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Heterosis for various quantitative traits in rice

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ABSTRACT

A study was conducted to estimate the extent of heterobeltiosis, standard heterosis and the nature of gene action for various quantitative traits using line x tester analysis. Among the parents, GR 11, GR 7, NWGR 98002, GR 102, M 45-20-1, TN 1, NWGR 9635 and NWGR 97042 were the best performing parents for grain yield plant^{-1} and its component traits. Cross combinations GR 7 x IR 64, GR 7 x Narmada, Gurjari x Jaya, Gurjari x GR 102, GR 104 x NWGR 97042 and GR 11 x TN 1 exhibited high significant sca effects with high per se performance and standard heterosis over GR 7. High magnitude of heterobeltiosis and standard heterosis were observed for grain yield plant^{-1}, plant height, effective tillers plant^{-1}, 1000-grain weight, grains panicle^{-1} and harvest index. Cross combinations GR 7 x IR 64, GR 7 x Narmada, Gurjari x Jaya, Gurjari x GR 102, GR 104 x NWGR 97042 and GR 11 x TN 1 exhibited highly significant heterosis over GR 7.

Key words: *Rice, gene action, heterosis*

All the commercial rice hybrids are currently being based on cytoplasmic gene male sterility (CGMS) system. Even though this system is very stable, excessive dependence on a single source of cytoplasm, cumbersome process of hybrid seed production and parental line development warrant the development of alternate approaches to exploit hybrid vigour. Heterosis breeding is one such possibility. Commercial exploitation of heterosis in rice is being exploited at present in all the rice growing countries (Yuan,1994). The present study was an attempt to assess the possibilities of commercial exploitation of heterosis and to identify hybrids, which can throw better segregants in future generations.

MATERIALS AND METHODS

The experimental material consisted of 16 parents including 4 lines, 12 testers and 48 hybrids derived through line x tester mating design. The parents and their F_1s were grown for generating data pertaining to various quantitative traits. Observations were recorded from ten randomly selected plants in each plot for nine characters *Viz,* Days to 50 % flowering, days to maturity, plant height (cm), effective tillers plant^{-1}, panicle length (cm), grains panicle^{-1}, 1000-grain weight (gm), harvest index (%) and grain yield plant^{-1} (gm) The replication wise mean values obtained for each character were analyzed by the usual standard statistical procedure (Panse and Sukhatme,1978).

RESULTS AND DISCUSSION

Heterosis expressed as per cent increase or decrease in the mean value of F_1 hybrid over better parent (heterobeltiosis) and over standard check GR-7 (standard heterosis) are presented in Table 1 and 2. Out of 48 crosses, 42 crosses depicted significant negative heterosis for days to 50 % flowering. The spectrum of variation was from -24.35 (GR 104 x NWGR 97042) to 8.16 percent (Gurjari x Pusa Basmati). Out of 48 crosses, seven crosses showed significant negative heterosis over the check. The highest negative heterosis of -3.33 per cent was recorded by GR 7 x NWGR 98002, GR 7 x Pusa Basmati and GR 104 x NWGR 97042.

For days to maturity, the heterobeltiosis ranged from -17.86 for (GR 104 x TN 1) and (GR 104 x NWGR 9635) to 7.69 percent (Gurjari x M 45-20-1) for this character. Out of the 48 crosses, 31 crosses showed significant heterobeltiosis in negative direction. Most of the crosses expressed heterosis in positive direction, however, only nine crosses exhibited heterosis in desirable direction over the check GR 7. The standard

Table 1. Heterosis over better parent (BP) and standard check (SC) for Days to 50% flowering, days to maturity, plant height (cm) and effective tillers per plant in rice

