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Assessment of combining ability, gene action and heterosis for yield and grain characters in rice (*Oryza sativa* L.)

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Abstract
Twenty four hybrids were tested along with eight lines and three testers for various yield and grain characters to understand the nature of gene action in the inheritance of various traits. *gca/sca* variance analysis exhibited the dominance of non-additive gene action for the traits *viz.,* plant height, flag leaf length, flag leaf width, spikelet fertility, 1000 grain weight, single plant yield, grain length, grain breadth and L/B ratio. The lines ADT (R) 45, ADT 53, CO 54, ANNA (R) 4 and the testers 3-11-11-1 and 3-11-11-2 were determined to be good general combiners since they have contributed alleles with a positive effect on improving essential characters. The hybrids ADT (R) 45 × 3-11-11-2, ADT 37 × 3-11-11-1, ADT 37 × 3-11-11-2, ADT 53 × 3-11-11-1, CB 12132 × 3-11-11-1, CO 52 × 3-11-11-1, CO 52 × 3-11-11-2, CO 52 × 3-11-11-1 and CO 54 × 3-11-11-1 were found to be good specific combiners. The crosses ADT 37× 3-11-11-2, CB 12132 × 3-11-11-1, ADT 53 × 3-11-11-2, ADT 53 × TR 13069 and CO 54 × 3-11-11-2 demonstrated significant results with respect to mean, *sca* and standard heterosis. These five crosses can be successfully used in further breeding programmes.

Key words: Line × tester, standard heterosis, combining ability, gene action, rice

INTRODUCTION

Rice is known as the "grain of life" (Singh *et al.*, 2020) because it is the most important and staple food for more than half of the world's population, making it a critical component of food security (RICEPEDIA). It not only meets a basic need but also serves as a primary grain in the human diet, providing 21% of worldwide human per capita energy and 15% of per capita protein. Despite the fact that India is the world's largest country by area, it ranks second in terms of production behind China. According to the Directorate of Economics and Statistics (D&ES, 2019-20), India has 43.78 million hectares of area, produces 118.43 million tonnes, and holds a productivity of 2705 kg per hectare.

Combining ability analysis is a strong technique for identifying good and poor combiners, as well as selecting appropriate parental material and the nature of gene action involved in the inheritance of traits. The plant breeder's understanding of the impacts of combining ability and their magnitude is critical. For various economic features, the parents involved in the crop improvement programme should have a strong combining ability and vast genetic diversity. Many biometrical tools are accessible to the breeder for selecting appropriate parents. Combining ability analysis is one of the most potent tools for estimating combining ability effects and assisting in the selection of appropriate parents and crosses for heterosis exploitation. In determining the relative ability of female and male lines to produce better hybrid combinations, line x tester analysis (Kempthorne *et al*., 1957) is useful. To take advantage of heterosis, parents with strong genetic potential are highly essential. The use of heterosis in rice has been suggested as a valuable strategy for overcoming current yield constraints. The most crucial prerequisite for any heterosis breeding effort is a study of the magnitude of heterosis. With this background, combining ability, gene action and standard heterosis for grain yield and yield contributing characters in 24 rice hybrids were investigated.

MATERIALS AND METHODS

The current investigation was carried out at the Department of Rice, Tamil Nadu Agricultural University, Coimbatore during 2020 - 21. The study material comprises 11 genotypes which include eight lines *viz.,* ADT (R) 45, ADT 37, ADT 53, CO 52, CO 54, Anna (R) 4, CB 12132 and RNR 15048 and three testers *viz.,* 3-11-11-1, 3-11-11-2 and TR 13069. Crossing block was raised during *Rabi,* 2020, for facilitating synchronization in flowering three staggered sowings was taken up. Kempthorne's line x tester method (1957) was used to make the crosses and 24 hybrids were synthesized.

During *Kharif,* 2021, 24 F_1 hybrids along with parents and two high yielding check varieties *viz.,* CO 51 and ADT 54 were raised in randomized block design with two replications. Seedlings with 25 days duration were transplanted in the main field with a spacing of 20 × 40 cm in a 2.6 meter single row length. For effective crop growth, all prescribed agronomic procedures and plant protection measures were followed. Twelve biometrical and grain quality traits *viz.,* days to 50 per cent flowering, plant height, the number of productive tillers, single plant yield, panicle length, flag leaf length, flag leaf width, spikelet fertility, 1000 grain weight, grain length, grain width and L/B ratio were recorded. Observations were recorded on five randomly selected plants in each entry and the mean value was calculated. The approach described by Kempthorne (1957) was used to calculate the *gca* and *sca* variance. Sprague and Tatum's (1942) *gca* and s*ca* effects were used to determine good combiners among parental genotypes and good combiners from crosses. The statistical analysis was carried using the TNAUSTAT.

