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Combining Ability Studies of Promising Restorer Lines for Yield and Yield Components in Rice (*Oryza sativa* L.)

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Abstract

Background: The present inquisition was carried out at Regional Agricultural Research Station, Maruteru with a set of 30 experimental hybrids developed by crossing three male sterile lines with 10 testers in Line × Tester mating design during *Kharif*, 2022.

Methods: The resultant 30 hybrids were studied in randomized block design with two replications along with the parents and hybrid check, HRI-174 during *Rabi*, 2022-23. Predominant non-additive gene action was found in the analysis of combining ability for lines, testers and line testers for grain production per plant, days to 50% flowering, days to maturity, ear bearing tillers per plant, filled grains per panicle and 1000-grain weight.

Result: The results revealed RGL 5613 and MTU 2055 to be effective combiners for grain yield per plant, filled grains per panicle, spikelet fertility percentage and grain weight of one thousand grains. For five hybrids, the *sca* effects on grain yield per plant were large and favourable. These hybrids had recorded significantly higher grain yield perplant, more than 30 per cent, compared to the check, HRI-174, in addition to significant desirable *sca* effects for grain yield per plant.

Key words: Combining ability, Grain yield, Hybrids, Lines, Rice, Testers.

Introduction

Rice (*Oryza sativa* L.) is a staple food crop that plays a crucial role in global food security, feeding nearly half of the world's population (Kumar *et al*., 2023). India has been the largest producer after China. In India the cultivated area of paddy is 46.3 million hectares with a production and productivity of 129.5 million tonnes and 2798 kg ha^{-1}, respectively during 2021-22 (Ministry of Agriculture and Farmer Welfare, GOI, 2022). In Andhra Pradesh, it is cultivated in expand of 2.6 million ha with a production of 13.1 million tonnes and the productivity of about 5130 kg ha^{-1} (Ministry of Agriculture and Farmers Welfare, Directorate of Economics and Statistics, 2021-2022).

Selecting suitable parents cannot rely solely on individual performance and necessitates the consideration of gene interactions. Breeders have a variety of biometrical tools at their disposal to aid in the selection of suitable parents. Among these tools, combining ability stands out as a potent technique for recognizing strong combiners and for choosing the right parental materials to exploit heterosis (Manivelan *et al*., 2022). Employing a (L × T) mating design allows for the evaluation of parental genetic effects and facilitates the exploration of general combining ability (GCA) along with specific combining ability (SCA), even when working with limited sample sizes (Gramaje *et al*., 2020).

Combining ability plays a vital role in understanding how genes influence the expression of quantitative traits by identifying potential superior parents and hybrid combinations, General Combining Ability (GCA) is associated with additive gene effects and additive × additive epistasis and it is theoretically stable. In contrast, specific combining ability (SCA) is linked to non-additive gene effects, which may stem from dominance, epistasis, or both and it is not theoretically stable (Hussein, 2021). The presence of non-additive genetic variance is a primary motivation for initiating hybrid breeding programs and choosing appropriate parents (Lal *et al*., 2023). In light of this, the current exploration was conducted to find parents and experimental

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rice hybrids with good combining ability for grain yield and yield component traits.

MATERIALS AND METHODS

The study was undertaken at Regional Agricultural Research Station (RARS), Maruteru, West Godavari District of Andhra Pradesh. The experimental site is situated at 26°38′N latitude, 81°44′E longitude and 5 m above mean sea level with semi-humid climate with black alluvial clayey soils and falls under Godavari Zone of Andhra Pradesh. Table 1 summarizes the key characteristics of the parents and the check. 30 rice hybrids were created during *Kharif*, 2022, by mating the male sterile lines with the testers. The resultant 30 hybrids, were evaluated along with their parents and the hybrid check variety, HRI-174 for grain yield and yield components during *Rabi,* 2022-2023.

Evaluation of the 30 hybrids along with their parents, *i.e.*, three CMS lines and 10 restorers and the hybrid check, HRI-174 was carried out in a randomized block design with two replications during *Rabi*, 2022-2023. We made observations related to the grain yield per plant and various characteristics contributing to yield, such as plant height, the number of tillers bearing ears per plant, panicle length and spikelet fertility. To do this, we randomly selected five plants from each genetic group within each replication and the resulting averages were subjected to statistical analysis. Nevertheless, we recorded the "days to 50 percent flowering" on a per-plot basis. In contrast, we obtained observations for test weight and grain density by taking random grain samples from each plot within each genetic group and replication, following standard sampling procedures. Additionally, we recorded observations for yield and characteristics related to yield on the maintainer (B) lines of the corresponding male sterile lines. As for panicle exertion and the duration of floret opening, these were observed on the male sterile lines themselves. The fundamental statistical concepts of general and specific combining abilities were initially formulated as given by (Sprague and Tatum, 1942). To analyse the collected data, we applied standard statistical methods (Panse and Sukhatme, 1967). Statistical analysis for (L × T) mating design to carry out heterosis and combining abilities were performed using R (R Development Core Team 2008).

