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Evaluation of CMS system based rice hybrids for heterosis over locations

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ABSTRACT

One hundred and fifteen hybrids developed by crossing five CMS lines and 23 testers in line x tester fashion were evaluated for extent of heterobeltiosis and standard heterosis of ten characters under irrigated conditions over three locations viz., Hyderabad, Warangal and Jagtial representing different agro climatic zones in Andhra Pradesh. The pooled analysis of variance revealed significant differences among locations and genotypes for all the characters studied. The line x tester interactions contributed up to 71.89 per cent for days to 50% flowering followed by productivity day^{-1} (68.54%), grain yield plant^{-1} (67.69%) and spikelet fertility per cent (66.02%). The highest percentage of average heterosis was observed for productive tillers plant^{-1} followed by productivity per day and grain yield plant^{-1}, whereas the highest percentage of standard heterosis was observed for filled grains panicle^{-1} and flag leaf width. Pooled standard heterosis for grain yield plant^{-1} was manifested through panicle weight, number of filled grains panicle^{-1} and productivity day^{-1}. Negative standard heterosis was observed for days to 50% flowering due to earliness in six hybrids over standard checks KRH 2 and PA 6201. Five crosses viz., APMS 6A x 1005, APMS 6A x GQ-25, PUSA 5A x IR 43, APMS 6A x SC5 9-3 and PUSA 5A x KMR-3 were identified as potential hybrids with more than 28% standard heterosis for grain yield over better yielding commercial hybrid check KRH2.

Key words: *heterosis, hybrid rice, multilocation testing, yield attributes*

Among the several options available, the exploitation of hybrid vigour is a commercially viable option for enhancing productivity and production of rice in the country. Distinct yield advantage over high yielding check varieties and wider adaptability has been instrumental in rapid spread of hybrid rice in India and hence it is included as an important component of National Food Security Mission (NFSM) of Government of India. Yield is a cumulative function of various components, the contribution of components of yield are through component compensation mechanism (Adams, 1967). Hybrid vigour of even small magnitude for individual component may result in significant hybrid vigour for yield *per se*. Commercial exploitation of heterosis in rice today is profitable proposition. In this regard, it is obviously important that the crosses are compared with released hybrids rather than merely comparing with their mid / better parent. So in the present study the performance of the experimental hybrids were compared with that of the most popular released hybrids *viz.,* KRH 2 and PA 6201 in order to estimate the magnitude of standard heterosis and its stability over location, so that the hybrids with high heterotic potential could be identified for commercial exploitation.

MATERIAL AND METHODS

One hundred and fifteen CMS based hybrids, 23 restorers, maintainers of 5 CMS lines and two checks (*viz.,* KRH 2 and PA 6201) were evaluated during wet season, 2007 at three different locations *viz.,* Directorate of Rice Research, Hyderabad (Southern Telangana agro- climatic zone), Regional Agricultural Research Station, Warangal (Central Telangana agro-climatic zone) and Regional Agricultural Research Station, Jagtial (Northern Telangana agro-climatic zone). All the entries at the age of 28 days were transplanted in randomized complete block design with two replications. Each entry was planted in two rows of 1.8 m length. Single seedling was transplanted hill^{-1} by adopting a spacing of 20 x 15 cm and all recommended package of practices were followed to raise a healthy crop. Observations were recorded for yield and its attributes such as plant height, flag leaf length, productive tillers plant^{-1}, panicle length, panicle weight, number of filled grains panicle^{-1}, spikelet fertility percentage, 1000 seed weight, grain yield plant^{-1} and productivity day^{-1} on five plants of each entry in each replication. Days to 50 per cent flowering was recorded on plot basis. The pooled mean value over three locations for each parent and hybrid was taken for computation of heterobeltiosis and standard heterosis over KRH2 and PA 6201 using standard methods.

RESULTS AND DISCUSSION

The pooled analysis of variance (line x tester) over three locations revealed significant differences for locations for all the characters studied (Table 1). Significant differences for replications x locations were recorded for only flag leaf width. The differences among the parents, parents vs. crosses and crosses were observed to be significant for all the characters studied. Partitioning of crosses into lines, testers and lines x testers revealed that the variance due to lines were significant for all the characters except days to fifty per cent flowering, plant height and 1000 grain weight, whereas for testers, plant height, flag leaf length, productive tillers plant^{-1}, panicle length, filled grains panicle^{-1} and 1000 grain weight were found significant. The interaction due to lines x testers were significant for all the traits studied. Interaction effects of (Parents vs. crosses) x locations, parents x locations and crosses x locations were significant for all the characters, except flag leaf width in case of (parents vs. crosses) x locations interaction.

Further partitioning of crosses x locations indicated that the interaction of lines x locations showed significant differences for productive tillers plant^{-1} flag leaf length and flag leaf width, while testers x locations was significant only for filled grains panicle^{-1}. Interaction effects of lines x testers x locations were significant for all the characters studied.

