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Research Article

Heterotic expression of two line hybrids in rice (*Oryza sativa* L.)

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Abstract

Heterosis explored in four Thermo-sensitive Genic Male Sterile (TGMS) lines and 22 non-TGMS testers by making 88 crosses.The magnitude of relative heterosis, heterobeltiosis and standard heterosis with checks (CORH 2 and ADTRH 1) wereestimated.Thehybrids,GD98029xIR61608-213,GD9804xIR61608-213and GD 98014 x RR 166-645 could be exploited for earliness as they exhibited negative and significant standard heterosis for days to 50 per cent flowering over the checks. Top yielding hybrids *viz.,* GD 98049 x IR 63875-196-2-2-1-3, GD 98014 x TKM11, GD 98049 x TKM 11, GD 99017 x TKM 12 exhibited significant standard heterosis over CORH 2 and ADTRH 1. Most of the high yielding hybrids manifested significant positive heterosis for yield contributing characters *viz.,* more number of productive tillers per plant, long panicles, more number of filled grains per panicle, spikelet fertility and 1000 grain weight. Hence, these hybrids may be used for commercial cultivation in two line hybrid rice.

Key words: TGMS lines, twoline hybrids, *per se* performance, Heterosis, grain yield

Introduction

The commercial exploitation of hybrid vigour in rice was demonstrated in China in 1976 by Professor Yuan Long Ping and his team of scientists. Hybrid rice had an yield advantage of 20% over semi-dwarf varieties. The high productivity of hybrid rice enabled China to increase its rice production from 129 to 200 million tonnes. Developments in China encouraged the International Rice Research Institute (IRRI) and other countries to initiate research on exploring potentials of hybrid rice technology. Virmani and Edwards (1983) reviewed the status and prospects for breeding hybrid rice and concluded that exploitation of heterosis through hybrid breeding offered an important option to increase yield in this self-pollinated crop. Even though tremendous gains in heterosis breeding have been achieved by China and other countries during the last two decades, it is felt that the maximum yield potential of hybrid rice has not been fully studied and exploited as yet. The problem associated with the classical three line system may be overcome by two line system of hybrid rice breeding (Yuan *et al.,* 2000). The present investigation was initiated with the objective to analyze the extent of heterosis in two line hybrids and to identify the heterotic hybrids.

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Materials and methods

The investigation was carried out on two line rice hybrids obtained by crossing four Thermo-sensitive Genic Male Sterile lines (GD 98014, GD 99017, GD 98029 and GD 98049) as female parents with 22 Non-TGMS testers (ADT 39, ADT 43, ASD 19, CO 43, CO 47, IR 36, IR 66, IR 72, IR 65515-47-2-1-19, IR68763-46-1-2-5-2, IR 62030-54-1-2-2, IR 65514-5-1-2-19, IR 59624-34-2-2, IR 63877-43-2-1-3-1, IR 61608-213, IR 10198-66-2, IR 63875-196-2-2-1-3, Padmini, RR 166-645, TKM 11, TKM 12, TRY 2) as male parents in line x tester mating design at Paddy Breeding Station, Tamil Nadu Agricultural University, Coimbatore to evolve 88 cross combinations. These hybrid combinations were evaluated in randomized block design with two replications along with their parents and two check hybrids *viz.,* CORH 2 and ADTRH 1. Thermo-sensitive genic male sterile lines were maintained by multiplying stubbles. Standard agronomic practices were followed for raising the crop. Observations were recorded on days to 50% flowering, plant height, number of productive tillers per plant, panicle length, number of filled grains per panicle, spikelet fertility, 1000 grain weight, grain yield per plant, harvest index and biomass yield on five randomly selected plants at the time of maturity. Relative heterosis, heterobeltiosis and standard heterosis were worked out utilizing the overall mean of each hybrid for each trait. Significance of heterosis was tested using the formula given by Snedecor and Cochran (1967).

Results and discussion

The prime objective of any hybrid programme is to converge the desirable genes present in the parent into a single genetic background. The hybrid thus obtained can be used directly as F_1 to exploit hybrid vigour. Heterosis was expressed in relation to mid parent and better parent involved in the cross. But the hybrids chosen for cultivation on the basis of their heterotic performance relative to their parental inbreds may not be economically viable. A hybrid is commercially viable, when it is superior to the locally adopted best variety. Banumathy *et al.* (2003) emphasized the need for computing heterosis over the standard variety or hybrid. Hence in the present study, the hybrids were evaluated by their heterotic performance over high yielding three line hybrid checks, ADTRH 1 and CORH 2. The magnitude of heterosis based on standard checks and *per se* performances of two line hybrids are presented in Table 1 and Table 2 respectively.

