UNDERSTANDING GENE ACTION AND COMBINING ABILITY IN RICE (*Oryza sativa* L.) A LINE × TESTER ANALYSIS APPROACH

Abstract

The study was carried out to know the nature of gene action and combining ability in rice hybrids for grain yield and its component traits. For this, five lines were crossed with two testers in an L x T mating design. The analysis of variance revealed significant variance for all the characters studied among the parents and hybrids. SCA variances were higher than GCA variances for majority of traits *viz.,* days to 50 % flowering, number of tillers per plant, number of productive tillers per plant, number of grains per panicle, 1000 grain weight, grain yield per plant, hulling. Milling and kernel length-breadth ratio, which indicating the predominance of non additive gene action, while GCA variances were higher than SCA variances, which indicating the predominance of additive gene action. Among the lines WGL 962 was the best combination for grain yield and important yield components due to positive GCA effects and in testers IET 23993 for early and dwarfness, as well as hybrids JGL 27356 x PTB 33 and KPS 3018 x IET 23993, were stable with favourable SCA effects, heterosis and per se performance for grain yield and its component traits. Therefore, the aforementioned cross combinations may be employed in the upcoming breeding programmes in order to develop a higher heterosis for yield.

Keywords: Gene action, Combining ability, GCA, SCA, Line x Tester

Introduction

Rice (*Oryza sativa*) is one of the world's most important staple foods, feeding over half of the global population daily. Cultivated primarily in Asia, where over 90% of the world's rice is grown and consumed, this crop is a foundation for food security, economic stability and cultural heritage. Its cultivation, which dates back thousands of years, has profoundly influenced agricultural practices, rural livelihoods and even social structures in societies worldwide.

Globally, rice is being cultivated in an area of 167.2 million hectares with an annual production of 769.6 million tonnes and productivity of 4,600 kg ha^{-1}. In India, during 2022-23, rice crop was cultivated in an area of 47.83 million ha with an annual production of 150.04 million tonnes and productivity of 2,838 kg ha^{-1}. (Indiastat, 2022-23). Since the 1960s, the adoption of semi-dwarf varieties, combined with the green revolution, has resulted in spectacular growth in rice production, with the country becoming self-sufficient in rice during the 1980s.

Economically, rice is a major contributor to the GDP of many developing countries, where it not only provides sustenance but also supports millions of smallholder farmers. In many regions, rice cultivation is more than a source of income, it is integral to cultural identity and community traditions. However, as the global population continues to grow, the demand for rice increases, placing pressure on agricultural systems to produce more with limited resources.

Climate change, water scarcity and soil degradation are emerging challenges that threaten rice production, underscoring the need for innovative solutions to ensure sustainable cultivation. Advances in agricultural technology, from high-yield rice varieties to water efficient farming practices offer potential pathways to meet these challenges. The genetic improvement of rice through breeding programs aimed at increasing yield, disease resistance and other desirable traits is essential for meeting the food demands of a growing global population. The selection of appropriate parental lines with high grain yield and resistance to biotic and abiotic stresses plays a pivotal role in crop improvement programmes. The precise knowledge of the nature of gene action for yield and yield-attributing traits helps to choose an effective breeding strategy to accelerate the pace of genetic improvement of seed yield and quality traits in rice.

Gene action and combining ability two fundamental elements that guide the selection of superior parental lines and development of high yielding varieties. Gene action refers to the underlying genetic mechanisms by which traits are inherited. These mechanisms include the types of gene interactions (additive, dominance, and epistatic effects) that govern the expression of agronomic traits. Understanding gene action allows breeders to predict how traits will behave in progeny, facilitating more efficient breeding strategies. Combining ability is a measure of a parent's genetic potential for contributing to the performance of hybrid offspring. It assesses the ability of different parental lines to combine and transmit desirable traits to the next generation. By evaluating combining ability, breeders can identify the best parents for hybridization, thus optimizing the genetic progress made through breeding programs.

