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RESEARCH ARTICLE

GENETIC DISSECTION ON HETEROSIS FOR YIELD AND GRAIN QUALITY TRAITS IN RICE (*Oryza sativa* L).

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ABSTRACT

The present study was carried out in rice with a view to know the extent of heterosis, heterobeltiosis and standard heterosis for grain yield per plant and six rice grain quality traits *viz.,* hulling percentage, milling percentage, head rice recovery percentage, kernel length, kernel breadth, kernel length/breadth ratio in rice. Twelve high yielding rice genotypes *viz.,* ADT 39, ADT 42, ADT 43, ADT (R) 45, ADT (R) 46, ADT (R) 47, TNAU Rice ADT 49, CO 47, ASD 16, TKM 11, TKM 12 and TRY 2 were crossed to five testers *viz.,* Pusa 1460, Imp. Samba Mahsuri, Ajaya, IRBB 60 and IRBB 21 in a line x tester analysis to generate 60 hybrids. Significant heterosis over mid parent, better parent and standard parent in desired direction was observed in many crosses for various traits under study. The higher magnitude of heterosis for the grain yield per plant and quality traits were not expressed in a single cross. It varied from cross to cross due to diverse genetic background of their parents. Computing standard heterosis based on best cultivar for commercial exploitation of hybrid vigour is a primary need. Among the top ranking hybrids , the hybrids ADT (R) 46/Pusa 1460 (145.21 per cent) for grain yield per plant, CO 47/Imp. Samba Mahsuri for hulling percentage (16.87 per cent) and milling percentage (33.79 per cent), ASD 16/Ajaya (18.90 per cent) for head rice recovery percentage, TRY 2/Pusa 1460 for kernel length (28.25 per cent), revealed highest standard heterotic value and need to be further tested in multi-location trials to exploit their heterotic potential.

INTRODUCTION

Known in Ancient India as the "Sustainer of the Human Race" rice is perhaps the best showcase for the wonders of farmer innovation. Domesticated in South Asia about 12000 years ago, rice [*Oryza sativa* (L.)] being the staple food of Asian countries, is consumed by more than half of the world's population. Rice is high in carbohydrates, low in fat, moderate in proteins, vitamins, minerals and contributes to two third of calorific needs of the consumers. It had been used as a major food for over ten thousand years and has been cultivated in 114 countries. Major advances had occurred in rice production during the past four decades due to adoption of hitech packages. After the achievement of self sufficiency in rice production through high yielding varieties/hybrids, the demand for fine rice is increasing. Rice quality is of great importance for all people involved in producing, processing and consuming rice, because it affects the nutritional and commercial value of grains (Lodh, 2002 and Babu *et al.* 2013). The primary components of rice grain quality influencing the commercial value include appearance, milling, cooking and eating quality which are determined by their physical and chemical properties. Generally, the appearance of rice grain is determined by of grain length, grain breadth, grain thickness and grain shape as length: breadth ratio (L/B ratio).Usually short and long slender grains normally command high premium in the market. Negative direction of heterosis for kernel breadth is considered to be desirable. The milling quality is assessed by using three principal characters *viz.,* hulling, milling yield and head rice recovery. While heterosis has been reported in rice for agronomic characters, physiological traits, low temperature tolerance and productivity, reports of heterosis for the physicochemical grain quality characters in rice are limited. On the other hand knowledge on these genetic aspects is very important for maximum exploitation of heterotic effects in rice and for building up of gene pools to be employed in breeding programmes. Hence, present investigation was undertaken in rice on heterotic manifestations in grain yield per plant and six milling quality traits involving high yielding genotypes

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susceptible to bacterial leaf blight disease as 'lines' and five donors for the said disease as 'testers'.

MATERIALS AND METHODS

The present investigation was carried out at Plant Breeding and Genetics Unit of Tamil Nadu Rice Research Institute, Aduthurai. A total of twelve high yielding genotypes susceptible to bacterial leaf blight disease as 'lines' and five donors for the said disease as 'testers' are the materials chosen for the present study. The 12 lines were ADT 39, ADT 42, ADT 43, ADT (R) 45, ADT (R) 46, ADT (R) 47, TNAU Rice ADT 49, CO 47, ASD 16, TKM 11, TKM 12 and TRY 2 and the five testers were Pusa 1460, Imp. Samba Mahsuri, Ajaya, IRBB 60 and IRBB 21.All the parents were raised in a crossing block at the South Farm, Tamil Nadu Rice Research Institute, Aduthurai during *kharif 2014*. Sowing and transplanting of parents were done thrice at weekly intervals in order to ensure synchronization in flowering of lines and testers which have duration range of 105 to 135 days. Twenty five days old seedlings of 17 entries were transplanted under irrigated condition in each three rows of three meter row length in the main field adopting a spacing of 30 x 20 cm. A wider spacing of 60cm was maintained between three rows of each entry for ease of hybridization All the recommended agronomical package of practices were well adopted to keep the plants uniformly good throughout the crop growth period. Five testers and 12 lines were grown, and at flowering stage, they were crossed with each other in a line × tester manner as described by Kempthorne (1957) to produce 60 hybrids. During kharif *2015,* the resultant 60 F_1s together with 17 parental lines were grown in a Randomized Complete Block Design with three replications. Twenty five days old seedlings were transplanted in 3m row with 20 x 10cm spacing.

To estimate Milling Percentage (MP), **a**fter hulling, the brown rice was milled and polished in a Kett polisher for a standard time to find out the milling percentage. Milling percentage was estimated as follows,

$$\text{Milling percentage} = \frac{\text{Weight of milled rice(g)}}{\text{Weight of rough rice(g)}} \times 100$$

To estimate Head Rice Recovery Percentage (HRR**),t**he milled samples were sieved to separate whole grains from the brokens. Small portion of broken kernels which passed along whole kernels were separated by hand. Head rice recovery, which is the estimate of full size plus three fourth size kernels was expressed in percentage.

$$\text{Head rice recovery} = \frac{\text{Weight of head rice(g)}}{\text{Weight of rough rice(g)}} \times 100$$

Kernel length and breadth of ten dehusked rice kernels before milling (brown rice) in three sets was measured using graph sheet and the mean was expressed in millimeters (mm). The heterosis per cent was calculated for different traits as per cent deviation of the mean F_1 performance over mid parent, better parent and standard check (ADT 43) values The significance of Relative heterosis, Heterobeltiosis and Standard heterosis were tested using the formulae suggested by Turner (1953).

