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Studies on Variability, Heterosis and Combining ability analysis in Rice (*Oryza sativa* L.)

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ABSTRACT: The current study examined variability, heterosis, and combining ability in elite rice genotypes using four lines and six testers, including two check varieties, Swarna and Improved Samba Mahsuri. For analysis of variance, GCA, SCA, and heterosis, observation data for twelve yield and their contributing traits were acquired. High PCV and GCV was found in effective tillers plant^{-1} and grain yield, confirming variability in the hybrids and selection for these traits will be beneficial for genetic improvement. RP 5706-112-4-5-3-2 and IR10N134 are the best general combiners among the lines and testers since they have highly substantial GCA effects on grain yield plant^{-1} as well as several important traits. The estimates of SCA effects on grain yield in the cross combinations R2321-165-1-148-1/IR09N496 and R2296-341-1-212-1/RB-59 were highly significant. The heterosis over mid-parent and better parent was found to be highly significant for the hybrid RP5706-112-4-5-3-2 / IR09N496 for grain yield. The main challenge regarding the combining ability analysis is to select best cross combination out of all hybrids so that multilocation trails can be done for further study.

Keywords: Heterosis, general combining ability, specific combining ability, phenotypic coefficient of variation, genotypic coefficient of variation.

INTRODUCTION

Rice is known as a grass crop as it's semi-aquatic, indicating it spends half of its life cycle submerged in water and the other half on land. It belongs to the Poaceae family. Globally, rice is grown on an area of 164.19 million hectares with an annual output of 756.74 million tonnes and a productivity of 4.60 tonnes per hectare, where there is a gain of 1.47 percent in area and 0.99 percent in production compared to 2019 (Anonymous, 2020). China is the leading producer, accounting for 27.99 per cent of total production followed by India with 23.56 percent, Bangladesh with 7.25 per cent, Indonesia with 7.22 per cent, Vietnam with 5.65 per cent, Thailand with 3.99 per cent, Myanmar with 3.31 per cent, Philippines with 2.54 per cent, Brazil with 1.46 per cent and Cambodia with 1.44 per cent are the top 10 countries which constitute nearly 85 % of global rice production.Combining ability and hybrid vigour are the most essential genetic characteristics for producing superior cultivars. Breeding techniques based on hybrid development demand a high degree of heterosis as well as the specific combining ability (SCA) of crossings. So, combining ability is necessary for picking the most elite parents by undertaking numerous cross combinations through Line × Tester analysis (Kempthorne, 1957). Jones (1926) originally documented heterosis in riceand noted a considerable increase in culm quantity and grain production in several F_1 hybrids in contrast to their parents.

MATERIAL AND METHODS

The experimental material used for the experiment are elite rice genotypes which comprise four lines *viz.,* R1138-688-3-533-1, R2296 -341-1-212-1, RP5706-112-4-5-3-2, R2321-165-1-148-1and six testers *viz.,* IR09N496, IR10N134, IR14A150, IR14V1020, IRRI-186, IRBB-59 and their cross combinations along with 2 checks were evaluated in Randomised block design (RBD) in two replications. To fulfil the objective and intent of the analysis, various yield and yield attributing traits were examined and evaluated. Randomly five plants are chosen from each row to obtain information on different observations during the optimum plant growth cycle. Average results from the sampled plantsregarding different traits weresubjected for statistical analysis. The observations recorded during the crop period are days to 50 % flowering, days to maturity, plant height (cm), panicle length (cm), effective tillers plant^{-1}, panicle weight (g), total number of spikelets panicle^{-1}, number of filled spikelets panicle^{-1}, spikelet fertility %, grain yield plant^{-1}, 1000 seed weight (g) and harvest index (%). As per standard statistical procedure, analysis of variance was calculated for each of the characters separately using a randomized block design (Panse and Sukhatme 1978). The significance was tested by referring to the values of 'F' table (Fisher and Yates, 1967).

$$\mathbf{Y_{(ij)}=\mu+g_i+r_j+e_{ij}}$$

where,

Y_{ij} = phenotypic observation of i^{th} genotype and j^{th} replication

μ = general mean

g_i = effect of i^{th} genotype

r_j = effect of j^{th} replication

e_{ij} = random error associated with i^{th} genotype and j^{th} replication

The genotypic and phenotypic coefficient of variation were calculated according to the formula given by Falconer (1981). Heritability in a broad sense was calculated as the ratio of genotypic variance to the phenotypic variance and expressed as a per centage (Falconer, 1981). Genetic advance as per cent of mean for each character was worked out as suggested by Johnson *et al*. (1955). The combining ability analysis was done using line × tester model given by Kempthrone (1957). Heterosis may be defined as superiority of an F_1 hybrid over both of its parents in terms of yield and any other character. It is manifested as increase in size, vigour, growth, yield, or any other characteristic may be considered.The significance of different types of heterosis was calculated by employing t-test suggested by Nadarajan and Gunashekharan (2005).

RESULTS AND DISCUSSION

The analysis of variance for 36 genotypes revealed significant variability among the genotypes and selection is effective for genetic improvement. In the present research, the estimates of GCV and PCV were mentioned in table 1. Higher estimates of PCV were recorded in grain yield plant^{-1}, effective tillers plant^{-1}, harvest index. Higher estimates of genotypic coefficient of variation were recorded in grain yield plant^{-1} followed by effective tillers plant^{-1}. The values of the phenotypic coefficient of variation were found to be higher than those of the genotypic coefficient of variation indicating the influence of the environment. Higher estimates of genotypic coefficient of variation and phenotypic coefficient of variation were recorded in grain yield plant^{-1} followed by effective tillers plant^{-1} indicating the presence of sufficient variability in the hybrids and thereby suggesting that selection of these traits will be useful for genetic improvement. Similar findings were reported by Noatia *et al*. (2021) for grain yield.