Crosses	Days to 50% flowering		Days to maturity		Plant height (cm)		Effective tillers plant^{-1}	
	BP	GR 7 (SC)	BP	GR 7 (SC)	BP	GR 7 (SC)	BP	GR 7 (SC)
GR 7 x NWGR 97042	-19.09**	-1.11	-2.17**	12.50**	-6.48**	9.22**	-23.37**	0.54
GR 7 x TN 1	-13.46**	0.00	-3.03**	6.67**	8.04**	8.04**	1.34	1.34
GR 7 x WC 1240	-16.36**	2.22**	-2.17**	12.50**	-22.26**	7.59**	-24.43**	1.87
GR 7 x IR 64	-2.08**	4.44**	-3.03**	6.67**	-8.60**	5.27**	1.22	11.11**
GR 7 x NWGR 9635	-21.43**	-2.22**	-1.46**	12.50**	-10.19**	-5.00**	-8.72**	-4.69
GR 7 x NWGR 98002	-20.91**	-3.33**	-5.60**	-1.67**	8.78**	8.78**	0.76	24.10**
GR 7 x Jaya	-22.61**	-1.11	-2.17**	12.50**	4.02*	4.02*	-7.38**	-0.80
GR 7 x Narmada	-15.93**	5.56**	-5.00**	10.83**	-4.74**	-1.56	-16.70**	-1.87
GR 7 x GR 102	-4.55**	16.67**	-2.13**	15.00**	4.21**	14.75**	0.88	8.03**
GR 7 x IET 13475	5.88**	20.00**	-1.44**	14.17**	13.46**	13.46**	-10.59**	16.47**
GR 7 x Pusa Basmati	-11.22**	-3.33**	-2.14**	14.17**	-17.41**	-17.41**	-15.74**	6.02*
GR 7 x M 45-20-I	1.08	4.44**	3.85**	12.50**	-9.74**	-6.25**	-27.27**	7.10**
Gurjari x NWGR 97042	-5.45**	15.56**	-9.42**	4.17**	-15.60**	-1.43	0.71	32.13**
Gurjari x TN 1	-15.38**	-2.22**	4.55**	15.00**	-2.83	9.31**	1.35	0.40
Gurjari x WC 1240	-12.73**	6.67**	-16.67**	-4.17**	-22.43**	7.35**	-23.83**	2.68
Gurjari x IR 64	0.00	6.67**	6.82**	17.50**	-6.98**	7.14**	2.07	12.05**
Gurjari x NWGR 9635	-16.07**	4.44**	-1.46**	12.50**	-7.46**	4.11*	-9.10**	-5.09
Gurjari x NWGR 98002	-12.73**	6.67**	-10.40**	15.00**	-22.92**	-13.29**	-20.76**	-2.41
Gurjari x Jaya	-23.48**	-2.22**	-0.72	14.17**	-15.08**	-4.46**	-8.13**	-1.61
Gurjari x Narmada	-15.04**	6.67**	-10.71**	4.17**	-18.47**	-8.28**	-15.11**	0.00
Gurjari x GR 102	-4.55**	16.67**	-0.71	16.67**	-10.42**	0.78	2.50	9.77**
Gurjari x IET 13475	2.94**	16.67**	0.00	15.83**	-9.63**	1.67	-10.28**	16.87**
Gurjari x Pusa Basmati	8.16**	17.78**	1.43**	18.33**	-23.63**	-14.08**	-19.26**	1.61
Gurjari x M 45-20-I	5.38**	8.89**	7.69**	16.67**	-20.37**	-10.42**	-28.27**	5.62**