Most of the hybrids flowered earlier as compared to check hybrids CORH 2 and ADTRH 1. The hybrids, GD 98029 x IR 61608-213, GD 98049 x IR 61608-213and GD 98014 x RR 166-645 could be exploited for earliness as they exhibited negative and significant standard heterosis for days to 50 per cent flowering over the checks ADTRH 1 and CORH 2. The earliness may be due to earliness nature of parental lines involved in these crosses. Negative heterosis for days to 50 per cent flowering had also been reported by Latha (2001) and Patil *et al.* (2003).

Plant height may not have significant role to play in the expression of hybrid vigour by the hybrids (Dwivedi, 1985). The hybrid, GD 98049 x IR 66 had desirable *per se* performance and significant and negative heterosis over checks for plant height. Negative heterosis for plant height was also reported by Patil *et al.* (2003).

Number of productive tillers per plant is generally associated with higher productivity. The hybrids, GD 98014 x IR 66, GD 98014 x IR 59624, GD 98029x TKM 12, GD 98029 x Padmini, GD 98014 x TKM 11 produced more productive tillers than checks. The male parents involved in these crosses had more number of productive tillers per plant. Present observations are supported by Sun *et al.* (2000),Radhidevi *et al.* (2002) and Patil *et al.* (2003).

Heterosis for panicle length was relatively high in GD 99017 x Padmini, GD 99017 x TKM 12, GD 98029 x Padmini, GD 98049 x TKM 11, GD 98014 x TKM 12. These hybrids possessed long panicles compared to the checks. More length of panicles in these hybrids was due to the involvement of male parents with long panicles. Significant standard heterosis for panicle length was also indicated by Banumathy *et al.* (2003).

Number of spikelets per panicle is one of the most important components of yield and probably this character will be helpful in breaking the yield ceiling (Singh and Maurya, 1999). Significant positive heterosis for grains per panicle has been reported by Suresh *et al.* (2000). Longer panicle is generally associated with more number of spikelets. The hybrids, GD 99017 x Padmini, GD 99017 x CO 43, GD 98049 x TRY 2, GD 98049 x TKM 11 and GD 98049 x Padmini produced more number of filled grains compared to checks since the male parents involved in these crosses had favourable alleles for this character.

The hybrids, GD 99017 x TKM 11, GD 99017 x CO 47, GD 98049 x IR 66, GD 99017 x ADT 43 exhibited high *per se* performance and significant heterosis for spikelet fertility over both the checks due to the involvement of male parents with high spikelet fertility. Similar results were reported by Radhidevi *et al.* (2002) and Patil *et al.* (2003). Most of the hybrids had negative heterosis due to the problem of spikelet sterility, as reported by Virmani *et al.* (1982).

The hybrid, GD 99017 x TKM 12 exhibited high per se performance and significant heterosis for 1000 grain weight. Significant positive heterosis for 1000 grain weight has also been reported by Ramalingam *et al.* (2001) and Suresh *et al.* (2000). Standard heterosis for 1000 grain weight in F_1 hybrids depends upon the grain characters of parental lines. In the present study, the TGMS line GD 99017 had bold grain. Hence, most of the hybrids involving GD 99017 registered significant positive standard heterosis for this trait.

Yield contributing characters *viz.,* panicle length, number of filled grains per panicle and 1000 grain weight had contributed much for increased grain yield (Mishra and Pandey, 1998). The five top ranking hybrids identified with *per se* performance and standard heterosis is presented in Table 3.

In the present study, estimates of heterosis for various yield components indicated that the significant yield increase was mainly due to increased number of productive tillers per plant, number of filled grains per panicle in GD 98014 x TKM 11, whereas in GD 98049 x TKM 11, it was due to long panicle length, more number of filled grains per plant, high 1000 grain weight and more biomass yield (Table 3).

