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Expression of heterosis in rice hybrids over three environments

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ABSTRACT

Sixty rice hybrids developed through a line x tester fashion involving five cytoplasmic male sterile lines and 12 restorer lines were evaluated in a randomized complete block design over three locations for yield and its components. In most of the heterotic crosses, significant positive standard heterosis for single plant yield achieved due to positive and significant standard heterosis for component characters like panicle length, panicle weight, number of productive tillers per plant, number of filled grains per panicle, 1000-grain weight. The top most heterotic combinations identified for single plant yield were APMA6A x IR-54742R, APMS6A x IR-24R, APMS6A x BR-827-35R, IR-80555A x IR-54742R, IR-80559A x IR-54742R and IR-80559A x KMR-3R over three locations.

Key words: *rice, heterosis, line, tester, pooled analysis, stability, yield components*

Success of heterosis breeding in several cross fertilizing species prompted the scientists to study the prospects of its application in self pollinated crops as well. With the serious limitations of strictly self fertilizing nature of rice and absence of a usable form of male sterility, research continued, however, with no tangible results until the Chinese scientists released the first rice commercial hybrid in 1976. Since then many investigators have reported significant heterosis in certain hybrids. However, to be of practical value, a hybrid should be more profitable than the best available commercial variety to the farmer. Several cytoplasmic genetic male sterile (GMS) lines have been developed for this purpose. Presently, the hybrids in India have shown 20-30% higher yield than the commercial varieties and found to possess better and wider adaptability. Yield heterosis is a variable trait and depends not only on the parental combinations alone but on the effect of environmental conditions also (Virmani *et al*., 1982; Young and Virmani, 1990).

Hence, the present investigations was undertaken to identify heterotic rice hybrids for yield and yield attributes from hybrids utilizing the CGMS lines and their effective restorers over three environments.

MATERIAL AND METHODS

Experimental material consisted of 60 hybrids developed in a line x tester mating design (Kempthorn, 1957) involving five CMS lines as females and 12 restorer lines as the male parents. The hybrids between five female parents and 12 male parents were attempted during dry season, 2008-2009. The resulting 60 F_1 hybrids along with their 17 parents and five checks (three hybrid checks *viz.,* KRH-2, PA-6201 and DRRH-2 and two varietal checks *viz.,* Jaya and IR-64) were sown during wet season, 2009 at three different locations *viz.,* Directorate of Rice Research, Hyderabad for Southern Telangana agro- climatic zone, Regional Agricultural Research Station, Warangal for Central Telangana agro-climatic zone and Regional Agricultural Research Station, Karimnagar for Northern Telangana agro-climatic zone. Twenty one days old seedlings were transplanted with a spacing of 20 cm between the rows and 15 cm between the plants in a row. At flowering and maturity stages, observations were recorded on eight characters from five randomly selected plants in each entry in replications. Performance of F_1 hybrids was evaluated on the basis of estimates of heterobeltiosis and standard heterosis against standard check, PA-6201. Statistical significant of heterosis values were tested by comparing these values with the critical difference values.

RESULTS AND DISCUSSION

In the present investigation, 82 genotypes including 60 hybrids, 17 parents and five checks were subjected to pooled analysis of variance for eight characters (Table 1). The GxE interactions were significant for five characters *viz.,* panicle weight, number of productive tillers per plant, number of filled grains per panicle, 1000-grain weight and single plant yield implying differential response of genotypes under three locations for these characters. The GxE interactions for the remaining three characters (*viz.,* days to 50% flowering, panicle length and spikelet fertility percentage) were found to be non-significant. Significant genotype x environment interactions implying differential behaviour of genotypes for yield and it's components under three different locations. Similar reports were earlier made by Hegde and Vidyachandra (1998), Arumugam *et al*. (2007) and Ramya and Senthil kumar (2008).

Partitioning of sum of squares into that of varieties, environments (genotype x environment) and pooled error revealed that mean squares due to genotypes were highly significant for all the characters studied, indicating the presence of genetic variability in the experimental material (Arumugam *et al*.,2007 and Krishnappa *et al*.,2009). Mean squares due to environments were significant for five characters *viz.,* panicle weight, number of productive tillers per plant, number of filled grains per panicle,1000-grain weight and single plant yield depicted the existence of GxE interaction. These findings are in conformity with Young and Virmani (1990), Deshpande *et al*. (2003), Ramya and Senthil kumar (2008) and Krishnappa *et al*. (2009).