Kempthorne's (1957) Line x Tester analysis of combining ability is the most widely used method for determining general and specific combiners and studying the nature of gene action governing the inheritance of different characters. The study of gene action and combining ability plays a crucial role in designing effective breeding schemes for improving complex traits such as yield, resistance to biotic and abiotic stresses and grain quality.

Material and Methods

The material for the current study, which included 19 genotypes (5 lines (BPH susceptible), 2 testers (BPH resistant), 10 hybrids and one resistant check for BPH and one varietal check (PTB 33 and RNR 15048,) was evaluated during the *Kharif* season of 2022-23 at the Agricultural Research Station, Kampasagar, Nalgonda.

To raise and maintain a healthy crop, all recommended practices were followed. Days to 50% flowering, Plant height, panicle length, number of tillers per plant, number of productive tillers per plant, number of grains per panicle, grain yield per plant, 1000 grain weight, grain length, grain breadth and length-breadth ratio were all observed. The mean data of various traits were analysed using standard statistical and biometrical methods for combining ability.

Results and discussion

Analysis of variance for combining ability revealed that treatments registered highly significant differences for all the characters **(Table 1).** The parents differed significantly for all the characters except for number of tillers per plant and effective bearing tillers per plant indicating the existence of sufficient variability in the material studied. The lines differed significantly for most of the traits except for number of tillers per plant and effective bearing tillers per plant, number of grains per panicle and head rice recovery (%). Whereas the testers differed significantly for all the characters except number of tillers per plant and effective bearing tillers per plant. The interaction between lines and testers were significant for the traits *viz.,* days to 50% flowering, plant height, test weight, grain yield per plant, kernel length, kernel length breadth ratio, hulling, milling and head rice recovery (%).

Mean squares due to parents *vs.* hybrids were significantly different for all the characters except for kernel L/B ratio and revealing good scope for manifestation of heterosis in most of the characters studied. The effect of hybrids was partitioned into lines, testers and their interactions. The mean squares due to lines effect were non significant for all traits and mean squares due to testers effect was significant observed in kernel length. The mean squares due to Line × Tester interaction effects were significant for all the characters studied, it revealed that the significant contribution of hybrids for specific combining ability variance components.

Estimates of combining ability variances and gene action

Genetically, general combining ability (*gca*) variance is associated with genes which are additive in their effect, while specific combining ability (*sca*) variance is attributed to dominance and epistatic gene action (Kambal and Webster, 1965). Genetic information about the combining ability of parents and the nature of gene action involved in the inheritance of a trait would be of immense value to breeders to judge the suitability of parents, to identify potential hybrids and breeding methodology.

The variance estimates for GCA and SCA, as well as their ratios, are presented in the (**Table 2**). In the current study, it was observed that SCA variances were higher than GCA variances for most of the characters, which indicated the predominance of non additive gene action for the traits *viz*., days to 50 % flowering, number of tillers per plant, number of productive tillers per plant, number of grains per panicle, 1000 grain weight, hulling, milling, kernel length-breadth ratio and grain yield per plant. Various studies in rice by other researchers show that non-additive gene action predominates over additive gene action, which is ideal for exploitation via heterosis breeding (Bhadru *et al.,* 2013; Devi *et al.,* 2017, AnandaLekshmi *et al.,* 2020 and Gunasekaran *et al.,* 2023). The GCA variances were higher than SCA variances, which indicates the predominance of additive gene action for traits like plant height, panicle length, head rice recovery (%), kernel length and kernel breadth. The findings of Sharma *et al.,* (2013), Pratap *et al.,* (2013), Samrath and Deepak (2014), Ramesh *et al.,* (2018) and Lingaiah *et al.,* (2023) support the present results of predominance of additive gene action for majority of traits.

From the above discussion, it is clearly evident that most of the traits were controlled by non-additive gene action. To exploit the non-additive gene action of these traits, heterosis breeding or hybridization followed by selection in later generations is recommended for the improvement of these traits in rice.

These findings highlighted the significance of combining ability studies in indicating variability in the material studied and there is a good opportunity for identifying promising parents and hybrid combinations for improving yield through its components.

