Madras Agric. J., 99 (4-6): 202-209, June 2012
https://doi.org/10.29321/MAJ.10.100047

Evaluation of Rice Hybrids for Heterosis of Yield and Yield Attributing Traits over Locations

P. Saidaiah*, M.S. Ramesha, S. Sudheer Kumar and A. Geetha
Hybrid Rice Section, Crop Improvement Division
Directorate of Rice Research, Rajendranagar, Hyderabad - 500 030, Andhra Pradesh, India

The extent of heterobeltiosis and standard heterosis of ten characters of one hundred and fifteen rice hybrids developed by crossing five CMS lines and 23 testers in line x tester fashion were evaluated under irrigated conditions during *kharif*, 2008 over three locations *viz.,* Hyderabad, Warangal and Jagtial representing different agro climatic zones in Andhra Pradesh, India. The pooled analysis of variance (line x tester) 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 per day (68.54%), grain yield per plant (67.69%) and spikelet fertility *per cent* (66.02%). The highest percentage of average heterosis was observed for productive tillers per plant followed by productivity per day and grain yield per plant whereas the highest percentage of standard heterosis was observed for filled grains per panicle 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. Testing of these hybrids in all India coordinated trials across different states of the country may result in identification of better hybrids in the near future for commercial exploitation.

Key words: Heterosis, hybrid rice, multilocation testing, yield attributes

Rice occupies the enviable prime place among the food crops cultivated around the world. Rice is the staple food crop of India. India has the largest area among the rice growing countries and enjoys the second rank in rice production. India produces 89.09 million tons from an area of 41.92 million hectares with a productivity of over two tons per hectare (Department of Agriculture and Cooperation, 2011). Since land is shrinking resource, increasing food production by expanding the area under cultivation is impossible. So the only way out is to enhance marginal land productivity.

Introduction of semi dwarf varieties possessing improved harvest index, non lodging, and erect plant type with high responsiveness to fertilizers in mid-sixties boosted the rice production of India subsequently. However the productivity has come to stagnation since the last two decades and all efforts have failed to give tangible results to break the present genetic yield barrier in rice, successful demonstration of substantial yield increase through exploitation of hybrid rice technology. It has encouraged scientists in other rice growing countries including India to adopt hybrid technology as a practical option to enhance the productivity of rice.

*Corresponding author email: saidu_genetics@yahoo.co.in

China started its hybrid rice research in 1964 with the identification of wild abortive cytoplasm. CMS lines with WA cytoplasm were developed in 1974 and the first hybrid was developed in 1976 under the guidance of Prof. Yuan Long Ping. Even though the hybrid rice research activities were initiated in India during early seventies, which were confined to studies of basic research and there was no serious effort towards commercial exploitation mainly because of not availability of new heterotic hybrids and anticipated seed production difficulties.

As a result of concerted and coordinated efforts for the first time in the country the states released four rice hybrids for commercial cultivation during 1994. Since then a total of 46 rice hybrids have been released both from public and private sectors. Concerted research efforts are needed to identify and improve the diverse parental lines suited to local conditions. Development and evaluation of highly heterotic hybrids and studying their stability over different seasons and locations will go a long way in identifying the appropriate hybrids to meet the research gaps especially in tropics. 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 cultivation.

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 *kharif,* 2008 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 per hill 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 per plant, panicle length, panicle weight, number of filled grains per panicle, spikelet fertility percentage, 1000 seed weight, grain yield per plant and productivity per day on five plants of each entry in each replication. Days to 50 per cent flowering was recorded on plot basis. The analysis of variance for each trait was calculated as per Panse and Sukhatme (1978). 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 according to the method of Fonseca and Patterson (1968).

Results and Discussion

Pooled analysis of variance

The pooled analysis of variance (line x tester) over three locations revealed significant differences for locations for all the characters studied (Table 1a and 1b). 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 per plant, panicle length, filled grains per panicle 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 per plant, flag leaf length and flag leaf width, while testers x locations was significant only for filled grains per panicle. 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 per panicle, 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).