RESULTS AND DISCUSSION

Specific combining ability (SCA) assesses non-additive gene effects that cannot be fixed, while general combining ability (GCA) quantifies additive gene effects and additive × additive interactions, which are modifiable. The estimates of general (GCA) and specific (SCA) combining effects can be found in Table 2 to Table 5 and are further elucidated below:

Analysis of variance

Table 2 provides the results of the Analysis of Variance. In all the characteristics examined, there were notable and statistically significant mean sums of squares for the parent lines, hybrid offspring and the comparison between parent lines and hybrids, except for the "days to 50% flowering" and "days to maturity" in the parent lines and "days to maturity" in the hybrid offspring. The results indicate the presence of heterosis for the traits that displayed significant mean sums of squares in the comparison between parent lines and hybrids, as well as significant distinctions between the parent lines and their hybrid progeny.

A review of the results on the *gca*:*sca* variance ratio revealed preponderant non-additive gene action to the grain yield per plant (Shanti *et al*., 2011 and Prasad *et al*., 2019) and the greater part of the yield components studied,

Table 1: Salient features of experimental material.

Genotype	Source	Salient features
Lines		
APMS 15A	RARS, Maruteru	Medium duration, medium slender, straw glume, moderately tolerant to BPH
APMS 17A	RARS, Maruteru	Medium duration, medium slender, straw glume, fine
APMA 18A	RARS, Maruteru	Medium duration, medium slender, straw glume, tolerant to leaf blast
Testers		
RGL 5613	ARS, Ragolu	Medium duration, long slender, straw glume, moderately tolerant to leaf blast
MTU 2716	RARS, Maruteru	Medium duration, medium slender, straw glume
MTU 1224	RARS, Maruteru	Medium duration, medium slender, straw glume
RM 409-26-1-1-1	RARS, Maruteru	Medium duration, medium bold, straw glume
MTU 2055	RARS, Maruteru	Medium duration, long slender, straw glume
MTU 2347-158-3-1-1	RARS, Maruteru	Medium duration, medium bold, straw glume, moderately tolerant to leaf blast
RM 67-60-1-1-1	RARS, Maruteru	Medium duration, medium slender, bold grain
UTR 76	ARS, Utukuru	Medium duration, long slender, straw glume, moderately tolerant to leaf blast
MTU 2846-34-1-1	RARS, Maruteru	Medium duration, medium slender, straw glume
MTU 1213	RARS, Maruteru	Early duration, medium slender, straw glume
Check		
HRI-174	Bayer Bioscience, Hyderabad	Early duration, long bold, straw glume

Table 2: Line × Tester analysis of variance for different traits in rice.

Source of variation	Degrees of freedom	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	Ear bearing tillers per plant	Panicle length (cm)	Filled grains per panicle	Un-filled grains per panicle	Spikelet fertility (%)	1000-grain weight (g)	Grain density	Grain yield per plant (g)
Replications	1	1.96	8.47	0.06	0.31	0.44	138.65	6.75	4.24	0.00	0.04	2.02
Parents	12	6.51	10.32	181.91**	2.06**	8.77**	6543.70**	721.06**	26.15*	13.17**	12.87**	109.78**
Hybrids	29	18.15**	14.88	102.79**	4.18**	3.54**	10603.41**	3597.75**	571.15**	5.06**	7.09**	170.58**
Lines	2	7.17	10.17	12.09	0.71*	0.40	3781.87**	112.61**	14.25	11.21**	7.52**	15.86
Testers	9	5.80	10.78	220.96**	2.18**	11.20**	3372.99**	101.66**	8.254	11.32**	3.05**	133.53**
Line×Tester	18	14.50**	18.79*	38.64	3.21**	1.285	5183.79**	1398.16**	172.76**	3.99**	5.06**	86.94**
Parent vs. Hybrids	1	193.41**	126.40**	1303.56**	7.99**	10.76**	7832.81**	27980.15**	3472.69**	5.01**	2.95**	44.16*
Error	42	6.04	9.19	25.03	0.15	1.40	105.72	8.33	10.55	0.47	0.18	14.36
$\sigma^2 GCA$		1.45	0.50	16.10	0.73	0.59	1882.18	727.66	119.31	0.77	1.39	27.67
$\sigma^2 SCA$		4.23	4.79	6.80	1.53	0.06	2539.04	694.91	81.10	1.76	2.43	36.29
$\sigma^2 GCA/\sigma^2 SCA$		0.34	0.11	2.37	0.48	9.83	0.74	1.05	1.47	0.44	0.57	0.76

*, **Significant at 5 and 1 per cent levels, respectively.