The estimates of broad sense heritability and genetic advance as a percent of mean were mentioned in Table 1. All the characters under study except the harvest index showed higher estimates of broad-sense heritability (*i.e.,* > 60% as suggested by Johnson *et al.,* 1995). High degree of the genetic advance as a per cent of mean observed for characters, grain yield plant^{-1}, effective tillers plant^{-1}, number of filled spikelets panicle^{-1}, total number of spikelets panicle-^{1}, harvest index, panicle weight and 1000 seed weight. High heritability coupled with high genetic advance as a per cent of mean was reported for the traits ofeffective tillers plant^{-1}, panicle weight, total number of spikelets panicle^{-1}, number of filled spikelets panicle^{-1}, grain yield plant^{-1} and 1000 seed weight indicating that the expression of such charactersiscontrolled by the additive gene action and thus simple selection will be effective for the improvement of this character. Similar findings were reported by Sao and Motiramani (2006); Priyanka *et al.* (2020) for total number of spikelets panicle^{-1} and filled number of spikelets panicle^{-1}, Noatia *et al*. (2021) for total number of spikelets panicle^{-1} filled number of spikelets panicle^{-1} grain yield and 1000 seed weight.

High heritability coupled with moderate genetic advance as a percentage of mean was observed for traits such as plant height, panicle length, days to maturity, and days to 50% flowering, implying that expression control by both additive and non-additive gene action cannot be used to improve these traits and thus heterosis breeding could be successful.

The analysis of variance for combining ability was mentioned in Table 2. The variance due to line × tester was recordedas significant for all the characters. This suggests that sufficient variability is available in the material used for study. The GCA effects is main criteria for selection of good general combiners among the lines and testers. The estimates of GCA effects are mentioned in Table 3. The best general combiner among the lines is RP 5706-112-4-5-3-2 as it has highly significant GCA effects with the grain yield plant^{-1} along with some important traits like harvest index, total number of spikelets panicle^{-1}, filled spikelets panicle^{-1} and spikelet fertility %. IR10N134 came to be the best general combiner out of all testers for grain yield plant^{-1}, the total number of spikelets panicle^{-1}, number of filled spikelets panicle^{-1} and spikelet fertility %. The estimates of SCA effects of the 24 cross combinations were mentioned in Table 4. The highest negative significant SCA effects for days to 50 % flowering have shown by cross R1138-688-3-533-1/ IR14A150 followed by R2296-341-1-212-1/ IR09N496 and R2321-165-1-148-1/ IRBB-59. Negative values indicate that these are good combinations for early flowering. The highest negative significant SCA effects for days to maturity have shown by cross R1138-688-3-533-1/ IR14A150 followed by R2296 -341-1-212-1/ IR09N496 and R2321-165-1-148-1/ IRBB-59. Negative values indicate that these are good combinations for early maturity so that harvesting can be done earlier. The highest negative significant SCA effects for plant height have shown by cross RP5706-112-4-5-3-2/ IR10N134 followed by R1138-688-3-533-1/ IRRI-186 and R2296 -341-1-212-1/ IR14A150. Negative values indicate that these are good combinations for developing dwarf and semi-dwarf hybrids. The highest positive significant SCA effects for panicle length havebeen shown by cross R1138-688-3-533-1/ IR14V1020 followed by R2296 -341-1-212-1/ IRRI-

186 and RP5706-112-4-5-3-2/ IR14A150. The highest positive significant SCA effects for effective tillers plant^{-1} have been shown by cross R2296 -341-1-212-1/ IR09N496 followed by RP5706-112-4-5-3-2/ IR14A150 and RP5706-112-4-5-3-2/ IRRI-186. The highest positive significant SCA effects for panicle weight was shown by cross R2321-165-1-148-1/IRBB-59. The highest positive significant SCA effects for total number of spikelets panicle^{-1} have been shown by cross R2296-341-1-212-1/ IRBB-59 followed by RP5706-112-4-5-3-2/ IR10N134 and RP5706-112-4-5-3-2/ IR14A150. The highest positive significant SCA effects for number of filled spikelets panicle^{-1} have been shown by cross R2296-341-1-212-1/ IRBB-59 followed by RP5706-112-4-5-3-2/ IR10N134 and RP5706-112-4-5-3-2/ IR14A150. The highest positive significant SCA effects for spikelet fertility % have shown by cross R2296-341-1-212-1/IRBB-59. The highest positive significant SCA effects for grain yield have been shown by cross R2321-165-1-148-1/ IR09N496 followed by R2296 -341-1-212-1/ IRBB-59 and RP5706-112-4-5-3-2/ IRRI-186. Positive values indicate that these are good combinations for developing high-yielding varieties. Similar findings were also supported by Keerthiraj *et al*. (2021), Hussein *et al.* (2021); Yadav *et al.* (2021) and Gaballah *et al.* (2021). The highest positive significant SCA effects for 1000 seed weight have been shown by cross R2296 -341-1-212-1/ IR10N134 followed by RP5706-112-4-5-3-2/ IRBB-59 and R1138-688-3-533-1/ IR14A150. The highest positive significant SCA effects have been shown by cross RP5706-112-4-5-3-2/IR10N134 followed by R2321-165-1-148-1/ IRBB-59. Best general and specific combiners for yield and its attributing traits are mentioned in the Table 5.

The heterosis over mid parent (relative heterosis), over better parent (heterobeltiosis) and over standard check (standard heterosis/ useful heterosis) was estimated for all the characters under study and mentioned in Table 6. The highest significant positive heterosis for grain yield over mid parent and better parent was found in RP5706-112-4-5-3-2/ IR09N496 and R2321-165-1-148-1/ IR09N496 over standard varieties. Similar findings were reported by Nanditha *et al.* (2021); Ray *et al.* (2021); Barhate *et al.* (2021).

Table 1: Genetic parameters for yield and its contributing traits.