GR 104 x NWGR 97042	-24.35**	-3.33**	-1.43**	15.00**	-29.46**	-7.41**	-34.08**	-13.52**
GR 104 x TN 1	-16.52**	6.67**	-17.86**	-4.17**	-31.18**	-9.67**	1.49	0.54
GR 104 x WC 1240	-15.65**	7.78**	-12.86**	1.67**	-21.89**	8.10**	-26.71**	-1.20
GR 104 x IR 64	-6.96**	18.89**	-10.00**	5.00**	-16.33**	9.82**	3.29	13.39**
GR 104 x NWGR 9635	-8.70**	16.67**	-17.86**	-4.17**	-15.65**	10.71**	-15.26**	-11.51**
GR 104 x NWGR 98002	-4.35*	22.22*	-0.71	15.83**	-37.41**	-17.86**	-19.78**	-1.20
GR 104 x Jaya	-17.39**	5.56**	-3.57**	12.50**	-33.18**	-12.30**	-2.25	4.69
GR 104 x Narmada	-14.78**	8.89**	-2.86**	13.33**	-26.28**	-3.24	-10.57**	5.35**
GR 104 x GR 102	-8.70**	16.67**	0.71	18.33**	-26.73**	-3.84*	0.88	8.03**
GR 104 x IET 13475	-6.96**	18.89**	-17.14**	-3.33**	-28.30**	-5.89**	-31.96**	-11.38**
GR 104 x Pusa Basmati	-13.91**	10.00**	-0.71	15.83**	-27.07**	-4.29*	-18.62**	2.41
GR 104 x M 45-20-I	-11.30**	13.33**	0.71	17.50**	-16.60**	9.46**	2.09	50.33**
GR 11 x NWGR 97042	-3.64**	17.78**	-2.17**	12.50**	-19.55**	-6.04**	1.43	33.07**
GR 11 x TN 1	2.83**	21.11**	3.70**	16.67**	-2.38	3.72*	-18.66**	0.94
GR 11 x WC 1240	-20.00**	-2.22**	-15.22**	-2.50**	-32.06**	-5.98**	-9.33**	22.22**
GR 11 x IR 64	-11.32**	4.44**	2.22**	15.00**	-13.88**	-0.80	-2.91	20.48**
GR 11 x NWGR 9635	3.57**	28.89**	3.65**	18.33**	-5.80**	0.09	-26.97**	-9.37**
GR 11 x NWGR 98002	-1.82**	20.00**	-14.81**	-4.17**	-16.08**	-10.83**	-3.99	19.14**
GR 11 x Jaya	-8.70**	16.67**	-2.17**	12.50**	-17.65**	-12.50**	-22.33**	-3.61
GR 11 x Narmada	-13.27**	8.89**	-4.29**	11.67**	-14.12**	-8.75**	-16.94**	3.08
GR 11 x GR 102	-17.27**	1.11	-17.02**	-2.50**	-13.91**	-5.21**	-6.58**	15.93**
GR 11 x IET 13475	-1.89**	15.56**	-0.72	15.00**	-10.42**	-4.82**	-2.67	26.77**
GR 11 x Pusa Basmati	7.55**	26.67**	-17.14**	-3.33**	-5.44**	0.47	-4.26*	20.48**
GR 11 x M 45-20-I	4.72**	23.33**	1.48**	14.17**	-6.95**	-1.13	-9.09**	33.87**
Range Min.	-24.35	-3.33	-17.86	-4.17	-37.41	-17.86	-34.08	-13.52
Max.	8.16	28.28	7.69	18.33	13.46	14.75	3.29	50.33
S.E.	0.760		0.520		1.990		0.200	