The mean squares due to parents were significant for grain yield and all the component traits, thus, justifying their use in the present investigation. Similarly, crosses also varied considerably between themselves. Wide genetic variability was evident among the five CMS lines derived with diverse cytoplasmic source. The lines were found to be superior for flag leaf width, panicle weight and filled grains panicle^{-1}, while, testers exhibited substantial differences among themselves for flag leaf length, flag leaf width, days to 50% flowering, plant height, productive tillers, spikelet fertility per cent, 1000 grain weight, grain yield and per day productivity. Interaction between lines and testers were also significant for majority of the yield contributing characters. This was illustrated when the proportional contribution of each character was studied (Table 2).

Lines and their interaction with testers contributed more than 70 per cent of total variance for days to 50% flowering, while testers' contribution was high for flag leaf length, days to 50% flowering, plant height, productive tillers plant^{-1}, spikelet fertility *per cent* and 1000 grain weight. For flag leaf width and filled grains panicle^{-1}, contribution of both lines and testers was equally important. Similarly, line x tester interactions contributed up to 71.89 per cent for days to 50% flowering followed by productivity per day (68.54%), grain yield plant^{-1} (67.69%) and spikelet fertility per cent (66.02%).

To draw the valid conclusions regarding the extent of heterosis for various characters, the overall means of parents F_1 and standard checks were computed to obtain average and standard heterosis for all the character studied (Table 3). The degree of heterosis varied considerably for grain yield plant^{-1} and its attributes. The highest percentage of average heterosis was observed for productive tillers plant^{-1} followed by productivity day^{-1}, grain yield plant^{-1}, panicle weight and filled grain panicle^{-1}. The negative heterosis was observed for spikelet fertility % and flag leaf length. The hybrids averaged about 29.09% heterosis for productivity day^{-1} and 28.23% for grain yield plant^{-1} over the means of their parents. The observed highest heterosis for grain yield plant^{-1} was due to expressions of heterosis in component characters like productive tillers plant^{-1} (33.09%), panicle weight (24.38%) and filled grains panicle^{-1} (17.7%). The highest percentage of standard heterosis was observed for filled grains panicle^{-1} and flag leaf width, whereas negative heterosis was observed for characters spikelet fertility %, productivity day^{-1}, 1000 grain yield plant^{-1} suggesting

Table 1. Pooled analysis of variance (Lines x Testers) for yield and yield components in rice

Source of variation	d.f	Mean Sum of Squares											
		Days to 50% flowering	Plant height	Flag leaf length	Flag leaf width	Productive tillers plant^{-1}	Panicle length	Panicle weight	Filled grains panicle^{-1}	Spikelet fertility %	1000 grain weight	Grain yield plant^{-1}	Productivity per day
Locations	2	8166.540 **	6484.604 **	6451.716 **	6.618 **	86.747 **	202.405 **	10.027 **	12805.560 **	4297.021 **	34.324 **	876.645 **	4823.378 **
Replications x Locations	2	4.938	29.056	0.375	0.134 **	0.175	0.379	0.268	160.089	0.282	0.221	1.522	12.162
Treatments	142	63.697 **	336.490 **	80.313 **	0.175 **	12.895 **	11.118 **	3.027 **	7583.527 **	119.148 **	25.561 **	160.233 **	714.219 **
Parents	27	105.061 **	805.453 **	81.219 **	0.256 **	2.885 **	10.987 **	1.932 **	6297.925 **	79.294 **	40.342 **	52.871 **	240.599 **
Parent vs. Crosses	1	42.894 **	1930.397 **	1593.886 **	0.203 **	1058.221 **	514.087 **	98.811 **	100092.800 **	375.922 **	51.517 **	4458.350 **	20275.250 **
Crosses	114	54.083 **	211.438 **	66.821 **	0.155 **	6.097 **	6.737 **	2.446 **	7076.527 **	126.335 **	21.832 **	147.958 **	654.804 **
Lines	4	39.357	394.483	245.108 **	0.870 **	10.618 *	19.280 **	21.533 **	49802.710 **	312.097 *	21.425	503.279 **	1960.378 *
Testers	22	71.607	372.022 **	109.044 **	0.189	13.195 **	10.127 *	2.359	9377.320 **	165.686	54.209 **	156.382	711.171
Lines x Testers	88	50.371 **	162.972 **	48.162 **	0.114 **	4.116 **	5.319 **	1.600 **	4559.229 **	108.053 **	13.756 **	129.701 **	581.368 **
Parents x Locations	54	33.297 **	92.719 **	40.486 **	0.095 **	2.260 **	3.337 **	0.829 **	1856.914 **	60.818 **	9.070 **	30.227 **	139.273 **
(Parent vs. Crosses) x Locations	2	597.974 **	858.389 **	81.341 **	0.030	26.055 **	37.831 **	3.983 **	13293.420 **	104.211 **	42.976 **	150.846 **	545.955 **
Crosses x Locations	228	54.380 **	87.636 **	42.938 **	0.079 **	4.269 **	2.818 **	0.935 **	2449.021 **	98.394 **	13.826 **	68.936 **	319.323 **
Lines x Locations	8	42.079	130.372	200.827 **	0.289 **	10.170 *	1.735	1.043	3146.987	190.423	17.752	82.201	357.870
Testers x Locations	44	65.061	91.173	47.957	0.090	4.533	2.515	1.131	2587.760 **	85.863	16.059	62.670	297.621
Lines x Testers x Locations	176	52.269 **	84.809 **	34.506 **	0.067 **	3.935 **	2.943 **	0.882 **	2382.610 **	97.344 **	13.089 **	69.899 **	322.996 **
Error	426	3.812	9.963	8.677	0.021	0.967	0.796	0.152	138.777	6.252	0.390	3.688	16.505