Sum of squares due to G x E was further partitioned into that of environment (linear), genotype x environment (linear) and pooled deviation. Significant variation due to environment (linear) was observed for all the eight characters studied except 1000-grain weight revealing the linear contribution of environmental effects and additive environment variance on these characters. Similar results were reported earlier by Hegde and Vidyachandra (1998), Deshphande *et al*. (2003), Arumugam *et al*. (2007), Ramya and Senthil kumar (2008) and Krishnappa *et al*. (2009) for yield and it's components. The linear component of genotype x environment was significant for all the characters except days to 50% flowering, panicle length and spikelet fertility percentage suggesting that the genotypes significantly differing for their linear response to environments. Similar results were observed by Ramya and Senthil kumar (2008) and Krishnappa *et al*. (2009) for yield and its components. Higher magnitude of environment (linear) effects in comparison to GXE (linear) may be responsible for high adaptation in relation to yield and its components.

The mean sum of squares for pooled deviation was significant for all the eight characters indicating the non-linear response and unpredictable nature of genotypes by significantly differing for stability. Significant non-linear responses were observed earlier by Hegde and Vidyachandra (1998), Arumugam *et al*. (2007), Ramya and Senthil kumar (2008) and

Table 1. Analysis of variance for yield and yield components for stability in rice

Source	d.f	Days to 50% flowering	Panicle length (cm)	Panicle weight (cm)	Number of productive tillers plant^{-1}	Number of filled grains panicle^{-1}	Spikelet fertility (%)	1000-grain weight (g)	Single plant yield (g)
Varieties	81	100.97 **	4.90 **	1.09 **	7.55 **	2717.52 **	41.23 **	6.46 **	96.99 **
Envi. + (Var.*Envi.)	164	1.44	1.56	0.18 **	1.10 **	514.85 **	15.82	0.30 *	15.08 **
Environments	2	14.52 **	51.44 **	2.32 **	12.00 **	5859.23 **	91.59 **	0.11	201.28 **
Var.* Envi.	162	1.28	0.94	0.16 **	0.96 *	448.87 *	14.88	0.31 *	12.78 *
Environments (linear)	1	29.05 **	102.88 **	4.64 **	24.00 **	11718.45 **	183.17 **	0.22	402.55 **
Var.* Envi.(linear)	81	1.49	0.67	0.22 **	1.30 **	574.19 **	16.44	0.39 *	16.51 **
Pooled Deviation	82	1.06 **	1.20 **	0.09 **	0.61 **	319.60 **	13.16 **	0.22 *	8.95 **
Pooled Error	486	0.19	0.18	0.04	0.24	68.88	6.61	0.15	3.04

* Significant at 5% level ; ** Significant at 1% level

Table 2. Heterosis over better parent and standard check for days to 50% flowering, panicle length, panicle weight and number of productive tillers plant^{-1} in pooled analysis.

