RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
50 (1) 46-61, 2018

HETEROTIC EFFECTS AND COMBINING ABILITY FOR YIELD TRAITS IN RICE DEVELOPED FOR SEMI-DRY AEROBIC CULTIVATION

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SUMMARY

An experiment was conducted to estimate combining ability and heterosis for yield and yield attributing traits in 28 rice crosses. Four testers; IR64, MAS26, Moroberekan, OYC145 and seven lines; IM192, IM49, IM98, IM109, IM114, IR50, MAS946-1 were used to generate hybrids by line\tester RCBD design. Significant differences were observed for interaction among the traits except for days between flowering- maturity time, maturity time and straw weight. General combining ability (GCA) variance was lower than specific combining ability (SCA) indicating the preponderance of non-additive gene action. Five lines and one tester were found to be good general combiner for grain yield. The results showed that out of 28 hybrid combinations, 5 crosses for 50% flowering time, 4 crosses for maturity time exhibited negatively significance indicating usefulness for short duration genotype selection. GCA and SCA effects were significant for most of the characters indicating the importance of both additive and non-additive gene effects. Ten hybrids showed negative heterosis over the check variety for flowering time. Three hybrids exhibited significant positive standard heterosis for days between flowering and maturity time. Out of 21 significant crosses identified, 7 expressed negative and 14 expressed positive standard heterosis for maturity time. Among 16 significant hybrids, 8 showed positive and negative each for plant height. Two hybrids were found to be superior for productive tiller number per plant. Mean performance of hybrids for 100 grain weight was superior for 6 hybrids over standard checks. Significant standard heterosis was evident in 20 crosses, out of which 2 hybrids were desirable for panicle length. Significant positive standard heterosis observed for 9 hybrids out of 28 crosses for grain yield.

Key words: Rice, line × tester crosses, combining ability, heterosis

Key findings: This study was conducted to investigate the combining ability and heterosis of 28 hybrids suitable for aerobic condition. Five crosses had significant SCA for flowering time, four for maturity time and 10 hybrids for plant height, suggesting the predominance of non-additive gene action. Hence, based on the results, it can be concluded that heterosis was playing an important role in determining grain yield, making it ideal for commercial exploitation. The degree of heterosis varied from cross to cross and from character to character. Nine hybrids with mean yields superior than the standard check Jaya, are recommended for heterosis breeding.

Manuscript received: August 21, 2017; Decision on manuscript: December 12, 2017; Accepted: February 9, 2018.

Communicating Editor: Dr. CN Neeraja

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important food crops, feeding two thirds of the world's population (Kahani and Hittalmani, 2015; Sathya and Jebaraj, 2013) and demand is expected to continue to grow as population increases (Yogendra *et al*., 2014; Carriger and Vallee, 2007). Globally rice is grown over an area of about 149 million ha with and annual production of 600 million tonnes (Bernier *et al.,* 2008). It accounts for around 23 per cent of the global calorie intake and 16 per cent of per capita protein (Li *et al.,* 2011).India ranks second in area (42.41 Mha) and second in production (157.8 Mt) among the rice producing countries in the world. In India, West Bengal stands first in production (15.31mt) followed by Uttar Pradesh (14.63 Mt) and Andhra Pradesh (13.03 Mt) (Directorate of economics and statistics, Department of Agriculture and cooperation, GOI, 2014).

The global water crisis threatens the sustainability of irrigated rice production in all the rice producing countries. For rice to be successful as an aerobic crop, it should tolerate intermittent water deficits and high soil impedance created due to aerobic conditions (Lafitte and Bonnett, 2002). The distinguishing feature of aerobic production system is that crops are direct seeded in free draining; non-puddled soils where no standing water layer is maintained in the field and roots grow mainly in aerobic environment (Atlin *et al*., 2006). Saving irrigation water and increased water productivity would be possible, if rice is grown under aerobic soil conditions. However, a key component for the success of aerobic system is to develop appropriate cultivars (Sheeba *et al*., 2005). Hence, specific aerobic rice cultivars with high yield potential and tolerance to water deficit are essential.

The combining ability studies of the parents and their crosses provide information for the selection of high order parents for effective breeding. Success of any plant breeding program depends on the choice of right type of genotypes as parents in the hybridization program. Combining ability analysis provides information on two components of variance additive and dominance variance. Its role is important to decide parents, crosses and adoption of appropriate breeding procedures to be followed to select desirable segregants. The success of a plant breeding program greatly depends on correct choice of parents for hybridization and the gene action involving different economic traits. Combining ability analysis provides such information so as to frame the breeding program effectively (Dwivedi and Pandey, 2012). Among the different methods adopted, the line × tester analysis has been recommended for early evaluation of parents, because of its simplicity in both experimentation and analysis (Dhillon, 1975).