RESULTS AND DISCUSSION

Analysis of variance showed significant differences among all the traits under study in lines except for flag leaf width, spikelet fertility and 1000 grain weight. In the case of testers, the traits single plant yield, flag leaf length, spikelet fertility and 1000 grain weight had significant differences while the remaining traits had non significance (**Table 1**). The interaction between lines and testers showed significance for days to 50 per cent flowering, plant height, the number of productive tillers, single plant yield, spikelet fertility, 1000 grain weight, grain length, grain breadth and L/B ratio. Among the crosses, significant differences were noted for all the traits except for flag leaf width. This revealed that the treatments had a lot of genetic divergence among them.

The per se performance of parents and hybrids are depicted in **Table 2** and **Table 3.** Among the parents, ADT (R) 45, ADT 37, ADT 53 and TR 13069 were found highly significant for days to 50% flowering. For single plant yield, the genotypes ADT (R) 45, ADT 53, CO 54, CO 52, RNR 15048 and 3-11-11-2 shown significance. Similarly, for test weight ADT 37, CO 52, ANNA (R) 4, RNR 15048 were

Table 1. Analysis of variance for combining ability in rice

Source of variation	df	Days to 50 % flowering	Plant height	Number of productive tillers	Single plant yield	Panicle length	Flag leaf length	Flag leaf breadth	Spikelet fertility	1000 grain weight	Grain length	Grain breadth	L/B ratio
Replication	1	0.000	0.0567	0.0817	6.4900	11.4954	0.0147	0.0385	0.1692	0.0910	0.0001	0.0012	0.0016
crosses	23	240.7681**	185.8252 **	20.3341 **	76.5662**	11.3472 **	29.9342 **	0.0505	15.8607 **	13.5051 **	0.1916**	0.1158 **	0.1761**
Lines	7	783.3333**	543.7540 **	53.1718 **	180.859**	32.7234 **	87.4333 **	0.0427	16.4957	41.3488	0.5817 **	0.3478 **	0.5205 **
testers	2	1.0208	11.8942	2.4905	93.9676**	0.0072	87.4333 *	0.0881	63.9147 **	0.8179 **	0.0079	0.0134	0.0216
Lines x Testers	14	3.7351 **	31.7080 **	6.4644 **	21.9335**	2.2792	3.1614	0.0490	8.6784 **	1.3957 **	0.0228 **	0.0145 **	0.0260 **
error	23	0.0870	2.8986	0.7921	2.4709	1.6629	1.1128	0.0621	1.3607	0.2194	0.0021	0.0013	0.0032
gca		8.1858	5.3224	2.8361	1.8867	0.3132	0.9246	0.0001	0.2480	0.4182	0.0058	0.0035	0.0052
sca		1.8241	14.4047	1.9159	9.7313	0.3081	1.0243	-0.0066	3.6589	0.5881	0.0103	0.0066	0.0114
gca/sca		4.4875	0.3694	1.4802	0.1938	1.0165	0.9026	-0.01515	0.0677	0.7111	0.563107	0.530303	0.45614

** Significant at 1 per cent level

Table 2. ***Per se*** **performance of parents**

Name of the parents	Days to 50% flowering	Plant height (cm)	Number of productive tillers	Single plant yield (g)	Panicle length (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Spikelet fertility %	1000 grain weight (g)	Grain length (mm)	Grain breadth (mm)	L/B ratio
Lines												
ADT (R) 45	82.50**	89.50**	19.70	37.63**	19.22	21.63	1.16	73.83	14.95	5.66**	1.93	2.93**
ADT 37	87.00**	98.88**	16.50	35.91	21.43	25.76	1.29	76.01	17.83**	4.69	2.57	1.83
ADT 53	94.50**	102.50	22.68	36.68**	20.95	20.09	1.19	71.56	14.97	5.79**	2.05	2.82**
CO 52	110.00	118.25	24.40**	39.76**	23.1	31.99**	1.26	73.91	16.77**	5.49	1.79**	3.07**
CO 54	108.00	113.13	22.60	37.35**	24.42	26.45	1.31	75.67	15.21	5.38	1.90	2.83**
ANNA (R) 4	102.00	100.63**	23.20*	33.09	24.83	26.61	1.19	79.87**	22.77**	5.74**	2.09	2.75
CB 12132	115.00	110.88	16.60	34.65	28.85**	33.66**	1.57	71.43	14.92	5.21	1.91	2.73
RNR 15048	111.00	121.13	21.40	38.06**	27.9**	31.18**	1.40	72.32	18.97**	5.13	1.61**	3.19**
Testers												
3-11-11-1	106.00	87.00**	22.80	32.44	17.73	26.11	1.33	81.60	15.35	4.99	1.90	2.63
3-11-11-2	105.00	92.88**	24.10	36.89**	18.53	28.04	1.32	88.19**	14.15	5.33**	1.81	2.95
TR 13069	102.00**	117.75	24.30	30.92	26.85**	32.56**	1.45	75.52	14.17	5.24	1.63**	3.21
Mean (Lines)	101.25	106.85	20.87	34.76	23.83	27.17	1.29	74.32	15.67	5.38	1.98	2.76
Mean(Testers)	104.33	99.20	23.73	34.08	21.03	28.90	1.36	81.78	14.55	5.18	1.78	2.92
CD (0.05)	0.597	4.735	2.351	1.313	2.373	2.817	0.422	2.706	1.091	0.122	0.083	0.115