Cross	Days to 50% flowering		Panicle length		Panicle weight		Number of productive tillers plant^{-1}	
	BP	SC	BP	SC	BP	SC	BP	SC
IR- 80151Ax IR- 66 R	-9.78**	-3.22**	1.81	-1.76	21.00**	-6.72	7.26	-16.18**
IR- 80151Ax IR-10198 R	-10.89**	-4.41**	4.95**	4.01**	35.95**	10.83 **	31.02 **	2.94
IR- 80151Ax DR-714-1-2 R	-11.33**	-4.89**	2.30	-0.29	38.08**	6.45	33.87 **	4.62
IR- 80151Ax IR -40750R	-10.67**	-4.17**	1.30	-2.30	10.67*	-14.68 **	2.69	-19.75**
IR- 80151Ax IR-72R	-8.11**	-1.43**	-5.79**	-4.25**	2.19	-14.89 **	0.79	-19.96**
IR- 80151Ax IR-24R	-4.44**	2.50**	-1.41	5.74**	29.05**	6.61	24.60 **	-2.63
IR- 80151Ax IR-21567 R	-10.78**	-4.29**	0.22	2.28	19.19**	9.94 *	25.27 **	-2.10
IR- 80151Ax KMR-3 R	-8.00**	0.12	-1.85	6.66**	23.79**	13.22 **	32.24 **	10.29**
IR- 80151Ax IR-32809 R	-15.14**	-7.15**	-5.88**	-6.99**	-2.03	-24.47 **	-1.34	-22.90**
IR- 80151Ax IR-63883-41-3 R	-5.33**	1.55**	-3.86**	-0.93	18.53**	12.86 **	33.95 **	6.09
IR- 80151Ax IR-54742 R	-4.36**	7.27**	-0.70	12.33**	27.72**	28.32 **	39.90 **	14.92**
IR- 80151Ax BR-827-35 R	-5.15**	5.36**	-1.25	2.89*	22.06**	16.66 **	38.40 **	12.82**
IR- 80555Ax IR- 66 R	-7.93**	-3.10**	-0.88	-4.36**	10.80*	-16.14 **	1.10	-23.11**
IR- 80555Ax IR-10198 R	-12.57**	-7.99**	-0.99	-1.89	10.47*	-9.94 *	23.53 **	-2.94
IR- 80555Ax DR-714-1-2 R	-8.15**	-3.34**	-0.82	-3.33*	46.81**	10.05 *	34.25 **	2.10
IR- 80555Ax IR -40750R	-9.40**	-4.65**	-2.78*	-6.24**	12.10*	-15.15 **	4.97	-20.17**
IR- 80555Ax IR-72R	-11.90**	-5.60**	-6.90**	-5.38**	16.06**	-3.33	13.76 **	-9.66*
IR- 80555Ax IR-24R	-13.12**	-8.46**	-5.94**	0.89	16.82**	-3.49	27.63 **	-0.53
IR- 80555Ax IR-21567 R	6.36**	13.59**	0.71	2.78*	21.67**	12.23 **	25.27 **	-3.15
IR- 80555Ax KMR-3 R	-9.09**	-1.07**	-5.26**	2.95*	12.35**	2.76	32.82 **	10.78**
IR- 80555Ax IR-32809 R	-14.05**	-5.96**	-2.74*	-3.88**	10.97*	-15.72 **	-4.14	-27.10**
IR- 80555Ax IR-63883-41-3 R	-5.29**	0.36	1.40	4.49**	-2.13	-6.82	13.26 **	-10.29**
IR- 80555Ax IR-54742 R	-3.72**	7.99**	-2.78*	9.97**	16.99**	17.54 **	41.94 **	16.60**
IR- 80555Ax BR-827-35 R	-3.65**	7.03**	-0.85	3.31*	13.78**	8.75 *	41.24 **	15.13**
IR- 80559Ax IR- 66 R	-6.25**	-1.67**	-2.67*	-4.00**	-0.91	-14.78 **	-4.52	-24.58**
IR- 80559Ax IR-10198 R	-12.27**	-7.99**	1.71	0.79	13.08**	-2.76	10.64 *	-12.61**
IR- 80559Ax DR-714-1-2 R	-9.66**	-5.24**	1.82	0.43	13.98**	-1.98	16.22 **	-8.19*
IR- 80559Ax IR -40750R	-7.16**	-2.62**	0.99	-0.39	2.54	-11.82 **	3.75	-18.05**
IR- 80559Ax IR-72R	-12.90**	-6.67**	1.99	3.65**	16.40**	0.10	29.89 **	3.15