Contribution of parents towards variance

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 per plant, spikelet fertility *per cent* and 1000 grain weight. For flag leaf width and filled grains per panicle, 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 per plant (67.69%) and spikelet fertility *per cent* (66.02%).

Table 1a. Pooled analysis of variance (L X T) for yield and yield components in rice

Source of variation	d.f	Mean of Squares					
		Days to 50% flowering	Plant height	Flag leaf length	Flag leaf width	Productive tillers/plant	Panicle length
Locations	2	8166.540**	6484.604**	6451.716**	6.618**	86.747**	202.405**
Replications x Locations	2	4.938	29.056	0.375	0.134**	0.175	0.379
Treatments	142	63.697**	336.490**	80.313**	0.175**	12.895**	11.118**
Parents	27	105.061**	805.453**	81.219**	0.256**	2.885**	10.987**
Parent vs. Crosses	1	42.894**	1930.397**	1593.886**	0.203**	1058.221**	514.087**
Crosses	114	54.083**	211.438**	66.821**	0.155**	6.097**	6.737**
Lines	4	39.357	394.483	245.108**	0.870**	10.618*	19.280**
Testers	22	71.607	372.022**	109.044**	0.189	13.195**	10.127*
Lines x Testers	88	50.371**	162.972**	48.162**	0.114**	4.116**	5.319**
Parents x Locations	54	33.297**	92.719**	40.486**	0.095**	2.260**	3.337**
Parent vs. Crosses) x Locations	2	597.974**	858.389**	81.341**	0.030	26.055**	37.831**
Crosses x Locations	228	54.380**	87.636**	42.938**	0.079**	4.269**	2.818**
Lines x Locations	8	42.079	130.372	200.827**	0.289**	10.170*	1.735
Testers x Locations	44	65.061	91.173	47.957	0.090	4.533	2.515
Lines x Testers x Locations	176	52.269**	84.809**	34.506**	0.067**	3.935**	2.943**
Error	426	3.812	9.963	8.677	0.021	0.967	0.796

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

Table 1b. Pooled analysis of variance (L X T) for yield and yield components in rice

Source of variation	d.f	Mean of Squares					
		Days to 50% flowering	Plant height	Flag leaf length	Flag leaf width	Productive tillers/plant	Panicle length
Locations	2	10.027**	12805.560**	4297.021**	34.324**	876.645**	4823.378**
Replications x Locations	2	0.268	160.089	0.282	0.221	1.522	12.162
Treatments	142	3.027**	7583.527**	119.148**	25.561**	160.233**	714.219**
Parents	27	1.932**	6297.925**	79.294**	40.342**	52.871**	240.599**
Parent vs. Crosses	1	98.811**	100092.800**	375.922**	51.517**	4458.350**	20275.250**
Crosses	114	2.446**	7076.527**	126.335**	21.832**	147.958**	654.804**
Lines	4	21.533**	49802.710**	312.097*	21.425	503.279**	1960.378*
Testers	22	2.359	9377.320**	165.686	54.209**	156.382	711.171
Lines x Testers	88	1.600**	4559.229**	108.053**	13.756**	129.701**	581.368**
Parents x Locations	54	0.829**	1856.914**	60.818**	9.070**	30.227**	139.273**
(Parent vs. Cross) x Locations	2	3.983**	13293.420**	104.211 **	42.976**	150.846**	545.955**
Crosses x Locations	228	0.935**	2449.021**	98.394 **	13.826**	68.936**	319.323**
Lines x Locations	8	1.043	3146.987	190.423	17.752	82.201	357.870
Testers x Locations	44	1.131	2587.760**	85.863	16.059	62.670	297.621
Lines x Testers x Locations	176	0.882**	2382.610**	97.344 **	13.089**	69.899**	322.996**
Error	426	0.152	138.777	6.252	0.390	3.688	16.505

