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Research Article

Combining ability and gene action analysis for yield and yield attributing traits in rice (*Oryza sativa.L*)

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Abstract
Six lines and four testers were involved in the combining ability and gene action study in line x tester mating design to discern desirable general and specific combiner for breeding programme. The combining ability variance indicated that *sca* variance was higher than *gca* variance indicating the preponderance of non-additive gene action for the characters studied *viz*., days to 50 percent flowering, panicle length, plant height, the number of grains per panicle, the number of tillers per plant, the number of productive tillers per plant, flag leaf length, flag leaf breadth, spikelet fertility, test weight and single plant yield. Among the parents, Improved White Ponni, RG192, RG163 and RG105 were discovered as the best general combiners for single plant yield. The cross combinations *viz.,* ADT37 X RG163, ADT43 X RG105, ADT45 X RG163, ADT(R)48 X RG105, CO51 X Kavuni and Improved White Ponni X RG192 were the ideal specific combiners for single plant yield. Therefore, the aforementioned cross combinations may be employed in the upcoming breeding programmes in order to develop a higher heterosis for yield.

Key words
Rice, Line x tester, gene action, combining ability.

INTRODUCTION

Rice being the predominant staple food for more than 70 percent of the population in India is cultivated in an area of 44.0 million ha with a production of 116.48 million tonnes and a productivity of 2647 kg/ha (Director IIRR Report, 2019-20). Although, India holding second place in world rice production and had accomplished a self sufficiency in rice production, as per the projections made by the Population Foundation of India, the country's population will be 1824 million by the end of 2050. It has also been envisioned that with the current production scenario, India has to produce 137 million tonnes of rice on 37 million ha of land in 2050. As a consequence, an upswing in yield of about 50 per cent have to be accomplished within the next three decades to keep India's food secure (Mohanthy and Yamano,2017). Therefore, the development of high yielding varieties is the only way to address the forthcoming food security crisis. Conscientious selection of suitable genotypes as parents for hybridization lays the foundation for an efficient breeding programme which eventually results in the development of potential high yielding cultivars. Combining ability analysis besides furnishing knowledge on nature and magnitude of gene effects governing yield and yield contributing traits, also helps in recognizing the superior parents, cross combinations and development of systemic breeding plan for augmenting yield. Accordingly the current research was carried out to know the combining ability of yield and its component attributes with intend to figure out good combiners and cross combinations towards the development of best high-yielding varieties.

MATERIALS AND METHODS

The current study was conducted at the Department of Rice, Centre for Plant Breeding and Genetics, Coimbatore, during 2019 to 2020. The materials for the present study comprised of six high yielding superior varieties as lines *viz.,* ADT37, ADT43, ADT45, ADT(R)48 and CO51 and four traditional cultivars as testers *viz.,*RG192, RG105, RG163 and Kavuni. To achieve synchronization between the female and male parents staggered sowing of entries were done. Crossing programme was carried out during *Kharif* 2019 following Line x Tester mating design of Kempthrone (1957) to generate hybrids.

Twenty-four hybrids were planted in randomized block design in two replications along with parents at a spacing of 20cm x 20cm during *summer,* 2020. Proposed package of practices were followed for the establishment and growth of the crop. The biometrical observations *viz.,* days to 50 percent flowering, plant height (cm), panicle length (cm), the number of tillers per plant, the number of productive tillers per plant, the number of grains per panicle, spikelet fertility (%), flag leaf length (cm), flag leaf breadth (cm), test weight (g) and single plant yield (g) were noted down in five randomly tagged plants in each one of the cross combinations and parents in each replication and the mean performance was worked out and tabulated. Out of the parental genotypes and 24 crosses, good combiners and good cross combinations were deduced using *gca* and *sca* effects (Sprague and Tatum, 1942).

RESULTS AND DISCUSSION

The mean performance of genotypes and hybrids on different biometrical traits were depicted in **Table (1 and 2)**. Among parents ADT(R) 48, RG192 and RG105 found highly significant for days to 50 per cent flowering. Similarly for test weight among lines ADT37 and the tester RG192 were found highly significant. The mean performance of cross combinations indicated that hybrid ADT(R) 48 X RG192 recorded significance for most of the traits studied. The cross combination ADT37 X RG163, ADT43 X RG105 and Improved White Ponni X RG192 found highly significant for single plant yield.

