S x C 20R). Eleven hybrids manifested significant positive standard heterosis over PA 6444 ranging from 6.28 (DRR 17S x C 20R) to 30.10 per cent (DRR 1S x PMS 17B) (Table 3). But this

Table 1. Pooled analysis of variance for grain yield and yield components in rice

Source of variation	df	Days to 50% flowering	Plant height	No. of productive tillers plant^{-1}	Panicle length	No.of spikelets panicle^{-1}	Spikelet fertility	100 grain weight	Grain yield plant^{-1}
Locations	2	1848.16**	944.50**	123.33**	73.38**	162.03	63.49	0.08**	66.55**
Replications x locations	4	0.74	4.02	1.98	0.61	98.76	41.83	0.004	5.37
Treatments	61	701.67**	512.84**	44.58**	51.67**	9503.25**	566.37**	0.11**	154.69**
Parents	13	957.33**	1029.42**	21.68**	74.96**	3254.76**	1013.39**	0.10**	15.91*
Parents vs. Hybrids	1	337.04**	469.68**	859.17**	85.49**	22145.36**	11488.43**	0.19**	4473.09**
Hybrids	47	638.71**	370.88**	33.58**	44.51**	10962.57**	210.34**	0.11**	101.19**
Error	366	3.11	7.09	2.5	1.98	95.53	32.81	0.003	7.31

* - Significant at 1% level
** - Significant at 5% level

Table 2. Estimates of heterosis, heterobeltiosis and standard heterosis for days to 50% flowering, plant height and number of productive tillers plant^{-1} over locations