*: Significant at 5% level and **: Significant at 1% level

Table 2. Proportional contribution of lines, testers and their interactions to total variance

Character	Contribution		
	Line (%)	Tester (%)	LinexTester(%)
Days to 50% flowering	2.55	25.55	71.89
Plant height	6.55	33.95	59.50
Flag leaf length	12.87	31.49	55.64
Flag leaf width	19.68	23.47	56.85
Productive tillers plant^{-1}	6.11	41.77	52.12
Panicle length	10.04	29.01	60.95
Panicle weight	30.89	18.61	50.50
Filled grains panicle^{-1}	24.69	25.57	49.73
Spikelet fertility %	8.67	25.31	66.02
1000 grain weight	3.44	47.92	48.64
Grain yield plant^{-1}	11.94	20.40	67.69
Productivity day^{-1}	10.50	20.96	68.54

that checks performed better than the hybrids in the present study.

Positive and negative heterosis was observed for all the growth and yield attributing traits (Table 4). Early maturing hybrids are desirable as they produce more yields per day and fit well in multiple cropping systems. Among the 115 hybrids, 13 hybrids exhibited significant negative heterobeltiosis over their respective better parents in pooled analysis. Six hybrids *viz.,* IR 58025A x BR 827-35, IR 58025A x EPLT 109, IR 79156A x IBL-57, PUSA 5A x IR 60 and CRMS 32A x IBL-57 were significantly heterotic for earliness over standard checks KRH 2 and PA 6201. The early flowering in hybrids has been reported earlier (Peng and Virmani, 1991 and Mishra and Pandey,1998). Shorter plant type is an important character of a hybrid to withstand lodging. All the hybrids were taller than their better parents and hence exhibited significant positive heterobeltiosis. The significant reduction in plant height was observed in six hybrids *viz.,* CRMS 32A x IR 43, PUSA 5A x IR 60, PUSA 5A x IR 55, PUSA 5A x 517, PUSA 5A x EPLT 109 and IR 79156A x GQ-25 over standard check PA 6201. Negative standard heterosis estimates for plant height were reported by Virmani *et al. (*1982).

Table 3. Average performance of parents, F_1s, checks and average and standard heterosis for grain yield plant^{-1} and other components in rice

Character	Average performance			Average Heterosis (%)	Standard heterosis (%)
	Parents	Crosses	Checks		
Days to 50% flowering	35.12	38.54	33.62	9.78	4.92
Plant height	1.74	1.78	1.56	2.22	0.22
Flag leaf length	100.66	100.09	98.29	-0.56	1.80
Flag leaf width	102.74	106.52	100.68	3.68	5.85
Productive tillers plant^{-1}	8.46	11.25	10.66	33.09	0.60
Panicle length	23.99	25.95	25.65	8.13	0.30
Panicle weight	3.51	4.37	3.93	24.38	0.45
Filled grains plant^{-1}	153.69	180.91	160.24	17.70	20.67
Spikelet fertility%	83.10	81.43	85.27	-2.01	-3.84
1000 grain weight	20.88	21.48	22.80	2.95	-1.32
Grain yield plant^{-1}	20.35	26.09	26.60	28.23	-0.51
Productivity day^{-1}	42.11	54.36	56.18	29.09	-1.82

Higher flag leaf length is a desirable feature of hybrid rice for efficient photosynthesis at and after flowering. For this trait, as many as 22 hybrids registered significant positive heterobeltiosis ranging from 10.79 to 37.60 per cent. Fifty seven hybrids registered significant positive standard heterosis over KRH 2 and PA 6201. Two hybrids CRMS 32A x SC5 9-3 and CRMS 32A x IBL-57 were found to be highly consistent with significant positive heterobeltiosis and standard heterosis at all the three locations tested. Many other hybrids were inconsistent in their superiority with respect to heterobeltiosis and standard heterosis over the locations (Mishra and Pandey, 1998 and Yadav *et al.,* 2004)

Number of productive tillers plant^{-1} is known to directly contribute towards grain yield. Hundred and two hybrids recorded positive significant heterobeltiosis while, seven hybrids *viz.,* IR 79156A x IBL-57, APMS 6A x 612-1, APMS 6A x GQ 37-1, APMS 6A x SC5 9-3, APMS 6A x 124, PUSA 5A x 1096 and CRMS 32A x GQ 37-1 exhibited significant positive standard heterosis over KRH 2 and PA 6201. (Singh *et al.,* 2006 and Deoraj *et al.,* 2007)