Table 1. Mean performance of parents for yield and yield related traits

Parents	DFF(%)	PH (cm)	PL (cm)	TP	PTP	GP	FL (cm)	FB (cm)	SF (%)	TW (g)	SPY (g)
LINES											
ADT37	86.00	87.50*	15.59	14.00	21.38	171.50	24.50	0.90	86.70	23.40**	37.50
ADT43	82.00	88.00	19.59	17.41	23.25	125.50	24.00	0.90	90.78	15.22	29.30
ADT45	82.00	99.75	20.09	18.75	26.34	174.50	34.92*	0.80	88.08	12.82	37.00
ADT48	76.00**	84.42**	21.84	19.41	26.09	117.50	26.66	0.78	75.11	17.08	31.50
CO51	81.00	97.17	26.16	22.50	26.09	250.00	33.17	1.43*	89.60	16.03	48.13
Improved White Ponni	107.00	138.58	14.34	13.25	24.50	151.00	29.66	1.38*	86.48	17.75	42.15
Mean (Lines)	85.67	99.24	19.60	17.55	24.61	165.00	28.82	1.03	86.125	16.20	37.59
TESTERS											
RG192	87.50**	101.25*	28.91	28.00	24.59	134.50	27.34	0.82	92.56	23.63*	29.13
RG105	82.50**	115.00*	24.84	21.00	24.09	127.00	31.50	0.63	87.17	15.60	40.18
RG163	97.00	144.33	29.91	25.50	24.59	156.00	31.67	0.80	88.29	21.68	44.57
KAVUNI	116.50	154.75	10.50	8.50	26.37	115.00	32.60	1.21*	67.51	18.50	43.00
Mean (Testers)	95.88	128.83	23.54	20.75	24.91	133.13	30.78	0.87	83.87	19.85	39.22
Mean (Parents)	**89.75**	**111.08**	**21.18**	**18.83**	**24.73**	**152.25**	**29.60**	**0.96**	**85.23**	**17.66**	**38.25**
SE	**2.52**	**5.12**	**4.73**	**5.38**	**1.84**	**15.49**	**2.82**	**0.156**	**10.63**	**1.65**	**7.32**
CD at 5 %	**5.06**	**10.29**	**9.50**	**10.82**	**3.69**	**31.05**	**5.66**	**0.31**	**21.37**	**3.33**	**14.70**
CD at 1 %	**6.73**	**13.72**	**2.67**	**14.43**	**4.92**	**41.40**	**7.55**	**0.42**	**28.50**	**4.44**	**19.61**

Combining ability analysis indicated highly significant differences among the crosses for all the characters studied (**Table 3**). Mean squares due to lines (female parents) and testers (male parents) were significant for all the characters except panicle length indicating the preponderance of additive variance. Mean square due to Line x Tester was significant for all the characters studied indicating the presence of non-additive variance. From the perusal of the results it was observed that ratio of *gca* variance to *sca* variance was less than one for all the characters studied. The results signify the presence of non-additive gene action and it can be concluded that dominance and epistatic gene interaction govern the expression of traits. Thus offering scope for heterosis breeding by exploiting hybrid vigor. The present findings were in conformation with earlier findings of Bineenta Devi and Lal (2015), Ambikabathy *et al.(*2019) and Mohanasundaram *et al.*(2019). The proportional contribution to the total variance by lines, testers and interactions revealed that the testers and line x testers interaction have contributed more than lines for all the characters except for days to 50 percent flowering, plant height and breadth of flag leaf (**Table 4**).