** Significant at 1 per cent level

found highly significant *per se* performance. Considering grain quality traits, the genotypes ADT (R) 45 and ADT 53 obtained significant *per se* performance for grain length as well as for L/B ratio. The cross combinations *viz.,* ADT (R) 45 × 3-11-11-2, ADT 37×3-11-11-1, ADT 37× 3-11-11-2, ADT 53× 3-11-11-1, ADT 53× 3-11-11-2, CO 52× 3-11-11-1, CO 52 × 3-11-11-2, CO 52 × TR 13069, CO 54× 3-11-11-1. ANNA (R) 4×3-11-11-1, ANNA (R) 4 × 3-11-11-2, CB 12132 × 3-11-11-1 were found highly significant for single plant yield.

In the present study, results showed that the ratios of *gca/sca* variances were less than unity for most of the traits indicating the predominance of non – additive gene action. The characters that are controlled by non-additive gene action were plant height, flag leaf length, flag leaf width, spikelet fertility, 1000 grain weight, single plant yield, grain length, grain breadth and L/B ratio. The traits with non- additive gene action can be further subjected to heterosis breeding. Many researchers Saidaiah *et al*. (2010), Thorat *et al.* (2017), Singh *et al*. (2020), Yousef *et al*. (2020) and Sandhyakishore *et al*. (2021) have reported the predominance of non-additive gene action for the above mentioned traits. The characters controlled by additive gene action were days to 50% flowering, the number of productive tillers and panicle length. Pureline selection or pedigree breeding can be employed to improve the above traits. Similar results are reported by Widyastuti *et al*. (2017) and Zewdu *et al.* (2020).

General combining ability aids in the identification of superior parents, whereas specific combining ability aids in the identification of superior cross combinations. The results of *gca* effects on parental phenotypes have been depicted in **Table 4.** In the present study, good general combiners, for single plant yield were ADT 53, CO 52, CO 54, ANNA (R) 4, 3-11-11-1 and 3-11-11-2. Among the parental genotypes ANNA (R) 4 was found to be a good general combiner for the traits *viz.,* plant height, the number of productive tiller, panicle length, flag leaf length, spikelet fertility, 1000 grain weight and grain length whereas CO 54 exhibited significant *gca* effect for the traits number of productive tillers, single plant yield, grain length, grain breadth and L/B ratio. The parents ADT (R) 45 ADT 37, ADT 53 and TR 13069 were found to be good general combiners for days to 50% flowering and plant height. Latha *et al.* (2013), Priyanka *et al.* (2014) adjudged several parents with desirable *gca* effects for plant height in rice. The parents CO 52, CO 54 and ANNA (R) 4 were shown to be good general combiners for the number of productive tillers. Significant positive *gca* values were obtained from the lines ANNA (R) 4 and RNR 15048 for the traits *viz.,* panicle length and flag leaf width. Two testers (3-11-11-1, 3-11-11-2) and two lines (ADT (R) 45, ANNA (R) 4) had significant positive *gca* values for spikelet fertility. General combining ability effects were found to be significant in the lines *viz.,* ADT (R) 45, CO 54, CB 12132, RNR 15048 and the tester TR 13069 for grain breadth and L/B ratio and grain length