In case of GD 99017 x TKM 12, long panicle length, high 1000 grain weight were responsible for increased grain yield per plant. The hybrid, GD 98014 x TKM 11 recorded 26.73 per cent increased grain yield over ADTRH 1. Latha (2001) reported up to 26.11 per cent increase in grain yield over the check CORH 2 in a two line hybrid. The hybrids, GD 98014 x TKM 11, GD 98049 x TKM 11, GD 99017 x TKM 12 and GD 98049 x RR 166-645 also recorded more than 30 per cent yield advantage over ADTRH 1 and CORH 2. Hence, these hybrids may be used for commercial cultivation in two line hybrid rice.

References

Banumathy, S., K. Thiyagarajan and P. Vaidyanathan. 2003. Study on magnitude of heterosis of rice hybrids for yield and its components. Crop Res., 25: 287-293.

Dwivedi, J.L. 1985. Heterosis in rice and its exploitation. ***In:*** Genetics and Rice Improvement. National Symposium held at Directorate of Rice Research, Hyderabad, India, 17-18 Aug. 1985.

Latha, R. 2001. Genetic and molecular analyses of thermosensitive genic male sterility and its utilization in two line heterosis breeding of rice (*Oryza sativa* L.). Ph.D. Thesis, Tamil Nadu Agricultural University, Coimbatore (Unpublished).

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

Patil, D. V., K. Thiyagarajan and K. Puspha. 2003. Heterosis Exploration in two line hybrid rice (*Oryza sativa* L.). Crop Res., 25: 514-519.

Radhidevi, R.P., P. Nagarajan, P. Shanmugusundaram, R. Chandra Babu, S. Jayanthi and S. Subramani. 2002. Combining ability analysis in three line and two line rice hybrids. Plant Arch., 2: 99-102.

Ramalingam J, Nadrajan N and Vanniarajan C. 2001. Heterotic ability involving cytoplasmic male sterile lines in rice. Madras Agric. J. 87 : 140-141.

Singh and Maurya, D.M. 1999. Heterosis and inbreeding depression in rice for yield and yield components using CMS systems. Oryza, 36 :24-37.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical Methods. VI Edition, Iowa state university press, Iowa, USA.

Sun, C., C. Wu, T. Jiang, L. Chen, Z. Li and X. Wang. 2000. Studies on the relationship between heterosis and genetic differentiation in hybrid rice. **In:** *International Rice Research Conference,* Mar. 31 – Apr. 3, 2000, International Rice Research Institute, Manila, Philippines. pp. 143.

Suresh, S., Paramasivan, K.S. and Muppidathi, N. 2000. Study of heterosis for yield components rice. Madras Agri. J. 86 : 520-522.

Virmani, S. S. and I. B. Edwards.1983. Current status and future prospects for breeding hybrid rice. Agron. Abst., 119.

Virmani, S. S., Aquino, R.C. and Khush, G.s. 1982. Heterosis breeding in rice (*Oryza sativa* L.). Theor. Appl. Genet. 63: 373-80

Yuan,S., Wen, S., Li, Z., Wan, J., Tian, Y. and Liu, C. 2000. Study on the combining ability of indica two line hybrid rice. J. Huazhong Agric. Univ. 19: 204-08.

Table 1. Magnitude of standard heterosis of selected hybrids for yield characters