A hybrid is commercially valuable only when it exhibits significantly high standard heterosis over the best local variety or hybrid. Biju *et al*. (2006) reported the presence of exploitable level of heterosis is yet another pre - requisite for the success of hybrid breeding and is recognized as the genetic yield ceiling in areas where yields have already approached their potential. Generally, yield under aerobic condition is very poor. So, we need to develop rice varieties suitable for aerobic rice cultivation. The objective may be achieved by heterosis breeding by using desired lines / varieties. Heterosis breeding an important genetic tool which can facilitate yield enhancement and helps enrich other desirable quantitative characters in rice (Srivastava, 2000). With this basic information, the present study was undertaken with the objective to assess the combining ability of 11 lines and heterosis for yield and other component characters suitable for improvement under aerobic conditions.

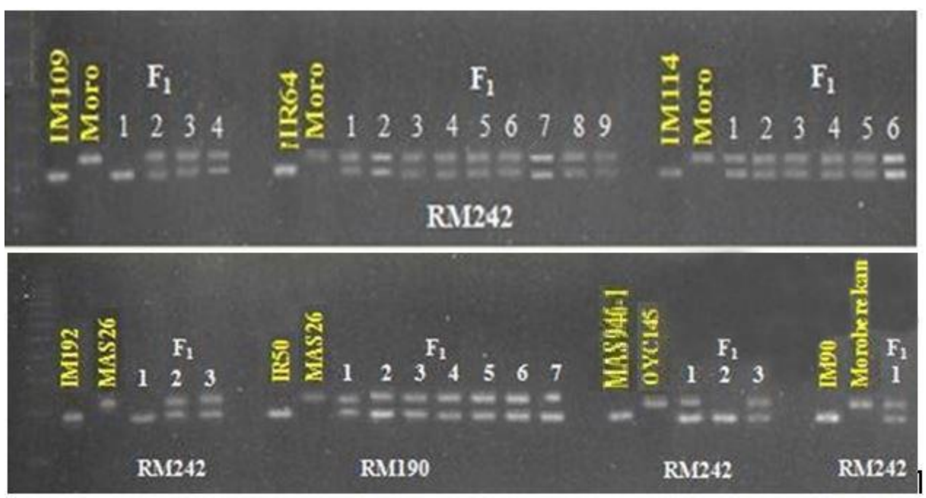
MATERIALS AND METHODS

Four *indica* rice genotypes (Testers) *i.e.,* IR64, MAS26, Moroboroken and OYC145 were crossed with seven Lines i.e., IM192, IM49, IM98, IM109, IM114, IR50 and MAS946-1 during the wet-season of 2013. The seed of 28 F_1 hybrids obtained along with their parents and two rice genotypes, Rasi and Jaya, as check varieties were raised during 2014 in RCBD design with two replications to evaluate combining ability and heterotic potential of the crosses (Figure 1). Recombination in hybrids was confirmed by using polymorphic SSR markers (Figures 2 and 3).

Twenty-five days old seedlings were transplanted and arranged in 5 rows and 5 columns in the field with standard spacing of 25 × 20 cm was followed for the planting. Single seedling per hill was planted and recommended package of practices followed. Observations were recorded in two replications for fourteen traits: 50% flowering time, days between flowering and maturity, maturity time, plant height (cm), number of tillers, number of productive tillers, 100 grain weight (g), grain length (cm), grain breadth (mm), leaf width (cm), panicle length (cm), panicle exertion (cm), straw weight (g) and grain yield plant^{-1}(g).

Combining ability analysis was carried out by the method suggested by Kempthorne (1957). Heterosis values and character-wise estimations of GCA and SCA effects were determined and their significance was tested using a t-test.

Figure 1. Parents, F_1 hybrid seeds development in panicle and F_1 plants of various crosses in field under aerobic cultivation.



Figures 2 and 3. Identification of true F_1 in different crosses using polymorphic SSR markers.

RESULTS AND DISCUSSION

The recorded data on different agronomic parameters were subjected to analysis of variance to confirm the differences among rice genotypes. Mean squares from analysis of variance of fourteen traits of rice are presented in Table 1. The table depicted highly significant differences

Table 1. ANOVA for combining ability for different traits in rice.

Source of variations	d.f.	FT	DFM	MT	PH	NT	PT	100GW	GL
Replicates	1	0.24	28.74	0.34	1.99	9.81	3.93	0.001	0.012
Treatments	38	39.67***	36.32*	104.27***	277.48***	93.92***	100.78***	0.26***	0.46***
Parents	10	38.71***	79.41***	143.81***	325.64***	83.63***	104.95***	0.17***	0.31***
Parents (Line)	6	21.33***	42.16*	138.46***	292.82***	35.32***	71.62***	0.11***	0.33***
Parents (Testers)	3	70.72***	179.03***	157.07***	478.64***	208.12***	202.45***	0.31***	0.22***
Parents (L vs. T)	1	46.97***	4.12	136.14***	63.51	0.04	12.40	0.13***	0.46***
Parents vs. Crosses	1	70.57***	142.62**	169.17***	342.69***	34.20*	60.23**	0.24***	3.72***
Crosses	27	38.88***	16.43	87.22***	257.23***	99.95***	100.74***	0.30***	0.39***
Line Effect	6	104.11**	19.32	182.33*	393.34	180.08	182.88	0.29	0.45
Tester Effect	3	24.75	25.14	75.25	96.18	5.66	6.83	0.14	0.30
Line*Tester Eff.	18	19.49***	14.01	57.51	238.70***	88.95***	89.01***	0.33***	0.38***
Error	38	1.22	17.60	4.29	19.17	5.69	7.34	0.006	0.005
Total	77	20.18	26.98	53.5	146.42	49.29	53.41	0.13	0.23
σ^2 gca		5.746	0.421	11.319	20.508	7.925	7.955	0.02	0.034
σ^2sca		9.133	-1.792	26.611	109.767	41.631	40.836	0.163	0.191
σ^2gca/ σ^2sca		0.629	0.234	0.425	0.186	0.19	0.194	0.122	0.178

Table 1 (cont'd.)**.** ANOVA for combining ability for different traits in rice.

