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Combining Ability for Grain Yield, Yield Components and Quality Parameters in Rice (*Oryza sativa* L.)

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Abstract Combining ability of two male sterile lines and 25 testers was studied for grain yield, yield components and quality parameters by Line ×Tester analysis. The results revealed pre ponderant non-additive gene action for all the traits studied. A perusal of *gca* effects revealed MTU 2247-55-2, JMP 16, MTU 2336-70-46-25-44, MTU 2336-62-25-39-16, MTU 2337-216-1-1 and MTU 2331-216-1-1 testers to be good combiners for grain yield plant^{-1}. In addition, JMP 16, MTU 2336-70-46-25-44, MTU 2337-216-1-1 and MTU 2331-216-1-1 were noticed to be good combiners for quality traits.These parents had also recorded high *per se* performance for the traits, indicating their suitability in breeding programs for development of high yielding and quality hybrids. Among the hybrids, 13 crosses had exhibited significant and desirable *sca* effects for grain yield plant$^{1.}$ Of these nine crosses had recorded significant and desirable *sca* effects in addition to high *per se* performance,compared to hybrid mean. Among these, APMS 8A ×MTU 2247-55-2, APMS 8A × MTU 2331-216-1-1 and APMS 8A × MTU 2337-216-1-1 involving poor and good combiner parents for grain yield plant^{-1}, had recorded maximum grain yield plant^{-1}, in addition to desirable *sca* effects for grain yield and are identified for commercial exploitation.

Keywords Combining ability, Grain yield, Quality, Rice, Yield components.

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Introduction

The concept of combining ability plays a significant role in crop improvement, since it helps the breeder to determine the nature and magnitude of gene action involved in the inheritance of traits. Combining ability is also useful in selection of desirable parents. Its role is important in deciding parents, hybrids and the appropriate breeding produres to be followed for selection of desirable segregants. General combining ability has been defined Sprague and Tatum (1942) as the average performance of a line in a series of hybrid combinations and specific combining ability as deviation in performance of the hybrid from average performance of the lines involved. It was further stated that *gca* effects were due to the additive type of gene action whereas, sca effects were due to the genes which are non-additive (dominant or epistatic) in nature. Line × Tester analysis is an important tool for estimating the general combining ability (GCA) of parents and selecting desirable parents and crosses with high specific combining ability (SCA) for exploitation of heterosis (Salgotra 2009).

In this context, the present investigation was undertaken to identify parents with better potential to transmit desirable characteristics to the progenies and identify the best specific crosses for grain yield, yield components and the quality characters studied. Analysis of quantitative inheritance was also an equally important objective for determining the nature and magnitude of gene action for decision on choice of most appropriate and efficient breeding procedures.

Materials and Methods

The experimental material comprised of two CMS lines namely, APMS 6A and APMS 8A and 25 testers namely, BPT 5204, RP6112-MS-128-5-2-3-1- 4-5, MTU 2244-128-18, MTU 2201-34-3-1, MTU 2049-5-2-1, MTU 2247-55-2, BPT 2659, JMP 16, MTU 1061, RM 168-28-1-1-1, MTU 2336-70-46-25-44, MTU 2347-158-3-1-1, MTU 2336-62-25-39-16, MTU 2284-103-1-7, HR L4, NLR 5815-10-1-1-1, UTR 51, NLR 3445, BPT 2782, MTU 2284-103-1-9, MTU 2345-98-3, MTU 2067-9-1-1-2, RM 138-80-3-1-1-1, MTU 2337-216-1-1 and MTU 2331-216-1-1 obtained from RARS, Maruteru and their 50 hybrids derived from the 2 × 25 line × Tester mating design. The hybrids and parents were evaluated in a randomized block design with two replications at RARS, Maruteru during *rabi* 2017-18 for grain yield, yield components and quality characters. The sowings were undertaken in nursery during the second fortnight of November 2017 and transplanting of the seedlings was taken up 25 days after sowing, depending on growth of the seedlings. The normal, healthy and vigorus seedlings of each genotype were transplanted in a six-row plot of 4.5-meter length, with a spacing of 20 ×15 cm and the crop was raised following recommended package of practices. Data was recorded on five randomly selected plants in each replication for the characters, namely, plant height, ear bearing tillers plant^{-1}, panicle length, number of grains panicle^{-1}, spikelet fertility percentage and grain yield plant^{-1} for all the genotypes. However, days to 50% flowering was recorded on plot basis, while observations on 1000-seed weight, L/B ratio, hulling, milling and head rice recovery percentage were obtained from a random grain sample drawn from each genotype in each replication. The estimates of combining ability variances and effects were obtained using Line × Tester analysis (Kempthorne 1957).