Hybrids	Days to 50 % flowering		Plant height (cm)		No. of productive tillers		Panicle length (cm)		No. of filled grains per panicle	
	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$
GD 98014 x IR 66	7.74 **	9.70 **	-13.45 **	-5.60	33.22 **	31.08 **	-4.73	-8.87	11.65 **	42.30 **
GD 98014 x IR 72	33.33 **	35.76 **	-15.29 **	-7.61	7.10	5.38	4.71	0.16	1.99	29.99 **
GD 98014 x IR 62030-54-1-2-2	8.33 **	10.30 **	-13.70 **	-5.87	6.29	4.58	-4.69	-8.83	-16.85 **	5.98
GD 98014 x IR 59624-34-2-2	3.57	5.45 *	-10.39 **	-2.25	32.86 **	30.72 **	1.32	-3.08	-17.82 **	4.74
GD 98014 x IR 65515-47-2-1-19	9.52 **	11.52 **	-10.98 **	-2.90	4.29	2.61	-2.79	-7.01	-11.54 **	12.75 **
GD 98014 x RR 166-645	-8.93 **	-7.27 **	-9.91 *	-1.73	3.22	1.57	-4.34	-8.49	-17.89 **	4.65
GD 98014 x TKM 11	10.71 **	12.73 **	7.25	16.99 **	23.55 **	21.57 *	6.13	1.52	12.62 **	43.54 **
GD 98014 x TKM 12	8.33 **	10.30 **	22.69 **	33.82 **	8.16	6.43	16.94 **	11.85 *	-23.66 **	-2.70
GD 99017 x ADT 43	-5.95 *	-4.24	-5.70	2.85	-12.24	-13.65	-1.05	-5.35	14.75 **	46.25 **
GD 99017 x CO 43	4.76	6.67 **	-3.77	4.96	6.53	4.82	2.15	-2.29	53.30 **	95.38 **
GD 99017 x CO 47	-5.95 *	-4.24	-1.47	7.47	-2.45	-4.02	1.07	-3.32	12.72 **	43.67 **
GD 99017 x IR 62030-54-1-2-2	-9.52 **	-7.88 **	-1.46	7.49	-18.78 *	-20.08 *	-1.69	-5.97	9.20 **	39.18 **
GD 99017 x IR 61608-213	-9.52 **	-7.88 **	14.00 **	24.35 **	-9.80	-11.24	3.97	-0.55	-19.17 **	3.02
GD 99017 x IR 63875-196-2-2-1-3	2.98	4.85	0.83	9.98 *	-10.61	-12.05	-2.52	-6.76	19.31 **	52.06 **
GD 99017 x Padmini	2.98	4.85	45.69 **	58.91 **	6.12	4.42	30.09 **	24.44 **	76.96 **	125.55 **
GD 99017 x TKM 11	-1.19	0.61	24.80 **	36.13 **	-4.90	-6.43	4.85	0.30	12.61 **	43.53 **
GD 99017 x TKM 12	4.76	6.67 **	23.42 **	34.62 **	-9.39	-10.84	26.68 **	21.18 **	-2.30	24.52 **
GD 99017 x TRY 2	4.17	6.06 *	49.06 **	62.58 **	2.45	0.80	2.38	-2.07	-4.33	21.94 **
GD 98029 x IR 61608-213	-11.90 **	-10.30 **	0.72	9.86 *	-2.45	-4.02	-6.13	-10.21 *	-17.85 **	4.70
GD 98029 x IR 10198-66-2	0.60	2.42	0.21	9.30 *	7.35	5.62	3.26	-1.22	-13.83 **	9.83 *
GD 98029 x Padmini	7.74 **	9.70 **	24.99 **	36.34 **	24.90 **	22.89 **	22.02 **	16.71 **	31.12 **	67.12 **
GD 98029 x TKM 12	6.55 **	8.48 **	28.06 **	39.68 **	26.53 **	24.50 **	12.56 *	7.66	-2.87	23.80 **
GD 98049 x IR 66	-3.57	-1.82	-16.32 **	-8.72 *	-3.67	-5.22	-7.89	-11.89 *	-41.17 **	-25.02 **
GD 98049 x IR 65514-5-1-2-19	4.76	6.67 **	-4.99	3.63	0.41	-1.20	-1.22	-5.51	10.18 **	40.43 **
GD 98049 x IR 65515-47-2-1-19	8.33 **	10.30 **	-12.60 **	-4.67	7.76	6.02	1.86	-2.57	-32.27 **	-13.67 **
GD 98049 x IR 63877-43-2-1-3-1	-3.57	-1.82	-8.44 *	-0.13	-9.39	-10.84	0.78	-3.60	-12.25 **	11.84 **
GD 98049 x IR 61608-213	-10.71 **	-9.09 **	21.62 **	32.66 **	-2.45	-4.02	3.61	-0.89	-29.66 **	-10.35 **
GD 98049 x IR 63875-196-2-2-1-3	2.38	4.24	-6.31	2.19	4.08	2.41	3.24	-1.24	-16.12 **	6.91
GD 98049 x Padmini	9.52 **	11.52 **	8.89 *	18.77 **	22.86 *	20.88 *	-1.73	-6.01	36.40 **	73.84 **

Table 1. Contd..