Table 3: General combining ability of lines and testers for yield and yield attributes.

Character	Lines			Testers		
	Range	Number of lines with desirable and significant *gca* effects	Best line	Range	Number of lines with desirable and significant *gca* effects	Best tester
Grain yield per plant	-0.86 to 0.93	-	-	-7.45 to 15.38	2	RGL 5613
Days to 50 per cent flowering	-0.35 to 0.15	-	-	-2.18 to 4.66	1	MTU 1213
Days to maturity	-0.28 to 0.31	-	-	-1.45 to 1.89	-	-
Plant Height	-0.39 to 0.67	-	-	-12.01 to 13.98	1	MTU 1224
Ear bearing tillers per Plant	-0.26 to 0.49	1	APMS 18A	-2.51 to 1.28	4	RGL 5613
Panicle length	-0.23 to 0.37	-	-	-1.33 to 2.58	1	MTU 2055
Filled grains per panicle	-6.82 to 8.07	1	APMS 18A	-139.88 to 103.44	5	MTU 2055
Un-filled grains per panicle	-7.63 to 4.00	1	APMS 15A	-43.70 to 83.79	6	RGL 5613
Spikelet fertility	-1.57 to 2.56	1	APMS 15A	-39.69 to 15.26	6	MTU 2055
1000-grain weight	-0.44 to 0.36	1	APMS 15A	-1.57 to 2.12	3	MTU 2055
Grain density	-0.46 to 0.69	1	APMS 17A	-2.23 to 1.94	5	UTR 76

including days to 50% flowering (Ramesh *et al*., 2018), days to maturity (Ariful-Islam *et al*., 2015), ear bearing tillers per plant (Anandlekshmi *et al*., 2020). Since the lines employed in the current experiment are all cytoplasmic male sterile lines that facilitate the utility of heterosis, non-additive gene activity is preferable in the current setting. However, it was shown that additive gene action predominated in the areas of plant height, panicle length, unfilled grains per panicle and spikelet fertility percentage. Patel *et al.* (2019) reported an earlier finding of a similar preponderant additive gene action for plant height.

General combining ability effects

The results from Table 3 and Fig 1-3 exhibit the findings of general combining ability effects on grain yield and yield components for lines and testers. The results revealed the absence of association between *Per se* performance and *gca* effects of the parents for yield and yield attributes. Similar results were reported by earlier workers (Rao *et al*., 1980; Kumar and Chandrappa, 1994). Additionally, the results showed that APMS 15A was a good combiner with high *Per se* performance for unfilled grains per panicle, spikelet fertility percentage and 1000-grain weight, whereas APMS 17A was found to be a good combiner with high mean for grain density. APMS 18A, on the other hand, was found to be a good combiner with high *Per se* performance for ear bearing tillers per plant and may therefore be used in hybrid breeding programs intended to generate superior hybrids for the afore mentioned qualities. Further, RGL 5613 and MTU 2055 were also found to be effective combiners for grain yield per plant, filled grains per panicle, spikelet fertility percentage and 1000-grain weight. As a result, they may be used in hybrid breeding programs to create hybrids that are high yielders with more filled grains and heavier seeds. The promising heterotic hybrids, APMS 15A × RGL 5613, APMS 15A × MTU 2055, APMS 17A × RGL 5613 and APMS 15A × MTU 2055, included the testers RGL 5613 and MTU 2055, validating their identification as good combiners in the current investigation.

Specific combining ability effects

The specific combining ability effects regarded to the 30 hybrids resulting from the crossbreeding of three lines with ten testers for yield and yield-related traits can be found in Table 4-5 and Fig 4. An examination of the results concerning individual performance, heterosis and specific combining

Table 4: Specific combining ability of rice hybrids for yield and yield attributes.