Source of variations	d.f.	GB	LW	PL	PE	SW	GY
Replicates	1	0.11	0.0001	1.54*	0.12	0.47	1.47
Treatments	38	0.622**	0.15***	13.18***	4.32***	115.57***	146.39***
Parents	10	0.06	0.21***	8.35***	5.47***	160.95***	94.52***
Parents (Line)	6	0.05	0.06***	13.53***	5.03**	173.38***	33.63***
Parents (Testers)	3	0.05	0.45***	0.29	7.24**	179.79***	246.89***
Parents (L vs T)	1	0.12	0.39***	1.42	2.80	29.80	2.73
Parents vs. Crosses	1	0.90	0.26***	36.59***	7.12*	2265.25***	69.19***
Crosses	27	0.82***	0.13***	14.10***	3.79***	19.15	168.46***
Line Effect	6	0.88	0.14	18.78	6.02	28.30	496.1***
Tester Effect	3	1.32	0.007	19.78	5.84	33.30	75.72
Line*Tester Eff.	18	0.71**	0.15***	11.59***	2.71*	13.74	74.68***
Error	38	0.26	0.001	0.34	1.20	10.87	3.26
Total	77	0.44	0.07	6.69	2.72	62.41	73.87
σ^2gca		0.076	0.007	1.721	0.43	1.812	25.7
σ^2sca		0.224	0.074	5.624	0.756	1.436	35.708
σ^2gca/ σ^2sca		0.339	0.094	0.306	0.568	1.261	0.719

FT= Flowering time; DFM: Days between Flowering and maturity; MT= Maturity time: PH= Plant Height (cm); NT= Number of Tillers; PT= Number of Productive Tillers; 100GW= 100-Grain Weight (gr); GL= Grain Length (mm); GB= Grain Breadth (mm); LW= Leaf Width (cm); PL= Panicle Length (cm); PE= Panicle Exertion (cm); SW= Straw Weight (gr); GY=Grain Yield (gr), *Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level.

Table 2. Proportional contribution of lines, testers and their interactions towards total variance in rice.

Traits	Lines	Testers	Line × Tester
Flowering time	59.51	7.07	33.42
Days between Flowering and maturity	26.13	17.00	56.87
Maturity time	46.45	9.59	43.96
Plant Height (cm)	33.98	4.15	61.86
Number of Tillers	40.04	0.63	59.33
Productive Tillers	40.34	0.75	58.91
100-Grain Weight (g)	21.64	5.41	72.95
Grain Length (mm)	25.83	8.63	65.55
Grain Breadth (mm)	23.91	17.97	58.12
Leaf Width (cm)	24.62	0.61	74.77
Panicle Length (cm)	29.60	15.58	54.82
Panicle Exertion (cm)	35.26	17.10	47.64
Straw Weight (g)	32.83	19.32	47.85
Grain Yield (g)	65.45	4.99	29.55

among rice genotypes for all the characters studied. Sum of squares of rice genotypes for these traits were further portioned into parents, cross and parents vs crosses, which revealed highly significant differences among themselves. The sum of squares calculated for rice crosses were further portioned into lines, testers and line × tester components. Highly significant ($P \leq 0.01$) differences were displayed among line × tester interaction for all the characters except for traits days between flowering and maturity, maturity time and straw weight. However, non-significant differences existed among lines and testers for all traits except flowering time, maturity time and grain yield. The value of variance of general combining ability (σ^2GCA) was less than variance of specific combining ability (σ^2SCA) for all traits showing the preponderance of non-additive gene action. It was further supported by ratio (σ^2GCA/σ^2SCA) being less than one. Predominance of non-additive gene action for grain yield and its components was also reported by many other workers (Satyanarayana *et al*., 2000; Rita and Motiramani, 2005; Singh and Kumar, 2004; Venkatesan *et al*., 2007; Dalvi and Patel, 2009).

The contribution of lines, testers and interactions to total variance are presented in Table 2. It is evident from the table that proportional contribution of lines was much higher than testers and hybrids for flowering time (59.51%), maturity time (46.45%) and grain yield (65.45%) contribute maximum in the total phenotypic variance. The contribution of line × tester were high for days between flowering and maturity (56.87%), plant height (61.86%), number of tillers (59.33%), productive tillers (58.91%), 100-grain weight (72.95%), grain length (65.55%), grain breadth (58.12%), leaf width (74.77%), panicle length (54.82%), panicle exertion (47.64%) and straw weight (47.85%). The maximum contribution to the total variance of flowering time, maturity time and grain yield were made by female parents indicating predominant maternal influence for these traits.