Hybrids	Days to 50% flowering			Plant height			No. of productive tillers plant^{-1}		
	Heterosis	Hetero beltiosis	Standard Heterosis	Heterosis	Hetero beltiosis	Standard Heterosis	Heterosis	Hetero beltosis	Standard Heterosis
DRR 1S x APMS 6B	2.77 **	-11.50 **	-9.25 **	1.40	-3.25 *	-8.19 **	5.38	0.73	-16.29 *
DRR 1S x PMS 17B	7.01 **	-6.99 **	-6.70 **	-3.46 *	-5.54 **	-14.91 **	30.97 **	26.19 **	-4.38
DRR 1S x CRMS 32B	-1.99 *	-15.49 **	-13.60 **	-4.42 **	-4.80 *	-17.94 **	-7.62	-13.03	-25.37 **
DRR 1S x IR 58025B	3.66 **	-8.73 **	-11.16 **	-2.83	-4.24 *	-14.99 **	29.66 **	17.12 *	10.02
DRR 1S x KMR 3R	-10.84 **	-25.19 **	-18.28 **	-13.06 **	-24.46 **	-11.73 **	-3.17	-10.34	-20.26 **
DRR 1S x EPLT 109R	15.15 **	-3.04 **	4.99 **	-21.64 **	-28.86 **	-24.83 **	57.51 **	40.95 **	6.81
DRR 1S x C 20R	10.89 **	-6.33 **	0.64	8.26 **	3.30 *	-1.97	32.18 **	26.67 **	-4.02
DRR 1S x BCW 56R	-16.24 **	-30.53 **	-21.89 **	-7.90 **	-15.14 **	-13.20 **	31.63 **	22.86 **	-6.91
DRR 6S x APMS 6B	10.18 **	5.39 **	8.08 **	-8.90 **	-14.11 **	-18.49 **	10.39	6.45	-4.74
DRR 6S x PMS 17B	4.88 **	1.38	1.70	-5.08 **	-8.26 **	-17.36 **	0.84	-10	-19.46 **
DRR 6S x CRMS 32B	5.59 **	1.14	3.40 **	-0.15	-1.02	-15.36 **	36.26 **	33.47 **	19.43 **
DRR 6S x IR 58025B	2.06 *	0.11	-2.55 *	4.62 **	1.83	-9.60 **	11.74 *	9.09	2.48
DRR 6S x KMR 3R	6.02 **	-1.56	7.55 **	-19.94 **	-31.18 **	-19.58 **	3.14	2.82	-7.99
DRR 6S x EPLT 109R	-5.47 **	-11.87 **	-4.57 **	-4.00 **	-13.83 **	-8.95 **	33.38 **	11.29	-0.41
DRR 6S x C 20R	2.11 *	-4.45 **	2.66 *	2.50	-3.36 *	-8.30 **	9.88	-2.42	-12.68 *
DRR 6S x BCW 56R	6.96 **	-1.98 *	10.20 **	-5.72 **	-14.13 **	-12.17 **	23.72 **	7.26	-4.02
DRR 7S x APMS 6B	7.56 **	6.73 **	11.16 **	6.75 **	2.72	-2.52	73.26 **	61.51 **	34.23 **
DRR 7S x PMS 17B	7.17 **	5.20 **	9.56 **	6.21 **	4.83 **	-5.57 **	49.33 **	47.66 **	6.08
DRR 7S x CRMS 32B	6.08 **	5.10 **	9.46 **	-0.81	-2.06	-14.08 **	30.30 **	19.70 *	2.71
DRR 7S x IR 58025B	-7.59 **	-10.61 **	-6.91 **	10.96 **	10.31 **	-2.08	48.88 **	31.37 **	23.40 **
DRR 7S x KMR 3R	-6.57 **	-8.75 **	-0.32	-18.72 **	-28.85 **	-16.86 **	32.86 **	20.09 **	6.81
DRR 7S x EPLT 109R	1.15	-0.79	7.44 **	-14.58 **	-21.83 **	-17.40 **	46.87 **	34.61 **	-3.3