General and specific combining ability effects

The GCA effects of the parents revealed that the *gca* effect was significant and positive for WGL 962 (9.49), among lines and none of the tester was exhibited significant positive gca effect for grain yield per plant **(Table 3).**

For grain yield per plant SCA effects ranged from -5.58 (RNR 21278 x PTB 33) to 5.58 (JGL 27356 x PTB 33). Out of 10, two hybrids JGL 27356 x PTB 33 (5.58) and KPS 3018 x IET 23993 (4.55) showed significant positive SCA effects and were selected as desirable hybrids for higher grain yield. Hybrids demonstrated significant positive SCA effects, making such hybrids desirable. Similar findings have been reported by Raju *et al.,* (2014), Parimala *et al.*, (2018), Yadav *et al.,* (2020) and Nivedha *et al*., (2024).

An overall appraisal of *gca* effects revealed that among the lines, WGL 962 was a good general combiner for the traits *viz.,* days to 50% flowering, number of grains per panicle, 1000 grain weight, grain yield per plant, hulling, milling and head rice recovery percent and in testers IET 239933 was a good general combiner for the days to 50% flowering, plant height and kernel length. These findings were supported by Satheeshkumar *et al*., (2016), Azad *et al*., (2022) and and El- Agoury *et al*., (2024).

In hybrids, JGL 27356 x PTB 33 (5.58), was discovered to be a good specific combiner for traits such as Days to 50% flowering, plant height, number of grains per panicle, 1000 grain weight, grain yield per plant and hulling percent and KPS 3018 x IET 23993 (4.55) for 1000 grain weight, kernel breadth, kernel length breadth ratio, grain yield per plant, hulling, milling and head rice recovery per cent. Previously, Priyanka *et al.,* (2014), Mallikarjuna *et al*., (2016), Saravanan *et al*., (2018), Manivelan *et al*., (2022) and Abd-El-Aty *et al*., (2024) reported similar findings.

Conclusion

According to the study, the line WGL 962 was the best combination for grain yield and important yield components due to positive GCA effects and the tester IET 23993 for early and dwarfness, as well as hybrids, JGL 27356 x PTB 33 and KPS 3018 x IET 23993, were stable with favourable SCA effects, heterosis and per se performance for grain yield and its component traits. Testing these hybrids in multi-environment trials could indeed pave the way for their potential commercial application, offering resilience and yield improvements across different growing conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Table:1 Analysis of variance for combining ability in rice

Source of variations	Degrees of freedom	Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Productive tillers per plant	Panicle length (cm)	No. of filled grains /panicle	1000 grain weight (g)
Replicates	2	4.47	23.60	2.39	1.48	1.37	133.45	0.32
Treatments	16	169.29**	849.36**	12.54**	5.75**	6.18**	7560.20**	38.36**
Parents	6	265.94**	2091.09**	3.02	1.25	7.16**	1414.16**	48.12**
Parents (Line)	4	66.43**	9.66*	3.19	1.45	6.91**	159.46	8.37**
Parents (Testers)	1	228.17**	1209.84**	4.51	1.50	10.72*	4471.74**	3.34**
Parents (L vs T)	1	1101.72**	1129.03**	0.88	0.23	4.63	79743.34	251.90**
Parents vs Crosses	1	155.47**	39.96*	48.24**	15.31**	25.43**	1077.46**	168.47**
Crosses	9	106.39**	111.48**	14.91	7.68**	3.39*	2815.10**	17.39**
Line Effect	4	150.83	170.85	12.38	6.62	4.62	2817.13	11.81
Tester Effect	1	67.50	124.30	3.47	2.95	5.89	1.20	39.93
Line * Tester Eff.	4	71.67**	48.91**	20.30**	9.92**	1.54**	3516.53**	17.34**
Error	32	4.35	7.52	3.44	1.74	1.51	4.19	0.34
Total	50	57.13	277.56	6.31	3.01	3.00	277.20	12.51