General Combining ability

The results from present study revealed that none of the parents showed significant GCA effects simultaneously in desired direction for all the traits studied (Table 3). Negative GCA effects are desirable for flowering time and plant height, while in other traits positive GCA effects were desirable. Five lines (Line 1, Line 2, Line 3, Line 4 and Line 7) and one tester (Tester 3) were found to good general combiners for grain yield per plant. Line 2 is also good general combiner for other yield component characters like grain breadth and panicle length, while Line 3 for 100-grain weight, Line 4 for flowering time, 100-grain weight, grain length, grain breadth, leaf width, panicle length and panicle excretion. Line 7 is good combiner for characters number of panicles, productive tillers and panicle length. GCA effects of testers also revealed that Tester 3 is also a good combiner for characters 100-grain weight, grain length, and grain breadth and leaf width. According to the kind breeding target, it is possible to use parents with high positive or negative GCA. For example, parents having high positive GCA for 100-grain weight, grain length, grain breadth, leaf width, panicle length, panicle excretion and grain yield could be used in further breeding program. While for flowering time and plant height, parents with high negative GCA could be used. Venkatesan *et al*. (2008), Swamy *et al*. (2003) and Tiwari *et al*. (2011) for flowering time; Rashid *et al*. (2007), Won and Yoshida (2000), Roy and Mandal (2001), Sarker *et al*. (2002) observed significant negative GCA and SCA effects for plant height; Rashid *et al*. (2007), Singh and Kumar (2004), Roy and Mandal (2001), Sarker *et al*. (2002) for productive tillers; Pradeep Kumar and Reddy (2011) for panicle length; Nadali (2010), Rashid *et al*. (2007) Pradeep Kumar and Reddy (2011) for grain yield per plant.

Specific combining ability

Specific combining ability (SCA) of a cross is the estimation and understanding of non-additive gene action effect for a trait. Non-additive gene action of a trait is an indicator for the selection of a hybrid combination. Therefore, a highly significant SCA effect is desirable for a successful hybrid breeding program. Based on the estimates of SCA effects none of the cross combinations exhibited significant and desirable SCA effect for all the parameters simultaneously indicating that no specific combination was desirable for all traits (Table 4). These results are in complete agreement with earlier findings (Sanghera and Hussain, 2012; Tiwari *et al.,* 2011). They also found that none of the crosses exhibited high specific combining ability for all the characters in rice (Table 4). The results of SCA effect of the present study are given in the Table 4. The SCA results showed that out of 28 hybrid combinations five of them: IM49 × OYC145 (-1.792), IM98 × IR64 (-2.557), IM109 × MAS26 (-5.446), IR50 × Moroberekan (-3.019) and IR50 × OYC145 (-6.396) were found to be negatively significant forflowering time. For maturity time crosses IM98 × IR64 (-4.850), IM109 × MAS26 (-6.568), IR50 × Moroberekan (-4.511) and IR50 × OYC145 (-12.388), for the character plant height crosses IM192 × OYC145 (-9.926), IM49 × IR64 (-8.944), IM98 × Moroberekan (-11.826), IM98 ×

Table 3. Estimates of GCA effects of parental lines for 14 characters in rice.

Traits	FT	DFM	MT	PH	NP	TP	100GW	GL	GB	LW	PL	PE	SW	GY
Lines														
Line 1	-0.843***	-0.828***	-1.807***	-5.131***	2.115	1.396	-0.081***	-0.125***	-0.097***	-0.159***	-2.693***	-0.146***	0.565	3.153**
Line 2	-0.993***	-0.534***	-1.063***	-2.856***	-0.235***	0.277	-0.055***	-0.098***	0.417**	-0.011***	0.327*	-0.108***	0.798	4.431**
Line 3	-3.893***	0.097	-3.807***	-2.993***	0.740	-0.291***	0.129***	0.303***	-0.528***	-0.136***	-0.770***	-1.308***	0.622	3.516**
Line 4	3.057***	-0.953***	2.193	-1.181***	-1.860***	-1.829***	0.348***	0.095***	0.243*	0.018***	1.074***	1.162**	-3.051***	1.805*
Line 5	6.619***	3.197	9.806***	15.332*	-7.385***	-7.129***	0.004*	0.206***	0.172*	0.146***	-0.835***	1.043*	-2.083***	-15.203***
Line 6	-1.590***	0.485	-1.491***	0.659	-1.689***	-1.320***	-0.259***	0.036***	-0.316***	0.204***	1.235***	-0.067***	0.775	-5.677***
Line 7	-2.356***	-1.465***	-3.832***	-3.831***	8.315**	8.896**	-0.087***	-0.418***	0.108	-0.063***	1.662***	-0.575***	2.374	7.975***
SE±	0.39	1.48	0.72	1.54	0.84	0.95	0.02	0.02	0.18	0.01	0.20	0.38	1.16	0.63
Testers														
Tester 1	1.632***	1.679	3.275**	-1.531***	-0.182***	-0.229***	-0.129***	-0.187***	0.380***	0.013***	0.852***	0.161	1.225	0.801
Tester 2	-0.429***	0.344	-0.007***	-2.884***	-0.435***	-0.236***	-0.012***	0.022***	-0.141***	-0.034***	0.874***	-0.153***	1.344	-1.158***
Tester 3	0.330	-1.460***	-1.465***	1.889	0.941	1.023	0.020***	0.174***	0.094*	0.011***	-1.161***	-0.779***	-1.798***	2.842**
Tester 4	-1.533***	-0.563***	-1.803***	2.526	-0.324***	-0.558***	0.121***	-0.008***	-0.333***	0.010***	1.183***	0.771**	-0.771***	-2.484***
SE±	0.29	1.12	0.55	1.17	0.63	0.72	0.02	0.02	0.13	0.01	0.15	0.29	0.88	0.48