RESULTS AND DISCUSSION

Analysis oof variance

The analyses of variances for present study have been given in Table 1. Analysis of combining ability for most of the characters revealed significant differences among genotypes, crosses, lines, testers and line x testers.

Table 1. Analysis of variance (Mean sum of squares) for yield and different grain quality traits in rice

Sl. No	Sources	DF	Mean sum of squares						
			Grain yield per plant	Hulling percentage	Milling percentage	Head rice recovery percentage	Kernel length	Kernel breadth	Kernel length/ breadth ratio
1	Genotypes	76	112.6561**	71.7662**	58.0941**	102.4519**	0.7767**	0.0781**	0.2976**
2	Cross	59	76.1463**	75.7859**	63.3439**	105.3265**	0.7063**	0.0682**	0.2679**
3	Line	11	119.8878**	85.8072	94.0144	122.4278	1.7656**	0.1300**	0.4379**
4	Tester	4	284.4071**	108.2899	107.1632	443.5339**	2.9716**	0.1547*	1.2382**
5	Line × Tester	44	46.2781**	70.3256**	51.6927**	70.3050**	0.2356**	0.0449**	0.1372**
6	Parent	16	18.4969**	61.2807**	41.6477**	46.4163**	0.9901**	0.1195**	0.4155**
7	Crosses vs Parents	1	3773.2861**	2.3750	11.5000*	829.4219**	1.5160**	0.0005**	0.1683**
8	Error	152	1.7862	2.6039	2.7336	1.7765	0.0212	0.0064	0.0146
9	σ^2GCA		0.3802	0.0695	0.1483	0.4458	0.0060	0.0003	0.0017
10	σ^2SCA		14.8567	22.7756	16.5835	22.8847	0.0718	0.0131	0.0413
11	σ^2GCA/σ^2SCA		0.0255	0.0030	0.0087	0.0194	0.0835	0.0223	0.0411

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

The resultant 60 hybrids along with their parents were studied to the heterotic manifestations in grain yield per plant and six grain quality traits *viz.,*hulling percentage (HP), milling percentage(MP), head rice recovery percentage(HRR), kernel length(KL), kernel breadth (KB) and kernel length/breadth ratio(KLBR). To estimate Hulling Percentage(HP), a known quantity of rough rice (paddy) was cleaned, dried to 12-14% moisture content and dehulled with a McGill Laboratory Sheller and hulling percentage was estimated as follows,

$$\text{Hulling percentage} = \frac{\text{Weight of hulled rice(g)}}{\text{Weight of rough rice(g)}} \times 100$$

The results indicated sufficient variability existing in material used in the present study. Significance of mean squares of lines and testers suggested the prevalence of additive gene effects. The heterosis per cent observed for different traits over mid parent, better parent and standard check (ADT 43) and three best crosses are given in Tables 2 to 4. The findings suggested that the magnitude of heterosis differed from character to character depending on hybrid combination. Latha *et al*. (2013) also reported in rice that the magnitude of heterosis varied from trait to trait and cross to cross and none of the cross combinations recorded significant heterosis for all the traits studied.

Table 2. Estimates of heterosis (per cent) for grain yield per plant, hulling percentage, milling percentage and head rice recovery percentage in rice