Results and Discussion

Analysis of variance for combining ability (Table1) revealed significant mean sum of squares for par-

Table 1. Combining ability ANOVA for grain yield, yield attributes and quality parameters in rice. *,** Significant at 5 and 1% levels, respectively.

Source of variation	df	Days to 50% flowering	Plant height	Ear bearing tilling plant^{-1}	Panicle length	Number of grains panicle^{-1}	Spikelet fertility (%)
Replications	1	71.59	389.17	0.91	0.34	271.62	2.72
Parents	26	60.34**	156.36**	11.32**	12.40**	5338.96**	145.49**
Hybrids	49	104.77**	38.38	4.50**	6.44**	5557.09**	761.54**
Lines	1	49.00**	28.73	5.00	22.71**	8281.00**	35.64
Testers	24	44.79**	152.39**	11.63**	12.30**	4835.55**	147.63**
Line × Tester	24	77.94**	36.89	2.92**	3.05	3291.55**	636.48**
Parents vs Hybrids	1	3704.27**	2025.44**	88.28**	281.52**	602360.38**	1699.92**
Error	76	5.63	42.36	1.28	2.34	243.62	13.47
σ^2GCA		2.28	-0.70	0.21	0.10	1264.51	23.21
σ^2SCA		35.68	-5.29	0.82	0.36	1524.01	311.61
σ^2GCA/ σ^2SCA		0.06	0.13	0.26	0.29	0.83	0.07

Table 1. Continued.

Source of variation	df	Grain yield plant^{-1}	1000-Seed weight	L/B ratio	Hulling (%)	Milling (%)	HRR (%)
Replications	1	0.02	0.48	0.07	1.45	0.77	2.65
Parents	26	35.69**	9.16**	0.09*	9.94	57.15**	127.97**
Hybrids	49	182.85**	36.27**	0.61**	469.44**	361.72**	334.54**
Lines	1	85.19**	14.40**	0.04	0.01	2.84	2.28
Testers	24	24.81**	6.42**	0.09*	8.82	60.14**	131.98**
Line × Tester	24	113.48**	31.85**	0.55**	452.17**	339.80**	318.04**
Parents vs Hybrids	1	1932.52**	38.72**	0.31*	225.29**	0.82	1087.90**
Error	76	3.93	2.62	0.05	11.82	12.05	11.74
σ^2GCA		4.68	0.78	0.01	9.39	8.96	8.69
σ^2SCA		54.80	14.64	0.25	220.27	163.97	153.25
σ^2GCA / σ^2SCA		0.09	0.05	0.04	0.04	0.05	0.06

ents, hybrids and parents vs hybrids components of variation for all the characters studied, except hulling percentage for parents, plant height for hybrids and milling percentage for parents vs hybrids com-

Table 2. Charcterization of parents based on *per se* performance and *gca* effects for grain yield, yield attributes and quality characters.