Table 3. ***Per se*** **performance of hybrids**

Name of crosses	Days to 50 % flowering	Plant height (cm)	Number of productive tillers	Single plant yield (g)	Panicle length (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Spikelet fertility %	1000 grain weight (g)	Grain length (mm)	Grain breadth (mm)	L/B ratio
ADT (R) 45 × 3-11-11-1	84.50**	88.05**	21.25	34.40	21.29	28.62	1.16	79.01**	14.78	5.56**	1.85**	1.85
ADT (R) 45 × 3-11-11-2	84.50**	89.25**	22.51	44.23**	22.36	31.57	1.18	77.04	14.39	5.46	1.84**	1.84
ADT (R) 45 ×TR 13069	84.50**	89.63**	22.00	34.65	24.26	31.36	1.46	75.02	13.77	5.52**	1.85**	1.85
ADT 37×3-11-11-1	87.00**	90.25**	20.65	39.90**	24.35	32.32**	1.21	74.39	18.32**	4.96	2.32	2.32
ADT 37× 3-11-11-2	86.00**	100.88**	20.30	43.67**	23.15	32.46**	1.28	73.10	18.05**	5.16	2.41	2.41
ADT 37×TR 13069	87.00**	101.38	20.40	31.03	23.57	31.07	1.25	70.59	17.49**	5.08	2.42	2.42
ADT 53× 3-11-11-1	92.50**	104.13	22.70	41.18**	20.69	23.09	1.24	79.01**	15.33	5.69**	2.12	2.12
ADT 53× 3-11-11-2	95.00**	101.63	23.75	39.11**	21.89	24.40	1.07	77.04	15.84	5.88**	2.10	2.10
ADT 53×TR 13069	92.00**	103.5	23.45	37.74	21.17	24.38	1.86	70.52	13.54	5.53**	1.86**	1.86
CO 52× 3-11-11-1	108.00	111.88	32.25**	44.96**	22.04	24.16	1.18	74.63	13.62	5.18	1.95	1.95
CO 52 × 3-11-11-2	110.00	115.13	28.25**	42.95**	21.26	25.06	1.16	80.17**	14.12	5.20	1.92	1.92
CO 52 × TR 13069	107.00	118.00	24.35	38.85**	22.23	26.63	1.18	70.98	13.95	5.16	1.95	1.95
CO 54× 3-11-11-1	108.00	118.63	24.60	41.44**	23.78	24.76	1.46	74.23	14.78	5.51**	1.98	1.98
CO 54× 3-11-11-2	106.00	109.38	24.47	38.27	24.53	26.34	1.29	73.26	14.39	5.60**	1.87**	1.87
CO 54× TR 13069	108.00	118.5	23.45	38.40**	24.78	30.15	1.44	71.11	13.77	5.46	1.90	1.90
ANNA(R)4×3-11-11-1	102.00	108.00	26.80**	39.73**	25.48	32.27	1.27	78.3**	21.63**	5.75**	2.25	2.25
ANNA(R)4 × 3-11-11-2	106.00	102.63	23.65	40.53**	25.98	32.08	1.18	77.24	19.52**	5.68**	2.13	2.13
ANNA(R)4 ×TR 13069	103.00	98.75**	23.75	35.55	26.33	35.45	1.18	73.69	22.58**	5.87**	2.22	2.22
CB 12132 × 3-11-11-1	115.00	107.13	16.65	43.20**	24.80	28.59	1.32	75.19	14.70	5.39	1.85**	1.85
CB 12132 ×3-11-11-2	114.00	114.25	17.90	35.43	25.01	30.38	1.27	77.78**	13.70	5.12	1.87**	1.87
CB 12132 × TR 13069	115.00	113.38	20.45	33.45	21.75	28.61	1.24	73.85	14.76	5.11	1.59**	1.59
RNR 15048 × 3-11-11-1	112.00	114.38	22.10	33.85	29.58**	33.29**	1.37	72.64	13.78	4.90	1.58**	1.58
RNR 15048 × 3-11-11-2	109.00	112.88	22.75	36.40	27.73**	35.42**	1.37	72.84	14.51	4.89	1.63**	1.63
RNR 15048 ×TR 13069	110.00	112.63	22.85	34.90	28.15**	35.19**	1.36	74.52	13.55	4.93	1.66**	1.66
Mean	101.08	106.01	22.97	37.12	24.01	29.49	1.29	74.84	15.62	5.36	1.96	2.76
CD (0.05)	0.597	4.735	2.351	1.313	2.373	2.817	0.422	2.706	1.091	0.122	0.083	0.115

** Significant at 1 per cent level

Table 4. General combining ability effects of parents for different quantitative and grain characters in rice