Sl. No	Hybrids	Grain yield per plant			Hulling percentage			Milling percentage			Head rice recovery percentage		
		MP	BP	SH	MP	BP	SH	MP	BP	SH	MP	BP	SH
1	ADT 39/Pusa 1460	69.59**	56.01**	68.37**	-8.08 **	-16.99 **	-14.78 **	0.31 ns	-4.32 *	-1.32 ns	-13.88 **	-19.82 **	-16.06 **
2	ADT 39/Imp. Samba Mahsuri	81.66**	66.51**	79.70**	-4.27 **	-5.06 **	-0.90 ns	4.82 **	0.92 ns	12.45 **	-4.61 **	-5.35 **	0.65 ns
3	ADT 39/Ajaya	88.20**	75.60**	89.51**	-8.09 **	-10.76 **	-8.39 **	1.19 ns	0.90 ns	4.65 *	-18.32 **	-18.93 **	-15.12 **
4	ADT 39/IRBB 60	67.64**	58.28**	70.82**	-0.87 ns	-3.79 *	-1.23 ns	7.12 **	5.85 **	9.17 **	-10.20 **	-13.00 **	-8.91 **
5	ADT 39/IRBB 21	72.65**	48.62**	60.39**	-10.46 **	-12.21 **	-9.87 **	-0.56 ns	-0.94 ns	2.95 ns	-1.60 ns	-7.09 **	-2.73 ns
6	ADT 42/Pusa 1460	34.86**	10.07**	57.78**	13.70 **	2.04 ns	6.23 **	7.62 **	-3.99 *	14.60 **	-31.15 **	-39.03 **	-28.64 **
7	ADT 42/Imp. Samba Mahsuri	30.83**	6.45ns	52.59**	-6.04 **	-6.17 **	-2.06 ns	-12.08 **	-15.00 **	1.46 ns	-7.87 **	-12.07 **	2.91 ns
8	ADT 42/Ajaya	35.49**	11.92*	60.43**	-4.28 **	-7.68 **	-3.90 *	-9.72 **	-15.64 **	0.69 ns	-19.58 **	-24.36 **	-11.48 **
9	ADT 42/IRBB 60	14.94**	-4.09ns	37.47**	-7.21 **	-10.55 **	-6.87 **	-4.75 **	-12.21 **	4.79 *	-17.57 **	-24.21 **	-11.30 **
10	ADT 42/IRBB 21	47.88**	14.11**	63.56**	-3.74 **	-6.26 **	-2.41 ns	-6.00 **	-12.07 **	4.95 *	-8.95 **	-18.30 **	-4.38 *
11	ADT 43/Pusa 1460	125.45**	114.91**	114.91**	3.58 *	-5.35 **	-5.35 **	6.30 **	2.91 ns	2.91 ns	-5.92 **	-10.51 **	-10.51 **
12	ADT 43/Imp. Samba Mahsuri	128.02**	116.53**	116.53**	-2.31 ns	-4.36 **	-0.17 ns	-4.66 **	-9.55 **	0.78 ns	-1.53 ns	-4.47 *	1.59 ns
13	ADT 43/Ajaya	87.35**	81.23**	81.23**	-1.48 ns	-3.11 ns	-3.11 ns	8.23 **	6.29 **	10.24 **	-2.68 ns	-4.16 *	-1.16 ns
14	ADT 43/IRBB 60	119.33**	114.81**	114.81**	-6.66 **	-8.24 **	-8.24 **	2.45 ns	2.10 ns	2.80 ns	4.16 **	3.20 ns	3.20 ns
15	ADT 43/IRBB 21	45.93**	29.78**	29.78**	-5.60 **	-6.24 **	-6.24 **	2.32 ns	0.39 ns	4.33 *	-14.98 **	-17.96 **	-17.96 **
16	ADT (R) 45/Pusa 1460	146.10**	143.70**	125.30**	7.40 **	-0.08 ns	-3.93 *	4.38 **	-1.34 ns	3.72 ns	-5.10 **	-9.83 **	-9.62 **
17	ADT (R) 45/Imp. Samba Mahsuri	132.36**	129.18**	111.88**	2.46 ns	-1.58 ns	2.73 ns	3.53 *	0.61 ns	12.10 **	15.07 **	11.76 **	18.85 **
18	ADT (R) 45/Ajaya	24.06**	23.39**	15.33*	-3.49 **	-3.76 *	-6.94 **	-4.73 **	-5.37 **	-0.51 ns	-17.93 **	-19.08 **	-16.55 **
19	ADT (R) 45/IRBB 60	127.49**	123.43**	114.21**	-6.33 **	-6.56 **	-9.71 **	-2.35 ns	-4.42 *	0.49 ns	-8.88 **	-9.81 **	-9.61 **
20	ADT (R) 45/IRBB 21	59.28**	46.72**	35.65**	-10.32 **	-11.45 **	-12.66 **	-6.31 **	-6.85 **	-2.06 ns	-21.30 **	-24.13 **	-23.96 **
21	ADT (R) 46/Pusa 1460	148.51**	129.82**	145.21**	8.40 **	0.66 ns	-2.80 ns	8.18 **	2.44 ns	7.29 **	-14.02 **	-20.48 **	-15.55 **
22	ADT (R) 46/Imp. Samba Mahsuri	111.50**	94.87**	107.92**	-5.58 **	-9.12 **	-5.14 **	0.38 ns	-2.64 ns	8.48 **	-14.41 **	-14.47 **	-9.04 **
23	AD T(R) 46/Ajaya	60.42**	50.48**	60.56**	2.14 ns	2.06 ns	-1.31 ns	-3.81 *	-4.28 *	0.25 ns	-11.18 **	-12.46 **	-7.04 **
24	ADT (R) 46/IRBB 60	42.83**	35.59**	44.67**	-0.02 ns	-0.06 ns	-3.43 *	4.76 **	2.74 ns	7.60 **	-1.50 ns	-5.22 **	0.65 ns
25	ADT (R) 46/IRBB 21	68.88**	46.06**	55.85**	-10.74 **	-11.68 **	-12.88 **	-8.30 **	-8.65 **	-4.33 *	-19.73 **	-24.72 **	-20.05 **
26	ADT (R) 47/Pusa 1460	70.27**	49.22**	79.70**	2.64 ns	-3.34 ns	-9.45 **	3.21 ns	-0.22 ns	0.04 ns	-3.60 *	-6.39 **	-10.33 **
27	ADT (R) 47Imp. Samba Mahsuri	62.65**	42.05**	71.07**	1.95 ns	-3.28 *	0.97 ns	1.72 ns	-3.37 ns	7.66 **	6.89 **	1.59 ns	8.03 **
28	ADT (R) 47/Ajaya	32.42**	17.60**	41.62**	-1.46 ns	-3.00 ns	-6.20 **	6.75 **	4.97 *	8.88 **	-1.49 ns	-4.99 **	-2.02 ns
29	ADT (R) 47/IRBB 60	64.28**	47.53**	77.66**	-0.16 ns	-1.68 ns	-5.00 **	5.10 **	4.88 *	5.59 **	1.03 ns	-0.19 ns	-2.02 ns
30	ADT (R) 47/IRBB 21	32.78**	9.32ns	31.65**	15.05**	12.15 **	10.63 **	10.72 **	8.77 **	13.04 **	12.13 **	10.50 **	5.85 **
31	TNAU Rice ADT 49/Pusa 1460	78.56**	68.16**	72.52**	16.12 **	7.66 **	4.31 *	1.65 ns	-5.03 *	2.34 ns	-20.72 **	-28.91 **	-19.12 **
32	TNAU Rice ADT 49/Imp. Samba Mahsuri	95.54**	83.46**	88.22**	-1.15 ns	-4.70 **	-0.52 ns	-7.93 **	-9.45 **	0.89 ns	-11.82 **	-14.69 **	-2.95 ns
33	TNAU Rice ADT 49/Ajaya	41.76**	35.46**	38.97**	-5.59 **	-5.68 **	-8.61 **	-5.81 **	-7.57 **	-0.40 ns	-22.93 **	-26.53 **	-16.42 **
34	TNAU Rice ADT 49/IRBB 60	61.59**	56.30**	60.35**	-9.48 **	-9.61 **	-12.41 **	-6.81 **	-9.87 **	-2.88 ns	-20.67 **	-26.11 **	-15.94 **
35	TNAU Rice ADT 49/IRBB 21	45.81**	28.24**	31.56**	-11.72 **	-12.51 **	-13.69 **	-9.37 **	-10.97 **	-4.07 ns	-13.51 **	-21.40 **	-10.58 **
36	CO 47/Pusa 1460	2.89ns	-3.95ns	0.41ns	12.34 **	10.06 **	-5.06 **	9.77 **	7.34 **	5.14 *	-7.86 **	-10.72 **	-14.08 **
37	CO 47/Imp. Samba Mahsuri	57.58**	46.56**	53.21**	22.60 **	11.96 **	16.87 **	27.80 **	20.08 **	33.79 **	12.97 **	7.60 **	14.43 **
38	CO 47/Ajaya	47.15**	39.36**	45.69**	11.03 **	5.04 **	1.57 ns	8.08 **	5.07 *	8.98 **	-15.64 **	-18.45 **	-15.90 **
39	CO 47/IRBB 60	41.68**	35.81**	41.97**	-6.03 **	-11.07 **	-14.07 **	-3.07 ns	-4.39 *	-3.74 ns	-18.28 **	-19.08 **	-20.56 **
40	CO 47/IRBB 21	47.11**	28.35**	34.18**	7.68 **	0.93 ns	-0.44 ns	6.76 **	3.68 ns	7.76 **	7.19 **	5.39 **	1.43 ns