Characters	GCV	PCV	h² (bs)	Genetic advance as % of mean
Days to 50 % flowering	4.565	4.819	89.7	11.415
Days to maturity	4.594	4.654	97.4	11.972
Plant height(cm)	6.716	7.058	90.6	16.872
Panicle length (cm)	6.168	7.157	74.3	14.033
Effective tillers plant^{-1}	21.622	23.458	85	52.616
Panicle weight (g)	12.527	15.142	68.4	27.36
Total number of spikelets panicle^{-1}	16.764	17.432	92.5	42.56
Number of filled spikelets panicle^{-1}	19.05	19.783	92.7	48.429
Spikelet fertility %	3.535	4.338	66.4	7.605
Grain yield plant^{-1}	27.956	29.525	89.7	69.883
1000 seed weight (g)	10.833	11.409	90.2	27.158
Harvest Index (%)	15.295	21.825	49.1	28.299

Table 2: ANOVA for Line × Tester mating design.

Source of variations	Df	1	2	3	4	5	6	7	8	9	10	11	12
Replicates	1	6.76	2.12	19.12	1.43	1.51	0.09	41.98	171.94	9.93	10.65	1.78	6.95
Treatments	33	40.60	60.70	104.99	4.92	6.82	0.32	1768.02	1741.39	24.31	66.09	11.88	85.22
Parents	9	14.45	19.12	142.30	3.99	3.55	0.25	1145.49	1230.24	40.25	73.69	17.83	50.42
Parents (Line)	3	2.17	1.83	295.33	5.09	0.67	0.30	945.03	1157.80	77.97	125.66	47.75	88.69
Parents (Testers)	5	12.95	15.28	63.69	3.47	5.03	0.23	521.38	724.41	25.04	56.58	3.38	13.19
Parents(LvsT)	1	58.80	90.13	76.26	3.25	4.78	0.26	4867.44	3976.71	3.18	3.32	0.35	121.73
ParentsvsCrosses	1	414.85	676.21	131.27	2.62	16.04	1.94	1871.51	863.51	18.82	6.14	11.07	172.20
Crosses	23	34.56	50.22	89.26	5.39	7.69	0.27	2007.11	1979.58	18.31	65.73	9.59	95.05
Line Effect	3	121.52	179.13	90.53	9.26	1.88	0.40	3506.15	4380.53	63.42	99.42	17.45	271.45
Tester Effect	5	29.97	45.07	153.48	6.20	9.95	0.39	1818.55	1769.51	12.75	101.77	3.31	78.86
Line×Tester effect	15	18.70	26.15	67.59	4.34	8.10	0.21	1770.16	1569.41	11.13	46.97	10.11	65.17
Error	33	2.16	0.82	7.10	0.90	0.49	0.06	65.16	64.47	5.03	3.88	0.75	31.59
Total	67	21.21	30.33	55.50	2.89	3.62	0.19	903.54	892.02	14.60	34.62	6.25	57.63

*Significant at p= 0.05% level, **Significant at p= 0.01% level

1= Days to 50% flowering, 2= Days to maturity, 3= Plant height(cm), 4= Panicle length (cm), 5= Effective tillers plant^{-1}, 6= Panicle weight (g), 7= Total number of spikelets panicle^{-1}, 8= Number of filled spikelets panicle^{-1}, 9= Spikelets fertility %, 10= Grain yield plant^{-1} (g), 11= 1000 seed weight (g), 12= Harvest Index (%)

Table 3: General combining ability effects of parents for yield and its contributing traits.

	1	2	3	4	5	6	7	8	9	10	11	12
R1138-688-3-533-1	-1.27**	-1.52**	-1.50	-0.90**	0.47*	0.22**	-2.02	-2.30	-0.36	1.66**	-0.71**	-3.22
R2296 -341-1-212-1	1.56**	1.65**	-2.61**	-0.18	-0.49*	0.08	-10.93**	-12.44**	-1.88**	-4.25**	-0.10	-4.19*
RP5706-112-4-5-3-2	3.48**	4.396**	0.45	-0.11	-0.10	-0.1	24.77**	27.70**	3.32**	1.88**	-0.92**	6.21**
R2321-165-1-148-1	-3.77**	-4.52**	3.66**	1.20**	0.12	-0.19*	-11.82**	-12.97**	-1.09	0.71	1.73**	1.20
IR09N496	1.23*	0.98**	-1.02	0.46	1.26**	-0.43**	-13.59**	-13.36**	-1.14	2.89**	-0.43	2.18
IR10N134	2.10**	3.60**	4.58**	0.54	0.67 *	0.15	24.30**	25.14**	2.11*	3.57**	0.50	3.48
IR14A150	1.10*	0.48	-1.21	-0.64	0.77**	0.16	11.48**	10.34**	0.05	1.51*	-0.50	2.12
IR14V1020	-2.90**	-3.15**	-7.10**	-1.51**	-1.74**	0.02	-13.91**	-11.47**	0.35	-6.00**	-0.41	-4.86*
IRRI-186	-1.77**	-2.02**	4.70**	0.51	-0.26	-0.02	-5.26	-5.02	0.08	0.11	1.08**	-1.26
IRBB-59	0.23	0.10	0.07	0.65	-0.71**	0.12	-3.00	-5.63	-1.45	-2.07**	-0.25	-1.67
CD95%GCA (Line)	0.88	0.54	1.60	0.57	0.42	0.14	4.82	4.80	1.34	1.18	0.52	3.36
CD95%GCA (Tester)	1.07	0.67	1.94	0.70	0.51	0.18	5.90	5.88	1.64	1.44	0.63	4.110

*Significant at p= 0.05% level, **Significant at p= 0.01% level

1= Days to 50% flowering, 2= Days to maturity, 3= Plant height(cm), 4= Panicle length (cm), 5= Effective tillers plant^{-1}, 6= Panicle weight (g), 7= Total number of spikelets panicle-1, 8= Number of filled spikelets panicle^{-1}, 9= Spikelets fertility %, 10= Grain yield plant^{-1} (g), 11= 1000 seed weight (g), 12= Harvest Index (%)

Table 4: Specific combining ability effects of hybrids for yield and its contributing traits.