Line/Tester	Days to 50% flowering		Plant height		Ear bearing tillers plant^{-1}		Panicle length		Number of grains panicle^{-1}		Spikelet fertility (%)	
	per se	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*	*per se*	*gca*
Lines												
APMS 6A	H	L	H	L	L	L	L	L	L	L	H	H
APMS 8A	L	L	L	L	H	L	H	L	H	H	L	L
Testers												
BPT 5204	L	L	H	L	L	H	L	L	L	H	H	H
RP6112-MS-128-5-23-1-4-5	L	L	H	L	H	L	L	L	L	L	H	H
MTU 2244-128-18	L	L	H	L	H	L	H	L	H	H	L	H
MTU 2201-34-3-1	L	L	H	L	H	L	L	L	L	H	H	L
MTU 2049-5-2-1	L	L	L	L	L	L	H	L	L	L	L	L
MTU 2247-55-2	L	L	H	L	H	H	L	H	L	L	H	H
BPT 2659	L	L	L	L	H	L	H	L	H	L	L	H
JMP 16	H	H	L	L	L	L	H	H	H	H	L	H
MTU 1061	L	L	L	L	H	H	H	L	L	L	H	L
RM 168-28-1-1-1	H	H	L	L	H	L	H	L	H	L	H	L
MTU 2336-70-46-25-44	H	H	L	L	H	L	L	L	L	L	H	H
MTU 2347-158-3-1-1	L	L	L	L	H	H	H	L	H	L	L	L
MTU 2336-62-25-39-16	L	H	L	L	L	L	H	L	H	H	H	H
MTU 2284-103-1-7	H	H	H	L	L	L	H	L	H	H	L	L
HRL4	L	L	L	L	H	L	H	L	H	H	H	L
NLR 5815-10-1-1-1	H	H	H	L	L	L	L	L	L	L	H	L
UTR 51	H	L	H	L	L	L	L	L	L	L	H	L
NLR 3445	H	H	H	L	L	L	L	L	L	L	H	H
BPT 2782	H	L	H	L	L	L	H	L	L	H	L	H
MTU 2284-103-1-9	L	H	L	L	L	L	L	L	L	H	L	L
MTU 2345-98-3	H	L	L	L	H	L	H	H	L	H	L	H
MTU 2067-9-1-1-2	H	H	L	L	L	L	H	L	L	L	L	H
RM 138-80-3-1-1-1	H	H	L	L	H	L	H	H	H	L	L	L
MTU 2337-216-1-1	L	L	H	L	H	L	H	H	H	H	L	H
MTU 2331-216-1-1	L	L	L	L	H	H	H	H	H	H	L	H
Range												
Minimum	95	-0.05	95.7	-0.4	6.2	-0.3	20.1	-0.03	107.5	-25.2	66.6	-1.9
Maximum	118	0.05	133.3	0.4	15.2	0.3	29.8	0.03	293.0	25.2	96.2	1.9
Mean	108		113.0		11.2		24.9		189.6		81.1	

Table 2. Continued.