Hybrids	Days to 50 % flowering		Plant height (cm)		No. of productive tillers		Panicle length (cm)		No. of filled grains per panicle	
	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$
GD 98049 x RR 166-645	4.76	6.67 **	33.31 **	45.41 **	-4.49	-6.02	10.16 *	5.37	20.60 **	53.71 **
GD 98049 x TKM 11	8.33 **	10.30 **	48.09 **	61.52 **	13.06	11.24	19.06 **	13.89 **	42.82 **	82.03 **
GD 98049 x TRY 2	5.36 *	7.27 **	4.34	13.81 **	0.82	-0.80	1.43	-2.98	47.00 **	87.36 **
GD 98014 x IR 66	22.63 **	39.45 **	-21.99 **	-19.90 **	-16.72 *	13.42	-45.53 **	-39.09 **	54.64 **	87.87 **
GD 98014 x IR 72	22.83 **	39.68 **	-4.02	-1.46	-21.68 **	6.66	-28.46 **	-20.00 **	9.21	32.68 **
GD 98014 x IR 62030-54-1-2-2	19.42 **	35.80 **	-16.78 **	-14.56 **	-24.39 **	2.98	-26.83 **	-18.18 **	3.40	25.62 **
GD 98014 x IR 59624-34-2-2	25.25 **	42.42 **	19.62 **	22.82 **	-20.35 *	8.47	-16.26 **	-6.36	-4.57	15.94
GD 98014 x IR 65515-47-2-1-19	13.85 **	29.47 **	-21.99 **	-19.90 **	-16.25 *	14.06	-46.34 **	-40.00 **	55.70 **	89.16 **
GD 98014 x RR 166-645	23.79 **	40.77 **	-9.69 **	-7.28	-27.72 **	-1.56	-52.03 **	-46.36 **	50.65 **	83.03 **
GD 98014 x TKM 11	21.72 **	38.42 **	-3.07	-0.49	26.73 **	72.60 **	7.32	20.00 **	18.57 *	44.05 **
GD 98014 x TKM 12	19.48 **	35.87 **	-5.44	-2.91	-30.17 **	-4.89	-45.53 **	-39.09 **	28.86 **	56.55 **
GD 99017 x ADT 43	31.15 **	49.14 **	13.57 **	16.60 **	-32.68 **	-8.31	-47.15 **	-40.91 **	27.45 **	54.84 **
GD 99017 x CO 43	28.50 **	46.13 **	-22.88 **	-20.83 **	12.56	53.30 **	-4.07	7.27	12.71	36.94 **
GD 99017 x CO 47	33.90 **	52.26 **	19.15 **	22.33 **	6.68	45.29 **	-21.14 **	-11.82 *	25.91 **	52.97 **
GD 99017 x IR 62030-54-1-2-2	15.46 **	31.29 **	11.16 **	14.13 **	-51.46 **	-33.89 **	-60.98 **	-56.36 **	22.98 **	49.41 **
GD 99017 x IR 61608-213	27.21 **	44.66 **	23.45 **	26.75 **	-23.78 **	3.81	-15.45 **	-5.45	-2.10	18.94 *
GD 99017 x IR 63875-196-2-2-1-3	25.75 **	42.99 **	5.58	8.40 *	-6.19	27.76 *	4.07	16.36 **	-9.77	9.62
GD 99017 x Padmini	24.61 **	41.70 **	6.95	9.81 *	-2.88	32.28 **	-61.79 **	-57.27 **	153.16 **	207.57 **
GD 99017 x TKM 11	34.34 **	52.77 **	10.35 **	13.30 **	-25.64 **	1.28	-29.27 **	-20.91 **	38.64 **	68.43 **
GD 99017 x TKM 12	4.39	18.71 **	37.26 **	40.92 **	-2.43	32.88 **	-30.08 **	-21.82 **	45.20 **	76.41 **
GD 99017 x TRY 2	14.21 **	29.88 **	49.50 **	53.50 **	24.13 **	69.05 **	1.63	13.64 *	13.36	37.73 **
GD 98029 x IR 61608-213	12.51 **	27.94 **	13.95 **	16.99 **	-14.39	16.59	-26.02 **	-17.27 **	16.50 *	41.54 **
GD 98029 x IR 10198-66-2	21.21 **	37.84 **	14.89 **	17.96 **	3.37	40.78 **	0.81	12.73 *	2.98	25.11 **
GD 98029 x Padmini	18.12 **	34.32 **	-0.71	1.94	21.03 **	64.84 **	4.07	16.36 **	16.25 *	41.23 **
GD 98029 x TKM 12	4.78	19.15 **	16.31 **	19.42 **	20.12 *	63.59 **	-8.94	1.82	32.25 **	60.68 **
GD 98049 x IR 66	33.16 **	51.43 **	8.75 *	11.65 **	-26.43 **	0.19	-28.46 **	-20.00 **	3.08	25.23 **

Table 1. Contd..