Longer panicle is generally associated with more number of spikelets and this is one of the attributes for higher grain yields in rice hybrids. For this trait, 68 hybrids recorded significant positive heterobeltiosis. Five hybrids *viz.,* IR 79156A x SG 26-120, IR 79156A

Table 4. Heterosis of some promising hybrids for grain yield plant^{-1} and its components in rice

Hybrids	Flag leaf length			Days to 50% flowering			Plant height			Panicle length		
	HB	SH1	SH2	HB	SH1	SH2	HB	SH1	SH2	HB	SH1	SH2
APMS 6A x 1005	-5.98	25.33 **	13.14 **	3.43 **	7.65 **	8.21 **	9.78 **	-4.48 *	0.79	4.38 *	-5.41 **	-2.95
APMS 6A x 612-1	2.25	36.30 **	23.04 **	-3.17 **	-1.19	-0.68	29.72 **	12.88 **	19.11 **	10.57 **	3.90 *	6.60 **
APMS 6A x GQ-25	1.96	35.92 **	22.70 **	2.04	2.04	2.56 *	14.39 **	-0.47	5.03 **	4.85 *	-4.99 **	-2.52
APMS 6A x GQ-120	-8.88 *	21.47 **	9.65	-1.01	0.17	0.68	30.30 **	13.38 **	19.63 **	16.50 **	5.57 **	8.31 **
APMS 6A x SC5 9-3	5.80	41.05 **	27.32 **	0.33	4.42 **	4.96 **	11.79 **	-2.72	2.64	6.11 **	0.52	3.13
APMS 6Ax SG26-120	0.52	34.01 **	20.97 **	3.95 **	2.89 *	3.42 **	19.46 **	3.94 *	9.68 **	4.70 *	1.44	4.07 *
APMS 6A x 118	-18.88 **	8.14	-2.38	-5.23 **	-1.36	-0.85	22.53 **	6.62 **	12.50 **	8.00 **	0.28	2.88
APMS 6A x 517	0.00	33.30 **	20.33 **	3.76 **	7.99 **	8.55 **	12.83 **	-1.82	3.60 *	6.04 **	-3.91 *	-1.41
IR 58025A x GQ-37-1	10.79 *	18.71 **	7.16	5.49 **	1.36	1.88	33.46 **	5.58 **	11.40 **	12.79 **	3.66	6.36 **
IR 79156A x KMR-3	5.98	35.57 **	22.38 **	4.67 **	-0.85	-0.34	19.70 **	5.31 **	11.12 **	7.47 **	3.59	6.28 **
IR 79156A x IBL-57	-6.37	19.77 **	8.12	1.62	-3.74 **	-3.25 **	16.36 **	0.59	6.15 **	2.46	-1.25	1.32
IR 79156A x SG27-77	3.28	32.12 **	19.27 **	7.36 **	1.70	2.22	21.34 **	6.76 **	12.65 **	2.71	2.32	4.97 *
CRMS 32A x IBL-57	37.60 **	47.46 **	33.11 **	-6.41 **	-3.23 **	-2.74 *	15.55 **	-4.39 *	0.88	6.09 **	-5.21 **	-2.75
CRMS 32A x 517	8.31	25.03 **	12.86 **	1.64	5.10 **	5.64 **	27.47 **	5.47 **	11.29 **	13.61 **	1.50	4.14 *
PUSA 5A x IR 43	1.37	15.63 **	4.38	-0.32	4.59 **	5.13 **	27.42 **	-3.09	2.26	11.90 **	-4.90 *	-2.43
PUSA 5A x IR55	-0.35	13.68 *	2.62	-3.89 **	0.85	1.37	6.47 **	-11.92 **	-7.05 **	-0.35	-7.80 **	-5.41 **
PUSA 5A x 1096	2.64	24.51 **	12.40 *	-1.78	3.06 **	3.59 **	24.05 **	2.63	8.30 **	13.53 **	0.32	2.93
PUSA 5A x 124	2.78	17.25 **	5.84	-1.62	3.23 **	3.76 **	26.22 **	4.42 *	10.19 **	4.78 *	-2.90	-0.38
PUSA 5A x KMR-3	6.89	21.93 **	10.07 *	-7.13 **	-2.55 *	-2.05	29.67 **	7.28 **	13.20 **	2.26	-1.61	0.94
PUSA 5A x SG27-77	-4.87	20.82 **	9.07	-5.02 **	-0.34	0.17	26.29 **	4.48 *	10.24 **	2.98	2.59	5.25 **
Heterosis range	-24.25 to 37.60	-7.41 to 50.33	-16.42 to 35.70	-7.13 to 14.34	-4.76 to 9.86	-4.27 to 10.43	1.03 to 39.59	-15.81 to 15.55	-11.17 to 21.93	-7.86 to 16.50	-11.54 to 6.37	-9.24 to 9.13
+ ve significant	22	103	57		54	62		34	81	68	5	29
- ve significant	18	0	0		9	6		25	6	4	5	29
Top five crosses	IR 79156A X GQ-120			PUSA 5A X IR 60			CRMS32A X IR 43			IR 79156A X 124		
	CRMS32A X SC5 9-3			IR 58025A X BR 827-35			PUSA 5A X IR 60			IR 79156A X SG 26-120		
	CRMS32A X IBL 57			IR 79156A X IBL 57			PUSA 5A X 517			APMS 6A X GQ-120		
	IR 79156A X 1096			CRMS32A X IBL 57			PUSA 5A X IR 55			CRMS32A X 612-1		
	IR 79156A X GQ-7			IR 79156A X GQ 70			IR 79156A X EPLT-109			APMS 6A X 611-1		