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

Table 2. Heterosis over better parent (BP) and standard check (SC) for panicle length (cm), grains panicle^{-1}, 1000 grain weight , harvest index in rice and grain yield plant^{-1}.

Crosses	Panicle length (cm)		Grains per panicle		1000-grain weight		Harvest index		Grain yield plant^{-1} (gm)	
	BP	GR 7 (SC)	BP	GR 7 (SC)	BP	GR 7 (SC)	BP	GR 7 (SC)	BP	GR 7 (SC)
GR 7 x NWGR 97042	-4.50**	-4.50*	-2.46**	0.96*	2.68	2.68	-6.78**	0.86	14.45**	14.45**
GR 7 x TN 1	7.69**	7.69**	-6.73**	-6.73**	0.00	0.00	-3.27*	3.43*	7.69**	7.69**
GR 7 x WC 1240	2.08	2.08	0.65**	0.65	-0.16	-0.16	0.02	8.15**	14.66**	14.66**
GR 7 x IR 64	0.55	6.35**	4.25**	5.88**	-0.81	15.93**	1.10	6.16**	18.98**	21.01**
GR 7 x NWGR 9635	-4.23**	-4.23*	3.36**	3.36**	-0.47	-0.47	0.93	0.97	4.37	4.37
GR 7 x NWGR 98002	-3.08	-3.08	6.65	6.65**	-5.84*	-5.84*	-2.30	2.48	18.33**	21.73**
GR 7 x Jaya	3.85*	3.85*	-10.91**	-10.33**	-6.68**	16.88**	-5.87**	-0.05	7.28**	7.28**
GR 7 x Narmada	-24.83**	-16.15**	-6.54**	-6.54**	-6.47**	-6.47**	-4.02**	4.9**	9.56**	13.94**
GR 7 x GR 102	3.85*	3.85*	-4.53**	-4.53**	1.78	3.86	-3.98**	-3.98**	13.97**	13.97**
GR 7 x IET 13475	-15.38**	-15.38**	-3.84**	-1.00*	13.12**	15.62**	-5.12**	-5.12**	0.69	5.06
GR 7 x Pusa Basmati	-2.29	5.23**	10.60**	10.60**	2.68	2.68	-1.35	1.32	11.55**	11.55**
GR 7 x M 45-20-I	-31.73**	-31.73**	13.62**	13.62**	2.87	7.41**	-3.66*	-3.03*	5.92*	20.98**
Gurjari x NWGR 97042	14.89**	3.85*	14.62**	18.64**	3.44	28.23**	-0.24	7.94**	12.19**	7.82**
Gurjari x TN 1	-1.66	-13.65**	0.47	-4.59**	0.25	24.29**	0.06	6.99**	22.95**	18.07**
Gurjari x WC 1240	-20.14**	-22.69**	7.16**	-1.01*	-10.81**	10.57**	-2.18	5.77**	29.53**	24.39**
Gurjari x IR 64	-14.33**	-9.38**	3.90**	5.53**	1.53	25.87**	-1.59	4.82**	11.56**	13.46**
Gurjari x NWGR 9635	-1.88	-9.42**	6.32**	-4.43**	-8.52**	13.41**	-3.96**	2.29	-1.66	-2.56
Gurjari x NWGR 98002	17.10**	5.08**	0.68	-4.38**	-25.70**	-7.89**	-1.83	4.56**	25.71**	29.31**
Gurjari x Jaya	-10.06**	-12.31**	2.97**	3.64**	2.64	28.55**	-0.96	5.49**	23.27**	18.38**
Gurjari x Narmada	-24.31**	-15.58**	14.55**	2.98**	-26.34**	-8.68**	-1.67	7.48**	2.99	7.11*
Gurjari x GR 102	0.39	-11.85**	26.79**	18.26**	-3.56	19.56**	-11.87**	-6.14**	12.13**	7.69**
Gurjari x IET 13475	20.24**	5.58**	-17.58**	-15.14**	2.67	27.29**	-17.24**	-11.85**	22.30**	27.61**
Gurjari x Pusa Basmati	-2.82	4.65*	-19.62**	-27.74**	-14.25**	6.31**	-6.96**	-0.90	-3.74	-7.55