Hybrids	Days to 50 % flowering		Plant height (cm)		No. of productive tillers		Panicle length (cm)		No. of filled grains per panicle	
	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$	$d_{iii(1)}$	$d_{iii(2)}$
GD 98049 x IR 65514-5-1-2-19	23.18 **	40.08 **	18.20 **	21.36 **	4.98	42.98 **	-33.33 **	-25.45 **	57.68 **	91.57 **
GD 98049 x IR 65515-47-2-1-19	18.43 **	34.67 **	-5.44	-2.91	-36.83 **	-13.97	-56.10 **	-50.91 **	45.04 **	76.21 **
GD 98049 x IR 63877-43-2-1-3-1	28.81 **	46.48 **	18.68 **	21.84 **	-0.95	34.90 **	-14.63 **	-4.55	16.06 *	41.00 **
GD 98049 x IR 61608-213	15.33 **	31.15 **	15.84 **	18.93 **	7.85	46.88 **	-9.76	0.91	19.39 **	45.05 **
GD 98049 x IR 63875-196-2-2-1-3	26.01 **	43.29 **	37.12 **	40.78 **	28.97 **	75.65 **	-10.57 *	0.00	43.45 **	74.28 **
GD 98049 x Padmini	13.24 **	28.77 **	20.57 **	23.79 **	-23.65 **	3.99	-58.54 **	-53.64 **	81.89 **	120.99 **
GD 98049 x RR 166-645	23.71 **	40.67 **	14.42 **	17.48 **	24.05 **	68.95 **	-2.44	9.09	27.19 **	54.53 **
GD 98049 x TKM 11	28.16 **	45.74 **	37.35 **	41.02 **	26.46 **	72.23 **	-30.89 **	-22.73 **	85.07 **	124.84 **
GD 98049 x TRY 2	26.76 **	44.14 **	31.91 **	35.44 **	9.77	49.50 **	-17.89 **	-8.18	33.23 **	61.86 **

Significant at 5% level; ** Significant at 1% level; $d_{iii\,(1)}$-Standard heterosis over ADTRH 1; $d_{iii\,(2)}$-Standard heterosis over CORH 2

Table2. Mean performance of selected hybrids for various yield characters

Sl. No.	Hybrids	Days to 50 % flowering	Plant height (cm)	No. of productive tillers	Panicle length (cm)	No. of filled grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain yield per plant (g)	Harvest index	Biomass yield (g)
1	GD 98014 x IR 66	90.50	82.08	16.32	23.07	156.84	88.46	16.50	32.00	0.34	96.51
2	GD 98014 x IR 72	112.00	80.34	13.12	25.35	143.28	88.60	20.30	30.09	0.44	68.16
3	GD 98014 x IR 62030-54-1-2-2	91.00	81.84	13.02	23.07	116.81	86.14	17.60	29.05	0.45	64.53
4	GD 98014 x IR 59624-34-2-2	87.00	84.99	16.27	24.53	115.44	90.34	25.30	30.60	0.52	59.56
5	GD 98014 x IR 65515-47-2-1-19	92.00	84.43	12.78	23.54	124.27	82.12	16.50	32.18	0.33	97.17
6	GD 98014 x RR 166-645	76.50	85.44	12.64	23.16	115.35	89.29	19.10	27.77	0.30	94.02
7	GD 98014 x TKM 11	93.00	101.72	15.13	25.70	158.21	87.80	20.50	48.69	0.66	74.00
8	GD 98014 x TKM 12	91.00	116.36	13.25	28.31	107.24	86.18	20.00	26.83	0.34	80.42
9	GD 99017 x ADT 43	79.00	89.43	10.75	23.96	161.20	94.60	24.02	25.86	0.33	79.54

Table2. Contd..