Line/Tester	Grain yield plant^{-1} *per se*	*gca*	1000-Seed weight *per se*	*gca*	L/B ratio *per se*	*gca*	Hulling (%) *per se*	*gca*	Milling (%) *per se*	*gca*	HRR (%) *per se*	*gca*
Lines												
APMS 6A	L	L	L	L	H	L	L	L	L	L	L	L
APMS 8A	H	L	H	L	L	L	H	L	H	H	H	H
Testers												
BPT 5204	L	H	L	L	H	L	H	L	H	L	H	L
RP6112-MS-128-5-2-3-4-5	H	L	L	L	H	H	H	L	H	L	H	L
MTU 2244-128-18	L	L	L	L	L	L	H	L	H	L	H	L
MTU 2201-34-3-1	H	L	H	L	H	L	H	L	L	L	L	L
MTU 2049-5-2-1	L	L	H	L	L	L	H	L	H	L	H	L
MTU 2247-55-2	H	H	H	H	L	L	L	H	L	L	L	L
BPT 2659	L	H	H	H	L	L	H	H	H	H	H	H
JMP 16	H	H	L	H	L	L	H	H	H	H	H	H
MTU 1061	H	L	L	L	L	L	L	L	L	L	H	L
RM 168-28-1-1-1	H	L	H	L	H	L	L	L	L	H	L	L
MTU 2336-70-46-25-44	H	H	H	H	H	L	H	H	H	H	H	L
MTU 2347-158-3-1	L	L	H	L	L	L	L	L	L	L	L	L
MTU 2336-62-25-39-16	H	H	H	L	H	L	L	L	L	L	L	L
MTU 2284-103-1-7	H	L	L	L	H	L	H	H	H	H	H	H
HR L4	L	L	L	H	L	L	H	L	H	L	H	L
NLR 5815-10-1-1-1	L	L	H	L	H	L	H	H	L	H	L	H
UTR 51	L	L	L	L	H	L	H	H	H	L	L	L
NLR 3445	L	H	L	L	H	L	L	H	L	H	H	H
BPT 2782	L	L	H	L	L	L	H	L	H	L	H	H
MTU 2284-103-1-9	L	L	L	H	H	L	L	L	H	L	H	L
MTU 2345-98-3	H	L	L	H	H	L	L	L	L	H	L	H
MTU 2067-9-1-1-2	L	H	H	H	L	L	H	H	H	H	H	H
RM 138-80-3-1-1-1	H	L	H	H	H	H	L	L	L	L	L	L
MTU 2337-216-1-1	H	H	L	H	L	H	L	H	H	H	H	H
MTU 2331-216-1-1	H	H	H	H	H	H	H	H	L	H	H	H
Range												
Minimum	10.2	-0.07	14.0	-0.2	2.1	-0.01	70.0	-0.5	46.0	-1.1	36.7	-1.2
Maximum	27.0	0.07	22.8	0.2	3.0	0.01	79.5	0.5	70.7	1.1	66.2	1.2
Mean	16.7		19.5		2.6		76.1		64.2		54.6	

ponent of variation. The results thus indicated the existence of significant differences among the parents and hybrids in addition to significant levels of heterosis for majority of the characters studied. Further, partitioning of the hybrids component of variation into lines, testers and Line × Testers also revealed significant mean squares for grain yield plant^{-1}, days to 50% flowering, number of grains panicle^{-1} and 1000-seed weight indicating the importance of both additive and non-additive gene actions. A perusal of the results on *gca:sca* variance ratio however, indicated pre-ponderant non-additive gene action for grain yield plant^{-1}, days to 50% flowering, plant height, ear bearing tiller plant^{-1}, panicle length, spikelet fertility percentage and 1000-seed weight (Madhuri et al. 2017), number of grains panicle^{-1} (Sudeepthi et al. 2017), L/B ratio, hulling percentage, milling percentage and head rice recovery percentage (Thakare et al. 2013), similar, to the reports of earlier workers . Pre-ponderant non-additive gene action observed in the study for grain yield, yield components and quality traits is highly desirable in the present context for exploitation of heterosis, as lines used in the present investigation are cytoplasmic male sterile lines.

A perusal of the results on categorization of the parents based on *per se* performance and *gca* effects is presented in Table 2. The results revealed the absence of association between *per se* performance

Table 3. Good combiners identified for grain yield, yield components and quality characters.