HB = Heterobeltiosis, SH1 = Heterosis over KRH2, SH2 = Heterosis over PA 6201; * & ** significant at 5% and 1% levels, respectively.

Table 4 contd…

Hybrids		Panicle weight		Productive tillers plant^{-1}			Filled grains spikelet^{-1}			Spikelet fertility%		
	HB	HB	SH1	HB	HB	SH1	HB	SH1	SH2	HB	HB	SH1
APMS 6A x 1005	77.80 **	50.27 **	55.53 **	32.58 **	1.20	-1.83	32.58 **	1.20	-1.83	4.38 *	-5.41 **	-2.95
APMS 6A x 612-1	25.51 **	18.48 **	22.63 **	44.15 **	21.02 **	17.39 **	44.15 **	21.02 **	17.39 **	10.57 **	3.90 *	6.60 **
APMS 6A x GQ-25	48.26 **	36.28 **	41.04 **	42.84 **	9.03	5.76	42.84 **	9.03	5.76	4.85 *	-4.99 **	-2.52
APMS 6A x GQ-120	27.40 **	8.63	12.42 *	38.37 **	5.62	2.45	38.37 **	5.62	2.45	16.50 **	5.57 **	8.31 **
APMS 6A x SC5 9-3	36.84 **	57.36 **	62.86 **	49.80 **	19.42 **	15.84 **	35.10 **	58.15 **	56.55 **	-4.45 **	-1.92	5.36 **
APMS 6Ax SG26-120	39.10 **	17.56 **	21.68 **	37.75 **	13.09 *	9.70	25.29 **	17.17 **	15.99 **	-6.17 **	-0.45	6.94 **
APMS 6A x 118	26.96 **	52.04 **	57.36 **	41.81 **	8.25	5.00	29.83 **	54.70 **	53.14 **	-2.13	-0.83	6.53 **
APMS 6A x 517	8.03	13.76 *	17.74 **	13.90 *	-13.06 *	-15.67 **	9.48 *	16.10 **	14.93 **	-0.98	0.34	7.79 **
IR 58025A x GQ-37-1	-10.01	-4.82	-1.50	23.90 **	0.12	-2.88	-30.67 **	-10.98 **	-11.88 **	-3.32 *	-3.56 *	3.60 *
IR 79156A x KMR-3	11.98	-1.10	2.36	43.61 **	23.24 **	19.54 **	2.46	-9.49 *	-10.41 *	0.92	0.74	8.21 **
IR 79156A x IBL-57	33.38 **	-1.12	2.33	41.43 **	12.90 *	9.51	-3.92	13.45 **	12.31 **	4.03 *	-0.08	7.33 **
IR 79156A x SG27-77	27.73 **	26.42 **	30.84 **	26.93 **	1.32	-1.71	19.88 **	37.06 **	35.68 **	2.77	2.99	10.63 **
CRMS 32A x IBL-57	46.22 **	24.17 **	28.52 **	29.91 **	6.66	3.46	4.81	23.76 **	22.51 **	0.49	1.45	8.98 **
CRMS 32A x 517	32.39 **	39.42 **	44.30 **	21.46 **	-0.28	-3.27	41.30 **	49.84 **	48.33 **	3.00	3.99 *	11.71 **
PUSA 5A x IR 43	20.73 **	-7.22	-3.98	17.01 *	-7.90	-10.66 *	15.59 **	-12.37 **	-13.26 **	-0.83	-4.30 **	2.80
PUSA 5A x IR55	13.14	-6.04	-2.75	15.86 *	-8.81	-11.54 *	24.31 **	-13.92 **	-14.79 **	-9.33 **	-12.50 **	-6.01 **
PUSA 5A x 1096	32.01 **	32.44 **	37.08 **	60.29 **	26.16 **	22.38 **	23.49 **	31.87 **	30.54 **	0.15	-2.56	4.67 **
PUSA 5A x 124	3.68	-8.00	-4.78	18.50 **	-6.73	-9.53	10.84 *	-0.19	-1.19	5.06 **	1.38	8.91 **
PUSA 5A x KMR-3	13.12 *	-0.10	3.39	30.82 **	12.26 *	8.89	-1.57	-13.06 **	-13.94 **	-5.00 **	-5.17 **	1.87
PUSA 5A x SG27-77	-0.73	-1.74	1.69	33.48 **	5.07	1.92	-3.17	10.71 **	9.59 *	-3.07	-2.86	4.35 *
Heterosis range	-27.98 to 77.80	-23.83 to 57.36	-21.16 to 62.86	-5.64 to 60.29	-23.76 to 26.16	-26.04 to 22.38	-41.11 to 82.26	-33.40 to 80.46	-34.07 to 78.64	-22.58 to 6.31	-21.84 to 5.61	-16.04 to 13.45
+ ve significant	71	46	56	102	14	7	61	54	52	14	3	66
- ve significant	7	10	5	0	12	20	18	29	34	61	54	20
Top five crosses	APMS 6A X SC5 9-3		PUSA 5A X 1096		APMS 6A X 1005		CRMS 32 A X GQ-70					
	APMS 6A X 118		IR 79156A X KMR-3		APMS 6A X SC5 9-3		CRMS 32 A X 517					
	APMS 6A X 1005		APMS 6A X SC5 9-3		APMS 6A X 118		APMS 6A X 124					
	CRMS 32 A X 517		CRMS32A X GQ 37-1			CRMS 32 A X 517		CRMS 32 A X KMR-3				
	APMS 6A X SC5 2-2-1		APMS 6A X 124		CRMS 32 A X GQ-70		IR 79156A X SG 26-120					