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41	ASD 16/Pusa 1460	96.31**	88.45**	70.82**	2.77 ns	-1.83 ns	-10.76 **	4.60 **	0.12 ns	2.51 ns	-10.36 **	-15.08 **	-14.34 **
42	ASD 16/Imp. Samba Mahsuri	110.82**	103.16**	82.68**	-5.51 **	-11.61 **	-7.74 **	-0.90 ns	-4.92 *	5.94 **	-3.36 *	-5.84 **	0.13 ns
43	ASD 16/Ajaya	42.03**	34.37**	25.59**	15.14 **	11.69 **	8.00 **	14.01 **	13.28 **	17.49 **	16.57 **	15.30 **	18.90 **
44	ASD 16/IRBB 60	45.05**	35.60**	30.01**	7.38 **	4.20 *	0.69 ns	12.03 **	11.10 **	13.75 **	10.83 **	9.34 **	10.30 **
45	ASD 16/IRBB 21	56.51**	51.33**	26.19**	13.43 **	8.98 **	7.50 **	15.23 **	14.37 **	18.87 **	15.89 **	11.37 **	12.35 **
46	TKM 11/Pusa 1460	76.24**	73.24**	62.57**	-1.39 ns	-5.88 **	-14.29 **	-10.71 **	-14.42 **	-12.64 **	-6.06 **	-11.11 **	-10.11 **
47	TKM 11/ Imp. Samba Mahsuri	36.67**	33.81**	25.57**	0.84 ns	-5.59 **	-1.45 ns	0.64 ns	-3.57 ns	7.44 **	-9.33 **	-11.55 **	-5.94 **
48	TKM 11/Ajaya	65.12**	64.80**	54.65**	-1.05 ns	-3.93 *	-7.10 **	-0.46 ns	-1.25 ns	2.42 ns	-13.08 **	-13.92 **	-11.23 **
49	TKM 11/IRBB 60	47.84**	46.27**	40.23**	-0.91 ns	-3.76 *	-7.01 **	-0.33 ns	-1.01 ns	1.05 ns	-8.84 **	-10.17 **	-9.17 **
50	TKM 11/IRBB 21	63.62**	49.70**	40.48**	-6.52 **	-10.11 **	-11.33 **	-4.05 **	-4.90 *	-1.17 ns	-8.50 **	-12.17 **	-11.19 **
51	TKM 12/Pusa 1460	103.63**	98.99**	80.38**	4.56 **	0.28 ns	-9.59 **	-11.66 **	-13.72 **	-15.29 **	-2.81 ns	-5.70 **	-9.51 **
52	TKM 12/ Imp. Samba Mahsuri	59.03**	56.02**	40.29**	-6.94 **	-13.28 **	-9.48 **	0.45 ns	-5.52 **	5.27 *	1.91 ns	-3.07 ns	3.09 ns
53	TKM 12/Ajaya	50.78**	45.17**	35.69**	-0.96 ns	-4.31 *	-7.47 **	3.71 *	0.94 ns	4.69 *	0.95 ns	-2.56 ns	0.49 ns
54	TKM 12/IRBB 60	93.91**	84.45**	76.84**	-1.72 ns	-5.01 **	-8.22 **	4.50 **	3.20 ns	3.90 ns	-6.98 **	-8.02 **	-9.71 **
55	TKM 12/IRBB 21	44.34**	37.13**	18.64**	-8.24 **	-12.19 **	-13.38 **	1.31 ns	-1.50 ns	2.37 ns	-13.50 **	-14.83 **	-18.27 **
56	TRY 2/Pusa 1460	34.04**	22.34**	34.36**	3.33 *	-3.30 ns	-8.18 **	4.11 **	-3.01 ns	5.18 *	-9.52 **	-13.77 **	-14.11 **
57	TRY 2/Imp. Samba Mahsuri	97.80**	79.87**	97.55**	-5.36 **	-9.64 **	-5.68 **	-1.04 ns	-2.37 ns	8.78 **	-3.30 *	-6.36 **	-0.42 ns
58	TRY 2/Ajaya	47.55**	36.56**	49.98**	-7.26 **	-8.10 **	-11.13 **	-6.34 **	-8.38 **	-0.64 ns	-11.52 **	-13.03 **	-10.31 **
59	TRY 2/IRBB 60	46.39**	37.08**	50.56**	4.98 **	4.07 *	0.55 ns	3.14 *	-0.55 ns	7.84 **	7.48 **	6.71 **	6.28 **
60	TRY 2/IRBB 21	15.83**	-1.02ns	8.71ns	-9.45 **	-11.15 **	-12.35 **	-3.06 *	-5.08 **	2.94 ns	-12.70 **	-15.59 **	-15.93 **
	SE	0.82	1.09	1.09	0.99	1.32	1.32	1.02	1.35	1.35	0.81	1.08	1.08

* Significant at 5% level; ** Significant at 1 % level; MP – Mid parental heterosis; BP – Better parent heterosis; SH – Standard heterosis

Table 3. Estimates of heterosis (per cent) for kernel length, kernel breadth and kernel length/breadth ratio in rice