	1	2	3	4	5	6	7	8	9	10	11	12
R1138-688-3-533-1/ IR09N496	4.27**	5.77**	1.31	-1.77*	-0.78	0.31	20.40**	21.31**	2.56	-2.67	0.71	-2.21
R1138-688-3-533-1/ IR10N134	1.90	0.65	7.00**	0.78	0.34	-0.26	-26.27**	-25.89**	-1.25	2.27	-0.07	-5.95
R1138-688-3-533-1/ IR14A150	-5.60**	-5.73**	2.95	-0.91	-0.53	-0.09	10.71	10.27	1.00	1.83	1.97**	3.61
R1138-688-3-533-1/ IR14V1020	-0.60	-1.10	1.01	2.70**	1.28*	0.30	5.41	3.64	-0.84	3.13*	-0.39	2.96
R1138-688-3-533-1/ IRRI-186	-2.23*	-2.73**	-6.87**	-0.69	0.04	0.21	12.11*	11.41	0.20	0.13	-0.74	3.17
R1138-688-3-533-1/ IRBB-59	2.27*	3.15**	-5.40**	-0.12	-0.36	-0.46*	-22.37**	-20.74**	-1.67	-4.69**	-1.49*	-1.58
R2296 -341-1-212-1/ IR09N496	-4.06**	-5.40**	-4.51*	-0.10	-0.96	0.05	-15.77 *	-17.46**	-3.09	-3.78*	-0.89	0.36
R2296 -341-1-212-1/ IR10N134	-0.44	-0.52	6.11**	0.90	-0.59	0.23	-27.30**	-25.57**	-0.12	3.31*	4.29**	-0.01
R2296 -341-1-212-1/ IR14A150	0.06	0.10	-5.53**	-0.07	0.35	0.07	-20.61**	-17.70**	0.46	0.12	-1.21	-0.36
R2296 -341-1-212-1/ IR14V1020	0.06	0.73	-5.20*	-2.10**	-0.12	-0.21	-3.34	1.49	2.06	-3.93**	0.23	-2.23
R2296 -341-1-212-1/ IRRI-186	0.94	1.60*	6.29**	1.73*	-1.06*	-0.43*	1.73	-2.67	-3.12	-1.16	-0.45	0.67
R2296 -341-1-212-1/ IRBB-59	3.44**	3.48**	2.84	-0.37	2.36**	0.30	65.29**	61.90**	3.74*	5.43**	-1.98**	1.57
RP5706-112-4-5-3-2/ IR09N496	-1.98	-2.15**	-1.12	0.50	-1.99**	-0.05	-8.73	-11.76*	-1.87	-0.53	0.60	3.65
RP5706-112-4-5-3-2/ IR10N134	-1.35	-1.77*	-10.33**	-0.63	-1.45**	-0.12	52.59**	47.04**	-0.72	-4.36**	-0.34	9.64*
RP5706-112-4-5-3-2/ IR14A150	3.15**	2.36**	-0.23	1.48*	2.56**	-0.14	21.60**	21.54**	1.50	3.76*	-2.20**	3.24
RP5706-112-4-5-3-2/ IR14V1020	1.65	2.48**	6.62**	-1.68 *	0.44	0.25	-8.91	-8.65	0.22	5.37**	-1.44*	-0.34
RP5706-112-4-5-3-2/ IRRI-186	0.52	1.36*	1.83	-0.63	2.46**	0.29	-12.56*	-8.10	1.92	1.76	-0.35	-6.88
RP5706-112-4-5-3-2/ IRBB-59	-1.98	-2.27**	3.23	0.97	-2.02**	-0.24	-43.99**	-40.07**	-1.05	-6.00**	3.74**	-9.32*
R2321-165-1-148-1/ IR09N496	1.77	1.77*	4.31*	1.37	3.72**	-0.31	4.10	7.90	2.32	6.99**	-0.43	-1.80
R2321-165-1-148-1/ IR10N134	-0.10	1.65*	-2.77	-1.06	1.70**	0.15	0.98	4.40	2.09	-1.24	-3.87**	-3.68
R2321-165-1-148-1/ IR14A150	2.40*	3.27***	2.81	-0.50	-2.38**	0.16	-11.71	-14.10*	-2.96	-5.71**	1.44*	-6.50
R2321-165-1-148-1/ IR14V1020	-1.10	-2.10**	-2.44	1.09	-1.61**	-0.34	6.84	3.52	-1.44	-4.58**	1.60*	-0.40
R2321-165-1-148-1/ IRRI-186	0.77	-0.23	-1.24	-0.42	-1.44**	-0.06	-1.27	-0.64	1.01	-0.73	1.55*	3.03
R2321-165-1-148-1/ IRBB-59	-3.73**	-4.35**	-0.67	-0.49	0.02	0.40*	1.06	-1.08	-1.02	5.26**	-0.29	9.33*
CD95%SCA	2.15	1.32	3.90	1.39	1.02	0.35	11.808	11.745	3.28	2.88	1.26	8.22

*Significant at p= 0.05% level, **Significant at p= 0.01% level

1= Days to 50% flowering, 2= Days to maturity, 3= Plant height(cm), 4= Panicle length (cm), 5= Effective tillers plant^{-1}, 6= Panicle weight (g), 7= Total number of spikelets panicle^{-1}, 8= Number of filled spikelets panicle^{-1}, 9= Spikelets fertility %, 10= Grain yield plant^{-1} (g), 11= 1000 seed weight (g), 12= Harvest Index (%)

Table 5: Best general and specific combiners for yield and its attributing traits