Sl. No.	Hybrids	Days to 50 % flowering	Plant height (cm)	No. of productive tillers	Panicle length (cm)	No. of filled grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain yield per plant (g)	Harvest index	Biomass yield (g)
10	GD 99017 x CO 43	88.00	91.26	13.05	24.73	215.35	92.69	16.31	43.25	0.59	70.35
11	GD 99017 x CO 47	79.00	93.44	11.95	24.47	158.35	96.58	25.20	40.99	0.48	78.58
12	GD 99017 x IR 62030-54-1-2-2	76.00	93.46	9.95	23.80	153.40	83.28	23.51	18.65	0.24	76.75
13	GD 99017 x IR 61608-213	76.00	108.12	11.05	25.17	113.55	91.76	26.11	29.28	0.52	61.10
14	GD 99017 x IR 63875-196-2-2-1-3	86.50	95.63	10.95	23.60	167.60	90.70	22.33	36.04	0.64	56.31
15	GD 99017 x Padmini	86.50	138.18	13.00	31.49	248.60	89.88	22.62	37.31	0.23	158.00
16	GD 99017 x TKM 11	88.00	117.05	11.65	25.39	158.20	96.90	29.03	37.49	0.44	86.53
17	GD 99017 x TKM 12	87.50	141.37	11.10	30.67	137.25	75.30	31.62	47.69	0.43	90.62
18	GD 99017 x TRY 2	84.00	109.72	12.55	24.78	134.40	82.38	29.41	44.14	0.63	70.75
19	GD 98029 x IR 61608-213	74.00	95.53	11.95	22.73	115.40	81.15	24.10	32.89	0.45	72.71
20	GD 98029 x IR 10198-66-2	84.50	95.04	13.15	25.00	121.05	87.43	24.30	39.72	0.62	64.27
21	GD 98029 x Padmini	90.50	118.54	15.30	29.54	184.20	85.20	21.00	46.50	0.64	72.55
22	GD 98029 x TKM 12	89.50	121.45	15.50	27.25	136.45	82.22	24.60	46.15	0.56	82.54
23	GD 98049 x IR 66	81.00	79.36	11.80	22.30	82.64	96.05	23.00	28.26	0.44	64.33
24	GD 98049 x IR 65514-5-1-2-19	88.00	90.10	12.30	23.91	154.78	88.85	25.00	40.34	0.41	98.41
25	GD 98049 x IR 65515-47-2-1-19	91.00	82.89	13.20	24.66	95.15	85.42	20.00	24.27	0.27	90.52
26	GD 98049 x IR 63877-43-2-1-3-1	81.00	86.83	11.10	24.40	123.27	92.91	25.10	38.06	0.53	72.43
27	GD 98049 x IR 61608-213	75.00	115.35	11.95	25.09	98.81	83.19	24.50	41.43	0.56	74.51
28	GD 98049 x IR 63875-196-2-2-1-3	86.00	88.85	12.75	24.99	117.84	90.89	29.00	49.55	0.55	89.53
29	GD 98049 x Padmini	92.00	103.27	15.05	23.79	191.61	81.68	25.50	29.34	0.26	113.52
30	GD 98049 x RR 166-645	88.00	126.43	11.70	26.67	169.42	89.23	24.20	47.66	0.60	79.38
31	GD 98049 x TKM 11	91.00	140.44	13.85	28.83	200.63	92.44	29.05	48.58	0.42	115.50
32	GD 98049 x TRY 2	88.50	98.96	12.35	24.56	206.51	91.43	27.90	42.17	0.50	83.15
	Checks										
1	ADTRH 1	84.00	94.84	12.25	24.21	140.48	72.13	21.15	38.42	0.62	62.41
2	CORH 2	82.50	86.95	12.45	25.31	110.22	63.43	20.60	28.21	0.55	51.37

Table 3. Hybrids with high per se performance, standard heterosis and *sca* effects