*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level.

Table 4. Specific combining ability (SCA) effects of hybrids for characters under study.

F_1 hybrids	FT	DFM	MT	PH	NP	TP	100GW
IM192 × IR64	0.393	-1.779	-1.35	0.231	4.457*	4.604*	0.066
IM192 × MAS26	-0.946	-0.544	-1.568	1.984	2.41	3.111	-0.161*
IM192 × Moroberekan	-1.105	1.16	0.39	7.711*	5.734**	6.153**	-0.252***
IM192 × OYC145	1.658*	1.163	2.528	-9.926**	-12.601***	-13.868***	0.347***
IM49 × IR64	-0.257	0.027	-0.494	-8.944**	-4.393*	4.377*	0.315***
IM49 × MAS26	1.604	-0.113	0.813	-0.341	-8.040***	--8.345***	-0.337***
IM49 × Moroberekan	0.445	2.666	2.447	9.786**	4.084*	4.371*	0.427***
IM49 × OYC145	-1.792*	-2.58	-2.766	-0.501	8.349***	8.351***	-0.405***
IM98 × IR64	-2.557**	-2.204	-4.850**	22.693***	3.232	2.591	-0.254***
IM98 × MAS26	0.404	0.431	1.132	-0.953	6.985***	7.249***	-0.021
IM98 × Moroberekan	0.545	-0.665	-0.91	-11.826***	-8.391***	-7.860***	-0.302***
IM98 × OYC145	1.608*	2.438	4.628**	-9.914**	-1.826	-1.98	0.577***
IM109 × IR64	-0.607	-1.654	-1.55	-11.119**	4.232*	4.029*	-0.383***
IM109 × MAS26	-5.446***	-0.819	-6.568***	0.234	2.085	1.136	0.521***
IM109 × Moroberekan	1.795*	-1.015	0.89	12.461***	-3.791*	-3.623	0.499***
IM109 × OYC145	4.258***	3.488	7.228***	-1.576	-2.526	-1.543	-0.637***
IM114 × IR64	-0.469	-1.904	-2.463	-7.832*	1.157	1.129	0.166**
IM114 × MAS26	-0.758	1.531	0.569	7.472*	5.110**	4.436*	0.049
IM114 × Moroberekan	-0.368	-0.465	-0.622	-1.751	-1.766	-1.823	-0.197**
IM114 × OYC145	1.595	0.838	2.516	2.111	-4.501*	-3.743	-0.018
IR50 × IR64	3.840***	4.908	9.033***	11.441***	-6.340***	-5.880**	0.218***
IR50 × MAS26	5.575***	2.119	7.866***	-8.981**	-4.961**	-4.498*	-0.348***
IR50 × Moroberekan	-3.019***	-2.078	-4.511**	-6.794*	3.998*	3.829	0.246***
IR50 × OYC145	-6.396***	-4.949	-12.388***	4.334	7.303***	6.549**	-0.116
MAS946-1 × IR64	-0.344	2.608	1.675	-6.469*	-2.343	-2.096	-0.128*
MAS946-1 × MAS26	-0.433	-2.606	-2.243	0.584	-3.590*	-3.089	0.296***
MAS946-1 × Moroberekan	1.707*	0.397	2.315	-9.589**	0.134	-1.048	-0.421***
MAS946-1 × OYC145	-0.93	-0.399	-1.747	15.474***	5.799**	6.233**	0.253***

*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level.

Table 4 (cont'd)**.** Specific combining ability (SCA) effects of hybrids for characters under study.