Table 2. Mean performance of hybrids for yield and yield related traits

Hybrids	DFF(%)	PH (cm)	PL (cm)	TP	PTP	GP	FL (cm)	FB (cm)	SF (%)	TW (g)	SPY (g)
ADT37 X RG192	84.50	104.50**	28.50	18.50	18.50	88.00	32.07	1.45*	76.29	26.35**	39.83
ADT37 X RG105	85.00	101.90**	24.10	15.90	14.60	112.50	30.10	1.43	70.50	15.02	35.04
ADT37 X RG163	83.00	118.90	25.00	25.06	21.10	112.00	25.75	1.22	76.94	21.68	80.03**
ADT37 X Kavuni	90.00	113.50	26.50	15.50	14.60	10.50	36.50	0.85	8.95	22.30	8.40
ADT43 X RG192	87.00	112.10	27.30	18.50	17.50	134.00*	26.10	1.22	58.35	22.30	35.47
ADT43 X RG105	85.00	125.75	24.25	25.00	10.20	117.50	25.50	1.25	61.20	21.05	86.59**
ADT43 X RG163	84.00	132.86	26.70	37.70	32.60	140.00*	28.60	1.38	66.82	21.27	36.09
ADT43 X Kavuni	87.00	116.38	27.16	18.88	14.00	67.50	57.50	1.40	26.51	16.95	9.96
ADT45 X RG192	74.00**	109.50	25.84	27.66	25.91	142.00*	30.13	1.05	76.26	18.75	35.32
ADT45 X RG105	82.50	113.50	23.66	18.16	17.84	39.00	26.34	1.13	81.23	15.20	20.84
ADT45 X RG163	74.00**	118.51	23.59	23.84	29.75	22.50	23.15	0.80	92.33**	18.55	50.70
ADT45 X Kavuni	80.00	144.00*	30.75**	16.00	16.50	14.00	39.50*	1.40	45.65	18.55	17.69
ADT(R)48 X RG192	74.00**	100.13**	26.59	26.25	22.20	133.00*	31.00	1.20	85.67*	26.35**	47.45
ADT(R)48 X RG105	82.50	104.50**	24.00*	26.50	27.00	138.50*	36.00	1.00	50.19	15.02	46.66
ADT(R)48 X RG163	74.00**	122.00	28.00	53.50	47.50**	135.00*	26.75	0.65	13.51	21.68	9.55
ADT(R)48 X Kavuni	80.00	127.13	31.38**	21.33	19.47	18.50	22.75	1.05	11.88	22.30	10.99
CO51 X RG192	85.00	104.33**	26.66	31.91	31.09	151.50**	30.16	1.30	74.72	22.30	47.60
CO51 X RG105	75.5**	110.75	25.00	28.75	25.75	138.50*	27.00	1.15	71.58	21.05	18.59
CO51 X RG163	83.50	125.90	25.20	26.10	23.20	130.50	26.70	0.79	59.76	21.27	29.00
CO51 X Kavuni	86.00	138.00	27.09	18.66	12.84	18.00	41.50**	1.10	16.88	16.95	24.00
IW ponni X RG192	94.50	133.33	26.34	22.00	21.00	175.00**	32.50	1.20	57.73	20.30	67.59**
IW ponni X RG105	96.00	134.00	25.00	33.00	16.50	111.00	40.50	1.10	75.03	27.95**	41.50
IW ponni X RG163	92.00	137.50	27.50	17.75	17.75	142.50*	39.33*	1.13	79.40	18.13	44.30
IW ponni X Kavuni	93.50	138.00	28.25	15.50	16.00	39.50	34.00	1.05	11.26	13.60	25.50
Mean (Hybrids)	**83.85**	**120.29**	**26.43**	**24.25**	**21.39**	**97.13**	**32.06**	**1.14**	**56.19**	**20.20**	**36.20**
SEd (Standard error difference)	**2.34**	**5.561**	**1.20**	**5.58**	**6.24**	**17.21**	**2.89**	**0.15**	**12.20**	**1.89**	**8.23**
CD at 5 %	**4.81**	**11.46**	**2.48**	**11.26**	**12.92**	**35.63**	**5.99**	**0.32**	**25.26**	**3.92**	**17.05**
CD at 1 %	**6.54**	**15.57**	**3.37**	**15.30**	**17.54**	**48.37**	**8.14**	**0.43**	**34.20**	**5.33**	**23.1429**

Tables 3. Analysis of variance of combining ability for grain yield and its related traits