HB = Heterobeltiosis, SH1 = Heterosis over KRH2, SH2 = Heterosis over PA 6201; ; * & ** significant at 5% and 1% levels, respectively.

Table 4 contd…

Hybrids	Productivity day^{-1}			Grain yield plant^{-1}			Grain yield plant^{-1}	
	HB	SH1	SH2	HB	SH1	SH2	Mean performance	*sca*
APMS 6A x 1005	83.89 **	22.91 **	32.93 **	88.28 **	29.90 **	40.98 **	36.44**	7.56**
APMS 6A x 612-1	61.30 **	24.51 **	34.65 **	58.59 **	23.34 **	33.86 **	34.60**	6.99**
APMS 6A x GQ-25	74.12 **	33.92 **	44.83 **	77.48 **	36.54 **	48.18 **	38.31**	10.49**
APMS 6A x GQ-120	56.84 **	11.52 **	20.60 **	54.75 **	11.32 **	20.81 **	31.23**	4.68
APMS 6A x SC5 9-3	56.23 **	24.97 **	35.15 **	56.21 **	28.93 **	39.93 **	36.17**	7.63**
APMS 6Ax SG26-20	48.90 **	8.58 *	17.42 **	54.28 **	11.39 **	20.89 **	31.25**	1.80
APMS 6A x 118	52.87 **	14.56 **	23.90 **	47.65 **	13.57 **	23.25 **	31.86**	3.57**
APMS 6A x 517	56.05 **	4.30	12.80 **	61.95 **	11.74 **	21.27 **	31.35**	3.01
IR 58025Ax GQ-37-1	22.99 **	10.03 *	19.00 **	26.33 **	11.64 **	21.16 **	31.32**	6.82**
IR 79156A x KMR-3	46.02 **	18.43 **	28.08 **	39.48 **	16.44 **	26.37 **	32.67**	5.01**
IR 79156A x IBL-57	97.33 **	19.61 **	29.36 **	87.46 **	18.04 **	28.11 **	33.12**	7.55**
IR 79156Ax SG27-77	82.88 **	21.64 **	31.55 **	74.53 **	23.86 **	34.43 **	34.75**	5.96**
CRMS 32A x IBL-57	45.61 **	19.24 **	28.95 **	33.64 **	16.68 **	26.64 **	32.74**	3.02
CRMS 32A x 517	36.53 **	11.80 **	20.91 **	32.54 **	15.71 **	25.59 **	32.46**	3.85**
PUSA 5A x IR 43	119.13**	20.08 **	29.86 **	108.10 **	23.28 **	33.80 **	34.59**	10.08**
PUSA 5A x IR55	72.01 **	12.60 **	21.78 **	65.38 **	13.07 **	22.71 **	31.72**	7.89**
PUSA 5A x 1096	36.69 **	14.27 **	23.58 **	33.57 **	16.91 **	26.89 **	32.80**	4.45**
PUSA 5A x 124	56.82 **	8.91 *	17.78 **	54.91 **	11.53 **	21.05 **	31.29**	3.06
PUSA 5A x KMR-3	70.51 **	38.30 **	49.57 **	62.65 **	35.77 **	47.36 **	38.09**	7.10**
PUSA 5A x SG27-77	74.90 **	16.33 **	25.81 **	64.55 **	16.78 **	26.74 **	32.76**	0.65
Heterosis range	-21.73 to 119.13	-41.78 to 38.30	-37.04 to 49.57	-19.46 to 88.28	-42.28 to 36.54	-37.35 to 48.18	CD at 5 % =3.76	SE ij = 0.81
+ ve significant	71	20	37	72	23	42		
- ve significant	12	56	34	11	53	35		
Top five crosses	PUSA5A X KMR-3		APMS 6A X GQ-25					
	APMS 6A X GQ-25		PUSA5A X KMR-3					
	APMS 6A X SC5 9-3		APMS 6A X 1005					
	APMS 6A X 612-1		APMS 6A X SC5 9-3					
	APMS 6A X 1005		IR 79156A X SG 27-77					