Gurjari x M 45-20-I	-5.91**	-20.38**	-30.55**	-30.60**	-15.39**	4.89*	-9.93**	-4.08**	-20.46**	-9.16**
GR 104 x NWGR 97042	-22.14**	-16.15**	-9.56**	-6.38**	1.60	0.16	-0.60	7.55**	16.49**	11.96**
GR 104 x TN 1	-18.39**	-12.12**	-9.48**	-10.39**	-2.86	-3.47	-2.68**	5.12**	8.57**	-2.19
GR 104 x WC 1240	-3.64*	3.77*	-13.60**	-14.46**	2.58	0.32	-3.02**	4.86**	12.10**	0.99
GR 104 x IR 64	-22.14**	-16.15**	-18.31**	-17.04**	-2.97	13.41**	-2.49**	5.33**	-0.47	1.23
GR 104 x NWGR 9635	-18.57**	-12.31**	-12.29**	-13.17**	2.63	-1.42	-3.75**	3.96**	22.59**	21.46**
GR 104 x NWGR 98002-	20.71**	-14.62**	0.44	-0.56	-17.73**	-20.98**	-10.10**	-2.89	-1.43	1.40
GR 104 x Jaya	-14.29**	-7.69**	5.37**	6.06**	1.13	26.66**	-6.73**	0.74	19.53**	7.69**
GR 104 x Narmada	-24.14**	-15.38**	14.69**	13.55**	-2.13	-5.99*	-9.83**	-1.44	10.25**	14.66**
GR 104 x GR 102	-13.93**	-7.31**	1.67**	0.65	1.85	3.94	-11.60**	-4.51**	7.58*	-3.07
GR 104 x IET 13475	-27.14**	-21.54**	-22.47**	-20.17**	-3.86	-1.74	-11.10**	-3.98**	-13.72**	-9.98**
GR 104 x Pusa Basmati	-23.04**	-17.12**	-16.32**	-17.15**	0.63	0.32	-10.12**	-2.92	27.04**	14.45**
GR 104 x M 45-20-I	-30.36**	-25.00**	-4.32**	-4.38**	0.15	4.57	-11.21**	-4.10**	-5.71*	7.69**
GR 11 x NWGR 97042	-4.04	-13.27**	-18.02**	-10.60**	-26.24**	-27.29**	-9.57**	-2.15	15.76**	27.50**
GR 11 x TN 1	-0.57	-12.69**	-17.56**	-10.09**	-26.83**	-27.29**	-3.62**	3.06*	28.16**	41.17**
GR 11 x WC 1240	-21.33**	-23.85**	-21.72**	-14.63**	5.97*	3.63	-0.94	7.11**	22.64**	35.09**
GR 11 x IR 64	-30.91**	-26.92**	-20.32**	-13.10**	-0.13	16.72**	-1.94**	2.96	6.76**	17.59**
GR 11 x NWGR 9635	-11.25**	-18.08**	-10.00**	-1.86**	-17.13**	-29.02**	4.05**	4.10**	0.93	11.17**
GR 11 x NWGR 98002	-3.56	-13.46**	-9.23**	-1.01	-20.68**	-37.07**	-2.21	2.57	-0.59	9.50**
GR 11 x Jaya	6.51**	3.85*	-18.79**	-11.43**	-20.65**	-0.63	-13.67**	-8.34**	-21.53**	-13.56**
GR 11 x Narmada	-8.45**	2.12	-12.92**	-5.03**	-29.12**	-36.28**	-8.39**	0.14	-13.65**	-4.89
GR 11 x GR 102	17.30**	3.00	-7.71**	0.65	1.70	3.79	2.04	-2.55	9.55**	20.67**
GR 11 x IET 13475	22.16**	7.27**	-27.73**	-21.19**	-22.84**	-21.14**	0.12	-4.38**	-18.02**	-9.70**
GR 11 x Pusa Basmati	0.43	8.15**	-32.80**	-26.71**	-5.70*	-5.99*	-7.87**	-5.37**	3.35	13.84**
GR 11 x M 45-20-I	43.21**	4.65*	-23.57**	-16.65**	1.06	5.52*	-4.60**	-3.98**	-11.64**	0.92
Range Min.	-31.73	-31.73	-32.80	-30.60	-29.12	-37.07	-17.24	-11.85	-21.33	-13.56
Max.	43.21	8.15	26.79	18.64	13.12	28.55	4.05	8.15	29.53	41.17
S.E.	0.490		0.860		0.510		0.660		0.860	