Sources of variation	Df	DFF(%)	PH (cm)	PL (cm)	TP	PTP	GP	FL (cm)	FB (cm)	SF (%)	TW (g)	SPY (g)
Replication	1	35.020	56.401	3.78	25.3025	33.28	468.75	1.0591	0.0574	74.7003	0.1692	65.8477
Hybrid	23	85.15**	347.65**	8.35**	150.22**	132.31**	5626.23**	119.91**	0.089**	1433.41**	27.52**	881.88**
Lines	5	302.57**	640.83**	2.92	170.62**	162.22**	4865.40**	66.09**	0.113**	924.06**	13.83*	402.13**
Testers	3	40.74**	948.20**	36.55	339.18**	383.42**	27271.25**	243.87**	0.126**	7004.16**	41.94**	2197.60**
L x t interaction	15	21.55**	129.81**	4.52**	105.62**	72.12**	1550.83**	113.06**	0.074**	489.05**	29.20**	778.65**
Error	23	5.41	32.25	1.43	31.14	38.96	296.3152	8.38	0.023	148.93	3.59	67.83
GCA		4.81	16.48	0.28	3.373	4.554	308.33	0.51	0.00	71.44	-0.13	7.81
SCA		8.07	48.77	1.54	37.24	16.57	2509.03	52.33	0.02	170.05	12.80	355.410
GCA/SCA		0.59	0.33	0.18	0.09	0.27	0.12	0.009	0.04	0.42	-0.009	0.02

*significant at 5 per cent interval **significant at 1 per cent interval

DFF-Days to 50% Flowering, PH-Plant Height (cm), PL-Panicle length (cm), TP-Tillers per plant, PTP-Productive tillers per plant, GP-Grains per panicle, FL-Flag leaf length (cm), FB-Flag leaf breadth (cm), SF-Spikelet fertility (%),TW-Test weight (g), SPY-Single plant yield (g)

The effect of general combining ability (*gca*) recognizes superior parents, while the specific combining ability (*sca*) assists in detection of good hybrid combinations. Analysis of mean performance of the parents and their *gca* effects revealed that *gca* is indicative of mean for about all the character studied (Table 5). Negative *gca* effects were regarded as desirable for days to 50 per cent flowering and plant height while positive *gca* effects were important for other traits. Accordingly the lines ADT45 and ADT(R) 48 and the tester RG163 shown highly significant negative *gca* effect for days to 50 per cent flowering, hence could be best combiner for developing early duration varieties. Regarding plant height, genotypes *viz.,* ADT37, ADT(R)48, RG105, and RG192 recorded the desirable highly significant negative *gca* effect for plant height and therefore could be utilized for developing semi dwarf varieties.

Among the lines highly significant positive *gca* effect was displayed by Improved White Ponni for characters like flag leaf length, the number of grains per panicle and single plant yield hence it can be concluded as good combiner among lines. Correspondingly significantly positive *gca* values were recorded for various traits by three testers *viz.,* RG192 for single plant yield, test weight, spikelet fertility, the number of grains per panicle and flag leaf breadth; RG105 for spikelets fertility, the number of grains per panicle and single plant yield and RG163 for single plant yield, spikelet fertility, the number of grains per panicle, the number of tillers and productive tillers per plant. Hence these combiners could be utilized for developing promising and desirable hybrids (Table 5). Good general combiners for yield and yield attributing characters in rice were also reported by Suvathipriya and Kalaimagal (2018) and Kour *et al.,(*2019).

Table 4. Contribution (%) of lines, testers and their interaction

	DFF(%)	PH (cm)	PL (cm)	TP	PTP	GP	FL (cm)	FB (cm)	SF (%)	TW (g)	SPY (g)
Lines	77.25	40.07	7.61	24.69	26.65	18.8	11.98	27.50	14.01	10.93	9.91
Testers	6.24	35.58	57.09	29.45	37.80	63.22	26.53	18.38	63.73	19.88	32.50
Line x Testers	16.51	24.35	35.3	45.86	35.55	17.98	61.49	54.11	22.05	69.20	57.58

Table 5. General combining ability effects of parents for eleven characters in rice