Characters	Lines	Testers
Days to 50% flowering	—	NLR5815-10-1-1-1, MTU 2336-70-46-25-44, MTU 2284-103-1-7, RM138-80-3-1-1-1, RM 168-28-1-1-1,MTU 2336-62-25-39-16, JMP 16, MTU 2284-103-1-9, NLR 3445, MTU 2067-9-1-1-2.
Plant height	—	—
Ear bearing tillers plant^{-1}	—	MTU 2247-55-2, MTU 1061, MTU 2331-216-1-1, BPT 5204, MTU 2347-158-3-1-1
Panicle length	—	MTU 2337-216-1-1, MTU 2331-216-1-1, MTU 2345-98-3, RM 138-80-3-1-1-1, JMP 16, MTU 2247-55-2
Number of grains panicle^{-1}	APMS 8A	MTU 2284-103-1-9, MTU 2345-98-3, BPT 2782, MTU 2336-62-25-39-16, HR L4, MTU 2244 -128-18, MTU 2337-216-1-1, MTU 2201-34-3-1, JMP 16, MTU 2284-103-1-7, BPT 5204
Spikelet fertility percentage	APMS 6A	NLR 3445, MTU 2067-9-1-1-2, JMP 16, BPT 2659, MTU 2331-216-1-1, MTU 2345-98-3, MTU 2244-128-18, MTU 2247-55-2, BPT 5204, MTU 2336-70-46-25-44, MTU 2336-62-25-39-16, RP 6112-MS-128-5-2-3-1-4-5, MTU2337-216-1-1, BPT 2782
Grain yield plant^{-1}	—	MTU 2331-216-1-1, BPT 2659, JMP 16, MTU 2247-55-2, MTU 2067-9-1-1-2, NLR 3445, BPT 5204, MTU 2337-216-1-1, MTU 2336-70-46-25-44, MTU 2336-62-25-39-16
1000 Seed weight	—	RM 138-80-3-1-1-1, BPT 2659, MTU 2247-55-2, MTU 2331-216-1-1, MTU 2337-216-1-1, MTU 2067-9-1-1-2, MTU 2336-70-46-25-44, MTU 2345-98-3, JMP 16, MTU 2284-103-1-9
L/B ratio	—	RP 6112-MS-128-5-2-3-1-4-5, MTU 2331-216-1-1, MTU 2337-216-1-1, RM 138-80-3-1-1-1
Hulling percentage	—	BPT 2659, MTU 2331-216-1-1, MTU 2067-9-1-1-2, JMP 16, NLR 3445, MTU 2336-70-46-25-44, MTU 2337-216-1-1, MTU 2284-103-1-7, UTR 51, NLR 5815-10-1-1-1, MTU 2247-55-2
Milling percentage	APMS 8A	BPT 2659, MTU 2067-9-1-1-2, JMP 16, MTU 2331-216-1-1, MTU 2284-103-1-7, MTU 2337-216-1-1, MTU 2345-98-3, MTU 2336-70-46-25-44, RM 168-28-1-1-1, NLR 3445, NLR 5815-10-1-1-1
HRR percentage	APMS 8A	JMP 16, NLR 5815-10-1-1-1, MTU 2337-216-1-1,MTU 2067-9-1-1-2, BPT 2659, BPT 2782, MTU 2331-216-1-1, MTU2284-103-1-7, MTU 2345-98-3, NLR 3445

and *gca* effects of the parents for grain yield and yield components and quality characters. Similar, results were reported by earlier workers (Satheeshkumar et al. 2016).

The perusal of results on general combining ability effects revealed, presence of several good general combiners for different traits studied (Table 3). The results revealed APMS 8A to be a good combiner with high *per se* performance for number of grains panicle^{-1}, milling percentage and head rice recovery percentage and hence may be utilized in hy-

Table 4. Specific combining ability of rice hybrids for grain yield, yield attributes and quality parameters.

Characters	Range		Number of hybrids with significant and desirable *sca* effects	Best hybrid combination
	Minimum	Maximum		
Grain yield plant	-13.06	13.06	13	APMS 8A × MTU 2337-216-1-1
Days to 50% flowering	-11.55	11.55	8	APMS 6A × MTU 2347-158-3-1-1
Plant height	-6.89	6.89	—	—
Ear bearing tillers plant^{-1}	-2.25	2.25	2	APMS 8A × MTU 2337-216-1-1
Panicle length	-1.58	1.58	—	
Number of grains panicle^{-1}	-56.90	56.90	12	APMS 8A × MTU 2049-5-2-1
Spikelet fertility percentage	-43.97	43.97	9	APMS 6A × MTU 2049-5-2-1
1000-Seed weight	-9.71	9.71	3	APMS 6A × MTU 2049-5-2-1
L/B ratio	-1.27	1.27	2	APMS 6A × MTU 2049-5-2-1
Hulling (%)	-37.16	37.16	2	APMS 6A × MTU 2049-5-2-1
Milling (%)	-31.77	31.77	2	APMS 6A × MTU 2049-5-2-1
HRR (%)	-30.04	30.04	3	APMS 8A × HR L4

Table 5. Details of promising hybrids identified for grain yield plant^{-1} in rice (*Oryza sativa* L.). *,** Significant at 5 and 1% levels, respectively.