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

Extent of heterosis

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 and presented in Table
3. The degree of heterosis varied considerably for grain yield per plant and its attributes. The highest percentage of average heterosis was observed for productive tillers per plant followed by productivity per day, grain yield per plant, panicle weight and filled grain per panicle. The negative heterosis was observed for spikelet fertility % and flag leaf length. The hybrids averaged about 29.09% heterosis for productivity per day and 28.23% for grain yield per plant over the means of their parents. The observed highest heterosis for grain yield per plant was due to expressions of heterosis in component characters like productive tillers per plant (33.09%), Panicle weight (24.38%) and filled grains per panicle (17.7%). The highest percentage of standard heterosis was observed for filled grains per panicle and flag leaf width, whereas negative heterosis was observed for characters spikelet fertility %, productivity per day, 1000 grain yield per plant suggesting that checks performed better than the hybrids in the present study.

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

Character	Contribution		
	Line (%)	Tester (%)	Line x Tester (%)
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 per plant	6.11	41.77	52.12
Panicle length	10.04	29.01	60.95
Panicle weight	30.89	18.61	50.50
Filled grains per panicle	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 per plant	11.94	20.40	67.69
Productivity per day	10.50	20.96	68.54

Heterosis for maturity and plant height

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.

Heterosis for flag leaf length

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)

Table 3. Average performance of parents, F_1 s, checks and average and standard heterosis for grain yield per plant and other components in rice

Character	Average performance			Standard heterosis (%)	Average 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 per plant	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 per plant	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 per plant	20.35	26.09	26.60	28.23	-0.51
Productivity per day	42.11	54.36	56.18	29.09	-1.82

Heterosis for yield and yield components

Number of productive tillers per plant 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 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

Table 4. Heterosis of some promising hybrids for grain yield per plant 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 IBL57			IR 79156A X IBL 57			PUSA 5A X 517			APMS 6A X GQ-20		
	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 79156AX EPLT-109			APMS 6AX 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 per plant			Filled grains per spikelet			Panicle length		
	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 6AX 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 6AX 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 per day			Grain yield per plant			Grain yield per plant	
	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.

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 per panicle is one of the most important components of yield. Fifty four hybrids showed significant increase in number of filled grains per panicle 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 ultimate product (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). Thousand 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 per day 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 per plant. 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.* (2007) , Eradasappa *et al.* (2007), Rosamma and Vijayakumar (2007) and Singh *et al.* (2007).

Grain yield per plant is a multiplicative product of several basic components of yield. The increased grain yield is definitely 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 per panicle, panicle weight and productivity per day. 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 per panicle and panicle weight, PUSA 5A x KMR-3 for productivity per day and 1000-grain weight, both APMS 6A x 1005 and APMS 6A x SC5 9-3 for productivity per day, filled grains per panicle and IR 79156A x SG 27-77 for filled grains per panicle. This indicates that the yield attributes helped the hybrids to get high heterosis for grain yield per plant. 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 per plant (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 per panicle and productivity per day.

Table 5. Over all performance of top 20 heterotic hybrids for grain yield per plant in rice

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

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 per plant. The cross was also promising for panicle weight, filled grains per panicle and productivity per day. 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 per plant. Besides grain yield, the cross had shown promise for productivity per day.

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 per panicle and productivity per day, whereas, PUSA 5A x KMR-3 was promising for 1000-grain weight and productivity per day.

Twenty superior yielding hybrids with significant standard heterosis (> 13% over KRH 2, leading public hybrid) were compared for their stability parameters of grain yield and yield component traits (Table 5). The first 12 high yielding hybrids were unpredictable in their performance and a hybrid, CRMS 32A x 517 which was ranked 13th in grain yield was stable over the environments with predictable performance for grain yield per plant confirming the reports of Finlay and Wilkinson, (1963) that the yielding ability and response to environmental changes are the two independent attributes of a genotype and are governed by separate genetic systems. Other stable hybrids with predictable performance for yield and other yield traits were APMS 6A x 118 for grain yield per plant, productivity per day and flag leaf width; PUSA 5A x IR 55 for grain yield per plant and productivity per day. One hybrid PUSA 5A x 1096 with above average response was desirable for specific (favourable) environments. The hybrids with specific adaptability rather than general might overcame the problem of genetic vulnerability.