	DFF(%)	PH (cm)	PL (cm)	TP	PTP	GP	FL (cm)	FB (cm)	SF (%)	TW (g)	SPY (g)
Lines											
ADT37	1.77*	-10.59**	-0.41	-5.51*	-4.19	-16.38*	-0.95	0.1	1.98	0.13	4.63
ADT43	1.9*	1.48	-0.08	0.77	-2.82	17.63**	2.37*	0.17**	-2.97	0.19	5.83
ADT45	-6.23**	1.09	-0.47	-2.83	1.11	-42.75**	-2.28*	-0.04	17.67**	-2.44**	-5.06
ADT48	-6.23**	-6.85**	1.06*	7.65**	7.65**	9.13	-2.93**	-0.16**	-15.88**	0.13	-7.53*
CO51	-1.35	-0.54	-0.44	2.11	1.83	12.5	-0.72	-0.05	-0.46	0.19	-6.40*
IW PONNI	10.15**	15.42**	0.34	-2.19	-3.58	19.88**	4.52**	-0.02	-0.34	-0.21	8.533**
SE for lines	0.8225	2.0079	0.424	1.9731	2.2069	6.0860	1.024	0.054	4.31	0.6707	2.9118
Testers											
RG192	-0.69	-9.64**	0.44	-0.11	1.31	40.13**	-1.73*	0.1*	15.31**	2.52*	9.35**
RG105	0.56	-5.22**	-2.1**	0.3	-2.74	12.38*	-1.15	0.04	12.1**	-0.99	5.34*
RG163	-2.1 **	5.66**	-0.43	6.41**	7.26**	16.63**	-3.68**	-0.14**	8.6*	0.23	5.42*
Kavuni	2.23**	9.21**	2.09**	-6.6**	-5.82**	-69.13**	6.57**	0	-36.01**	-1.76**	-20.10**
SE for testers	0.671	1.6395	0.3462	1.6110	1.8019	4.9692	0.8361	0.0443	3.5230	0.5476	2.3775

*significant at 5 per cent interval **significant at 1 per cent interval IW Ponni- Improved white ponni

On analysis of *sca* effects and *per se* performance cross combinations ADT37 X RG163, ADT43 X RG105, ADT45 X RG163, ADT(R)48 X RG105, CO51 X Kavuni and Improved White Ponni X RG192 were promising for single plant yield. Besides yield, the cross combinations ADT45 X RG163 and ADT(R) 48 X RG105 showed desirable significant *gca* effect for plant height and flag leaf length respectively. These cross combinations involved three types of combination between parents of high and low *gca* effects *ie.,* low x low, low x high and high x low. The crosses *viz.,* ADT37 X RG163, ADT43 X RG105, ADT45 X RG163 and ADT(R)48 X RG105 with significant *sca* had parents with low x high *gca* effect which indicated the existence of dominance x additive type of gene interaction. The superiority of crosses CO51 X Kavuni in which both the parents had low *gca* was due to dominance epistatic effect. Out of six cross combinations showing significant *sca* effects, only the cross Improved White Ponni X RG192 had both the parents with high *gca* effect indicating additive gene action. These findings were in agreement with the results of Batti *et al*.(2015), Madhuri *et al*.(2017), Sudeepthi *et al.(*2018) and Ambikabathy *et al.(*2019).

Table 6. Specific combining ability effects of hybrids for eleven characters in rice