Name of the parents	Days to 50% flowering	Plant height	Number of productive tillers	Single plant yield	Panicle length	Flag leaf length	Flag leaf width	Spikelet fertility	1000 grain weight	Grain length	Grain breadth	L/B ratio
Lines												
ADT (R) 45	-16.58 **	-17.03 **	-1.05 **	0.64	-1.37 *	1.03 *	-0.02	2.18 **	-1.30 **	0.16 **	-0.12 **	0.23 **
ADT 37	-14.42 **	-8.51 **	-2.52 **	1.08	-0.32	2.46 **	-0.04	-2.15 **	2.33 **	-0.29 **	0.42 **	-0.63 **
ADT 53	-7.92 **	-2.92 **	0.33	2.22 **	-2.76 **	-5.53 **	0.10	0.68	-0.72 **	0.34 **	0.06 **	0.06 *
CO 52	7.25 **	8.99 **	5.31 **	5.14 **	-2.16 **	-4.20 **	-0.12	0.42	-1.72 **	-0.18 **	-0.02	-0.09 **
CO 54	6.25 **	9.49 **	1.20 **	2.25 **	0.36	-2.40 **	0.11	-1.98 **	-1.30 **	0.17 **	-0.05 **	0.13 **
ANNA(R)4	2.58 **	-2.88 **	1.76 **	1.49 *	1.92 **	3.78 **	-0.08	1.57 **	5.62 **	0.41 **	0.24 **	-0.14 **
CB 12132	13.58 **	5.58 **	-4.64 **	0.24	-0.15	-0.29	-0.01	0.77	-1.23 **	-0.15 **	-0.19 **	0.19 **
RNR 15048	9.25 **	7.28 **	-0.40	-13.07 **	4.48 **	5.15 **	0.08	-1.51 **	-1.68 **	-0.45 **	-0.34 **	0.26 **
Testers												
3-11-11-1	0.04	-0.70	0.41	1.46 **	-0.01	-1.10 **	-0.01	1.08 **	0.25 *	0.01	0.02 *	-0.03 *
3-11-11-2	0.23 **	-0.26	-0.02	1.33 **	-0.02	0.23	-0.07	1.22 **	-0.05	0.02	0.01	-0.01
TR 13069	-0.27 **	0.96 *	-0.38	-2.80 **	0.02	0.87 **	0.08	-2.31 **	-0.19	-0.03 *	-0.03 **	0.04 **
SE (lines)	0.12	0.96	0.47	0.14	0.48	0.57	0.08	0.54	0.22	0.024	0.01	0.023
SE (testers)	0.07	0.58	0.29	0.18	0.29	0.35	0.052	0.33	0.13	0.015	0.01	0.01

* Significant at 5 per cent level and ** Significant at 1 per cent level

in the lines ADT 45, ADT 53, CO 54 and Anna (R) 4. Parents exhibiting good general combining ability with significant *per se* performance can be used to produce better performing hybrids as these genotypes possess good inherent potential. The lines ADT (R) 45, ADT 53, CO 54, ANNA (R) 4 and the testers 3-11-11-1 and 3-11-11-2 were determined to be good general combiners. Hence, genotypes showing high *gca* can be used for pedigree breeding to obtain superior recombinants. The present findings are also in accordance with the results of Vadivel *et al*. (2018), Singh *et.al*. (2020) and Praveen *et al*. (2020).

The estimates of the specific combining ability of 24 hybrids for twelve characters are represented in **Table 5.** The specific combining abilities are due to non-additive gene action and epistatic gene action (Sprague and Tatum, 1942). The usefulness of a particular cross in the exploitation of heterosis is judged by the specific combining ability effects. The cross combinations ADT 53 × TR 13069, CO 54 × 3-11-11-2, RNR 15048 × 3-11-11-2 had exhibited positive significant *sca* effects for L/B ratio and negative significant *sca* effect for days to 50% flowering and grain breadth. The crosses ADT 37 × 3-11-11-1, CO 54 × 3-11-11-2, ANNA (R) 4 × TR 13069 and CB 12132 × 3-11-11-1 exhibited negative significant specific combining ability for plant height. For the yield and yield attributing traits the positive significant specific combining ability had been obtained from the cross combinations *viz.,* ADT (R) 45 × 3-11-11-2, ADT 37 × 3-11-11-1, ADT 37 × 3-11-11-2, ADT 53 × 3-11-11-1, CB 12132 × 3-11-11-1, CO 52 × 3-11-11-1, CO 52 × 3-11-11-2, CO 52 × 3-11-11-1 and CO 54 × 3-11-11-1. Hence the hybrids obtained from these crosses can be forwarded to further generations for improving desired traits. The present findings are also in accordance with the results of Suvathipriya *et al.* (2018), Ambikabathy *et al.* (2019) and Vadivel *et al.* (2018).