Sl. No	Hybrids	Kernel length			Kernel breadth			Kernel length/breadth ratio		
		MP	BP	SH	MP	BP	SH	MP	BP	SH
1	ADT 39/Pusa 1460	3.74 **	-7.96 **	17.51 **	11.86 **	8.20 *	13.79 **	-7.66 **	-20.37 **	3.16 ns
2	ADT 39/Imp. Samba Mahsuri	2.96 ns	-0.57 ns	-1.69 ns	7.56 **	4.92 ns	10.34 **	-4.11 ns	-5.11 ns	-10.91 **
3	ADT 39/Ajaya	-0.00 ns	-4.66 *	3.95 *	-1.49 ns	-9.59 **	13.79 **	1.09 ns	-2.90 ns	-8.83 **
4	ADT 39/IRBB 60	-5.72 **	-9.90 **	-2.26 ns	-0.00 ns	-4.48 ns	10.34 **	-5.69 *	-5.69 ns	-11.45 **
5	ADT 39/IRBB 21	2.45 ns	-2.08 ns	6.21 **	4.76 *	1.54 ns	13.79 **	-2.01 ns	-3.17 ns	-6.87 *
6	ADT 42/Pusa 1460	-11.48 **	-16.37 **	6.78 **	7.20 **	-1.47 ns	15.52 **	-18.32 **	-28.70 **	-7.63 *
7	ADT 42/Imp. Samba Mahsuri	-4.95 **	-13.93 **	-2.26 ns	1.59 ns	-5.88 *	10.34 **	-6.19 *	-8.47 *	-11.56 **
8	ADT 42/Ajaya	-5.58 **	-7.46 **	5.08 *	-7.80 **	-10.96 **	12.07 **	2.20 ns	-3.16 ns	-6.43 *
9	ADT 42/IRBB 60	2.80 *	0.50 ns	14.12 **	6.67 **	5.88 *	24.14 **	-3.38 ns	-4.74 ns	-7.96 *
10	ADT 42/IRBB 21	-6.36 **	-8.46 **	3.95 *	-3.76 ns	-5.88 *	10.34 **	-2.26 ns	-2.48 ns	-5.78 ns
11	ADT 43/Pusa 1460	0.74 ns	-10.18 **	14.69 **	4.35 ns	3.45 ns	3.45 ns	-3.56 ns	-14.56 **	10.69 **
12	ADT 43/Imp. Samba Mahsuri	1.18 ns	-2.82 ns	-2.82 ns	8.62 **	8.62 *	8.62 *	-7.05 **	-10.80 **	-10.80 **
13	ADT 43/Ajaya	-1.62 ns	-5.70 **	2.82 ns	9.92 **	-1.37 ns	24.14 **	-11.35 **	-17.34 **	-17.34 **
14	ADT 43/IRBB 60	11.11 **	6.77 **	15.82 **	-0.80 ns	-7.46 *	6.90 *	11.70 **	8.29 *	8.29 *
15	ADT 43/IRBB 21	-4.07 **	-7.81 **	0.00 ns	7.32 **	1.54 ns	13.79 **	-10.62 **	-12.32 **	-12.32 **
16	ADT (R) 45/Pusa 1460	-2.49 ns	-13.27 **	10.73 **	0.83 ns	-4.69 ns	5.17 ns	-4.27 ns	-18.77 **	5.23 ns
17	ADT (R) 45/Imp. Samba Mahsuri	2.65 ns	-1.14 ns	-1.69 ns	-1.64 ns	-6.25 *	3.45 ns	4.13 ns	3.20 ns	-5.13 ns
18	ADT (R) 45/Ajaya	-3.52 *	-7.77 **	0.56 ns	-9.49 **	-15.07 **	6.90 *	6.35 *	4.11 ns	-6.00 ns
19	ADT (R) 45/IRBB 60	4.89 **	0.52 ns	9.04 **	0.76 ns	-1.49 ns	13.79 **	3.85 ns	1.86 ns	-4.36 ns
20	ADT (R) 45/IRBB 21	-7.07 **	-10.94 **	-3.39 ns	-2.33 ns	-3.08 ns	8.62 *	-5.03 ns	-7.94 *	-11.45 **