HB = Heterobeltiosis, SH1 = Heterosis over KRH2, SH2 = Heterosis over PA 6201;
& ** significant at 5% and 1% levels, respectively.

x 124, APMS 6A x 612-1, APMS 6A x GQ-120 and CRMS 32A x 612-1 were found to be highly consistent with significant positive standard heterosis over both the standard checks KRH 2 and PA 6201 at all the three locations tested. Panicle weight is positively associated with grain yield and as many as 71 hybrids manifested significant positive heterobeltiosis ranging from 13.12 per cent (PUSA 5A x KMR-3) to 77.80 per cent (APMS 6A x 1005). Forty six and fifty six hybrids excelled superiorly in desirable direction over KRH 2 and PA 6201, respectively. (Lokaprakash *et al.,* 1992 and Ghosh, 2002). Number of filled grains panicle^{-1} is one of the most important components of yield. Fifty four hybrids showed significant increase in number of filled grains panicle^{-1} over KRH 2, whereas fifty two over PA 6201. (Deoraj *et al.,*2007, Rosamma and Vijayakumar, 2007 and Singh *et al.,*2007).

Low grain yields in rice hybrids are attributed mainly to the high sterility percentage. The extent of spikelet fertility directly influences the grain yield. Most of the hybrids exhibited negative heterosis at all the locations for this trait. Fourteen hybrids had significant positive heterobeltiosis. Only three hybrids *viz.,* CRMS 32A x GQ-70 (5.61%), CRMS 32A x 517 (3.99%) and APMS 6A x 124 (3.51%) registered significant positive standard heterosis over KRH 2. (Panwar *et al.,*2002). Hundred grain weight of a genotype serves as an indicator to the end product *i.e.,* grain yield. Over their better parents 31 and 53 hybrids had significantly higher and lower test weights, respectively. Thirty three and 52 hybrids showed significantly more standard heterosis over KRH 2 and PA 6201, respectively(Eradasappa *et al.,*2007, Rosamma and Vijayakumar, 2007 and Singh *et al.,*2007). Productivity day^{-1} is an important character for higher yield in shorter time. Seventy one hybrids could manifest significant positive heterobeltiosis ranging from 9.10 to 119.13 per cent. Twenty hybrids over KRH 2 and thirty seven hybrids over PA 6201 showed significant positive standard heterosis. Hossain *et al.* (2005) in their studies observed significant positive heterosis for productivity per day.

The present investigation revealed a high order of heterosis for grain yield plant^{-1}. Seventy two hybrids manifested significant positive heterobeltiosis ranging from 9.71 per cent (CRMS 32A x SC5 2-2-1) to 88.28 per cent (APMS 6A x 1005). Twenty three over KRH 2 and forty two over PA 6201 registered significant positive standard heterosis in pooled analysis. The hybrid which exhibited highest heterosis over KRH2 and PA 6201, was APMS 6A x GQ-25 (36.54% and 48.18%) followed by PUSA 5A x KMR-3 (35.77% and 47.36%), APMS 6A x 1005 (29.90% and 40.98%), APMS 6A x SC5 9-3 (28.93% and 39.93%) and IR 79156A x SG 27-77 (23.86% and 34.43%). Heterobeltiosis and standard heterosis of both positive and negative nature for grain yield per plant was reported by Peng and Virmani (1991), Deoraj *et al.*

Table 5. Over all performance of top 20 heterotic hybrids for grain yield plant^{-1}

Hybrid	Standard Heterosis %	Average Heterosis %	Heterobeltiosis %	Mean performance	*sca* effect	Stable/ unstable
APMS 6A x GQ-25	36.54	87.13	77.48	38.31	10.49	unstable
PUSA 5A x KMR 3	35.77	90.27	62.65	38.09	7.10	unstable
APMS 6A x 1005	29.90	13.31	88.28	36.44	7.56	unstable
APMS 6A x SC5 9-3	28.93	70.17	56.21	36.17	7.63	unstable
IR 79156A x SG27-77	23.86	74.53	98.68	34.75	5.96	unstable
APMS 6A x 612-1	23.34	58.59	68.08	34.60	6.99	unstable
PUSA 5A x IR 43	23.28	121.69	108.10	34.59	10.08	unstable
IR 79156 A X IBL 57	18.08	102.33	87.46	33.12	7.55	unstable
PUSA 5A x 1096	16.91	59.32	33.57	32.80	4.45	unstable
PUSA 5A x SG 27-77	16.78	79.37	64.55	32.76	0.65	unstable
CRMS 32A X IBL 57	16.68	55.29	33.64	32.74	3.02	unstable
IR 79156 A X KMR 3	16.44	69.75	39.48	32.67	5.01	unstable
CRMS 32A X 517	15.71	55.12	32.54	32.46	3.85	stable
APMS 6A x 118	13.57	55.67	47.65	31.86	3.57	stable
PUSA 5A x IR 55	13.07	77.21	365.38	31.72	7.89	stable
APMS 6A x 517	11.74	70.75	61.95	31.35	3.01	unstable
IR 58025 A x GQ-37-1	11.64	36.09	26.33	31.32	6.82	unstable
PUSA 5A x 124	11.53	69.97	54.91	31.29	3.06	stable
APMS 6A x SEG 26-120	11.39	57.78	54.28	31.25	1.80	unstable
APMS 6A x GQ-120	11.32	57.98	54.75	31.23	4.68	stable
				CD at 5 % =3.76	SE ij = 0.81	