Promising hybrid	*Per se* performance	*sca* effect	Characterization of parents w.r.t. *gca* effects	Desirable *per se* and *sca* effects notified for yield components and quality parameters
APMS 8A × MTU 2247-55-2	44.06	10.35**	Low × High	Days to 50% flowering, spikelet fertility percentage
APMS 8A × MTU 2331-216-1-1	42.83	4.29**	Low × High	—
APMS 8A × MTU 2337-216-1-1	41.13	13.06**	Low × High	Ear bearing tillers plant^{-1}, number of grains panicle^{-1}, spikelet fertility percentage
APMS 6A × BPT 2659	39.3	4.75**		Ear bearing tillers plant^{-1}
APMS 8A × MTU 2067-9-1-1-2	38.05	4.55**	Low × High	—
APMS 6A × JMP 16	37.95	2.83*	Low × High	—
APMS 8A × NLR 3445	34.92	3.39	Low × High	—
APMS 6 A × MTU 2336-62-25-39-16	33.35	7.02**	Low × High	Spikelet fertility percentage
APMS 6A × MTU 2336-70-46-25-44	31.35	4.80**	Low × High	—

brid breeding programs. It had also resulted in the best yielding hybrids identified in the present investigation, namely, APMS 8A × MTU 2247-55-2, APMS 8A × MTU 2331-216-1-1 and APMS 8A × MTU 2337-216-1-1. Further, the testers, MTU 2247-55-2, JMP 16, MTU 2336-70-46-25-44, MTU 2336-62-25-39-16, MTU 2337-216-1-1 and MTU 2331-216-1-1 had recorded high *per se* performance and desirable *gca* effects for grain yield plant^{-1}. Among these, JMP 16, MTU 2336-70-46-25-44, MTU 2337-216-1-1 and MTU 2331-216-1-1 had also recorded high *per se* performance and desirable *gca* effects for few yield attributes and quality characters studied indicating their importance in hybrid breeding programs.

A study on the specific combining ability effects for grain yield, yield components and the quality traits also revealed significant and desirable *sca* effects for several hybrids studied in the present investigation (Table 4). However, out of the 50 hybrids studied, none had exhibited consistently high *sca* effects for all the characters and the best cross combination was observed to vary from character to character. Similar, results were reported earlier (Kumar 2004). Further, nine hybrids (APMS 8A × MTU 2247-55-2, APMS 8A × MTU 2331-216-1-1, APMS 8A × MTU 2337-216-1-1, APMS 6A × BPT 2659, APMS 8A × MTU 2067-9-1-1-2, APMS 6A × JMP 16, APMS 8A × NLR 3445, APMS 6A × MTU 2336-62-25-39-16 and APMS 6A × MTU 2336-70-46-25-44) had recorded high *per se* performance and desirable *sca* effects for grain yield plant^{-1} (Table 5). A characterization of the parents of these hybrids with respect to their *gca* effects revealed low and high *gca* parents. Similar, production of superior hybrids involving low and high *gca* parents were reported earlier (Annadurai and Nadarajan 2001). The production of superior hybrids from parents with low and high *gca* effects was attributed to the favorable effect of additive × non-additive or dominance × recessive gene interactions (Kumar 2004).

The rice hybrids namely, APMS 8A × MTU 2247-55-2, APMS 8A × MTU 2331-216-1-1 and APMS 8A × MTU 2337-216-1-1 with high *per se* performance, significant and desirable *sca* effects are identified for further testing and commercial exploitation.

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