F_1 hybrids	GL	GB	LW	PL	PE	SW	GY
IM192 × IR64	0.482***	-0.59	0.137***	2.418***	-1.336	0.496	3.814**
IM192 × MAS26	-0.127*	0.021	-0.196***	1.104*	0.608	0.422	-0.032
IM192 × Moroberekan	-0.099	0.596	0.069*	0.721	1.164	1.94	1.428
IM192 × OYC145	-0.257***	-0.027	-0.01	-4.243***	-0.436	-2.858	-5.211***
IM49 × IR64	0.445***	1.466***	-0.042	-0.192	-0.034	0.119	3.467*
IM49 × MAS26	-0.310***	-0.673	-0.004	-2.731***	0.466	-4.141	-8.944***
IM49 × Moroberekan	-0.306***	-0.488	0.120***	1.951***	-0.193	3.537	0.961
IM49 × OYC145	0.171**	-0.306	-0.074*	0.972*	-0.239	0.485	4.516**
IM98 × IR64	0.074	0.151	-0.477***	-0.376	0.546	1.575	4.017**
IM98 × MAS26	-0.720***	0.197	0.076*	-2.605***	1.591*	-2.569	2.249
IM98 × Moroberekan	0.503***	0.287	0.315***	3.218***	-1.973*	0.113	0.179
IM98 × OYC145	0.142*	-0.636	0.086**	-0.237	-0.164	0.881	-6.444***
IM109 × IR64	-0.498***	-0.770*	-0.080*	-1.320**	-0.654	1.057	6.705***
IM109 × MAS26	0.373***	-0.099	0.017	2.507***	-0.509	4.003	5.646***
IM109 × Moroberekan	-0.322***	0.166	-0.029	-2.206***	0.217	-3.154	-3.814**
IM109 × OYC145	0.197**	0.703	0.093**	1.019*	0.946	-1.906	-8.538***
IM114 × IR64	0.101	-0.519	-0.198***	0.559	-0.055	-2.425	-4.634**
IM114 × MAS26	0.287***	0.447	0.189***	0.890*	-1.466	1.571	0.23
IM114 × Moroberekan	0.01	0.257	-0.206***	-3.988***	0.356	-1.892	-2.035
IM114 × OYC145	-0.398***	-0.186	0.215***	2.538***	1.165	2.746	6.440***
IR50 × IR64	0.151**	-0.002	0.733***	0.669	1.495	1.886	-11.106***
IR50 × MAS26	-0.068	0.04	-0.229***	-0.765	0.474	0.062	-0.066
IR50 × Moroberekan	-0.305***	-0.26	-0.240***	-0.993*	0.006	-0.075	6.299***
IR50 × OYC145	0.222***	0.222	-0.264***	1.088*	-1.975*	-1.873	4.874***
MAS946-1 × IR64	-0.755***	0.265	-0.074*	-1.757***	0.038	-2.708	-2.262
MAS946-1 × MAS26	0.565***	0.066	0.148***	1.599***	-1.163	0.653	0.917
MAS946-1 × Moroberekan	-0.126*	-0.559	-0.028	1.296**	0.423	-0.469	-3.018*
MAS946-1 × OYC145	0.316***	0.228	-0.046	-1.138*	0.703	2.524	4.363**

*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level.

Table 5. Standard heterosis (%) values for different yield contributing characters of 28 F1s in rice under aerobic condition.

F_1 hybrids	FT	DFM	MT	PH	NT	PT	100GW	GL	GB
IM192 × IR64	-0.93	-5.3	-4.30**	14.33	-4.83	-18.75*	-12.87**	-8.63**	-7.98
IM192 × MAS26	4.44**	-5.56	-6.81**	0.43	-12.76	-23.68*	-17.23**	-12.89**	3.64
IM192 × Moroberekan	-9.95**	-13.26	-10.92**	-11.27*	3.45	-9.54	-29.51**	-10.97**	43.06
IM192 × OYC145	-2.89*	-3.54	-5.16**	4.28	-64.14**	-80.59**	8.12*	-14.59**	-5.56
IM49 × IR64	4.62**	5.6	4.73**	2.46	-42.46**	-48.77**	19.28**	-3.82**	100.00**
IM49 × MAS26	3.88**	-1.36	2.8	0.36	-56.90**	-61.36**	-16.38**	-9.93**	-10.06
IM49 × Moroberekan	-8.60**	-9.07	-9.01**	-6.46	0	4.68	-5.03	-10.60**	7.92
IM49 × OYC145	-2.27 -	-7.33	-2.18	22.95**	11.54	10.2	-0.74	-4.88**	-2.57
IM98 × IR64	-1.1	4.11	0.79	18.24**	-12.28	-26.32*	-10.49**	-5.08**	-2.72
IM98 × MAS26	-0.6	1.68	0.93	-13.21*	-1.72	-6.73	4.5	-11.53**	-21.21
IM98 × Moroberekan	-11.30**	-15.35	-13.17**	-30.50**	-17.14	-5.6	-23.96**	2.62**	-8.56
IM98 × OYC145	-1.73	32.46*	1.38	-17.67**	-22.35*	-34.29**	35.76**	-2.35**	-61.09**
IM109 × IR64	8.68**	2.74	8.11**	-35.08**	-17.89*	-26.67**	5.06	-8.54**	-2.08
IM109 × MAS26	0.6	-4.27	-0.39	-24.61**	-27.59**	-34.55**	37.93**	1.42	4.17
IM109 × Moroberekan	-3.38**	-18.6	-7.85**	-6.81	-23.26*	-27.5	11.46**	-1.64	25
IM109 × OYC145	8.64**	36.95*	7.96**	-20.84**	-35.29**	-38.78**	7.94	-2.92**	29.58
IM114 × IR64	12.75**	13.11	10.34**	16.03*	-48.07**	-55.44**	1.49	-8.77**	4.55
IM114 × MAS26	9.62**	12.55	10.15**	35.82**	-36.21**	-41.82**	1.48	-4.55**	22.93
IM114 × Moroberekan	-2.03	-7.67	-3.69*	0.88	-26.97	-21.99	-24.65**	-5.88**	24.79
IM114 × OYC145	9.61**	14.48	10.18**	35.89**	-64.71**	-69.39**	4.26	-12.19**	-11.16
IR50 × IR64	8.46**	24.66*	13.54**	19.17**	-54.39**	-59.65**	4.77	-10.34**	7.56
IR50 × MAS26	7.57**	7.05	7.92**	-10.86	-51.29**	-53.18**	-25.65**	-10.45**	-5.45
IR50 × Moroberekan	-12.52**	-17.73	-14.05**	-20.90**	0.25	2.09	-18.40**	-11.35**	-6.71
IR50 × OYC145	-7.88**	-3.19	-9.88**	14.97*	3.92	-3.67	3.72	-7.68**	-4.17
MAS946-1 × IR64	-1.63	-1.9	-2.18	-5.19	-5.26	-10.53	-3.61	-16.57**	36.55
MAS946-1 × MAS26	-3.88**	-17.48	-7.42**	0.29	-12.07	-10.91	9.48*	-2.22*	15
MAS946-1 × Moroberekan	-8.70**	-16.51	-10.99**	-28.95	34.21**	41.12**	-35.59**	-12.13**	-0.47
MAS946-1 × OYC145	-5.56**	-14.39	-8.36**	33.33**	37.25**	36.73**	30.52**	-1.66	16.28
Total no. of significant crosses	20	3	21	16	15	17	17	25	2
+ve significant	10	3	7	8	2	2	6	1	1
-ve significant	10	0	14	8	13	15	11	24	1