DRR 7S x C20R	2.36 **	0.79	8.29 **	-7.22 **	-10.72 **	-15.27 **	22.58 **	20.54 *	-13.40 *
DRR 7S x BCW 56R	-2.26 **	-5.86 **	5.84 **	-6.23 **	-12.90 **	-10.91 **	60.59 **	53.69 **	10.41
DRR 17S x APMS 6B	0.71	-0.80	4.89 **	-6.27 **	-13.32 **	-17.74 **	11.09	10.93	-7.81
DRR 17S x PMS 17B	3.87 **	1.21	7.01 **	2.01	-3.34 *	-12.93 **	26.79 **	17.13 *	-2.94
DRR 17S x CRMS 32B	7.92 **	6.13 **	12.22 **	-7.38 **	-10.02 **	-23.05 **	0.97	-0.77	-14.84 *
DRR 17S x IR 58025B	7.80 **	3.52 **	9.46 **	-1.13	-5.66 **	-16.26 **	25.71 **	18.31 **	11.14
DRR 17S x KMR 3R	6.38 **	4.67 **	14.35 **	1.70	-14.06 **	0.43	27.69 **	23.34 **	9.69
DRR 17S x EPLT 109R	1.79 *	0.59	8.93 **	5.01 **	-7.43 **	-2.19	11.25	-4.21	-20.62 **
DRR 17S x C 20R	4.19 **	3.36 **	11.05 **	9.95 **	1.69	-3.50 *	26.02 **	15.82 *	-4.02
DRR 17S x BCW 56R	-1.02	-3.97 **	7.97 **	3.96 *	-7.04 **	-4.92 **	26.32 **	13.21	-6.18
DRR 20S x APMS 6B	-5.22 **	-11.50 **	-9.25 **	3.18 *	-4.58 **	-9.44 **	3.32	2.04	-13.05 *
DRR 20S x PMS 17B	6.34 **	0.32	0.64	7.07 **	1.45	-8.61 **	37.17 **	25.12 **	6.62
DRR 20S x CRMS 32B	8.73 **	1.66	3.93 **	5.46 **	2.45	-12.39 **	33.62 **	33.15 **	14.26 *
DRR 20S x IR 58025B	15.57 **	10.59 **	7.65 **	4.54 **	-0.26	-11.46 **	25.68 **	19.84 **	12.58 *
DRR 20S x KMR 3R	8.42 **	-1.65	7.44 **	-5.30 **	-19.98 **	-6.50 **	10.23	7.92	-4.02
DRR 20S x EPLT 109R	8.08 **	-1.57	6.59 **	9.58 **	-3.40 *	2.06	15.42 *	-1.76	-16.29 *
DRR 20S x C 20R	2.38 *	-6.43 **	0.53	8.47 **	0.32	-4.81 **	20.38 **	9.25	-6.91
DRR 20S x BCW 56R	-5.12 **	-15.03 **	-4.46 **	4.45 **	-6.61 **	-4.48 **	41.57 **	25.34 **	6.81
DRR 22S x APMS 6B	2.04 *	0.93	3.51 **	3.75 *	-2.68	-7.64 **	0.37	-2.31	-18.81 **
DRR 22S x PMS 17B	0.00	0.00	0.32	-5.64 **	-9.27 **	-18.27 **	49.28 **	41.28 **	11.14
DRR 22S x CRMS 32B	2.62 **	1.66	3.93 **	4.35 *	2.90	-12.00 **	-2.59	-6.65	-19.90 **
DRR 22S x IR 58025B	-2.80 **	-4.24 **	-3.93 **	6.69 **	3.31 *	-8.30 **	12.05 *	2.94	-3.3
DRR 22S x KMR 3R	3.96 **	-0.29	8.93 **	-10.48 **	-23.39 **	-10.48 **	8.51	2.24	-9.07
DRR 22S x EPLT 109R	-1.38	-5.00 **	2.87 **	5.69 **	-5.57 **	-0.23	46.94 **	29.36 **	1.75
DRR 22S x C 20R	1.69 *	-1.68	5.63 **	2.89 *	-3.48 *	-8.40 **	30.58 **	22.94 **	-3.3
DRR 22S x BCW 56R	-3.80 **	-8.98 **	2.34 *	0.44	-8.96 **	-6.88 **	35.00 **	23.85 **	-2.58