Jones initially described the heterosis in rice in 1926. Promising hybrid combinations with high heterosis have to

Table 5. Specific combining ability effects of hybrids for different quantitative and grain characters in rice

Name of crosses	Days to 50 % flowering	Plant height	Number of Productive tillers	Single Plant yield	Panicle Length	Flag Leaf length	Flag Leaf width	Spikelet fertility	1000 grain weight	Grain Length	Grain breadth	L/B ratio
ADT (R) 45 × 3-11-11-1	-0.27 **	-0.22	-1.08	-4.82 **	-1.34	-0.81	-0.09	0.90	0.22	0.04	-0.02	0.05
ADT (R) 45 × 3-11-11-2	-0.23	0.53	0.61	5.14 **	-0.26	0.83	-0.02	-1.20	0.13	-0.07 *	-0.01	-0.01
ADT (R) 45 ×TR 13069	0.27	-0.31	0.46	-0.32	1.60	-0.02	0.11	0.30	-0.35	0.03	0.04	-0.04
ADT 37×3-11-11-1	0.29	-6.54 **	-0.21	0.24	0.67	1.47	-0.02	0.61	0.12	-0.12 **	-0.09 **	0.04
ADT 37× 3-11-11-2	-0.90 **	3.63 **	-0.13	4.13 **	-0.52	0.28	0.10	-0.81	0.15	0.08	0.02	0.02
ADT 37×TR 13069	0.60 **	2.91 *	0.33	-4.37 **	-0.14	-1.75 *	-0.08	0.20	-0.27	0.04	0.07 *	-0.07
ADT 53× 3-11-11-1	-0.71 **	1.75	-1.01	0.37	-0.55	0.23	-0.14	2.40 **	0.18	-0.02	0.07 *	-0.10 *
ADT 53× 3-11-11-2	1.60 **	-1.20	0.47	-1.57	0.66	0.22	-0.25	0.30	0.99 **	0.16 **	0.07 *	-0.01
ADT 53×TR 13069	-0.90 **	-0.54	0.53	1.20	-0.10	-0.45	0.39 *	-2.70 **	-1.17 **	-0.14 **	-0.13 **	0.11 **
CO 52× 3-11-11-1	-0.38	-2.42	3.56 **	1.24	0.20	-0.02	0.02	-1.72 *	-0.53	-0.01	-0.01	0.02
CO 52 × 3-11-11-2	1.44 **	0.38	-0.01	-0.64	-0.57	-0.45	0.05	3.69 **	0.28	0.00	-0.03	0.05
CO 52 × TR 13069	-1.06 **	2.04	-3.55 **	-0.61	0.36	0.47	-0.07	-1.97 *	0.25	0.01	0.04	-0.06
CO 54× 3-11-11-1	0.63 **	3.83 **	0.02	0.61	-0.58	-1.23	0.08	0.28	0.22	-0.02	0.04	-0.07
CO 54× 3-11-11-2	-1.56 **	-5.87 **	0.32	-2.43 *	0.18	-0.97	-0.04	-0.83	0.13	0.06	-0.05 *	0.12 **
CO 54× TR 13069	0.94 **	2.04	-0.34	1.82	0.39	2.20 **	-0.04	0.55	-0.35	-0.04	0.02	-0.05
ANNA(R)4×3-11-11-1	-1.71 **	5.58 **	1.66 *	-0.34	-0.44	0.10	0.07	0.80	0.14	-0.03	0.03	-0.03
ANNA(R)4 × 3-11-11-2	2.10 **	-0.24	-1.06	0.60	0.07	-1.42	0.04	-0.39	-1.67 **	-0.10**	-0.08 **	0.05
ANNA(R)4 ×TR 13069	-0.40	-5.34 **	-0.60	-0.26	0.38	1.31	-0.11	-0.42	1.53 **	0.13 **	0.05	-0.02
CB 12132 × 3-11-11-1	0.29	-3.75 **	-2.09 **	4.37 **	0.95	0.49	0.06	-1.50	0.07	0.17 **	0.06 *	-0.01
CB 12132 ×3-11-11-2	-0.90 **	2.92 *	-0.41	-3.26 **	1.18	0.95	0.06	0.95	-0.63	-0.10 **	0.09 **	-0.21 **
CB 12132 × TR 13069	0.60 **	0.83	2.50 **	-1.11	-2.13 *	-1.45	-0.12	0.55	0.57	-0.07 *	-0.15 **	0.22 **
RNR 15048 × 3-11-11-1	1.63 **	1.79	-0.87	-1.66	1.10	-0.24	0.02	-1.78 *	-0.42	-0.02	-0.07 *	0.11 *
RNR 15048 × 3-11-11-2	-1.56 **	-0.16	0.21	-1.98	-0.74	0.56	0.07	-1.71 *	0.62	-0.03	-0.00	-0.01
RNR 15048 ×TR 13069	-0.06	-1.63	0.67	3.65 **	-0.36	-0.31	-0.09	3.49 **	-0.21	0.05	0.07 *	-0.09 *
SE (Hybrids)	0.20	1.66	0.82	0.79	0.83	0.99	0.14	0.95	0.38	0.04	0.02	0.04