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. The large scale testing of these hybrids in all India Coordinated Rice Improvement Project (AICRIP) trials may result in commercial release in near future and thereby help in accelerating the rate of adoption of rice hybrids in the India.

References

Adams, M.W. 1967. Basic of yield compensation in crop plants with special reference to field beans (*Phaseolous vulgaris* L.). *Crop Sci.,* **7**: 505-510.

Deoraj, Singh, D.N., Madhuviarya, and Praveen Singh, 2007. Heterosis in rainfed transplanted rice. *Oryza,* **44**: 264-267.

Dhillon, B.S. 1975. The application of partial diallel crosses in plant breeding - A review. *Crop improv*., **2**:1-7.

Eradasappa, E., Ganapathy, K. N., Satish, R.G., Shanthala, J. and Nadarajan, N. 2007. Heterosis studies for yield and yield components using CMS lines in rice (*Oryza sativa*). *Crop Res.,* **34**: 152-155.

Finlay, K.W. and Wilkinson, G.N. 1963. The analysis of adaptation in a plant breeding programme, *Australian J. Agric. Res*., **14**: 742-754.

Fonseca, S. and Patterson, F.L. 1968. Hybrid vigour in a seven parent diallel cross in common winter wheat. (*Triticum aestivum* L.). *Crop Sci.,* **8**: 85-95.

Ghosh, A. 2002. Studies on heterosis in upland rice. *Oryza,* **39**: 5-8.

Hossain, M.S., Zaman, F.V. and Singh, A.K. 2005. Heterosis and per day productivity in rice hybrids of different maturity groups, developed from indica / japonica derived lines. *Indian J. Genet.,* **65**: 41-42.

Lokaprakash, R., Shivashankar, G., Mahadevappa, M., Shankaregowda, and Kulkarni, R.S. 1992. Heterosis in rice. *Oryza,* **29** : 293-297.

Mishra, M. and Pandey, M.P. 1998. Heterosis breeding in rice for irrigated sub-humid tropics in north India. *Oryza,* **35**: 8-14.

Panse, V.G. and Sukhatme, P.V. 1978. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi.

Panwar, D.V.S., Rakeshkumar, Singh, A. and Mehla, B. S. 2002. Studies on heterosis in hybrid rice. *Oryza,* **39**: 54-55.

Peng, J.Y. and Virmani, S.S. 1991. Heterosis in some inter-varietal crosses of rice. *Oryza,* **28**: 1-10.

Rosamma, C.A. and Vijaya Kumar, N.K. 2007. Variation in quantitative characters and heterosis in F_1 rice (*Oryza sativa* L.) hybrids as affected by male sterile cytoplasm. *Indian J. Genet.,* **67**: 31-36.

Singh, N.K., Singh, S., Singh, A.K., Sharma, C.L., Singh, P. K. and Singh, O.N. 2007. Study of heterosis in rice (*Oryza sativa* L.) using line x tester mating system. *Oryza,* **44**: 260-263.

Singh, R.V., Verma, O.P., Dwivedi, J.L. and Singh, R.K. 2006. Heterosis studies in rice hybrids using CMS systems. *Oryza,* **43**: 154-156.

Virmani, S.S., Chaudhary, R.C. and Khush, G.S. 1982. Heterosis breeding in rice (*Oryza sativa* L.).*Theor. and Appl. Genet.,* **63**: 373-380.

Yadav, L.S., Maurya, D.M., Giri, S.P. and Singh, S.B. 2004. Nature and magnitude of heterosis for growth, yield and yield components in hybrid rice. *Oryza,* **41**:1-3.

Received: November 8, 2011; Accepted: March 19, 2012