IR- 80559Ax IR-24R	-6.56**	-1.55**	-7.40**	-0.67	19.98**	3.18	28.19 **	1.26
IR- 80559Ax IR-21567 R	-8.71**	-2.50**	4.85**	7.01**	18.68**	9.47 *	39.36 **	10.08**
IR- 80559Ax KMR-3 R	-9.86**	-1.91**	2.25	11.11**	29.03**	18.01 **	35.26 **	12.82**
IR- 80559Ax IR-32809 R	-16.45**	-8.58**	2.69*	1.48	9.14	-6.14	23.94 **	-2.10
IR- 80559Ax IR-63883-41-3 R	-4.72**	0.95**	2.73*	5.86**	3.17	-1.77	32.10 **	4.62
IR- 80559Ax IR-54742 R	-3.72**	7.99**	0.12	13.25**	16.89**	17.44 **	58.31 **	30.04**
IR- 80559Ax BR-827-35 R	-3.97**	6.67**	4.06**	8.42**	10.46*	5.57	36.60 **	11.34**
IR- 80561Ax IR- 66 R	-12.06**	-7.87**	-0.39	-3.88**	9.22	-17.33 **	-1.97	-26.68**
IR- 80561Ax IR-10198 R	-14.79**	-10.73**	1.32	0.41	2.87	-16.14 **	15.78**	-9.03*
IR- 80561Ax DR-714-1-2 R	-11.49**	-7.27**	-2.36	-4.84**	1.57	-26.08 **	2.60	-25.42**
IR- 80561Ax IR -40750R	-9.78**	-5.48**	-4.00**	-7.41**	3.71	-21.50 **	17.05**	-14.92**
IR- 80561Ax IR-72R	-9.12**	-2.62**	-6.75**	-5.23**	-10.19*	-25.20 **	3.70	-17.65**
IR- 80561Ax IR-24R	-6.33**	-1.31**	-10.59**	-4.09**	-3.47	-20.25 **	0.46	-21.70**
IR- 80561Ax IR-21567 R	-8.82**	-2.62**	-3.06*	-1.06	5.64	-2.55	38.86**	7.35
IR- 80561Ax KMR-3 R	-13.36**	-5.72**	-4.02**	4.30**	20.55**	10.26 *	34.51**	12.18**
IR- 80561Ax IR-32809 R	-13.07**	-4.89**	1.77	0.57	37.49**	4.42	49.57**	9.03*
IR- 80561Ax IR-63883-41-3 R	-8.55**	-3.10**	-6.04**	-3.17*	-12.03**	-16.24 **	17.77**	-6.72
IR- 80561Ax IR-54742 R	-3.93**	7.75**	-2.66*	10.10**	13.78**	14.32 **	45.27**	19.33**
IR- 80561Ax BR-827-35 R	-3.22**	7.51**	0.94	5.18**	18.36**	13.12 **	38.66**	13.03**
APMS 6Ax IR- 66 R	-12.79**	-4.89**	-2.18	-4.77**	-11.07*	-17.18 **	1.57	-18.49**
APMS 6Ax IR-10198 R	-14.75**	-7.03**	3.74**	2.80*	6.65	-0.68	27.23**	2.10
APMS 6Ax DR-714-1-2 R	-19.23**	-11.92**	5.30**	2.63*	16.21**	8.22 *	30.21**	4.50
APMS 6Ax IR -40750R	-14.86**	-7.15**	0.57	-2.09	-6.20	-12.65 **	5.24	-15.55**
APMS 6Ax IR-72R	-15.52**	-7.87**	-1.85	-0.25	-5.87	-12.34 **	15.97**	-6.93
APMS 6Ax IR-24R	-11.48**	-3.46**	-4.48**	2.46	22.25**	13.85 **	47.64**	18.49**
APMS 6Ax IR-21567 R	-14.43**	-6.67**	-0.38	1.67	4.47	-2.71	23.17**	-1.16
APMS 6Ax KMR-3 R	-12.68**	-4.77**	-3.69**	4.65**	23.92**	15.41 **	39.55**	16.39**
APMS 6Ax IR-32809 R	-13.29**	-5.13**	1.89	0.69	9.11*	1.61	21.20**	-2.73
APMS 6Ax IR-63883-41-3 R	-13.01**	-5.13**	-0.07	2.98*	12.36**	6.98	20.68**	-3.15
APMS 6Ax IR-54742 R	-4.04**	7.63**	-1.06	11.92**	23.06**	23.63 **	39.90**	14.92**
APMS 6Ax BR-827-35 R	-4.61**	5.96**	-0.25	3.94**	19.55**	14.26 **	42.78**	16.39**