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

heterosis varied from -4.17 (Gurjari x NWGR 9635) to 18.33 percent (GR 11 x NWGR 9635) for this trait.

For plant height, the heterobeltiosis ranged from -37.41 (GR 104 x NWGR 98002) to 13.46 percent (GR 7 x IET 13475). Forty one crosses exhibited significant heterobeltiosis in negative direction. Standard heterosis ranged from -17.86 (GR 104 x NWGR 98002) to 14.75 percent (GR 7 x GR 102) against check GR 7. Out of 48 crosses, 21 crosses expressed significant and negative heterosis over the check GR 7. Heterotic effects over better parent for effective tillers plant^{-1} varied from -34.08 (GR 104 x NWGR 97042) to 3.29 percent (GR 104 x IR 64).

Heterotic effects over GR 7 varied from -13.52 (GR 104 x NWGR 97042) to 50.33 per cent (GR 104 x M 45-20-1). As many as 23 hybrids expressed significant positive heterosis over standard check GR 7. Ten crosses expressed significant positive heterotic effects for panicle length. Heterobeltiosis ranged from -31.73 (GR 7 x M 45-20-1) to 43.21 per cent (GR 11 x M 45-20-1). With respect to standard heterosis, out of 48 crosses, fourteen crosses exhibited significant positive heterosis over GR 7. The cross GR 11 x Pusa Basmati recorded the highest standard heterosis of 8.15 per cent over the check GR 7.

The spectrum of variation for heterobeltiosis in grain panicle^{-1} was from -32.80 (GR 11 x Pusa Basmati) to 26.79 per cent (Gurjari x GR 102) for this trait. Only 15 crosses, out of 48 exhibited significant heterosis in desired direction. With respect to standard check GR 7, highest heterosis of 18.64 per cent was recorded by Gurjari x NWGR 9635. Of the 48 crosses, 13 crosses exhibited significant and positive heterosis over GR 7 and it ranged from -30.60 (Gurjari x M 45-20-1) to 18.64 per cent (Gurjari x NWGR 97042).

In case of 1000-grain weight, heterosis over better parent varied from - 29.12 (GR 11 x Narmada) to 13.12 per cent (GR 7 x IET 13475). Out of 48 crosses, only two hybrids GR 7 x IET 13475 (13.12%) and GR 11 x WC 1240 (5.97%) exhibited significant and positive heterosis over the better parent. With respect to standard check GR 7, the range was from -37.07 (GR 11 X NWGR 98002) to 28.55 per cent (Gurjari x Jaya). As many as 18 crosses expressed significant and positive heterosis over the check GR 7.

For harvest index (%), out of the 48 crosses, only one cross GR 11 x NWGR 9635 (4.05%) depicted significant and positive heterosis over its corresponding better parent. The range of heterobeltiosis for this character was from -17.24 (Gurjari x IET 13475) to 4.05 per cent (GR 11 x NWGR 9635). The standard heterosis varied from -11.85 (Gurjari x IET 13475) to 8.15 per cent (GR 7 x TN 1) over GR 7. As many as thirty two, of the total 48 hybrids, recorded significant positive heterosis.

For grain yield plant^{-1} (gm), Heterobeltiosis varied from -21.53 (GR 11 x Jaya) to 29.53 per cent (Gurjari x WC 1240). Thirty one crosses exhibited significant positive heterobeltiosis, the highest being by cross Gurjari x WC 1240 (29.53%). Thirty three hybrids were found with significant and desired standard heterosis for grain yield plant^{-1} over GR 7. Standard heterosis ranged from -13.56 (GR 11 x Jaya) to 41.17 per cent (GR 11 x TN 1).

Out of 48 hybrids tested, 31 hybrids exhibited significant positive heterosis over their respective better parental values, while 33 crosses showed significant positive heterosis over standard check GR 7 for grain yield plant^{-1}. This revealed that grain yield per plant was one of the most heterotic traits. Plant height was found to be emerged as the first heterotic trait, because out of 48 crosses, 41 and 21 crosses showed significant negative desirable heterosis over the better parent and check GR 7, respectively. This was followed by grains panicle^{-1} for which 12 crosses manifested significant positive heterosis over the check GR 7, number of effective tillers plant^{-1} (23 crosses) and 1000-grain weight (18 crosses). On the basis of number of heterotic crosses in a trait, the traits like plant height, grain yield per plant and harvest index were categorized as possessing high heterosis (each more than 30 crosses), effective tillers plant^{-1} under moderate heterosis (between 20 to 29) and remaining all traits under low heterosis (less than 20).