Table continues……

Table:1 Analysis of variance for combining ability in rice

Source of variations	Degrees of freedom	Grain yield per plant (g)	Kernel length (mm)	Kernel breadth (mm)	Kernel length breadth ratio (mm)	Hulling (%)	Milling (%)	Head rice recovery (%)
Replicates	2	41.78	0.01	0.002	0.01	0.13	1.24	1.43
Treatments	16	225.37**	0.53**	0.50**	0.94**	78.28**	64.09**	69.77**
Parents	6	115.87**	0.14**	0.75**	1.32**	50.13**	53.55**	56.41**
Parents (Line)	4	36.10*	0.12**	0.05**	0.27**	22.81**	9.97	8.98
Parents (Testers)	1	48.17*	0.14**	0.06**	0.09**	47.02**	72.41**	79.63**
Parents (L vs T)	1	502.65**	0.19**	4.26**	6.70**	162.53**	209.03**	222.91**
Parents vs Crosses	1	1523.21**	4.18**	0.24**	0.02	113.03**	97.76**	164.06**
Crosses	9	154.16**	0.38**	0.37**	0.80**	93.18**	67.37**	68.20**
Line Effect	4	234.28	0.14	0.39	0.97	94.39	69.86	71.01
Tester Effect	1	9.19	1.94	0.68	0.75	105.98	106.70	126.11
Line * Tester Eff.	4	110.28**	0.22**	0.27**	0.64**	88.77**	55.06**	50.92**
Error	32	11.50	0.01	0.02	0.01	5.58	5.45	4.98
Total	50	81.15	0.18	0.16	0.31	28.62	24.05	25.57

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

Table:2 Estimates of general and specific combining ability variances and proportionate gene action in rice for the characters under study.

Character	Source of variation			Degree of Dominance $(\sigma^2 sca/ \sigma^2 gca)^{1/2}$	Nature of gene action
	σ^2gca	σ^2sca	σ^2gca/ σ^2sca		
Days to 50% flowering	19.97	22.44	0.89	1.06	Non additive
Plant height (cm)	26.68	13.80	1.93	0.72	Additive
Number of tillers per plant	0.86	5.62	0.15	2.56	Non additive
Number of productive tillers per plant	0.58	2.73	0.21	2.17	Non additive
Panicle length (cm)	0.71	0.01	72.77	0.12	additive
Number of filled grains per panicle	190.85	1036.45	0.18	2.33	Non additive
1000 grain weight (g)	4.86	5.67	0.86	1.08	Non additive
Hulling per cent	18.02	27.73	0.65	1.24	Non additive
Milling per cent	15.78	16.54	0.95	1.02	Non-additive
Head Rice Recovery (%)	17.82	15.31	1.16	0.93	additive
Kernel length (mm)	0.20	0.07	2.84	0.59	Additive
Kernel breadth (mm)	0.10	0.09	1.15	0.93	Additive
Kernel length breadth ratio (mm)	0.16	0.21	0.77	1.14	Non additive
Grain yield per plant (g)	21.00	32.93	0.64	1.25	Non additive

Table:3 Estimates of general combining ability effects of lines and testers for yield and yield contributing characters in rice

Parents	Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Productive tillers per plant	Panicle length (cm)	No. of filled grains /panicle	1000 grain weight (g)
LINES							
WGL 962	-8.16**	-2.00	0.96	0.52	0.434	23.433 *	1.54 **
KNM 1638	4.66**	0.57	-2.00*	-1.48 *	-0.30	-30.06 **	-2.19 **
KPS 3018	-0.83	-4.97 **	-0.90	-0.71	-1.39*	-14.06	0.58*
RNR 21278	1.16	8.87 **	1.53	0.98	0.48	8.26	0.44
JGL 27356	3.16 **	-2.46*	0.40	0.68	0.78	12.43	-0.37
TESTERS							
IET 23993	-1.50 *	-2.03 *	-0.34	-0.31	0.44	0.20	-1.15 **
PTB-33	1.50 *	2.03 *	0.34	0.31	-0.44	-0.20	1.15 **

Table 3 continues…….