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21	ADT (R) 46/Pusa 1460	-5.34 **	-9.73 **	15.25 **	4.92 *	-1.54 ns	10.34 **	-10.44 **	-19.53 **	4.25 ns
22	ADT (R) 46/Imp. Samba Mahsuri	0.54 ns	-9.76 **	4.52 *	-2.44 ns	-7.69 *	3.45 ns	3.35 ns	-2.32 ns	0.87 ns
23	ADT (R) 46/Ajaya	-4.02 **	-6.83 **	7.91 **	-5.80 **	-10.96 **	12.07 **	1.61 ns	-6.65 *	-3.60 ns
24	ADT (R) 46/IRBB 60	4.03 **	0.73 ns	16.67 **	-8.33 **	-9.70 **	4.31 ns	13.27 **	8.13 **	11.67 **
25	ADT (R) 46/IRBB 21	3.78 **	0.49 ns	16.38 **	3.08 ns	3.08 ns	15.52 **	0.93 ns	-2.53 ns	0.65 ns
26	ADT (R) 47/Pusa 1460	-7.81 **	-19.03 **	3.39 ns	7.69 **	5.00 ns	8.62 *	-14.68 **	-26.60 **	-4.91 ns
27	ADT (R) 47/Imp. Samba Mahsuri	2.99 ns	0.58 ns	-2.82 ns	5.08 *	3.33 ns	6.90 *	-1.82 ns	-2.57 ns	-9.05 **
28	ADT (R) 47/Ajaya	-2.75 ns	-8.29 **	0.00 ns	-3.76 ns	-12.33 **	10.34 **	0.42 ns	-3.27 ns	-9.71 **
29	ADT (R) 47/IRBB 60	1.93 ns	-3.65 *	4.52 *	-7.09 **	-11.94 **	1.72 ns	9.49 **	9.18 **	2.51 ns
30	ADT (R) 47/IRBB 21	0.83ns	-4.69 *	3.39 ns	-4.00 ns	-7.69 *	3.45 ns	3.57 ns	2.04 ns	-1.85 ns
31	TNAU Rice ADT 49/Pusa 1460	-1.52 ns	-14.16 **	9.60 **	2.61 ns	1.72 ns	1.72 ns	-4.09 ns	-17.00 **	7.52 *
32	TNAU Rice ADT 49/Imp. Samba Mahsuri	5.74 **	4.17 *	-1.13 ns	-2.59 ns	-2.59 ns	-2.59 ns	8.59 **	7.03 *	1.31 ns
33	TNAU Rice ADT 49/Ajaya	-1.39 ns	-7.77 **	0.56 ns	-8.40 **	-17.81 **	3.45 ns	7.16 **	2.53 ns	-2.94 ns
34	TNAU Rice ADT 49/IRBB 60	3.89 **	-2.60 ns	5.65 **	-0.80 ns	-7.46 *	6.90 *	4.80 ns	4.38 ns	-1.20 ns
35	TNAU Rice ADT 49/IRBB 21	4.44 **	-2.08 ns	6.21 **	7.32 **	1.54 ns	13.79 **	-2.29 ns	-3.06 ns	-6.76 *
36	CO 47/Pusa 1460	-11.34 **	-22.12 **	-0.56 ns	1.69 ns	-1.64 ns	3.45 ns	-13.26 **	-25.93 **	-4.03 ns
37	CO 47/ Imp. Samba Mahsuri	17.96 **	15.20 **	11.30 **	4.20 ns	1.64 ns	6.90 *	13.18 **	13.05 **	3.93 ns
38	CO 47/Ajaya	-5.49 **	-10.88 **	-2.82 ns	-5.97 **	-13.70 **	8.62 *	0.24 ns	-2.62 ns	-10.69 **
39	CO 47/IRBB 60	4.68 **	-1.04 ns	7.34 **	3.12 ns	-1.49 ns	13.79 **	1.29 ns	0.12 ns	-6.00 ns
40	CO 47/IRBB 21	-9.64 **	-14.58 **	-7.34 **	-4.76 *	-7.69 *	3.45 ns	-4.82 ns	-7.03 *	-10.58 **
41	ASD 16/Pusa 1460	0.51 ns	-13.27 **	10.73 **	-6.57 **	-20.00 **	10.34 **	1.88 ns	-22.64 **	0.22 ns
42	ASD 16/Imp. Samba Mahsuri	5.81 **	5.49 *	-2.26 ns	1.45 ns	-12.50 **	20.69 **	1.30 ns	-12.34 **	-19.41 **
43	ASD 16/Ajaya	-8.68 **	-15.54 **	-7.91 **	-3.27 ns	-7.50 **	27.59 **	-6.17 *	-16.65 **	-27.92 **
44	ASD 16/IRBB 60	5.06 **	-2.60 ns	5.65 **	-11.56 **	-18.75 **	12.07 **	16.72 **	0.12 ns	-6.00 ns
45	ASD 16/IRBB 21	-6.18 **	-13.02 **	-5.65 **	14.48 **	3.75 ns	43.10 **	-19.49 **	-31.63 **	-34.24 **
46	TKM 11/Pusa 1460	9.37 **	-4.42 **	22.03 **	-2.44 ns	-9.09 **	3.45 ns	10.43 **	-9.09 **	17.78 **
47	TKM 11/ Imp. Samba Mahsuri	17.47 **	15.38 **	10.17 **	3.23 ns	-3.03 ns	10.34 **	13.47 **	8.42 *	-0.33 ns
48	TKM 11/Ajaya	9.94 **	3.11 ns	12.43 **	-5.04 *	-9.59 **	13.79 **	15.95 **	14.12 **	-1.31 ns
49	TKM 11/IRBB 60	12.47 **	5.73 **	14.69 **	0.75 ns	0.00 ns	15.52 **	-2.03 ns	-7.32 *	-12.98 **
50	TKM 11/IRBB 21	11.91 **	5.21 **	14.12 **	0.76 ns	0.00 ns	13.79 **	-5.21 ns	-11.34 **	-14.72 **
51	TKM 12/Pusa 1460	1.52 ns	-11.06 **	13.56 **	12.40 **	6.25 *	17.24 **	-10.18 **	-25.34 **	-3.27 ns
52	TKM 12/ Imp. Samba Mahsuri	7.51 **	5.29 *	1.13 ns	1.64 ns	-3.12 ns	6.90 *	6.13 *	2.61 ns	-5.67 ns
53	TKM 12/Ajaya	-4.68 **	-10.36 **	-2.26 ns	-10.95 **	-16.44 **	5.17 ns	7.97 **	7.57 *	-6.98 *
54	TKM 12/IRBB 60	7.73 **	1.56 ns	10.17 **	-11.45 **	-13.43 **	0.00 ns	22.69 **	17.42 **	10.25 **
55	TKM 12/IRBB 21	-3.31 *	-8.85 **	-1.13 ns	13.18 **	12.31 **	25.86 **	-13.96 **	-18.59 **	-21.70 **
56	TRY 2/Pusa 1460	9.13 **	0.44 ns	28.25 **	-0.80 ns	-8.82 **	6.90 *	8.43 **	-7.41 **	19.96 **
57	TRY 2/ Imp. Samba Mahsuri	9.35 **	1.58 ns	9.04 **	-1.59 ns	-8.82 **	6.90 *	11.05 **	10.91 **	1.96 ns
58	TRY 2/Ajaya	3.39 *	2.59 ns	11.86 **	-2.13 ns	-5.48 *	18.97 **	5.39 *	2.38 ns	-6.11 ns
59	TRY 2/IRBB 60	15.71 **	15.10 **	24.86 **	-2.22 ns	-2.94 ns	13.79 **	17.86 **	16.49 **	9.38 **
60	TRY 2/IRBB 21	12.57 **	11.98 **	21.47 **	8.27 **	5.88 *	24.14 **	3.89 ns	1.47 ns	-2.40 ns
	SE	0.08	0.12	0.12	0.05	0.06	0.06	0.07	0.10	0.10

* Significant at 5% level; ** Significant at 1 % level; MP – Mid parental heterosis; BP – Better parent heterosis; SH – Standard heterosis

Table 4. Five best hybrids selected for grain quality traits based on the expression of heterosis (Relative heterosis, Heterobeltiosis and Standard heterosis) in rice