* Significant at 5 per cent level and ** Significant at 1 per cent level

Table 6. Estimates of standard heterosis for quantitative and grain characters in rice (per cent)

Name of crosses	Days to 50 % flowering	Plant height	Number of productive tillers	Single plant yield	Panicle length	Flag leaf length	Flag leaf width	Spikelet fertility	1000 grain weight	Grain length	Grain breadth	L/B ratio
ADT (R) 45 × 3-11-11-1	-22.48 **	-25.54 **	-6.39	-4.26	-2.02	-7.89 *	-1.69	7.79 **	9.88 **	-3.47 **	-23.24 **	25.73 **
ADT (R) 45 × 3-11-11-2	-22.48 **	-24.52 **	-0.84	23.11 **	2.90	1.64	0.00	5.12 **	6.99 *	-5.21 **	-23.65 **	24.27 **
ADT (R) 45 ×TR 13069	-22.48 **	-24.20 **	-3.08	-3.58	11.64	0.97	23.73	2.35	2.34	-4.17 **	-23.24 **	24.90 **
ADT 37×3-11-11-1	-20.18 **	-23.67 **	-9.03 *	11.05 *	12.06	4.06	2.54	1.49	36.16 **	-13.89 **	-3.73 *	-10.46 **
ADT 37× 3-11-11-2	-21.10 **	-14.69 **	-10.57 *	21.53 **	6.53	4.47	8.47	-0.26	34.11 **	-10.42 **	0.00	-10.46 **
ADT 37×TR 13069	-20.18 **	-14.27 **	-10.13 *	-13.64 **	8.47	0.00	5.93	-3.69 *	29.95 **	-11.81 **	0.41	-12.13 **
ADT 53× 3-11-11-1	-15.14 **	-11.95 **	0.00	14.60 **	-4.79	-25.67 **	5.08	7.79 **	13.94 **	-1.22	-12.03 **	12.34 **
ADT 53× 3-11-11-2	-12.84 **	-14.06 **	4.63	8.84	0.74	-21.46 **	-9.32	5.12 **	17.73 **	2.08 *	-12.86 **	17.15 **
ADT 53×TR 13069	-15.60 **	-12.47 **	3.30	5.04	-2.58	-21.54 **	57.63 **	-3.79 *	0.63	-3.99 **	-22.82 **	24.48 **
CO 52× 3-11-11-1	-0.92 **	-5.39 **	42.09 **	25.13 **	1.43	-22.21 **	0.00	1.81	1.23	-10.07 **	-19.09 **	11.09 **
CO 52 × 3-11-11-2	0.92 **	-2.64	24.45 **	19.54 **	-2.16	-19.31 **	-1.69	9.39 **	4.94	-9.72 **	-20.33 **	13.18 **
CO 52 × TR 13069	-1.83 **	-0.21	7.27	8.13	2.30	-14.28 **	0.00	-3.16	3.72	-10.42 **	-19.09 **	10.67 **
CO 54× 3-11-11-1	-0.92 **	0.32	8.37 *	15.34 **	9.43	-20.31 **	23.73	1.28	9.88 **	-4.34 **	-17.84 **	16.53 **
CO 54× 3-11-11-2	-2.75 **	-7.51 **	7.82	6.53	12.89 *	-15.21 **	9.32	-0.05	6.99 *	-2.78 **	-22.41 **	25.52 **
CO 54× TR 13069	-0.92 **	0.21	3.30	6.86	14.04 *	-2.95	22.03	-2.99	2.34	-5.21 **	-21.16 **	20.50 **
ANNA(R)4×3-11-1 1-1	-6.42 **	-8.67 **	18.06 **	10.58 *	17.26 *	3.90	7.63	6.83 **	60.76 **	-0.17	-6.64 **	6.90 **
ANNA(R)4 × 3-11-11-2	-2.75 **	-13.21 **	4.19	12.82 **	19.56 **	3.27	0.00	5.39 **	45.08 **	-1.39	-11.62 **	11.51 **
ANNA(R)4 ×TR 13069	-5.50 **	-16.49 **	4.63	-1.06	21.17 **	14.12 **	0.00	0.54	67.82 **	1.91	-7.88 **	10.46 **
CB 12132 × 3-11-11-1	5.50 **	-9.41 **	-26.65 **	20.23 **	14.10 *	-7.97 *	11.86	2.59	9.29 *	-6.42 **	-23.24 **	21.76 **
CB 12132 ×3-11-11-2	4.59 **	-3.38 *	-21.15 **	-1.38	15.09 *	-2.22	7.63	6.13 **	1.86	-11.11 **	-22.41 **	14.44 **
CB 12132 × TR 13069	5.50 **	-4.12 **	-9.91 *	-6.90	0.09	-7.89 *	5.08	0.76	9.74 **	-11.28 **	-34.02 **	34.52 **
RNR 15048 × 3-11-11-1	2.75 **	-3.28 *	-2.64	-33.62 **	36.13 **	7.16	16.10	-0.89	2.38	-14.93 **	-34.44 **	29.71 **
RNR 15048 × 3-11-11-2	0.00	-4.55 **	0.22	-34.87 **	27.61 **	14.00 **	16.10	-0.61	7.88 *	-15.10 **	-32.37 **	25.52 **
RNR 15048 ×TR 13069	0.28	1.65	0.8931	-30.70 **	1.35	1.11	0.23	1.16	0.45	0.05	0.03	0.05