*: Significant at 1 per cent level; **: Significant at 5 per cent level

Table 3. Estimates of heterosis, heterobeltiosis and standard heterosis for panicle length, number of spikelets panicle[-1] and spikelet fertility over locations

Hybrids	Panicle length			No. of spikelets panicle^{-1}			Spikelet fertility		
	Heterosis	Hetero beltiosis	Standard Heterosis	Heterosis	Hetero beltiosis	Standard Heterosis	Heterosis	Hetero beltiosis	Standard Heterosis
DRR 1S x APMS 6B	6.45 *	2.10	-10.37 **	16.56 **	5.14	-9.38 **	16.95 **	0.88	-8.07 *
DRR 1S x PMS 17B	10.71 **	3.93	-4.53	64.17 **	45.87 **	30.10 **	10.96 *	-5.95	-10.61 *
DRR 1S x CRMS 32B	1.97	-3.7	-12.65 **	-29.51 **	-37.76 **	-43.69 **	15.09 **	-2.3	-7.49
DRR 1S x IR 58025B	21.89 **	16.43 **	-6.14 *	25.05 **	19.68 **	-9.27 **	22.76 **	5.52	-3.03
DRR 1S x KMR 3R	8.92 **	-0.72	-2.77	-0.12	-15.97 **	-14.68 **	24.00 **	1.79	4.83
DRR 1S x EPLT 109R	-5.38	-12.76 **	-16.67 **	15.76 **	5.89	-11.53 **	25.04 **	4.43	2.95
DRR 1S x C 20R	8.35 *	2.68	-17.23 **	10.43 *	5.31	-19.55 **	17.69 **	0.24	-5.85
DRR 1S x BCW 56R	-3.34	-13.53 **	-11.67 **	9.49 *	-1.70	-14.36 **	31.09 **	9.95 *	7.23
DRR 6S x APMS 6B	4.56	4.04	-8.67 *	19.09 **	7.74 *	-7.15 *	14.18 **	4.71	-4.58
DRR 6S x PMS 17B	3.57	0.78	-7.44 *	43.86 **	28.19 **	14.33 **	10.01 *	-1.01	-5.91
DRR 6S x CRMS 32B	-1.41	-3.47	-12.45 **	-10.94 **	-21.14 **	-28.65 **	18.68 **	6.97	1.28
DRR 6S x IR 58025B	8.75 *	0.29	-12.85 **	36.96 **	31.49 **	-0.32	7.76	-1.56	-9.53 *
DRR 6S x KMR 3R	4.07	-1.79	-3.82	10.28 **	-6.98 *	-5.55	13.64 **	-1.25	1.70
DRR 6S x EPLT 109R	-4.17	-8.50 *	-12.60 **	-19.33 **	-25.99 **	-38.16 **	24.59 **	10.33 *	8.76 *
DRR 6S x C 20R	21.31 **	11.03 **	-3.51	60.82 **	53.83 **	17.53 **	14.02 **	3.14	-3.12
DRR 6S x BCW 56R	4.48	-3.32	-1.23	27.22 **	14.55 **	-0.21	24.45 **	10.72 *	7.98 *
DRR 7S x APMS 6B	21.80 **	13.34 **	-0.50	2.37	-0.71	-14.43 **	10.85 *	-0.63	-9.45 *
DRR 7S x PMS 17B	-12.08 **	-19.86 **	-26.39 **	-26.30 **	-29.68 **	-37.28 **	21.89 **	7.27	1.96
DRR 7S x CRMS 32B	-4.34	-12.32 **	-20.47 **	-12.21 **	-16.80 **	-24.72 **	11.74 *	-1.5	-6.73
DRR 7S x IR 58025B	-0.12	-1.57	-25.60 **	-25.47 **	-27.87 **	-41.56 **	14.89 **	2.6	-5.71
DRR 7S x KMR 3R	7.33 *	-4.92	-6.89 *	21.32 **	9.06 **	10.73 **	21.48 **	3.35	6.44
DRR 7S x EPLT 109R	6.23 *	-4.85	-9.12 **	44.67 **	42.47 **	19.04 **	15.37 **	-0.04	-1.46