*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level.

Table 5 (cont'd)**.** Standard heterosis (%) values for different yield contributing characters of 28 F1s in rice under aerobic condition.

F_1 hybrids	LW	PL	PE	SW	GY
IM192 × IR64	5.83	-4.02	-161.54	-50.20**	7.4
IM192 × MAS26	-35.16**	-21.05**	-22.22	-50.86**	-6.76
IM192 × Moroberekan	-50.72**	-26.05**	-71.53	6.72	6.56
IM192 × OYC145	-34.27**	-38.53**	-32.48	-60.44**	-22.62**
IM49 × IR64	-1.85	-15.99**	3.33	-50.63**	13.84**
IM49 × MAS26	-4.11	-34.58**	34.17	-63.30**	-25.38**
IM49 × Moroberekan	-41.06**	-15.42**	-116.27**	-11.26	32.84**
IM49 × OYC145	-28.32**	-9.48**	70.83	-48.36**	6.67
IM98 × IR64	-52.38**	-8.44**	-100	-48.32**	12.91**
IM98 × MAS26	-8.22*	-29.95**	31.53	-59.76**	-0.31
IM98 × Moroberekan	-37.68**	-4.49	-217.29**	-61.07**	43.39**
IM98 × OYC145	-25.87**	-9.46**	-72.22	-55.97**	-22.98**
IM109 × IR64	-30.00**	-18.71**	-523.33	-59.12**	15.39**
IM109 × MAS26	-26.67**	-9.68**	98.2	-50.96**	3.8
IM109 × Moroberekan	-46.86**	-31.18**	-59.32	-79.06**	15.94**
IM109 × OYC145	-18.67**	-7.23**	-1260.00**	-72.01**	-32.48**
IM114 × IR64	0.95	-4.02	-213.64**	-66.47**	-56.38**
IM114 × MAS26	27.85**	-12.84**	-95.5	-55.17**	-50.89**
IM114 × Moroberekan	-49.28**	-39.95**	-58.64	-49.27*	-28.30**
IM114 × OYC145	2.8	3.82	-1094.44**	-50.46**	-37.54**
IR50 × IR64	70.12**	7.07*	-332.98**	-45.53**	-48.65**
IR50 × MAS26	-13.69**	-10.77**	54.05	-51.29**	-28.38**
IR50 × Moroberekan	-48.07**	-15.24**	-108.14**	-55.18**	4.55
IR50 × OYC145	-26.57**	6.86*	86.11	-57.70**	-17.67**
MAS946-1 × IR64	-5.34	-5.37	-86.15	-54.28**	8.3
MAS946-1 × MAS26	5.02	2.73	-179.38*	-44.99**	7.32
MAS946-1 × Moroberekan	-50.72**	-2	-111.19**	-56.25**	35.58**
MAS946-1 × OYC145	-30.07**	-1.96	-7.69	-44.43**	15.13**
Total no. of significant crosses	21	20	9	26	19
+ve significant	2	2	0	0	8
-ve significant	19	18	9	26	11

*Significant at 5% level, ** Significant at 1% level, ***Significant at 0.1% level.

OYC145 (-9.914), IM109 × IR64(-11.119), IM114 × IR64 (-7.832), IR50 × MAS26 (-8.981), IR50 × Moroberekan (-6.794), MAS946-1 × IR64 (-6.469) and MAS946-1 × Moroberekan (-9.589) were shown negatively significant indicating these hybrids could be used for traits of interest.