Table 3. Heterosis over better parent and standard check for number of filled grains per panicle, spikelet fertility percentage, 1000-grain weight and single plant yield in pooled analysis.

Cross	Number of filled grains panicle^{-1}		Spikelet fertility percentage		100-gram weight		Single plant yield	
	BP	SC	BP	SC	BP	SC	BP	SC
IR- 80151Ax IR- 66 R	6.61	-11.38**	-6.95 **	-6.76**	3.23 *	-1.74	37.46**	-13.51*
IR- 80151Ax IR-10198 R	32.42 **	12.07**	-2.86	2.60	0.85	1.12	62.77**	11.12
IR- 80151Ax DR-714-1-2 R	33.93 **	11.33**	0.38	2.01	3.76 **	-3.79 **	81.41**	14.15*
IR- 80151Ax IR -40750R	0.11	-16.79**	-17.27 **	-13.43**	0.08	-2.37	18.62*	-25.36**
IR- 80151Ax IR-72R	-7.55	-20.00**	-9.84 **	-8.04**	-0.90	-1.17	18.52*	-22.08**
IR- 80151Ax IR-24R	11.12 *	-1.11	-3.44	-3.26	-0.93	0.01	62.89**	13.47*
IR- 80151Ax IR-21567 R	36.64 **	17.51**	2.22	4.98*	0.50	2.30	48.58**	4.47
IR- 80151Ax KMR-3 R	20.22 **	14.20**	-1.58	2.24	16.86 **	12.59 **	50.41**	14.51*
IR- 80151Ax IR-32809 R	-2.04	-18.57**	-8.07 **	-10.54**	-4.08 **	-5.27 **	1.59	-36.08**
IR- 80151Ax IR-63883-41-3 R	26.77 **	12.07**	5.94 *	5.13*	-4.83 **	2.19	57.44**	12.46*
IR- 80151Ax IR-54742 R	48.16 **	33.77**	4.23	6.05*	1.97	16.12 **	57.53**	20.64**
IR- 80151Ax BR-827-35 R	47.55 **	24.40**	-1.67	4.24	-4.98 **	6.18 **	55.55**	16.30**
IR- 80555Ax IR- 66 R	-8.10	-21.45**	-8.34 **	-7.78**	3.81 **	-1.18	7.07	-28.00**
IR- 80555Ax IR-10198 R	6.77	-8.74*	-3.50	1.92	2.93 *	3.20 **	30.61**	-10.83
IR- 80555Ax DR-714-1-2 R	30.00 **	11.12**	0.80	2.44	8.46 **	-4.83 **	65.11**	11.04
IR- 80555Ax IR -40750R	-4.82	-18.65**	-8.39 **	-4.13	1.00	-1.47	6.07	-28.67**
IR- 80555Ax IR-72R	5.93	-8.34*	0.27	2.28	0.99	0.72	21.33*	-18.41**
IR- 80555Ax IR-24R	13.43 **	0.94	-1.51	-0.92	2.02	2.99 *	41.31**	-1.57
IR- 80555Ax IR-21567 R	40.69 **	21.00**	-1.01	1.66	-2.76 *	-1.02	61.97**	13.87*
IR- 80555Ax KMR-3 R	17.34 **	11.46**	-2.34	1.45	3.43 **	-0.35	46.09**	11.23
IR- 80555Ax IR-32809 R	-14.33 **	-26.78**	-5.75 *	-5.18*	0.17	-1.07	-14.16	-42.27**
IR- 80555Ax IR-63883-41-3 R	9.85 *	-2.89	-4.70	-4.12	-4.46 **	2.59 *	20.02*	-14.27*
IR- 80555Ax IR-54742 R	42.38 **	28.55**	0.13	1.88	-3.60 **	9.77 **	60.30**	22.75**
IR- 80555Ax BR-827-35 R	26.55 **	8.17*	-3.06	2.77	-4.86 **	6.32 **	48.64**	11.13
IR- 80559Ax IR- 66 R	-11.59 *	-21.87**	-3.76	-3.57	3.13 *	0.67	-7.43	-32.08**
IR- 80559Ax IR-10198 R	-8.11	-18.79**	-5.71 *	-0.42	2.43 *	2.70 *	18.31*	-13.19*
IR- 80559Ax DR-714-1-2 R	0.84	-10.89**	-1.27	0.33	3.72 **	1.24	20.48**	-11.60*
IR- 80559Ax IR -40750R	-9.42 *	-19.96**	-6.46 **	-2.11	2.95 *	0.49	-5.72	-30.82**
IR- 80559Ax IR-72R	23.47 **	9.11*	0.42	2.42	3.64 **	3.36 **	40.58**	3.15
IR- 80559Ax IR-24R	15.22 **	2.54	2.92	3.12	1.38	2.34	43.58**	5.35
IR- 80559Ax IR-21567 R	32.83 **	17.38**	2.82	5.58*	0.12	1.91	51.89**	11.45*
IR- 80559Ax KMR-3 R	40.24 **	33.21**	1.82	5.77*	5.49 **	2.97 *	58.97**	21.03**
IR- 80559Ax IR-32809 R	26.52 **	11.80**	1.11	0.82	3.35 **	2.07	34.70**	-1.16
IR- 80559Ax IR-63883-41-3 R	15.80 **	2.37	0.08	-0.20	-0.60	6.73 **	46.50**	7.49
IR- 80559Ax IR-54742 R	35.47 **	22.31**	3.60	5.41*	1.66	15.76 **	59.25**	21.95**
IR- 80559Ax BR-827-35 R	23.92 **	9.50*	-2.24	3.64	-1.41	10.17 **	50.37**	12.42*
IR- 80561Ax IR- 66 R	-2.13	-25.91**	-7.36**	-7.17**	-0.45	-5.25**	8.56	-33.18**
IR- 80561Ax IR-10198 R	8.70	-8.01	-5.83*	-0.54	-2.02	-1.76	22.65**	-16.27**
IR- 80561Ax DR-714-1-2 R	2.17	-19.07**	-6.54**	-5.03*	0.13	-10.00**	12.82	-32.22**
IR- 80561Ax IR -40750R	3.69	-17.50**	-6.89**	-2.56	-3.59 **	-5.94**	36.04**	-21.91**
IR- 80561Ax IR-72R	-7.41	-19.88**	-11.13**	-9.35**	1.14	0.87	13.53	-25.36**
IR- 80561Ax IR-24R	-9.92*	-19.84**	-8.81**	-8.64**	-3.59 **	-2.67*	9.87	-23.46**
IR- 80561Ax IR-21567 R	12.08*	-3.61	-2.57	0.06	-3.44 **	-1.70	49.82**	5.34
IR- 80561Ax KMR-3 R	33.18**	26.51**	-0.69	3.16	3.12 *	-0.65	53.68**	17.00**
IR- 80561Ax IR-32809 R	43.78**	13.16**	3.92	-0.63	1.74	0.48	94.26**	11.51*
IR- 80561Ax IR-63883-41-3 R	1.06	-10.66*	-7.02**	-7.73**	-6.24 **	0.68	31.39**	-6.15
IR- 80561Ax IR-54742 R	22.38**	10.49*	0.98	2.74	0.16	14.05**	50.37**	15.15**
IR- 80561Ax BR-827-35 R	38.78**	17.01**	-1.82	4.09	-3.88 **	7.41**	56.76**	17.20**
APMS 6Ax IR- 66 R	-30.87**	-20.37**	-3.46	-3.27	1.69	-3.21**	1.50	-26.88**
APMS 6Ax IR-10198 R	2.83	18.46**	-2.42	3.05	-3.81 **	-3.55**	48.58**	7.03
APMS 6Ax DR-714-1-2 R	3.81	19.59**	-1.36	0.24	3.88 **	-9.29**	58.48**	14.16*
APMS 6Ax IR -40750R	-22.57**	-10.80**	-4.63*	-0.20	0.93	-1.54	14.21	-17.73**
APMS 6Ax IR-72R	-11.67**	1.76	-4.21	-2.29	-0.58	-0.85	25.72**	-9.43
APMS 6Ax IR-24R	12.35**	29.42**	2.26	2.46	-1.52	-0.58	73.57**	25.04**
APMS 6Ax IR-21567 R	-8.54*	5.37	1.07	3.79	-3.43 **	-1.69	43.55**	3.41
APMS 6Ax KMR-3 R	12.00**	29.02**	0.27	4.16	-1.01	-4.63**	52.51**	16.11**
APMS 6Ax IR-32809 R	-8.58*	5.31	1.61	1.25	0.14	-1.10	41.06**	1.61
APMS 6Ax IR-63883-41-3 R	-2.24	12.62**	-0.59	-0.93	-6.43 **	0.47	48.98**	7.32
APMS 6Ax IR-54742 R	19.26**	37.39**	1.61	3.38	-6.95 **	5.95**	65.35**	26.62**
APMS 6Ax BR-827-35 R	22.90**	41.58**	-1.23	4.71	-5.23 **	5.90**	66.19**	24.25**