Sr. No.	Traits	Best general combiners		Best Specific Combiners
		Line	Tester	
1.	Days to 50% flowering	R2321-165-1-148-1	IR14V1020	R1138-688-3-533-1/ IR09N496 R2296 -341-1-212-1/ IR09N496 R2321-165-1-148-1/ IRBB-59
2.	Days to maturity	R2321-165-1-148-1	IR14V1020	R1138-688-3-533-1/ IR09N496 R2296 -341-1-212-1/ IR09N496 R2321-165-1-148-1 /IRBB-59
3.	Plant height(cm)	R2296 -341-1-212-1	IR14V1020	R1138-688-3-533-1/ IR10N134 R2296 -341-1-212-1/ IR09N496 R2296 -341-1-212-1/ IR14A150
4.	Panicle length (cm)	R2321-165-1-148-1	-	R1138-688-3-533-1/ IR14V1020 R2296 -341-1-212-1/ IRRI-186 RP5706-112-4-5-3-2/ IR14A150
5.	Effective tillers per plant	R1138-688-3-533-1	IR09N496	R2321-165-1-148-1/ IR09N496 RP5706-112-4-5-3-2/ IR14A150 RP5706-112-4-5-3-2/ IRRI-186
6.	Panicle weight (g)	R1138-688-3-533-1	-	R2321-165-1-148-1/ IRBB-59
7.	Total spikelets per panicle	RP5706-112-4-5-3-2	IR10N134	R2296 -341-1-212-1/ IRBB-59 RP5706-112-4-5-3-2/ IR10N134 RP5706-112-4-5-3-2/ IR14A150
8.	Filled spikelets per panicle	RP5706-112-4-5-3-2	IR10N134	R2296 -341-1-212-1 IRBB-59 RP5706-112-4-5-3-2/ IR10N134 RP5706-112-4-5-3-2/ IR14A150
9.	Spikelet fertility %	RP5706-112-4-5-3-2	IR10N134	R2296 -341-1-212-1/ IRBB-59 RP5706-112-4-5-3-2/ IR10N134 RP5706-112-4-5-3-2/ IR14A150
10.	Grain yield (g)	RP5706-112-4-5-3-2	IR10N134	R2321-165-1-148-1/ IR09N496 R2296 -341-1-212-1/ IRBB-59 RP5706-112-4-5-3-2/ IR14V1020
11.	1000 seed weight (g)	R2321-165-1-148-1	IRRI-186	R2296 -341-1-212-1/ IR10N134 RP5706-112-4-5-3-2 /IRBB-59 R1138-688-3-533-1/ IR14A150
12.	Harvest Index (%)	RP5706-112-4-5-3-2	-	RP5706-112-4-5-3-2/ IR10N134 R2321-165-1-148-1/ IRBB-59

Table 6: Mid parent Heterosis, Heterobeltiosis and Standard Heterosis for yield and its contributing traits.

Crosses	Days to 50 percent flowering				Days to maturity				Plantheight			
	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis
R1138-688-3-533-1/ IR09N496	12.43**	11.80 **	3.65 *	4.19 *	12.44 **	11.95 **	0.80	1.20	2.45	-2.35	19.36**	18.37**
R1138-688-3-533-1/ IR10N134	9.50 **	8.89 **	2.08	2.62	9.49 **	8.30 **	-1.20	-0.80	9.63**	6.62**	30.33**	29.25**
R1138-688-3-533-1/ IR14A150	0.56	0.56	-6.77 **	-6.28 **	1.55 *	0.88	-8.76 **	-8.40 **	0.88	-1.20	20.77**	19.77**
R1138-688-3-533-1/ IR14V1020	-0.82	-3.21	-5.73 **	-5.24 **	-0.22	-3.35 **	-7.97 **	-7.60 **	-8.05**	-8.67**	13.16**	12.23**
R1138-688-3-533-1/ IRRI-186	-1.37	-3.74 *	-6.25 **	-5.76 **	0.22	-2.13 *	-8.37 **	-8.00 **	-4.96*	-5.60*	16.97**	16.00**
R1138-688-3-533-1/ IRBB-59	5.75 **	3.21	0.52	1.05	6.72 **	3.80 **	-1.99 *	-1.60 *	-7.26**	-7.70**	13.91**	12.97**
R2296 -341-1-212-1/ IR09N496	7.12 **	6.82 **	-2.08	-1.57	5.80 **	4.87 **	-5.58 **	-5.20 **	-5.78**	-12.20**	12.62**	11.69**
R2296 -341-1-212-1/ IR10N134	10.99 **	9.44 **	2.60	3.14	11.75 **	10.04 **	0.40	0.80	5.32**	0.09	28.38**	27.32**
R2296 -341-1-212-1/ IR14A150	11.05 **	10.11 **	2.08	2.62	10.02 **	8.81 **	-1.59 *	-1.20	-9.19**	-13.11**	11.45**	10.52**
R2296 -341-1-212-1/ IR14V1020	3.87 *	0.53	-2.08	-1.57	4.56 **	0.84	-3.98 **	-3.60 **	-15.89**	-17.32**	6.05*	5.18
R2296 -341-1-212-1/ IRRI-186	6.08 **	2.67	0.00	0.52	7.22 **	4.26 **	-2.39 **	-2.00 *	2.05	0.31	28.67**	27.60**
R2296 -341-1-212-1/ IRBB-59	11.05 **	7.49 **	4.69 **	5.24 **	10.24 **	6.75 **	0.80	1.20	-3.98*	-5.80**	20.83**	19.83**
RP5706-112-4-5-3-2/ IR09N496	12.32 **	11.36 **	2.08	2.62	10.18 **	10.18 **	-0.80	-0.40	10.20**	7.32**	18.89**	17.91**
RP5706-112-4-5-3-2/ IR10N134	12.75 **	10.56 **	3.65 *	4.19 *	12.09 **	11.35 **	1.59 *	2.00 *	4.65*	-0.13	15.38**	14.43**
RP5706-112-4-5-3-2/ IR14A150	17.38 **	15.73 **	7.29 **	7.85 **	13.47 **	13.22 **	2.39 **	2.80 **	7.64**	2.03	19.57**	18.58**
RP5706-112-4-5-3-2/ IR14V1020	8.33 **	4.28 *	1.56	2.09	7.53 **	4.60 **	-0.40	0.00	5.29*	-2.75	20.51**	19.51**
RP5706-112-4-5-3-2/ IRRI-186	8.33 **	4.28 *	1.56	2.09	8.46 **	6.38 **	-0.40	0.00	11.24**	2.75	27.31**	26.25**
RP5706-112-4-5-3-2/ IRBB-59	7.78 **	3.74 *	1.04	1.57	6.70 **	4.22 **	-1.59 *	-1.20	8.74**	0.62	24.18**	23.15**
R2321-165-1-148-1/ IR09N496	7.39 **	7.39 **	-1.56	-1.05	6.70 **	5.75 **	-4.78 **	-4.40 **	17.69**	14.89**	27.28**	26.23**
R2321-165-1-148-1/ IR10N134	5.06 **	3.89 *	-2.60	-2.09	8.20 **	6.55 **	-2.79 **	-2.40 **	13.87**	8.93**	25.85**	24.81**
R2321-165-1-148-1/ IR14A150	7.34 **	6.74 **	-1.04	-0.52	7.35 **	6.17 **	-3.98 **	-3.60 **	12.84**	7.21**	25.65**	24.60**
R2321-165-1-148-1/ IR14V1020	-3.58 *	-6.42 **	-8.85 **	-8.38 **	-3.25 **	-6.69 **	-11.16 **	-10.80 **	0.10	-7.33**	14.82**	13.87**
R2321-165-1-148-1/ IRRI-186	-0.28	-3.21	-5.73 **	-5.24 **	0.22	-2.55 **	-8.76 **	-8.40 **	11.10**	2.85	27.44**	26.39**
R2321-165-1-148-1/ IRBB-59	-3.03 *	-5.88 **	-8.33 **	-7.85 **	-1.96 **	-5.06 **	-10.36 **	-10.00 **	7.90**	0.07	23.51**	22.48**