Hybrids	Mean	Standard heterosis		*sca*
		$d_{iii(1)}$	$d_{iii(2)}$	
Days to 50 % flowering				
GD 98029 x IR 61608-213	74.00	-11.90 **	-10.30 **	1.44
GD 98049 x IR 61608-213	75.00	-10.71 **	-9.09 **	-0.06
GD 99017 x IR 62030-54-1-2-2	76.00	-9.52 **	-7.88 **	-3.81 *
GD 99017 x IR 61608-213	76.00	-9.52 **	-7.88 **	4.19 *
GD 98014 x RR 166-645	76.50	-8.93 **	-7.27 **	-12.19 **
Plant height				
GD 98049 x IR 66	79.36	-16.32 **	-8.72 **	-7.90 **
GD 98014 x IR 72	80.34	-15.29 **	-7.61	-0.64
GD 98014 x IR 62030-54-1-2-2	81.84	-13.70 **	-5.87	2.13
GD 98014 x IR 66	82.08	-13.45 **	-5.60	6.27 *
GD 98049 x IR 65515-47-2-1-19	82.89	-12.60 **	-4.67	-8.91 **
Number of productive tillers				
GD 98014 x IR 66	16.32	33.22 **	31.08 **	2.50 **
GD 98014 x IR 59624-34-2-2	16.27	32.86 **	30.72 **	2.86 **
GD 98029 x TKM 12	15.50	26.53 **	24.50 **	1.76
GD 98029 x Padmini	15.30	24.90 **	22.89 **	1.10
GD 98014 x TKM 11	15.13	23.55 **	21.57 *	1.52
Panicle length				
GD 99017 x Padmini	31.49	30.09 **	24.44 **	3.28 **
GD 99017 x TKM 12	30.67	26.68 **	21.18 **	1.84 *
GD 98029 x Padmini	29.54	22.02 **	16.71 **	2.02 *
GD 98049 x TKM 11	28.83	19.06 **	13.89 **	2.73 **
GD 98014 x TKM 12	28.31	16.94 **	11.85 *	0.16
Number of filled grains/panicle				
GD 99017 x Padmini	248.60	76.96 **	125.55 **	50.18 **
GD 99017 x CO 43	215.35	53.30 **	95.38 **	27.79 **
GD 98049 x TRY 2	206.51	47.00 **	87.36 **	56.02 **
GD 98049 x TKM 11	200.63	42.82 **	82.03 **	29.70 **
GD 98049 x Padmini	191.61	36.40 **	73.84 **	-3.47
Spikelet fertility				
GD 99017 x TKM 11	96.90	34.34 **	52.77 **	7.70 **
GD 99017 x CO 47	96.58	33.90 **	52.26 **	8.49 **
GD 98049 x IR 66	96.05	33.16 **	51.43 **	7.27 **
GD 99017 x ADT 43	94.60	31.15 **	49.14 **	3.62
GD 98049 x IR 63877-43-2-1-3-1	92.91	28.81 **	46.48 **	7.02 **
1000 grain weight				
GD 99017 x TKM 12	31.62	49.50 **	53.50 **	4.79 **
GD 99017 x TRY 2	29.41	39.05 **	42.77 **	1.45 *
GD 98049 x TKM 11	29.05	37.35 **	41.02 **	2.44 **
GD 99017 x TKM 11	29.03	37.26 **	40.92 **	2.73 **
GD 98049 x IR 63875-196-2-2-1-3	29.00	37.12 **	40.78 **	3.12 **
Grain yield per plant				
GD 98049 x IR 63875-196-2-2-1-3	49.55	28.97 **	75.65 **	5.44 **
GD 98014 x TKM 11	48.69	26.73 **	72.60 **	11.54 **
GD 98049 x TKM 11	48.58	26.46 **	72.23 **	2.78
GD 99017 x TKM 12	47.69	24.13 **	69.05 **	6.26 **
GD 98049 x RR 166-645	47.66	24.05 **	68.95 **	12.12 **
Harvest index				
GD 98014 x TKM 11	0.66	7.32	20.00 **	0.21 **
GD 98029 x Padmini	0.64	4.07	16.36 **	0.24 **
GD 99017 x IR 63875-196-2-2-1-3	0.64	4.07	16.36 **	0.06 *

Table 3Contd..

Hybrids	**Mean**	**Standard heterosis**		***sca***
		$d_{iii(1)}$	**$d_{iii(2)}$**	
GD 99017 x TRY 2	0.63	1.63	13.64 *	0.10 **
GD 98029 x IR 10198-66-2	0.62	0.81	12.73	0.12 **
Biomass yield				
GD 99017 x Padmini	158.00	153.16 **	207.57 **	53.42 **
GD 98049 x TKM 11	115.50	85.07 **	124.84 **	17.03 **
GD 98049 x Padmini	113.52	81.89 **	120.99 **	4.64
GD 98049 x IR 65514-5-1-2-19	98.41	57.68 **	91.57 **	14.53 **
GD 98014 x IR 65515-47-2-1-19	97.17	55.70 **	89.16 **	15.45 **

Significant at 5% level; ** Significant at 1% level; $d_{iii\ (1)}$-Standard heterosis over ADTRH 1; $d_{iii\ (2)}$-Standard heterosis over CORH 2