Krishnappa *et al.* (2009), while both significant and non-significant linear responses were reported by Young and Virmani (1990) and Deshphande *et al.* (2003) for yield and its components (Table 1).

Considerable heterosis existed both in positive and negative directions for all the traits. Heterosis expressed as percent increase or decrease in the mean value of F_1 hybrid over better parent (heterobeltiosis) and standard check, PA-6201 (standard heterosis) were observed for various characters (Table 2 and 3). Early maturing hybrids are desirable as they produce more yields per day and fit well in multiple cropping systems. Majority of the hybrids exhibited significant negative heterobeltiosis implying early flowering in hybrids. Among the 60 crosses, 59 hybrids recorded significant negative heterobeltiosis ranging from -19.23 (APMS6A x DR-714-1-2R) to 6.36 percent (IR-80555A x IR-21567R). Out of 60 crosses, 44 crosses excelled significant negative standard heterosis over PA-6201 in which the highest significant negative standard heterosis of -11.92 percent recorded by APMS 6A x DR-714-1-2R was followed by -10.73 (IR-80561A x IR-10198R) and -8.58 percent (IR-80559A x IR-32809R). Presence of both negative and positive standard heterosis of similar trend was observed in their studies by Mishra and Pandey (1998), Singh *et al.* (2006), Deoraj *et al.* (2007), Rosamma and Vijay Kumar (2007) and Akarsh Parihar and Pathak (2008).