*Significant at p=0.05% level, **Significant at p=0.01% level

Crosses	Paniclelength				Effective tillers plant^{-1}				Panicleweight			
	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis
R1138-688-3-533-1/ IR09N496	-8.26 *	-12.79 **	11.86 *	-0.29	47.53 **	32.62 **	-6.03	33.57 **	-22.11 **	-23.45 **	0.91	0.91
R1138-688-3-533-1/ IR10N134	-2.79	-3.28	24.07 **	10.59 *	52.80 **	40.07 **	-0.75	41.07 **	-14.46 *	-23.31 **	1.09	1.09
R1138-688-3-533-1/ IR14A150	-12.77 **	-13.66 **	10.75 *	-1.28	21.00 *	13.81	-8.49	30.07 **	-10.64	-18.34 *	7.64	7.64
R1138-688-3-533-1/ IR14V1020	2.57	-3.75	23.47 **	10.06 *	3.99	-7.84	-15.48 *	20.14	-3.53	-11.45	16.73	16.73
R1138-688-3-533-1/ IRRI-186	-3.68	-8.70 *	17.11 **	4.39	8.81	-2.26	-13.07	23.57 *	-5.08	-15.03 *	12.00	12.00
R1138-688-3-533-1/ IRBB-59	-1.44	-6.13	20.40 **	7.32	-2.35	-12.61	-21.61 **	11.43	-16.12 *	-29.66 **	-7.27	-7.27
R2296 -341-1-212-1/ IR09N496	0.44	-4.88	22.98 **	9.62 *	34.29 **	24.15 *	-17.34 *	17.50	-28.30 **	-32.14 **	-13.64	-13.64
R2296 -341-1-212-1/ IR10N134	-0.15	-1.04	27.95 **	14.05 **	28.08 **	20.83	-19.55 *	14.36	4.33	0.16	13.82	13.82
R2296 -341-1-212-1/ IR14A150	-7.44 *	-8.74 *	17.99 **	5.17	23.62 **	13.00	-9.15	29.14 **	-2.86	-4.80	8.18	8.18
R2296 -341-1-212-1/ IR14V1020	-13.55 **	-19.17 **	4.50	-6.85	-22.98 **	-33.53 **	-39.05 **	-13.36	-16.65 *	-17.92 *	-6.73	-6.73
R2296 -341-1-212-1/ IRRI-186	7.83 *	1.83	31.66 **	17.36 **	-14.57	-25.31 **	-33.57 **	-5.57	-23.21 **	-26.40 **	-16.36	-16.36
R2296 -341-1-212-1/ IRBB-59	-0.09	-5.21	22.56 **	9.25 *	23.15 **	7.28	-3.77	36.79 **	13.44	1.28	15.09	15.09
RP5706-112-4-5-3-2/ IR09N496	9.39 **	9.06 *	26.07 **	12.37 **	30.60 **	26.78 *	-23.87 **	8.21	-32.26 **	-40.00 **	-23.64 *	-23.64 *
RP5706-112-4-5-3-2/ IR10N134	0.18	-4.59	21.17 **	8.01	27.00 *	25.94 *	-24.37 **	7.50	-6.73	-9.57	-5.45	-5.45
RP5706-112-4-5-3-2/ IR14A150	4.33	-0.13	25.49 **	11.86 **	66.37 **	45.31 **	16.83 *	66.07 **	-8.77	-13.33	-5.45	-5.45
RP5706-112-4-5-3-2/ IR14V1020	-6.07	-7.07	6.78	-4.82	-7.28	-23.29 **	-29.65 **	0.00	-0.52	-5.94	3.64	3.64
RP5706-112-4-5-3-2/ IRRI-186	5.35	5.35	21.05 **	7.90	41.65 **	18.64 *	5.53	50.00 **	2.43	-0.52	3.64	3.64
RP5706-112-4-5-3-2/ IRBB-59	11.82 **	11.26 **	29.13 **	15.10 **	-25.17 **	-37.54 **	-43.97 **	-20.36	-4.56	-8.89	-10.55	-10.55
R2321-165-1-148-1/ IR09N496	17.03 **	16.19 **	36.26 **	21.46 **	109.06 **	85.19 **	35.68 **	92.86 **	-48.45 **	-50.00 **	-36.36 **	-36.36 **
R2321-165-1-148-1/ IR10N134	2.63	-1.30	25.35 **	11.73 **	65.21 **	49.18 **	9.30	55.36 **	-9.98	-15.65 *	0.91	0.91
R2321-165-1-148-1/ IR14A150	0.79	-2.57	22.42 **	9.12 *	-9.74	-13.75	-30.65 **	-1.43	-10.97	-14.89	1.82	1.82
R2321-165-1-148-1/ IR14V1020	9.47 **	7.22	25.74 **	12.08 **	-37.01 **	-43.34 **	-48.04 **	-26.14 *	-31.49 **	-34.19 **	-21.27 *	-21.27 *
R2321-165-1-148-1/ IRRI-186	10.38 **	9.26 *	28.13 **	14.21 **	-15.49	-22.94 **	-31.46 **	-2.57	-22.01 **	-27.05 **	-12.73	-12.73
R2321-165-1-148-1/ IRBB-59	10.13 **	9.56 *	28.48 **	14.53 **	-3.48	-12.32	-21.36 **	11.79	4.44	-8.81	9.09	9.09