Significant positive heterosis for grain yield plant^{-1} has been reported by Durai (2002). For number of grains panicle^{-1} by Annadurai and Nadarajan (2001) and Singh and Kumar (2004), for 1000-grain weight by Ramalingam *et al.* (2001). The negative heterosis for days to 50 per cent flowering was reported by Singh and Kumar(2004); for plant height by Peng and Virmani (1991). With respect to effective tillers plant^{-1} significant positive heterosis was observed by Patil *et al.* (2003)

and Suresh *et al*. (2000). Ramalingam *et al*. (2001) reported significant positive heterosis for harvest index, Durai (2002) Ramalingam *et al*. (2001), Suresh *et al.* (2000) observed significant positive heterosis for grains panicle^{-1}, 1000-grain weight, effective tillers plant^{-1} and harvest index. Thus, the results obtained in the present study are akin to the results reported by above workers.

Although there were a total of 33 crosses which exhibited significant and positive heterosis over check GR 7 for grain yield plant^{-1}, only 16 crosses have been given in Table 3. as heterosis above 15 per cent is considered to be commercially exploitable. The heterosis for grain yield plant^{-1} was associated with heterosis for harvest index (9 crosses), effective tillers plant^{-1} (8 crosses), 1000-grain weight and grains panicle^{-1} (7 crosses each) and panicle length 5 (crosses). It was evident that all the yield contributing traits did not contribute equally towards heterosis for grain yield plant^{-1}. For instance, the cross GR 11 x TN 1 with highest mean value as well as standard heterosis was associated with only two yield contributing traits i.e. panicle length and harvest index. Similarly, cross GR 7 x IR 64 with higher grain yield plant^{-1} and heterosis was associated with all the five component traits *viz.*, effective tillers plant^{-1}, panicle length, grain panicle^{-1}, 1000-grain weight and harvest index. However, most of the heterotic crosses for grain yield were accompanied by heterosis for two to three component traits. This indicated that heterosis for grain yield in rice was associated with heterosis due to harvest index and/or grains panicle^{-1}, 1000-grain weight, effective tillers plant^{-1} and panicle length. This was due to the fact that all the component characters are responsible for sum total of metabolic substances produced by the plant and the conditions, which favor the development of one component, could have adverse effect on the other. 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 grain yield.

A comparative study of thirteen crosses with higher sca , gca effects of parents, heterosis over GR 7 and significant desirable heterosis and sca effects for other traits is presented in Table 4. All the crosses in this comparison with high sca effects for grain yield plant^{-1} had also desirable and significant sca effects for other traits like panicle length, grains panicle^{-1}, effective tillers plant^{-1} and 1000-grain weight. The

Table 3. Comparative study of sixteen most heterotic crosses for grain yield for mean, heterosis over GR 7 and desirable heterosis for other traits.

Crosses	Grain yield per plant(Mean)	Heterosis over GR 7	Desirable heterosis for other traits
GR 11 x TN 1	41.32	41.17**	Pl, HI
GR 11 x WC 1240	39.54	35.09**	DM, DF, PH, ET, HI
Gurjari x NWGR 98002	37.85	29.31**	PH, PL, HI
Gurjari x IET 13475	37.35	27.61**	ET, PL, GW
GR 11 x NWGR 97042	37.32	27.50**	PH, ET
Gurjari x WC 1240	36.41	24.39**	DM, GW, HI
GR 7 x NWGR 98002	35.63	21.73**	DF, DM, ET, GP
GR 104 x NWGR 9635	35.55	21.46**	DM, ET, HI
GR 7 x IR 64	35.42	21.01**	ET, PL, GP, GW, HI
GR 7 x M 45-20-I	35.41	20.98**	PH, ET, GP, GW
Gurjari x Jaya	34.65	18.38**	DF, PH, GP, GW, HI
Gurjari x TN 1	34.56	18.07**	DF, GW, HI
GR 11 x IR 64	34.42	17.59**	PH, ET, GW
GR 7 x WC 1240	33.56	14.66**	GP, HI
GR 7 x NWGR 97042	33.50	14.45**	DF, GP
GR 104 x Pusa Basmati	33.50	14.55**	PH, PL, GP