Hybrids are generally characterized by having larger panicles indicating their efficiency in partitioning of assimilates to reproductive parts. Panicle length is one of the important attributes for higher yields in hybrids. The spectrum of significant positive variation for heterobeltiosis in panicle length was from 2.69 (IR-80559A x IR-32809R) to 5.30 percent (APMS6A x DR-714-1-2R) for this trait and only seven hybrids manifested significant positive heterobeltiosis. The hybrids, 13.25 (IR-80559A x IR-54742R), 12.33(IR-80151A x IR-54742R) and 11.92 percent (APMS 6A x IR-54742R) exhibited highest standard heterosis over PA- 6201 for panicle length. Standard heterosis of both positive and negative nature was observed in their studies by Singh *et al.* (2006), Deoraj *et al.* (2007) Akarsh Parihar and Pathak (2008).

Panicle weight is positively associated with grain yield and is known to contribute grain yield via more number of filled grains panicle^{-1}. In respect of panicle weight, heterotic effects over PA-6201 varied from 8.75 (IR-80555A x BR-827-35R) to 28.32 percent (IR-80151A x IR-54742R). Out of 60 crosses, 21 hybrids recorded significant positive standard heterosis and the cross, IR-80151A x IR-54742R exhibited the highest standard heterosis of 28.32 percent over the check, PA6201. Heterobeltiosis ranged from -12.03 (IR-80561A x IR-63883-41-3R) to 46.81 percent (IR-80555A x DR-714-1-2R) and as many as 40 hybrids registered positive superior heterosis over better parent. Most of the hybrids expressed significant positive heterobeltiosis for this trait. In contrary to this, heterobeltiosis of both positive and negative nature in their studies were reported by Lokaprakash *et al.* (1992) and Ghosh (2002), while Lingaraju (1997) observed standard heterosis of similar nature in his experiment.

Number of productive tillers plant^{-1} is known to contribute directly towards grain yield can be exploited. Hence, heterosis over better parent and standard check in the positive direction is desirable for this trait. The spectrum of variation for heterobeltiosis in number of productive tillers plant^{-1} was from -4.52 (IR-80559A x IR-66R) to 58.31 percent (IR-80559A x IR-54742R) and 45 hybrids recorded significant positive heterobeltiosis. When compared to PA 6201, 18 hybrids registered significant positive standard heterosis with a range varying from 9.3 (IR-80561A x IR-32809R) to 30.04 percent (IR-80559A x IR-54742R) and the highest standard heterosis of 30.04 percent was recorded by (IR-80559A x IR-54742R) followed by (IR-80561A x IR-54742R) 19.33 percent and (APMS6A x IR-24R) 18.49 percent. Mishra and Pandey (1998), Singh *et al.* (2006), Deoraj *et al.* (2007), Akarsh Parihar and Pathak (2008) and Roy *et al.* (2009) reported both heterobeltiosis and standard heterosis in both positive and negative directions.

Number of filled grains panicle^{-1} is the most important yield contributing trait in the hybrids. The crosses, APMS 6A x BR-827-35R, APMS 6A x IR-54742R, IR-80151A x IR-54742R and IR-80559A x KMR-3R recorded more than 30% standard heterosis over PA 6201 for this trait. Thirty two hybrids with a range varying from 9.85 (IR-80555A x IR-63883-41-3R) to 48.16 percent (IR-80151A x IR-54742R) exhibited significantly higher filled grains panicle^{-1} over their better parents. Virmani *et al.* (1981 and 1982) reported that heterosis in yield was primarily due to increased number of spikelets panicle^{-1} further supported by Patel *et al.* (1994) and Reddy (1996) that confirms the present trend in different traits. Earlier rice workers *viz*., Singh *et al*. (2006), Rosamma and Vijay Kumar (2007) and Akarsh Parihar and Pathak (2008) reported both positive and negative heterobeltiosis and standard heterosis values for this trait.

The extent of spikelet fertility percentage is yet another important character which directly influences the ultimate product. Six hybrids, IR-80151A x IR-54742R, IR-80559A x KMR-3R, IR-80559A x IR-21567R, IR-80559A x IR-54742R, IR-80151A x IR-63883-41-3R and IR-80151A x IR-21567R manifested significant positive standard heterosis over the check, PA-6201, while none of the hybrids had significant positive superiority in respect of heterobeltiosis for this trait. Standard heterosis of both positive and negative nature was observed by Panwar *et al*. (2002) and Banumathy *et al*. (2003) whereas, similar nature for heterobeltiosis was reported by Hari ramakrishnan *et al*. (2009).