Character	Range	Number of hybrids with desirable and significant *sca* effects	Best hybrid combinations
Grain yield per plant (g)	-9.80 to 13.06	5	APMS 15A × MTU 1213
Days to 50 per cent flowering	-3.48 to 4.85	-	-
Days to maturity	-4.38 to 4.35	-	-
Plant Height (cm)	-10.33 to 6.50	1	APMS 18A × MTU 2347-158-3-1-1
Ear bearing tillers per Plant	-1.74 to 2.06	10	APMS 17A × RGL 5613
Panicle length (cm)	-1.12 to 1.26	-	-
Filled grains per panicle	-60.69 to 85.51	10	APMS 18A × MTU 2055
Un-filled grains per panicle	-43.83 to 44.98	13	APMS 18A × RM 67-60-1-1-1
Spikelet fertility (%)	-13.98 to 18.59	8	APMS 15A × MTU 2716
1000-grain weight (g)	-2.10 to 2.15	5	APMS 18A × MTU 1224
Grain density	-2.32 to 2.65	10	APMS 17A × MTU 2055

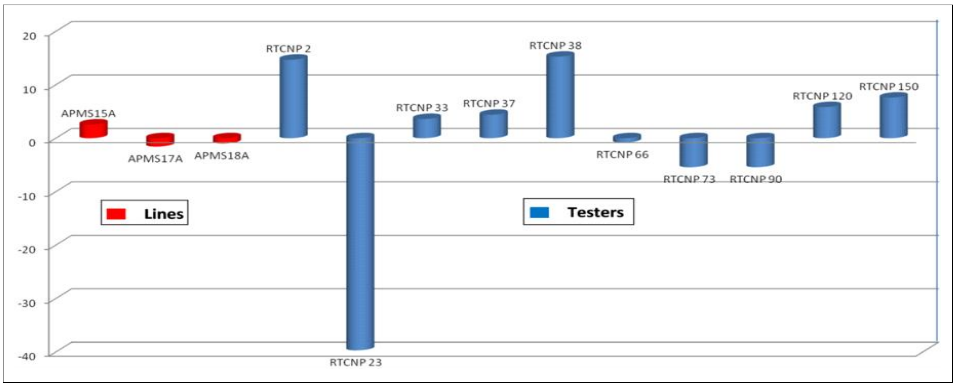

Fig 1: *GCA* effects of lines and testers for spikelet fertility per cent.

ability highlights the superiority of hybrids such as APMS 17A × MTU 2055, APMS 17A × RGL 5613, APMS 15A × MTU 1213, APMS 15A × RGL 5613 and APMS 15A × MTU 2055 (Table 4-5). These particular hybrids also demonstrated significantly increased grain yield per plant, surpassing 41.0 grams, in contrast to the reference variety, HRI-174, which yielded 31.50 grams. Additionally, these hybrids exhibited a considerable level of standard heterosis exceeding 30 per cent and significant and desirable specific combining ability effects for grain yield per plant. Therefore, the hybrids are identified as promising heterotic combinations for further evaluation

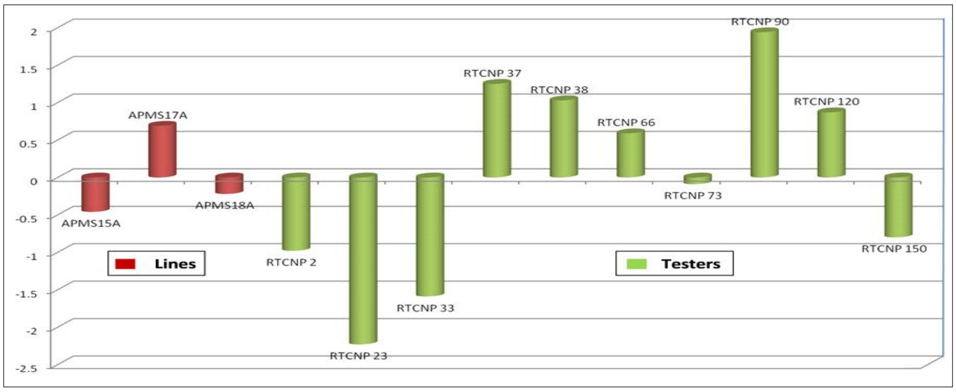

Fig 2: *GCA* effects of lines and testers for grain density.