Table:3 Estimates of general combining ability effects of lines and testers for yield and yield contributing characters in rice

Parents	Grain yield per plant (g)	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio (mm)	Hulling (%)	Milling (%)	Head rice recovery (%)
LINES							
WGL 962	9.49 **	-0.29 **	-0.07 **	-0.03	5.58 **	4.879 **	4.80 **
KNM 1638	-4.07 **	0.36 **	0.22 **	-0.17 **	-2.83 **	-3.147 **	-3.19 **
KPS 3018	-6.84**	-0.09	0.06 **	-0.10	0.63	0.815	1.02
RNR 21278	1.62	-0.02	-0.41 **	0.66 **	-4.66 **	-3.390 **	-3.49 **
JGL 27356	-0.20	0.05	0.21 **	-0.34 **	1.27	0.843	0.86
TESTERS							
IET 23993	-0.55	0.16 **	0.11**	-0.14 **	-1.88 **	-1.88 **	-2.05 **
PTB-33	0.55	-0.16**	-0.11 **	0.14 **	1.88 **	1.88 **	2.05 **

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

Table: 4 Estimates of specific combining ability effects of lines and testers for yield and yield contributing characters in rice

CROSSES	Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Productive tillers per plant	Panicle length (cm)	No. of filled grains /panicle	1000 grain weight (g)
WGL 962 x IET 23993	-0.83	-0.69	1.21	0.81	0.11	10.47	0.75 *
KNM 1638 x IET 23993	0.83	0.69	-1.21	-0.81	-0.11	-10.47	-0.75 *
KPS 3018 x IET 23993	-0.33	-0.46	0.91	0.61	0.25	23.63	1.77 **
RNR 21278 x IET 23993	0.33	0.46	-0.91	-0.61	-0.25	-23.63	-1.77 **
JGL 27356 x IET 23993	-5.16 **	-1.92	1.74	1.31	0.43	16.97	-2.50 **
WGL 962 x PTB 33	5.16 **	1.92	-1.74	-1.31	-0.43	-16.97	2.50 **
KNM 1638 x PTB 33	2.83 *	-1.90	-2.56 *	-1.59	-0.86	-19.03	0.87 *
KPS 3018 x PTB 33	-2.83 *	1.90	2.56 *	1.59	0.86	19.03	-0.87 *
RNR 21278 x PTB 33	3.50 **	4.96 **	-1.29	-1.15	0.06	-32.03 *	-0.89 *
JGL 27356 x PTB 33	-3.50 **	-4.96 **	1.29	1.15	-0.06	32.03 *	0.89 *

Table 4 continues…….

Table: 4 Estimates of specific combining ability effects of lines and testers for yield and yield contributing characters in rice

	Grain yield per plant (g)	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio (mm)	Hulling (%)	Milling (%)	Head rice recovery (%)
WGL 962 x IET 23993	-0.94	-0.29 **	0.00	-0.19*	0.64	0.05	0.16
KNM 1638 x IET 23993	0.95	0.29 **	0.00	0.19 *	-0.64	-0.05	-0.16
KPS 3018 x IET 23993	4.55 *	-0.07	-0.29**	0.427 **	6.37 **	5.11 **	4.86 **
RNR 21278 x IET 23993	-4.55 *	0.07	0.29**	-0.42**	-6.37 **	-5.11 **	-4.86 **
JGL 27356 x IET 23993	4.05	0.08	0.29 **	-0.41 **	-2.50	-0.76	-0.69
WGL 962 x PTB 33	-4.05	-0.08	-0.29 **	0.41 **	2.50	0.76	0.69
KNM 1638 x PTB 33	-2.08	0.21 **	0.05 *	-0.02	-1.36	-1.89	-1.72
KPS 3018 x PTB 33	2.08	-0.21 **	-0.05 *	0.02	1.36	1.89	1.72
RNR 21278 x PTB 33	-5.58 *	0.07	-0.05 *	0.19*	-3.15 *	-2.52	-2.62
JGL 27356 x PTB 33	5.58 *	-0.07	0.05 *	-0.19 *	3.15*	2.52	2.62

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