The general combining ability (GCA) and specific combining ability (SCA) effects are significant for most of the characters indicating importance of both additive and non-additive gene effects in their inheritance (Sanghera and Hussain, 2012). Similar result in rice has been reported by Chakraborty *et al*. (2009).

Heterosis

Percentage of heterosis over standard checks (Rasi and Jaya) for grain yield and other related characters are presented in Table 5. The degree of heterosis varied from cross to cross and from character to character. Among the significant standard heterosis for flowering time ranged from -12.52 (IR50 × Moroberekan) to 12.75 (IM114 × IR64). Ten hybrids showed negative heterosis over check Jaya for flowering time. Negative heterosis is desirable for flowering time as it enables the hybrid to mature early thereby increasing productivity per day per unit area. Malini *et al*. (2006), Veeresha *et al.* (2013a) observed negative heterosis for flowering time.

Significant Standard heterosis for days between flowering and maturity ranged from 24.66 (IR50 × IR64) to 36.95 (IM109 × OYC145). Among twenty hybrids, three hybrids showed significant positive standard heterosis. Significant standard heterosis for maturity time ranged from -14.05 (IR50 × Moroberekan) to 13.54 (IR50 × IR64). Out of 21 significant crosses, 7 expressed negative and 14 expressed positive standard heterosis. Khoyumthem *et al*. (2005), Malini *et al*. (2006a) and Sunil Kumar *et al*. (2012) observed significantly negative standard heterosis for maturity time in most of the hybrids indicating the possibility of exploiting heterosis for earliness.

The heterosis in plant height might introduce the problem of lodging and many scientists noted the importance of parental selection. High magnitude of standard heterosis for plant height ranged from -35.08 (IM109 × IR64) to 35.89 (IM114 × OYC145). Among 16 significant hybrids, 8 showed positive and negative significance respectively. Negative heterosis for plant height is desirable for breeding short statured hybrids and varieties. Patil *et al*. (2011) reported negative heterosis over better parent up to 15.97 percent. Similarly Sunil Kumar *et al*. (2012) also reported highly significant negative heterosis. Tiwari *et al*. (2011) observed significant heterobeltiosis and reported from heterobeltiosis and reported from his study that none of the cross combinations were common for both the heterosis, suggesting that heterosis for plant height is cross specific.

More panicle bearing tillers per plant is believed to be closely associated with high grain yield per plant resulting high productivity. Percent standard heterosis for productive tillers ranged from -80.59 (IM192 × OYC145) to 41.12 (MAS946-1 × Moroberekan). Out of 28 hybrids, 2 hybrids were found to be superior for productive tillers per plant. Tiwari *et al*. (2011) and Sunil Kumar *et al*.

(2012) reported significant desirable heterosis over better parent and mid parent. Rajkumar and Ibrahim (2013) reported significant positive heterosis over hybrid check CORH 3.

The 100 grain weight is one of the important common traits which influence the yield. Based on the mean performance hybrids for 100 grain weight was found to be superior for 6 hybrids over standard checks (Rasi and Jaya) percent significant standard heterosis ranged from -35.59 (MAS946-1 × Moroberekan) to 37.93 (IM109 × MAS26). Similar findings were reported by Tiwari *et al*. (2011). Significant positive standard heterosis over MDU 5 was reported by Muthuramu *et al*. (2010) for the cross NPT 107 / MDU 5.

Generally, larger panicle is associated with high number of grains panicle resulting into higher productivity; therefore, hybrids with positive heterosis for panicle length are desirable. Significant standard heterosis was evident in 20 crosses, out of which 2 hybrids were desirable for panicle length. Standard heterosis ranged from -39.95 (IM114 × Moroberekan) to 7.07 (IR50 × IR64). Abhinav (2014) reported significant positive standard heterosis for 2 hybrids over best available check PA6444 under rainfed conditions. Amudha *et al* (2010) reported two hybrids: IR 70372A / PSBRC 80 and IR 68887A / PR-26406-4-B-B-2 showed superior performance over all the three standard checks.

Rice, being a self-pollinated crop, the commercial exploitation of hybrid vigor depends on magnitude of heterosis for grain yield. Grain weight is one of the important traits that decide the final grain yield. Significant positive standard heterosis observed for 9 hybrids out of 28 crossed that showed significant standard heterosis. Tiwari *et al*. (2011) reported the standard heterosis as high as 30% in his study. Amudha *et al* (2010) reported significant positive heterosis for grain yield for four hybrids: IR 67684A /CT-6510-24-1-2, IR 70369A / IR 73718-3-1-3-3, IR 68885A/ IR 73718-3-1-3-3, and IR 70372A/PSBRC 80 over all the three checks ADTRH 1, CORH 2 and one aerobic rice variety CT-6510-24-1- 2.

ACKNOWLEDGEMENTS

The authors are thankful to DBT, New Delhi and NICRA, Hyderabad for funding in the form of research projects to Dr. Shailaja Hittalmani.

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