DRR 7S x C20R	14.47 **	11.89 **	-15.43 **	4.41	1.44	-17.82 **	21.41 **	7.40	0.88
DRR 7S x BCW 56R	-9.58 **	-21.34 **	-19.64 **	32.60 **	27.96 **	11.47 **	28.16 **	11.55 *	8.79 *
DRR 17S x APMS 6B	16.56 **	7.98 *	-5.21	2.77	-5.30	-18.39 **	15.88 **	5.54	-3.83
DRR 17S x PMS 17B	17.43 **	6.57 *	-2.12	-11.63 **	-19.82 **	-28.49 **	12.77 **	0.80	-4.19
DRR 17S x CRMS 32B	-6.50 *	-14.67 **	-22.60 **	-10.41 **	-19.24 **	-26.93 **	4.9	-6.08	-11.07 *
DRR 17S x IR 58025B	-6.37	-7.29	-30.60 **	-4.64	-6.63	-29.21 **	17.93 **	7.00	-1.66
DRR 17S x KMR 3R	4.93	-7.43 *	-9.34 **	20.97 **	3.76	5.35	19.06 **	2.81	5.88
DRR 17S x EPLT 109R	8.26 *	-3.45	-7.78 *	-0.41	-6.91	-22.22 **	17.76 **	3.59	2.12
DRR 17S x C 20R	-0.22	-2.01	-26.65 **	42.61 **	39.11 **	6.28 *	15.78 **	4.04	-2.28
DRR 17S x BCW 56R	8.83 **	-5.71	-3.68	-14.84 **	-21.91 **	-31.97 **	7.42	-5.06	-7.41
DRR 20S x APMS 6B	8.13 *	1.44	-10.95 **	52.97 **	36.02 **	17.23 **	15.06 **	1.57	-7.45
DRR 20S x PMS 17B	-1.39	-9.41 *	-16.79 **	50.17 **	31.56 **	17.34 **	13.95 **	-1.22	-6.11
DRR 20S x CRMS 32B	5.82	-2.21	-11.31 **	-13.95 **	-25.07 **	-32.21 **	20.85 **	4.93	-0.64
DRR 20S x IR 58025B	-1.83	-4.09	-26.23 **	-2.42	-8.04 *	-30.28 **	17.77 **	3.57	-4.81
DRR 20S x KMR 3R	7.72 *	-3.83	-5.82	27.99 **	6.28 *	7.91 *	18.24 **	-0.84	2.12
DRR 20S x EPLT 109R	10.03 **	-0.69	-5.14	30.33 **	17.48 **	-1.84	15.99 **	-0.97	-2.38
DRR 20S x C 20R	26.69 **	22.79 **	-5.55	34.71 **	26.50 **	-3.36	24.99 **	8.89 *	2.28
DRR 20S x BCW 56R	1.36	-11.16 **	-9.24 **	18.24 **	4.65	-8.84 *	21.08 **	3.83	1.26
DRR 22S x APMS 6B	-5.16	-16.08 **	-26.33 **	-10.19 **	-20.89 **	-31.82 **	19.44 **	5.99	-3.42
DRR 22S x PMS 17B	-4.31	-16.96 **	-23.72 **	-17.48 **	-28.38 **	-36.12 **	7.12	-6.66	-11.27 *
DRR 22S x CRMS 32B	3.54	-9.65 **	-18.06 **	-10.40 **	-22.70 **	-30.06 **	9.55 *	-4.38	-9.46 *
DRR 22S x IR 58025B	2.9	-1.17	-27.48 **	-10.91 *	-16.89 **	-36.99 **	23.49 **	9.17 *	0.33
DRR 22S x KMR 3R	8.67 *	-8.18 *	-10.07 **	39.23 **	14.61 **	16.37 **	17.80 **	-0.72	2.24
DRR 22S x EPLT 109R	10.70 **	-5.49	-9.72 **	9.24 *	-2.48	-18.52 **	27.74 **	9.61 *	8.06 *
DRR 22S x C 20R	13.03 **	9.43 *	-21.02 **	9.46 *	1.75	-22.26 **	28.71 **	12.72 **	5.88
DRR 22S x BCW 56R	15.05 **	-4.43	-2.36	29.78 **	13.78 **	-0.88	26.83 **	9.32 *	6.62