Hybrids	DFF(%)	PH (cm)	PL (cm)	TP	PTP	GP	FL (cm)	FB (cm)	SF (%)	TW (g)	SPY (g)
ADT37 X RG192	-0.44	4.44	2.04*	-0.13	-0.01	-32.88*	2.7	0.12	2.81	2.49	-10.34
ADT37 X RG105	-1.19	-2.58	0.17	-3.15	0.14	19.38	0.15	0.15	0.23	-5.33**	-11.12
ADT37 X RG163	-0.52	3.54	-0.59	-0.09	-3.36	14.63	-1.68	0.12	10.17	0.11	33.79**
ADT37 X Kavuni	2.15	-5.41	-1.61	3.36	3.22	-1.13	-1.17	-0.39**	-13.21	2.72	-12.32*
ADT43 X RG192	1.94	-0.03	0.51	-6.41	-2.38	-20.88	-6.59**	-0.2	-10.18	-0.62	-15.91*
ADT43 X RG105	-1.31	9.2	-0.01	-0.32	-5.63	-9.63	-7.77**	-0.1	-4.11	1.64	39.22**
ADT43 X RG163	0.35	5.44	0.78	6.27	6.77	8.63	-2.15	0.21	5	0.66	-11.35
ADT43 X Kavuni	-0.98	-14.61**	-1.28	0.46	1.25	21.88	16.51**	0.08	9.29	-1.68	-10.96
ADT45 X RG192	-2.94	-2.24	-0.56	6.36	2.11	47.50**	2.08	-0.14	-12.92	-1.53	-5.17
ADT45 X RG105	4.31*	-2.65	-0.2	-3.56	-1.92	-27.75*	-2.29	-0.01	-4.73	-1.58	-15.64
ADT45 X Kavuni	-1.52	-8.52*	-1.94*	-3.99	-0.01	-48.5**	-2.95	-0.15	9.86	0.56	14.15*
ADT(R)48 X RG192	0.15	13.41**	2.7**	1.19	-0.18	28.75*	3.16	0.3*	7.79	2.55	6.66
ADT(R)48 X RG105	-2.94	-3.67	-1.34	-5.53	-8.15	-13.38	3.61	0.13	30.05**	2.49	9.44
ADT(R)48 X RG163	4.31	-3.71	-1.39	-5.7	0.7	19.88	8.03**	-0.01	-2.22	-5.33**	12.66*
ADT(R)48 X Kavuni	-1.52	2.91	0.94	15.2**	11.2*	12.13	1.3	-0.18	-35.4**	0.11	-24.54**
CO51 X RG192	0.15	4.48	1.8*	-3.96	-3.75	-18.63	-12.94**	0.07	7.57	2.72	2.43
CO51 X RG105	3.19	-5.77	0.24	5.67	6.56	1.75	0.56	0.11	3.68	-0.62	8.46
CO51 X RG163	-7.56*	-3.77	1.11	2.09	5.28	16.50	-3.19	0.03	3.75	1.64	-16.55**
CO51 X Kavuni	3.1	0.5	-0.35	-6.67	-7.28	4.25	-0.96	-0.15	-4.57	0.66	-6.22
IW ponni X RG192	1.27	9.04*	-0.99	-1.09	-4.56	-22.50	3.59	0.01	-2.85	-1.68	14.30*
IW ponni X RG105	1.19	7.27	-0.88	0.05	1.88	17.88	-2.35	-0.02	-13.43	-2.22	13.52*
IW ponni X RG163	1.44	3.52	0.32	10.63*	1.43	-18.38	5.07*	-0.06	7.03	8.94**	-8.56
IW ponni X Kavuni	0.1	-3.86	1.16	-10.72*	-7.32	8.88	6.43**	0.15	14.95	-2.09	-5.84
SEd(standard error difference)	**1.64**	**4.016**	**0.848**	**3.95**	**4.41**	**12.17**	**2.05**	**0.108**	**8.63**	**1.34**	**5.823**

*significant at 5 per cent interval **significant at 1 per cent interval

Single plant selection in segregating generations is effective for yield improvement in crosses displaying high *sca* effects. This type of selection is effective when both the parents involved in the cross have high general combining ability (high X high). When we have crosses displaying high *sca* effects with high x low general combiners as parental combination population improvement approaches like mass selection with random mating in early segregating generations is an effective approach (Redden and Jensen, 1974). Heterosis breeding is a promising approach when we have crosses displaying high *sca* effects with low x low general combiners.

From the above results and discussion we can infer that the non additive gene action plays a pivotal role in expression of various characters in the current study. The best combiners Improved White Ponni, RG192, RG105 and RG163 could be utilized as parents in breeding programmes towards the development of high yielding varieties. Hybrids *viz.,* ADT37 X RG163, ADT43 X RG105, ADT45 X RG163, ADT(R)48/RG105, CO51 X Kavuniand Improved White Ponni X RG192 could be used for the exploitation of heterosis for yield.

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