*Significant at p=0.05% level, **Significant at p=0.01% level

Crosses	Total number of spikelets panicle^{-1}				Number of filled spikelets panicle^{-1}				Spikelet fertility %			
	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis
R1138-688-3-533-1/ IR09N496	-12.49**	-24.39**	-9.39*	7.43	-10.17*	-23.65**	-5.87	4.70	2.58	0.47	1.78	-2.08
R1138-688-3-533-1/ IR10N134	-14.41**	-28.27**	-14.03**	1.92	-12.52**	-28.05**	-11.29*	-1.33	2.22	-0.17	1.13	-2.70
R1138-688-3-533-1/ IR14A150	1.93	-17.60**	-1.25	17.07**	5.59	-17.26**	2.01	13.47*	4.48	0.05	1.35	-2.49
R1138-688-3-533-1/ IR14V1020	-23.53**	-31.15**	-17.48**	-2.17	-24.07**	-31.63**	-15.70**	-6.24	-1.57	-1.70	-0.43	-4.20
R1138-688-3-533-1/ IRRI-186	-15.18**	-24.38**	-9.37*	7.45	-15.62**	-24.44**	-6.85	3.61	-1.08	-1.34	0.46	-3.35
R1138-688-3-533-1/ IRBB-59	-30.69**	-38.59**	-26.40**	-12.74*	-34.20**	-41.00**	-27.26**	-19.09**	-5.86 *	-6.99 *	-3.48	-7.13 **
R2296 -341-1-212-1/ IR09N496	-25.86**	-28.10**	-33.22**	-20.83**	-29.90**	-33.22**	-36.34**	-29.19**	-5.51 *	-7.30 **	-6.42 *	-9.96 **
R2296 -341-1-212-1/ IR10N134	-7.18	-13.10**	-19.29**	-4.31	-5.52	-13.36*	-17.40**	-8.13	1.94	-0.27	0.67	-3.14
R2296 -341-1-212-1/ IR14A150	-7.09	-16.58**	-22.53**	-8.15	-5.28	-17.89**	-21.73**	-12.94*	2.21	-1.97	-1.04	-4.79
R2296 -341-1-212-1/ IR14V1020	-22.51**	-23.76**	-26.82**	-13.24*	-21.03**	-22.40**	-23.36**	-14.76*	0.18	0.14	1.17	-2.66
R2296 -341-1-212-1/ IRRI-186	-13.85**	-14.31**	-19.57**	-4.64	-19.03**	-19.94**	-21.93**	-13.17*	-6.44 **	-6.84 *	-5.15	-8.74 **
R2296 -341-1-212-1/ IRBB-59	24.30**	24.08**	15.24**	36.62**	22.10**	20.54**	17.91**	31.15**	-1.31	-2.65	1.02	-2.80
RP5706-112-4-5-3-2/ IR09N496	-4.25	-10.11*	-10.63*	5.96	3.39	0.14	-7.79	2.56	7.97 **	3.89	0.91	-2.91
RP5706-112-4-5-3-2/ IR10N134	57.19**	42.66**	41.83**	68.15**	78.12**	65.97**	52.83**	69.99**	13.76 **	9.77 **	6.00 *	1.99
RP5706-112-4-5-3-2/ IR14A150	36.93**	19.36**	18.67**	40.69**	57.66**	38.70**	27.73**	42.07**	16.36 **	14.53 **	6.17 *	2.15
RP5706-112-4-5-3-2/ IR14V1020	-8.80*	-10.37*	-10.89*	5.64	-0.10	-3.47	-4.67	6.03	10.10 **	3.99	5.05	1.07
RP5706-112-4-5-3-2/ IRRI-186	-5.06	-7.71	-8.25	8.78	5.16	2.24	-0.31	10.88	11.37 **	4.80	6.70 *	2.66
RP5706-112-4-5-3-2/ IRBB-59	-20.48**	-23.23**	-23.67**	-9.51	-16.39**	-18.84**	-20.61**	-11.70*	4.87 *	-2.19	1.50	-2.34
R2321-165-1-148-1/ IR09N496	-20.07**	-26.81**	-23.19**	-8.93	-21.09**	-30.74**	-20.87**	-11.99*	-1.42	-5.99 *	0.66	-3.15
R2321-165-1-148-1/ IR10N134	2.36	-9.30*	-4.81	12.85*	4.18	-11.66*	0.93	12.27*	2.29	-2.73	4.15	0.21
R2321-165-1-148-1/ IR14A150	-8.64*	-22.15**	-18.30**	-3.13	-12.93*	-29.82**	-19.81**	-10.81	-3.96	-10.41 **	-4.07	-7.70 **
R2321-165-1-148-1/ IR14V1020	-22.27**	-25.59**	-21.91**	-7.42	-27.17**	-32.11**	-22.43**	-13.72*	-5.78 *	-8.44 **	-1.96	-5.67 *
R2321-165-1-148-1/ IRRI-186	-21.16**	-25.33**	-21.63**	-7.08	-25.38**	-30.85**	-21.00**	-12.13*	-3.73	-6.09 *	0.55	-3.26
R2321-165-1-148-1/ IRBB-59	-18.18**	-23.01**	-19.20**	-4.21	-26.11**	-31.42**	-21.65**	-12.86*	-8.53 **	-9.94 **	-3.56	-7.21 **