*: Significant at 1 per cent level; **: Significant at 5 per cent level

Table 4. Estimates of heterosis, heterobeltiosis and standard heterosis for 100 grain weight and grain yield plant[-1] over locations

Hybrids	100 grain weight			Grain yield plant[-1]		
	Heterosis	Hetero beltiosis	Standard Heterosis	Heterosis	Hetero beltiosis	Standard Heterosis
DRR 1S x APMS 6B	-0.40	-0.68	-6.82 **	42.33 **	31.03 **	-7.73
DRR 1S x PMS 17B	1.20	1.08	-5.49 **	22.24 *	18.33	-25.11 **
DRR 1S x CRMS 32B	4.24 *	3.86 *	-2.4	44.60 **	31.52 **	-4.87
DRR 1S x IR 58025B	6.01 **	5.68 **	-0.8	70.24 **	53.89 **	12.85 *
DRR 1S x KMR 3R	7.85 **	5.52 **	2.88	34.86 **	19.43 *	-8.25
DRR 1S x EPLT 109R	6.71 **	2.92	3.36 *	49.60 **	36.52 **	-1.98
DRR 1S x C 20R	4.00 *	-3.70 *	5.44 **	37.33 **	23.22 *	-8.12
DRR 1S x BCW 56R	1.23	-3.23 *	-1.01	65.00 **	48.12 **	10.32
DRR 6S x APMS 6B	0.41	-1.48	-7.57 **	63.43 **	57.09 **	10.62
DRR 6S x PMS 17B	-4.41 *	-6.04 **	-12.15 **	51.61 **	49.66 **	-2.79
DRR 6S x CRMS 32B	-4.25 *	-6.13 **	-11.78 **	13.59	7.80	-22.02 **
DRR 6S x IR 58025B	7.84 **	5.79 **	-0.69	25.97 **	18.78 *	-12.90 *
DRR 6S x KMR 3R	13.48 **	9.29 **	6.56 **	57.67 **	45.50 **	11.77
DRR 6S x EPLT 109R	-4.30 **	-9.13 **	-8.74 **	6.94	1.84	-26.88 **
DRR 6S x C 20R	-9.18 **	-17.14 **	-9.28 **	43.31 **	34.07 **	-0.02
DRR 6S x BCW 56R	-1.02	-6.83 **	-4.69 *	65.72 **	55.13 **	15.54 *
DRR 7S x APMS 6B	0.68	-3.1	-1.71	29.79 **	28.35 **	-9.61
DRR 7S x PMS 17B	-0.08	-3.99 *	-2.61	7.17	2.83	-29.19 **
DRR 7S x CRMS 32B	4.42 **	0.58	2.03	29.88 **	26.76 **	-8.3
DRR 7S x IR 58025B	12.06 **	7.88 **	9.43 **	17.06 *	13.5	-16.77 *
DRR 7S x KMR 3R	6.59 **	4.52 *	6.02 **	51.70 **	43.84 **	10.5
DRR 7S x EPLT 109R	4.25 **	3.73 *	5.22 **	70.82 **	67.33 **	20.14 **
DRR 7S x C20R	-1.59	-5.21 **	3.78 *	24.78 **	20.00 *	-10.51
DRR 7S x BCW 56R	-5.76 **	-6.15 **	-4.00 *	42.44 **	37.07 **	2.09
DRR 17S x APMS 6B	-2.58	-6.80 **	-4.26 *	60.85 **	53.00 **	7.74
DRR 17S x PMS 17B	6.60 **	1.82	4.58 *	24.10 **	23.84 *	-21.30 **
DRR 17S x CRMS 32B	1.14	-3.17 *	-0.53	19.87 *	12.59	-18.56 **
DRR 17S x IR 58025B	-2.06	-6.28 **	-3.73 *	10.05	2.71	-24.68 **
DRR 17S x KMR 3R	1.86	-0.73	1.97	44.45 **	31.97 **	1.38
DRR 17S x EPLT 109R	-8.21 **	-9.24 **	-6.77 **	39.15 **	31.16 **	-5.83
DRR 17S x C 20R	-2.44	-5.45 **	3.52 *	49.95 **	38.87 **	3.56
DRR 17S x BCW 56R	-8.63 **	-8.82 **	-6.34 **	69.04 **	56.64 **	16.66 *
DRR 20S x APMS 6B	7.43 **	5.29 **	2.88	46.69 **	42.87 **	0.61
DRR 20S x PMS 17B	12.63 **	10.20 **	7.68 **	49.35 **	45.47 **	-2.89
DRR 20S x CRMS 32B	4.62 **	2.62	0.27	47.01 **	41.33 **	2.24
DRR 20S x IR 58025B	4.06 *	2.02	-0.32	31.91 **	25.99 **	-7.61
DRR 20S x KMR 3R	6.72 **	6.60 **	4.16 *	58.19 **	47.83 **	13.56 *
DRR 20S x EPLT 109R	6.16 **	4.72 **	5.17 **	42.41 **	37.40 **	-1.34
DRR 20S x C 20R	1.98	-3.51 *	5.65 **	27.90 **	21.20 *	-9.62
DRR 20S x BCW 56R	6.02 **	3.65 *	6.02 **	57.83 **	49.65 **	11.46
DRR 22S x APMS 6B	2.58	0.16	-1.39	22.39 *	17.44 *	-17.29 *
DRR 22S x PMS 17B	2.14	-0.43	-1.97	56.09 **	54.34 **	-0.09
DRR 22S x CRMS 32B	6.87 **	4.44 *	2.83	15.31 *	9.25	-20.97 **
DRR 22S x IR 58025B	-0.67	-2.98	-4.48 *	19.60 *	12.6	-17.44 *
DRR 22S x KMR 3R	6.64 **	6.12 **	4.48 *	68.25 **	55.01 **	19.08 **
DRR 22S x EPLT 109R	0.56	-0.42	0	30.75 **	24.32 *	-10.74
DRR 22S x C 20R	4.38 **	-0.88	8.53 **	14.31	6.77	-20.38 **
DRR 22S x BCW 56R	3.19 *	1.25	3.57 *	40.04 **	30.87 **	-2.53