* Significant at 5 per cent level and ** Significant at 1 per cent level

be identified for commercial exploitation. Typically, hybrid performance is forecasted as a percentage increase over the standard parent. The performance of F_1 hybrids was evaluated on the basis of standard heterosis against the best high yielding variety (Virmani *et al.,* 1982). As a result, plant breeders prefer standard heterosis to other types of heterosis while evaluating the hybrids. In the present study, the cross combinations ADT (R) 45 × 3-11-11-1, ADT (R) 45 × 3-11-11-2, ADT 53 × 3-11-11-1, ADT 53 × 3-11-11-2, ADT 53 × TR 13069, CO 52 × 3-11-11-1, CO 54 × 3-11-11-2, ANNA (R) 4 × 3-11-11-1, ANNA (R) 4 × 3-11-11-2 and ANNA (R) 4 × TR 13069 had significant positive standard heterosis for spikelet fertility, 1000 grain weight and L/B ratio and significant negative heterosis for days to 50% flowering, plant height and grain breadth, respectively **(Table 6)**. For the traits such as single plant yield and number of productive tillers, significant positive heterosis had been obtained in the hybrids CO 52 × 3-11-11-1, CO 52 × 3-11-11-2, CO 54 × 3-11-11-1, ANNA (R) 4 × 3-11-11-1. These results are in agreement with the findings of Utharasu and Anandakumar (2013), Vadivel *et al*. (2018), Kour *et al*. (2019) and Ambikabathy *et al*. (2019) for yield contributing traits. The hybrids ADT 37× 3-11-11-2 and CB 12132 × 3-11-11-1 regarded promising hybrids in improving single plant yield. Similarly, for grain length, the elite cross combinations obtained was ADT 53 × 3-11-11-2. The hybrids ADT 53 × TR 13069 and CO 54 × 3-11-11-2 was found superior for the L/B ratio. Based on mean, *sca* and standard heterosis, ADT 37× 3-11-11-2, CB 12132 × 3-11-11-1, ADT 53 × 3-11-11-2, ADT 53 × TR 13069 and CO 54 × 3-11-11-2 were found to be the best hybrids.

The characters that are controlled by non-additive gene action *viz.,* plant height, flag leaf length, flag leaf width, spikelet fertility, 1000 grain weight, single plant yield, grain length, grain breadth and L/B ratio. The traits with non-additive gene action can be further subjected to heterosis breeding. In the present study, ADT (R) 45, ADT 53, CO 54, ANNA (R) 4, 3-11-11-1 and 3-11-11-2 were adjudged as good general combiners among the parents with respect to yield and yield attributing characters. Based on the results of *per se* performance, standard heterosis and *sca*, the hybrids *viz.,* ADT 37× 3-11-11-2, CB 12132 × 3-11-11-1, ADT 53 × 3-11-11-2, ADT 53 × TR 13069 and CO 54 × 3-11-11-2 were identified as best hybrids. Hence, the above hybrids can be exploited in future breeding programs.

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