Grain weight (1000-grain weight) of a genotype serves as an indicator to the end product *i.e*., grain yield. Eighteen hybrids manifested significant positive standard heterosis over PA-6201 in which the hybrids, IR-80151A x IR-54742R, IR-80559A x BR-827-35R and IR-80561A x IR-54742R exhibited highest standard heterosis. The hybrids revealed a range of heterobeltiosis from -6.95 (APMS6A x IR-54742R) to 16.86 percent (IR-80151A x KMR-3R) and sixteen hybrids recorded significant positive heterosis over better parent. For this character, both significant positive and negative heterobeltiosis and standard heterosis was recorded. Similar results were reported by Deoraj *et al*. (2007), Narasimman *et al*. (2007) and Akarsh Parihar and Pathak (2008).

Heterosis for grain yield is mainly because of simultaneous manifestation of heterosis for yield component traits. Twenty one crosses over PA-6201 excelled significant positive standard heterosis in pooled analysis. The hybrid which exhibited the highest heterosis in the present study was APMA6A x IR-54742R over the standard check, PA-6201. This cross also expressed significant positive standard heterosis for panicle length, panicle weight, number of productive tillers plant^{-1}, number of filled grains panicle^{-1} and 1000-grain weight. This indicated that morphological traits helped the hybrid to get high heterosis for grain yield. Similarly other most promising hybrids which excelled significant standard heterosis over PA-6201 for this trait were APMS6AxIR-24R, APMS6AxBR-827-35R, IR-80555AxIR-54742R, IR-80559AxIR-54742R and IR-80559AxKM-3R and were also supported significant standard heterosis for yield contributing traits. Forty eight hybrids exhibited significant positive heterobeltiosis and it ranged from -14.16 (IR-80555A xIR-32809R) to 94.26 (IR-80555AxIR-32809R) percent. Heterobeltiosis of both positive and negative nature was reported which was supported by Ganesan *et al*. (1997) and Narasimman *et al*. (2007). Standard heterosis of

Table 4. Comparative study of ten most heterotic crosses for single plant yield for mean, heterosis over PA 6201 and desirable heterosis for other traits.

Crosses	Single plant yield (mean)	Heterosis over PA-6201	Desirable characters for other traits
APMA6A x IR-54742R	34.33	26.62**	PL, PW, NPT, NSP, GW
APMA6A x IR-24R	33.90	25.04**	DFF, PW, NPT, NSP,
APMS6A x BR-827-35R	33.69	24.25**	PL, PW, NPT, NSP, GW
IR-80555A x IR-54742R	33.28	22.75**	PL, GW
IR-80559A x IR-54742R	33.07	21.95**	PL, PW, NPT, NSP, SF, GW
IR-80559A x KMR-3R	32.82	21.03**	DFF, PL, PW, NPT, NSP, SF, GW
IR-80151A x IR-54742R,	32.71	20.64**	PL, PW, NPT, NSP, SF, GW
IR-80561A x BR-827-35R	31.78	17.20**	PL, PW, NPT, NSP, GW
IR-80561A x KMR-3R	31.73	17.00**	DFF, PL, PW, NPT, NSP
IR-80151A x BR-827-35R	31.54	16.30**	PL, PW, NPT, NSP, GW

* and ** significant at P= 0.05 and 0.01, respectively

DFF- days to 50% flowering, PL- panicle length, PW-panicle weight, NPT-number of productive tillers plant $^{-1}$, NSP-number of spikelets panicle^{-1}, SF-spikelet fertility percentage and GW-1000-grain weight mixed trend was observed in their studies by Singh *et al*. (2006), Deoraj *et al*. (2007), Rosamma and Vijay Kumar (2007) and Akarsh Parihar and Pathak (2008).

Although there were a total of 60 crosses which exhibited significant and positive heterosis over check, PA-6201 for single plant yield, only ten crosses have been discussed (Table 4) as heterosis above 15 percent is considered to be commercially exploitable. Most of the heterotic crosses for single plant yield were accompanied by heterosis for three to four component traits. This indicated that heterosis for single plant yield in rice was associated with heterosis due to panicle length, panicle weight, number of productive tillers per plant, number of filled grains panicle^{-1} and 1000-grain weight. This was due to the fact that all the component traits are responsible for sum total of metabolic substances produced by the plant and the conditions. Further, all the heterotic crosses had close correspondence with mean value, which suggested that *per se* performance of hybrids could be considered for judging heterosis for single plant yield.

Based on the present investigation, it can be emphasized that the hybrids *viz.*, APMA6A x IR-54742R, APMS6A x IR-24R, APMS6A x BR-827-35R, IR-80555A x IR-54742R, IR-80559A x IR-54742R and IR-80559A x KMR-3R are with the most desirable heterosis and *per se* performance for single plant yield and its other important attributes. Hence, these hybrids may be further tested extensively in different agro-climatic zones over seasons and years for their superiority and stability before commercial release.

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