*: Significant at 1 per cent level; **: Significant at 5 per cent level

superiority may not be considered for analyzing the yield because spikelet fertility varied across the crosses. Earlier workers have reported similar results on standard heterosis for this trait Yadav *et al*. (2004), Vanaja and Babu (2004) and Bhandarkar *et al*. (2005). The extent of spikelet fertility is an important character which directly influences the ultimate product, grain yield. The standard heterosis was varied from -11.27 to 8.79 per cent over PA 6444, and only four hybrids *viz*., DRR 6S x EPLT 109R, DRR 6S x BCW 56R, DRR 7S x BCW 56R and DRR 22S x EPLT 109R manifested significant positive standard heterosis. Superiority of this trait was reported by Panwar *et al*. (2002).

Hundred grain weight of a genotype serves as an indicator to the end product *i.e.,* grain yield. Heterosis for hundred grain weight, ranged from -9.18 (DRR 6S x C 20R) to 13.48 per cent (DRR 6S x KMR 3R) and heterobeltiosis from -17.14 (DRR 6S x C 20R) to 10.20 per cent (DRR 20S x PMS 17B) (Table 4). Seventeen hybrids showed higher grain weight than the standard check PA 6444. Similar results were reported by Lokaprakash *et al*. (1992), Verma *et al*. (2004) and Shanthala *et al*. (2006). In pooled analysis, heterosis and heterobeltiosis for grain yield plant^{-1} ranged from 6.94 to 70.82 per cent and from 1.84 to 67.33 per cent. The heterosis over the standard check PA 6444 ranged from -29.19 (DRR 7S x PMS 17B) to 20.14 per cent (DRR 7S x EPLT 109R). High heterosis over PA 6444 manifested by the crosses DRR 7S x EPLT 109R (21.15 and 20.14%), followed by DRR 22S x KMR 3R (19.08%), DRR 17S x BCW 56R (16.66%). Heterosis and heterobeltiosis of both positive and negative nature was reported by Lokaprakash *et al*. (1992), Vanaja and Babu (2004), Verma *et al*. (2004) and Chaudhary *et al*. (2007).

The hybrid DRR 7S x EPLT 109R exhibited highest heterosis among the different crosses in the present study over the standard check PA 6444. This cross also expressed significant positive heterosis for 100 grain weight and number of spikelets panicle^{-1}. This indicated that morphological traits helped the hybrid to get high heterosis for grain yield. Similarly other hybrids which manifested significant standard heterosis for this character were DRR 22S x KMR 3R, DRR 17S x BCW 56R, DRR 6S x BCW 56R, DRR 20S x KMR 3R and DRR 1S x IR 58025B and were also reported significant standard heterosis for different quantitative traits.

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