*Significant at p= 0.05% level, **Significant at p= 0.01% level

Crosses	Grain yield plant^{-1}				1000 seed weight				Harvest Index			
	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis	Mid Parent Heterosis	Better Parent Heterosis	Swarna Standard Heterosis	Improved Samba Mahsuri Standard Heterosis
R1138-688-3-533-1/ IR09N496	21.31*	-9.93	77.88**	89.55**	-3.04	-5.14	10.82*	42.57**	-21.73	-34.72**	2.38	24.01
R1138-688-3-533-1/ IR10N134	34.08**	11.98	121.15**	135.66**	-8.60**	-12.30**	11.48**	43.42**	-30.58*	-39.83**	-5.63	14.31
R1138-688-3-533-1/ IR14A150	14.01	2.24	101.92**	115.16**	0.86	-0.47	16.27**	49.59**	-15.16	-22.70	21.23	46.85*
R1138-688-3-533-1/ IR14V1020	-22.51**	-23.07**	54.15**	64.26**	-9.93**	-10.54**	5.93	36.29**	-31.46*	-38.61**	-3.73	16.61
R1138-688-3-533-1/ IRRI-186	-7.28	-9.85	78.04**	89.71**	-4.48	-4.90	11.09**	42.92**	-19.89	-30.66*	8.75	31.73
R1138-688-3-533-1/ IRBB-59	-36.50**	-37.10**	24.23	32.38	-10.82**	-12.96**	1.68	30.82**	-33.53**	-41.42**	-8.14	11.27
R2296 -341-1-212-1/ IR09N496	-12.71	-34.12**	23.85	31.97	-16.98**	-26.39**	6.39	36.87**	-14.81	-27.23*	7.62	30.36
R2296 -341-1-212-1/ IR10N134	14.67	-2.29	83.69**	95.74**	-1.26	-7.20*	34.11**	72.54**	-15.85	-25.19	10.63	34.01
R2296 -341-1-212-1/ IR14A150	-16.88*	-23.79**	43.27*	52.66**	-18.97**	-27.60**	4.64	34.62**	-24.12*	-28.98*	5.03	27.22
R2296 -341-1-212-1/ IR14V1020	-71.97**	-72.84**	-45.58**	-42.01*	-15.15**	-22.82**	11.55**	43.51**	-44.06**	-48.56**	-23.93	-7.86
R2296 -341-1-212-1/ IRRI-186	-34.48**	-34.74**	22.69	30.74	-11.46**	-20.27**	15.23**	48.25**	-25.83*	-34.16*	-2.64	17.94
R2296 -341-1-212-1/ IRBB-59	-17.95*	-19.17*	56.62**	66.89**	-20.02**	-29.23**	2.27	31.58**	-26.00*	-33.09*	-1.05	19.86
RP5706-112-4-5-3-2/ IR09N496	143.83**	104.66**	96.00**	108.85**	8.38*	-2.09	9.43*	40.79**	33.77*	23.82	52.43**	84.64**
RP5706-112-4-5-3-2/ IR10N134	74.16**	29.84*	71.88**	83.16**	0.65	-13.98**	9.34*	40.67**	48.06**	43.21**	76.31**	113.57**
RP5706-112-4-5-3-2/ IR14A150	97.02**	39.36**	118.42**	132.75**	-5.44	-15.24**	-3.59	24.04**	19.72	17.01	50.89**	82.78**
RP5706-112-4-5-3-2/ IR14V1020	30.43**	-13.63	73.08**	84.43**	-3.89	-15.36**	0.23	28.95**	-5.90	-6.27	16.30	40.87
RP5706-112-4-5-3-2/ IRRI-186	52.91**	3.09	92.31**	104.92**	8.73*	-3.30	11.95**	44.04**	-10.24	-13.32	6.72	29.27
RP5706-112-4-5-3-2/ IRBB-59	-10.52	-40.25**	15.77	23.36	23.64**	11.93**	24.50**	60.18**	-19.76	-20.92	-2.64	17.94
R2321-165-1-148-1/ IR09N496	85.84**	46.01**	144.73**	160.78**	1.32	-1.66	16.80**	50.26**	10.31	7.89	18.23	43.21
R2321-165-1-148-1/ IR10N134	24.62*	11.52	86.92**	99.18**	-14.32**	-17.13**	5.34	35.53**	3.54	1.08	16.30	40.87
R2321-165-1-148-1/ IR14A150	-15.83	-18.56	36.50*	45.45*	7.50*	5.22	24.98**	60.79**	-13.96	-20.42	2.62	24.31
R2321-165-1-148-1/ IR14V1020	-52.40**	-56.30**	-12.42	-6.68	6.34*	6.18	26.11**	62.25**	-14.62	-19.60	-0.25	20.83
R2321-165-1-148-1/ IRRI-186	-7.34	-12.04	64.08**	74.84**	13.08**	11.65**	32.61**	70.61**	9.48	7.06	22.75	48.69*
R2321-165-1-148-1/ IRBB-59	7.02	-0.20	93.38**	106.07**	2.81	-0.46	18.23**	52.11**	23.97	18.79	42.05*	72.06**

*Significant at p= 0.05% level, **Significant at p= 0.01% level

CONCLUSIONS

The analysis of variance was foundto besignificant for all the characters studies, where sufficient variability is present among the genotypes.Among the lines, RP5706-112-4-5-3-2 and among the testers, IR10N134 came out to be the best general combiners for more yield and its attributing traits. The highest significant positive heterosis for grain yield over mid parent and better parent was found in RP5706-112-4-5-3-2/ IR09N496 and R2321-165-1-148-1/ IR09N496 over standard varieties. The best performing crosses *i.e*., RP5706-112-4-5-3-2/ IR14A150, R1138-688-3-533-1/ IR14A150, RP5706-112-4-5-3-2/ IR10N134, R 2296-341-1-212-1/ IR14A150, R1138-688-3-533-1/ IRRI-186 and R2321-165-1-148-1/ IR14V1020 were the most promising based on mean grain yield, GCA, SCA and heterosis.

FUTURE SCOPE

Throughout the research work, the best general combiner among the lines and testers issuggested to be used for better combinations for further study. Six high-performing cross combinations identified were suggested to re-test and validate their outcome and do multilocation trials to monitor their favourable conditions for high yield. More lines and testers to be used in the crossing programme

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