* and ** significant at P= 0.05 and 0.01, respectively
DF-days to flowering, DM-days to maturity, PH-plant height, PL-panicle length, ET-effective tillers per plant, GP- grains panicle^{-1}, GW-1000-grain weight, HI-harvest index.

Table 4. Comparative study of thirteen crosses with higher sca , gca effects of parents, heterosis over GR 7 and significant desirable heterosis and sca effects for other traits

Crosses	Heterosis over GR 7	Sca effects	Gca effects of parents female	male	Desirable heterosis for other traits	Desirable sca effects for other traits
GR 104 x NWGR 97042	11.96**	4.31**	P	G	DF, PH, HI	PH, GP, HI
GR 7 x IET 13475	5.06	4.29**	G	A	ET, GW	ET, GP, GW
Gurjari x Pusa Basmati	7.55**	3.84**	P	P	PH, PL, GW	PH, PL, GP
GR 7 x IR 64	21.01**	3.78**	G	P	ET, PL, GP, GW, HI	PH, PL
GR 7 x Narmada	13.94**	3.55**	G	P	GP, HI	PH, GW
GR 11 x TN 1	41.17**	3.53**	G	G	GP, HI	ET, GP
Gurjari x Jaya	18.38**	3.34**	P	A	DF, PH, GP, GW, HI	DM, HI
Gurjari x GR 102	7.69**	2.46**	P	G	ET, GP, GW	PH, GP
GR 7 x NWGR 9635	4.37**	2.20**	G	G	DF, PH, GP	PH, ET, PL
GR 11 x M 45-20-1	0.92	2.03**	G	P	ET, PL, GW	PL, GW
GR 104 x WC 1240	0.99	1.97**	P	A	PL, HI	DF, DM, PL
GR 104 x GR 102	-3.07	1.58 *	P	G	PH, ET	Pl, GP
Gurjari x NWGR 9635	-2.56	1.38 *	P	G	GP, GW	DF, DM, ET, GW

* and ** significant at P= 0.05 and 0.01, respectively.
G=Good, A=Average, P=Poor, DF-days to flowering, DM-days to maturity, PH-plant height, GW-1000-grain weight, PL-panicle length, GP- grains panicle^{-1}, ET-effective tillers per plant, HI-harvest index , GYP- grain yield per plant

component traits like panicle length and grains panicle^{-1} (six crosses) were found to be associated with maximum number of crosses possessing desirable and significant sca effects for grain yield plant^{-1}, followed by 1000-grain weight and effective tillers plant^{-1} (four crosses). All the cross combinations with significant sca effects for grain yield did not possess significant and desirable sca effects for all the component traits which suggested that at least significant and desirable sca effects of two to three component traits resulted in significant sca effect for grain yield. Similar results have been reported by Ramalingam *et al.*(2001) and Patil *et al.* (2003). It was further noticed that out of 13 cross combinations, 10 crosses had atleast one parent as a good general combiner.

Among the thirteen crosses which depicted highly significant positive sca effects for grain yield plant^{-1}, eight crosses, *viz.*, GR 7 x IR 64, GR 7 x Narmada, Gurjari x Jaya, Gurjari x GR 102, GR 104 x NWGR 97042 and GR 11 x TN 1 showed high per se performance and high standard heterosis over GR 7 (Table 4). This suggested that high sca effects for grain yield are not necessarily associated with high heterotic effects. The cross combinations GR 11 x TN 1 and GR 7 x NWGR 9635 had high sca effects for grain yield plant^{-1}, high standard heterosis over the check. These crosses may be exploited to obtain early desirable segregants for grain yield by restoring pedigree breeding technique.

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