(2007), Eradasappa *et al.* (2007), Rosamma and Vijayakumar (2007) and Singh *et al.* (2007).

Grain yield plant^{-1} is a multiplicative product of several basic components of yield. The increased grain yield is because of increase in one or more than one yield components. In the above crosses the superiority of hybrids in grain yield was through number of filled grains panicle^{-1}, panicle weight and productivity day^{-1}. The major reason for the high degree of heterosis was due to genetic divergence in the parents, though the predominance of dominant gene action was operating in the inheritance of the traits, as explained by Virmani *et al*. (1982). Among these top five crosses, APMS 6A x GQ-25 also registered significant positive standard heterosis for productivity per day, 1000-grain weight, filled grains panicle^{-1} and panicle weight, PUSA 5A x KMR-3 for productivity day^{-1} and 1000-grain weight, both APMS 6A x 1005 and APMS 6A x SC5 9-3 for productivity day^{-1}, filled grains panicle^{-1} and IR 79156A x SG 27-77 for filled grains panicle^{-1}. This indicates that the yield attributes helped the hybrids to get high heterosis for grain yield plant^{-1}. Similarly other hybrids which manifested significant standard heterosis for this trait were: APMS 6A x 612-1, PUSA 5A x KMR-3, IR 79156A x IBL-57, PUSA 5A x 1096 and PUSA 5A x SG 27-77 and were also supported by different quantitative traits with significant standard heterosis.

Five cross combinations *viz.,* APMS 6A x 1005, APMS 6A x GQ-25, PUSA 5A x IR 43, APMS 6A x SC5 9-3 and PUSA 5A x KMR-3 have been identified as promising. The cross APMS 6A x 1005 possessed high *per se* performance (36.44 g), significant positive *sca* effect (7.56) and standard heterosis of 29.90 per cent over the best check KRH 2 for grain yield plant^{-1} (Table 5). Besides grain yield, the cross also showed high *per se* performance, significant positive *sca* effects and standard heterosis for other yield contributing characters like panicle weight, filled grains panicle^{-1} and productivity day^{-1}.

The cross APMS 6A x GQ-25 exhibited significant positive *sca* effect (10.49) and standard heterosis (36.54%) along with the high *per se* performance of 38.31 g for grain yield plant^{-1}. The cross was also promising for panicle weight, filled grains panicle^{-1} and productivity day^{-1}. The cross PUSA 5A x IR 43 was found to be good with significant positive *sca* effect (10.08) and standard heterosis (23.28%) along with the high *per se* performance of 34.59 g for grain yield plant^{-1}. Besides grain yield, the cross had shown promise for productivity day^{-1}.

The hybrids APMS 6A x SC5 9-3 and PUSA 5A x KMR-3 recorded high standard heterosis (28.93% and 35.77%) over KRH 2, significant positive *sca* effects (7.63 and 7.10) and high *per se* performance (36.17 g and 38.09 g) for grain yield per plant. Besides grain yield, the cross APMS 6A x SC5 9-3 was promising for panicle weight, filled grains panicle^{-1} and productivity day^{-1}, whereas, PUSA 5A x KMR-3 was promising for 1000-grain weight and productivity per day.

The overall results of heterobeltiosis and standard heterosis indicated that the parents involved in the crossing should have one high *per se* performing parent and over dominance may be the cause of heterosis. The main reason ascribed is diversified parents involved in the cross combinations or uncommon genes for a trait is the cause to exploit the maximum exploitable level of heterosis in rice. Different estimates show that in a self pollinated crop to be economically advantageous, hybrid must give at least 20-25% higher grain yield than the best commercial variety available or 5-10% over hybrid variety. It can be clearly brought out that the five cross combinations *viz.,* APMS 6A x 1005, APMS 6A x GQ-25, PUSA 5A x IR 43, APMS 6A x SC5 9-3 and PUSA 5A x KMR-3 with more than 28% standard heterosis for grain yield over high yielding commercial hybrid check KRH2 offers greater scope for exploitation of the hybrid vigour on commercial scale.

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