Characters	Relative heterosis	Heterobeltiosis	Standard heterosis
Grain yield per plant	ADT (R) 46/Pusa 1460, ADT (R) 45/Pusa 1460, ADT (R) 45/Imp. Samba Mahsuri, ADT 43/Imp. Samba Mahsuri, ADT (R) 45/IRBB 60	ADT (R) 45/ Pusa 1460, ADT (R) 46/,Pusa 1460, ADT (R) 45/Imp. Samba Mahsuri , ADT (R) 45/IRBB 60, ADT 43/Imp. Samba Mahsuri	ADT (R) 46/Pusa 1460, ADT (R) 45/Pusa 1460, ADT 43/Imp. Samba Mahsuri, ADT 43/Pusa 1460, ADT 43/IRBB 60
Hulling percentage	CO 47/Imp. Samba Mahsuri, TNAU Rice ADT 49/Pusa 1460, ASD 16/Ajaya, ADT (R) 47/IRBB21, ASD 16/IRBB 21	ADT (R) 47/IRBB21, CO 47/Imp. Samba Mahsuri, ASD 16/Ajaya, CO 47/Pusa 1460, ASD 16/IRBB 21	CO 47/Imp. Samba Mahsuri, ADT (R) 47/IRBB21, ASD 16/Ajaya, ASD 16/IRBB 21, ADT 42/Pusa 1460
Milling percentage	CO 47/Imp. Samba Mahsuri, ASD 16/IRBB 21, ASD 16/Ajaya, ASD 16/IRBB 60, TNAU Rice ADT 49/IRBB21	CO 47/Imp. Samba Mahsuri, ASD 16/IRBB 21, ASD 16/Ajaya, ASD 16/IRBB 60, TNAU Rice ADT 49/IRBB21	CO 47/Imp. Samba Mahsuri, ASD 16/IRBB 21, ASD 16/Ajaya, ADT 42/Pusa 1460, ASD 16/IRBB 60
Head Rice Recovery percentage	ASD 16/Ajaya , ADT (R) 47/Imp. Samba Mahsuri, ASD 16/IRBB 21, CO 47/Imp. Samba Mahsuri, ADT (R) 47/IRBB21	ASD 16/Ajaya, ADT (R) 45/Imp. Samba Mahsuri, ASD 16/ IRBB21, ADT (R) 47/IRBB21, ASD 16/IRBB 60	ASD 16/Ajaya, CO 47/Imp. Samba Mahsuri, ASD 16/IRBB 21, ASD 16/IRBB 60, ADT (R) 47/Imp. Samba Mahsuri
Kernel length	CO 47/Imp. Samba Mahsuri, TKM 11/Imp. Samba Mahsuri, TRY 2/IRBB 60, TRY 2/IRBB 21, TKM 11/IRBB 60	TKM 11/Imp. Samba Mahsuri, CO 47/Ajaya, TRY 2/IRBB 60, TRY 2/IRBB 21, TKM 11/IRBB 60	TRY 2/Pusa 1460, TRY 2/IRBB 60, TKM 11/Pusa 1460, TRY 2/IRBB 21, ADT 39/Pusa 1460
Kernel breadth	ASD 16/IRBB 60, TKM 12/IRBB 60, TKM 12/Ajaya, ADT (R) 45/Ajaya, ADT (R) 46/IRBB 60	ASD 16/Pusa 1460, ASD 16/IRBB 60, TNAU Rice ADT 49/Ajaya, TKM 12/Ajaya, ADT (R) 45/Ajaya	--
Kernel length/breadth ratio	TKM 12/IRBB 60, TRY 2/IRBB 60, ASD 16/IRBB 60, TKM 11/Ajaya, TKM 11/ Imp. Samba Mahsuri	TKM 12/ IRBB 60, TRY 2/ IRBB 60, TKM 11/Ajaya, CO 47/Imp. Samba Mahsuri, TRY 2/ Imp. Samba Mahsuri	TRY 2/Pusa 1460, TKM 11/Pusa 1460, ADT (R) 46/IRBB 60, ADT 43/Pusa 1460, TKM 12/IRBB 60

Grain yield per plant

The grain yield is a very complex trait. It is multiplicative end product of several basic components of yield (Grafius, 1959). A number of workers have reported wide range of variation in the expression of heterosis for this character in rice. For grain yield per plant, **t**he range of relative heterosis was from 2.89 per cent (CO 47/Pusa 1460) to 148.51 per cent (ADT (R) 46/Pusa 1460). Out of 60 hybrids, 59 combinations showed positive mid parental heterosis for this trait. The heterobeltiosis ranged from -4.09 (ADT 42/IRBB 60) to 143.70 per cent (ADT (R) 45/Pusa 1460). Fifty five hybrids showed significant positive heterobeltiosis. The standard heterosis ranged from 0.41 (CO 47/Pusa 1460) to 145.21per cent (ADT (R) 46/Pusa 1460) and fifty eight hybrids recorded significantly positive standard heterosis.. High heterotic vigour was found to be existing in all the three types of heterosis for grain yield per plant in the hybrids ADT (R) 46/Pusa 1460, ADT (R) 45/Pusa 1460 and ADT 43/Imp. Samba Mahsuri while the hybrid ADT (R) 45/ Imp. Samba Mahsuri expressed highest heterotic values for relative heterosis and heterobeltiosis for grain yield per plant. In the top ranking hybrid that expressed high standard heterosis for grain yield per plant, the tester Pusa 1460 was involved as one of the parents which is a moderate yielder. Rajendra Reddy *et al.* (2012) also reported .similar results.

Hulling percentage: For hulling percentage, the mid parental heterosis, better parental heterosis and standard heterosis ranged from -11.72 (TNAU Rice ADT 49/IRBB 21) to 22.60 (CO 47/Imp. Samba Mahsuri), -16.99 (ADT 39/Pusa 1460) to 12.15 (ADT (R) 47/IRBB 21) and -14.78 (ADT 39/Pusa 1460) to 16.87 (CO 47/Imp. Samba Mahsuri) respectively. Seventeen, nine and six hybrids over mid, better and standard parent respectively were significantly positive. For hulling percentage, CO 47/Imp. Samba Mahsuri, ASD 16/Ajaya, ADT (R) 47/ IRBB 21 and ASD 16/IRBB 21 showed high heterotic values for all the three types of heterosis. Similar results for this trait was reported by Sahai *et al.* (1986).

Milling percentage

For milling percentage, a total of twenty four, eleven and thiry hybrids, expressed positive and significant heterosis over mid, better and standard parent respectively. The mid parental heterosis ranged from -12.08 (ADT 42/ Imp. Samba Mahsuri) to 27.80 (CO 47/Imp. Samba Mahsuri) per cent. The range of better parent heterosis varied from -15.64 (ADT (R) 46/ Ajaya) to 20.08 (CO 47/Imp. Samba Mahsuri) per cent. The standard heterosis ranged from -15.29 (TKM 12/Pusa 1460) to 33.79 (CO 47/Imp. Samba Mahsuri) per cent. For milling percentage, CO 47/Imp. Samba Mahsuri, ASD 16/IRBB 21, ASD 16/Ajaya and ASD 16/IRBB 60 exhibited good amount of heterotic vigour for all the three categories of heterosis. The hybrid TNAU Rice ADT 49/IRBB 21 showed relative heterosis and heterobeltiosis. This is in confirmity with the results of Menaka (2002) and Hassan *et al.* (2011).