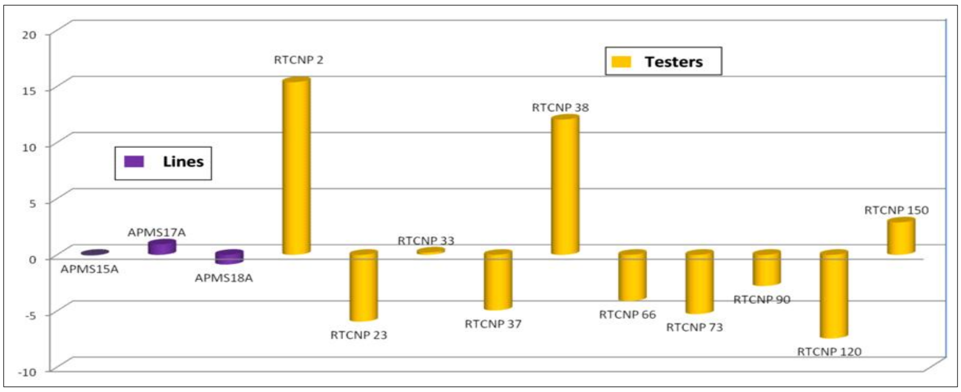

Fig 3: *GCA* effects of lines and testers for grain yield per plant.

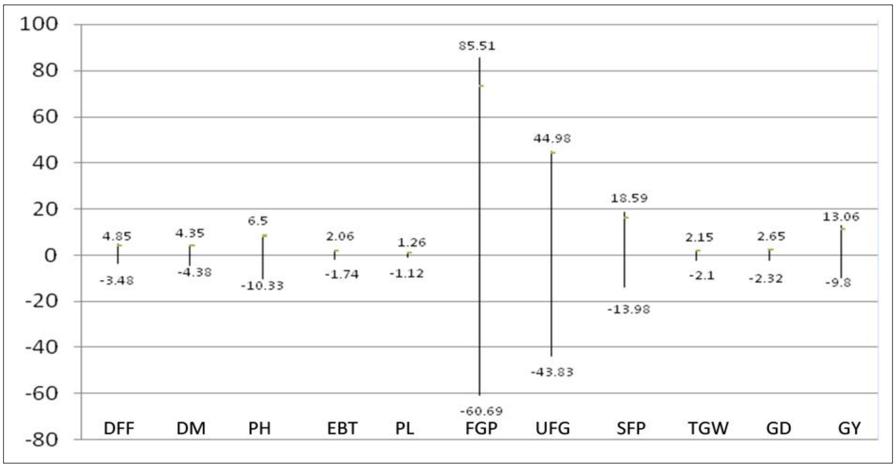

Fig 4: Range of specific combining ability for yield and yield component traits.

Table 5: Details of promising hybrids identified.

Hybrids	Grain yield per plant (g)			Desirable *sca* effects for other yield attributes	Characterization of parents with respect to *gca*	Days to maturity	Plant height (cm)	Spikelet fertility (%)	1000-grain weight (g)	Grain type
	Per se performance	Standard heterosis (%)	*Sca* effects							
APMS 17A × MTU 2055	46.50	47.62**	12.30**	Spikelet fertility, grain density	Low × High	121.50	131.70	93.55	19.20	Medium slender, straw glume
APMS 17A × RGL 5613	45.00	42.86**	6.90*	Ear bearing tillers per plant, filled grains per panicle, grain density	Low × High	120.50	118.45	91.50	17.20	Medium slender, straw glume
APMS 15A × MTU 1213	42.50	34.92**	13.06**	Ear bearing tillers per plant, filled grains per panicle, Spikelet fertility, grain density	Low × Low	122.50	115.95	89.25	19.30	Medium bold, straw glume
APMS 15A × RGL 5613	42.00	33.33**	9.06**	Filled grains per panicle, grain density	Low × High	120.50	118.50	87.40	18.75	Medium slender, straw glume
APMS 15A × MTU 2055	41.50	31.75**	7.90**	Ear bearing tillers per plant	Low × High	120.00	133.80	85.15	19.20	Medium bold, straw glume

and commercial exploitation as potential and early duration hybrids with medium semi-tall to tall plant height, good spikelet fertility and slender to medium bold, straw glume-colored grains.

CONCLUSION

The combining ability analysis for lines, testers and line × testers, it was evident that non-additive gene action predominated for traits such as grain yield per plant, days to 50 percent flowering, days to maturity, ear-bearing tillers per plant, filled grains per panicle and 1000-grain weight. In contrast, for plant height, panicle length, unfilled grains per panicle and spikelet fertility percentage, additive gene action was more prominent.Top of Form The crosses, APMS 17A × MTU 2055, APMS 17A × RGL 5613, APMS 15 A × MTU 1213, APMS 15 A × RGL 5613 and APMS 15 A × MTU 2055 are identified as promising heterotic combinations with potential for commercial exploitation after testing over locations and years for their stability in performance.

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Conflict of interest

The authors declare that they have no conflict of interest.

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