Head rice recovery percentage

For head rice recovery percentage, the per cent relative heterosis ranged from -31.15 (ADT 42/Pusa 1460) to 16.57

(ASD 16/Ajaya). Significant and positive relative heterosis was recorded in nine hybrids. The heterobeltiosis ranged from -39.03 (ADT 42/Pusa 1460) to 15.30 (ASD 16/Ajaya) per cent. Eight hybrids recorded significant and positive heterosis over better parent. The standard heterosis ranged from -28.64 (ADT 42/Pusa 1460) to 18.90 (ASD 16/ Ajaya) per cent. Significant and positive standard heterosis was expressed by eight hybrids. For head rice recovery percentage, ASD 16/Ajaya and ASD 16/IRBB 21were found to be with good amount of heterotic vigour for all the three categories of heterosis. Similarly, the hybrids ADT (R) 47/Imp. Samba Mahsuri and CO 47/Imp. Samba Mahsuri also had good heterotic vigour over mid parent and standard parent. This is in close agreement with the findings of Menaka (2002) and Mahalingam and Nadarajan (2010).

Kernel length

For kernel length, twenty five, ten and thirty six hybrids recorded positive and significant relative heterosis, heterobeltiosis and standard heterosis respectively. Long grains are more in demand than the shorter ones. Significant positive heterosis is desirable for the trait. The heterotic vigour for this trait was from -11.48 (ASD 42/Pusa 1460) to 17.96 (CO 47/Imp. Samba Mahsuri) for relative heterosis; -22.12 (CO 47/Pusa 1460) to 15.38 (TKM 11/Imp. Samba Mahsuri) for heterobeltiosis and -7.91 (ASD 16/Ajaya) to 28.25 (TRY 2/Pusa 1460) per cent for standard heterosis. The hybrids TRY 2/IRBB 60 and TRY 2/IRBB 21 produced significantly positive heterosis, under relative heterosis, heterobeltiosis and standard heterosis for kernel length while TKM 11/Imp. Samba Mahsuri also had good heterotic vigour over mid parent and better parent. Menaka (2002), Ranjit Kumar Ellur (2009), Mahalingam and Nadarajan (2010), Sanjeev Kumar *et al.* (2010) and Rajendra Reddy *et al.* (2012) and Venkanna *et al* (2014) reported similar positive heterosis for this trait.

Kernel breadth

For the trait kernel breadth, heterosis in negative direction is desirable for quality rice. The relative heterosis for kernel breadth ranged from -11.56 (ASD 16/IRBB60) to 14.48 (ASD 16/IRBB 21) per cent; heterobeltiosis from -20.00 (ASD 16/Pusa 1460) to 12.31 (TKM 12/IRBB 21) per cent and standard heterosis from -2.59 (TNAU Rice ADT 49/Imp. Samba Mahsuri) to 43.10 per cent (ASD 16/IRBB 21). A total of thirteen and twenty eight hybrids expressed significant and negative relative heterosis and heterobeltiosis respectively. None of the hybrids exhibited significant negative standard heterosis for this trait. The heterotic vigour was found to be significantly negative for kernel breadth in the hybrids ASD 16/IRBB 60, TKM 12/Ajaya and ADT (R) 45/Ajaya for relative heterosis and heterobeltiosis. This is in close agreement with the findings of Ranjit Kumar Ellur (2009), Mahalingam and Nadarajan (2010), Panwar and Mashiat Ali (2010), Rajendra Reddy *et al.*(2012) and Venkanna *et al.*(2014). None of the hybrids showed lesser kernel breadth than standard check ADT 43.

Kernel length/breadth ratio

For kernel length/breadth ratio, a total of eighteen, eleven and seven hybrids expressed significant positive heterotic values over mid parent, better parent and standard parent respectively. The width of kernel should be less and the high kernel length/breadth ratio is preferable. The heterotic vigour for this trait was from -19.49 (ASD 16/IRBB 21) to 22.69(TKM 12/IRBB 60) for relative heterosis; -31.63 (ASD 16/IRBB 21) to 17.42 (TKM 12/IRBB 60) for heterobeltiosis and -34.24 (ASD 16/IRBB 21) to 19.96(TRY 2/Pusa 1460) per cent for standard heterosis. High heterotic vigour was found to be existing in all the three types of estimation for kernel length/breadth ratio in the hybrid TKM 12/IRBB 60 while TKM 11/Ajaya and TRY 2/IRBB 60 expressed highest relative heterosis and heterobeltiosis for kernel length/breadth ratio. This is in confirmity with the findings of Sahai *et al.*(1986), Ranjit Kumar Ellur (2009) and Panwar and Mashiat Ali (2010) and Venkanna *et al.* (2014). Grakh and Chaudhry (1985) opined that the relative heterosis of limited importance because F_1 deviates should be given special attention. Bhandari (1978) while emphasing this point suggested that the productivity of hybrids should be assessed not only by the heterotic expression over the better parent alone, but in relation to best commercial variety or check. Kadambavanasundaram (1980) while stressing this point suggested that computing standard heterosis based on best cultivar for commercial exploitation of hybrid vigour is a primary need. Among the top ranking hybrids, ADT (R) 46/Pusa 1460 (145.21 per cent) for grain yield per plant , the hybrids CO 47/Imp. Samba Mahsuri for hulling percentage (16.87 per cent) and milling percentage (33.79 per cent), ASD 16/Ajaya (18.90 per cent) for head rice recovery percentage, TRY 2/Pusa 1460 for kernel length (28.25 per cent), revealed highest standard heterotic values. From the above results it is obvious that the higher magnitude of heterosis for yield and quality traits were not expressed in a single hybrid combination. It varied from cross to cross due to diverse genetic background of their parents. The rice hybrids recording high values of relative heterosis, heterobeltiosi sand standard heterosis need to be further tested in multi-location trials to exploit their heterotic potential.

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