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Combining ability and gene action analysis in red kernel rice (*Oryza sativa* L.)

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Abstract
The present investigation was undertaken to estimate the combining ability and gene action in 24 hybrids (F_1s) affected by six white kernel females (lines) and four red kernel males (testers) following line x testers mating design. All the F_1s had red kernel colour. The analysis of variance for combining ability revealed that general combining ability (gca) variances for testers were highly significant for all the characters except number of spikelets panicle^{-1}, spikelets fertility per cent, test weight, kernel length, kernel breadth and L:B ratio. On the other hand, specific combining ability (sca) variances for line x tester interaction were significant for all the characters. The magnitude of sca variances was higher than gca variances for all characters except plant height and straw yield plant^{-1}, which indicated the predominance of non-additive gene action. This was further supported by low magnitude of $б^2$gca/ $б^2$sca ratios.

The estimates of general combining ability effects of the parents revealed that among white kernel lines, Palghar 1, Ratnagiri 6 and Trombay Karjat Kolam whereas among red kernel testers Munga and Valai were recognized as good general combiners for grain yield plant^{-1} and some of other yield related traits. Tester Munga was good general combiner for most of the characters *viz.*; panicle length, productive tillers plant^{-1}, number of spikelets panicle^{-1}, spikelets fertility per cent, grain yield plant^{-1}, straw yield plant^{-1}, test weight and kernel length. Female Trombay Karjat Kolam was good general combiner for panicle length, productive tillers plant^{-1}, grain yield plant^{-1}, straw yield plant^{-1}, kernel length and L: B ratio.

In the present study, crosses *viz*., Karjat 9 x Munga, Trombay Karjat Kolam x Kudai, Karjat 4 x Valai and Trombay Karjat Kolam x Munga were the best specific combinations for grain yield plant^{-1}. For number of grains panicle^{-1}, crosses Ratnagiri 6 x Bela, Palghar 1 x Valai, Ratnagiri 5 x Munga and Karjat 4 x Bela were better combinations and for number of productive tillers plant^{-1}, crosses Ratnagiri 6 x Munga, Ratnagiri 5 x Bela, Karjat 4 x Valai and Karjat 9 x Kudai were the good specific combinations.

The estimates of average degree of dominance varied from greater to unity and emphasized predominance of non-additive gene effects. The lesser than unity value of predictability ratio also suggested prevalence of non-additive gene effects. The importance of additive as well as non-additive gene effects with predominance of non-additive gene effects in inheritance of grain yield and yield components of rice.

Keywords: Combining, ability, gene, red, kernel, *Oryza sativa* L.

Introduction

Rice (*Oryza sativa* L.) is not only most prominent crop of India but also the world. It is a staple food for most of the people of the country. This crop is the backbone of livelihood for millions of rural households and plays vital role in the country's food security, so the term "rice is life" is most appropriate in Indian context. Now a days, the quality considerations assume enhanced importance, especially in the countries which are self-sufficient in their production. As per capita income increases, the consumption preference of common man is shifting towards quality rice. Hence the nutritional quality has also become a primary consideration in rice breeding programs not only in India but also in various rice growing countries across the world. The quality rice include aromatic rice, red rice, black rice and golden rice. Red rice constitute a small but special group of rice which are considered the best in quality in view of nutritive purpose.

Combining ability studies have been conducted in many crops ranging from cereals, vegetables, legumes etc. indicating that it is a crucial tool in plant breeding. It describes the breeding value of parental lines to produce hybrids.

General Combining Ability (GCA) refers to the average performance of a parent in hybrid combinations and Specific Combining Ability (SCA) is the performance of a parent relatively better or worse than expected on the basis of the average performance of the other parents involved. The concept of combining ability was first proposed to estimate the performance of hybrids derived from certain inbred lines by Sprague and Tatum, in 1942.

In quantitatively inherited characters, prediction of ability of the parents to combine well, generate more variability and transmit desired genes to the progeny is rather difficult through parental phenotypes. Recent developments in biometrical genetics have made it possible to make such predictions with ease. Various biometrical methods used to select the right parents, multivariate analysis (Morishima and Oka, 1960) [11].

Based on combining ability analysis of different characters, higher SCA values refer to dominance gene effects and higher GCA effects indicate a greater role of additive gene effects controlling the characters. If both the GCA and SCA values are not significant, epistatic gene effects may play an important role in the genetic of characters. Crossing a line to several others provides the mean performance of the line in all its crosses. Combining ability or productivity in crosses is defined as the cultivars or parents ability to combine among each other during hybridization process such that desirable genes or characters are transmitted to their progenies.

On the basis of these definitions, the only way to select combining ability is to grow and examine the progeny. However, an experienced breeder can recognize a potential for hybrid vigor by identifying the dominant traits of the parents and deduce which lines may be combined favorably. Generally, predicting the combining ability of important traits is determined only by testing a set of designed progeny, followed by statistical analysis.

Material and Methods

The present investigation was carried out at Educational and Experimental Farm, Department of Agriculture Botany, College of Agriculture Dapoli, Tal- Dapoli, Dist- Ratnagiri during *Kharif* -2019 and *Rabi* 2019-20 and at experimental farm, Agriculture Research Station, Palghar, Dist. Palghar during *Kharif*-2020.

The experimental material for present investigation consisted of 36 entries including six females, four males, their 24 crosses and two check varieties of rice. All the females were semi-dwarf, high yielding, white kernel, fine grain type rice varieties which are used as lines, while all males were red kernel land races used as testers in this experiment. The crosses were developed by line x Tester fashion given by Kempthorne in 1957. The experiment was conducted using a randomized block design consisting of three replications. Observations were recorded for different characters such as plant height (cm), panicle length (cm), days to 50% flowering, number of productive tillers plant^{-1}, number of spikelet panicle^{-1}, spikelets fertility per cent, days to maturity, grain yield plant^{-1}, straw yield plant^{-1}, harvest index (%), test weight (g), kernel length (mm), Kernel breadth (mm) and Length breadth ratio.

The experimental data was collected on all the fourteen characters. The data was compiled by taking the mean values over five randomly selected plants in each plot in each replication. The combining ability analysis was carried out following line × tester mating design outlined by Kempthorne (1957) [10] and further elaborated by Arunachalam (1974) [2]. Line × tester analysis was used to estimate general combining ability (gca) and specific combining ability (sca) variances and their effects using the observations taken on F_1 generation of the line × tester set of crosses. In this mating system, a random sample of lines ‘l’ is taken and each line is mated to each of the testers ‘t’ (Singh and Chaudhary, 1977) [15].

Result and Discussion

The analysis of variance revealed that mean squares due to lines × testers were highly significant for all the fourteen characters. The mean square due to lines was non-significant in case of all the characters. Whereas, variance due to testers was highly significant for all characters except number of spikelets panicle^{-1}, spikelet fertility per cent, kernel breadth and L:B ratio (Table 1).

The summary of general combining ability effects of the parents (Table 2) revealed that among lines, Palghar 1, Ratnagiri 6 and Trombay Karjat Kolam and among testers Munga and Valai were recognized as good general combiners for grain yield plant^{-1} and some of other yield related traits. Male Munga was good general combiner for most of the characters *viz*.; panicle length, productive tillers plant^{-1}, number of spikelets panicle^{-1}, spikelets fertility per cent, grain yield plant^{-1}, straw yield plant^{-1}, test weight and kernel length. Female Trombay Karjat Kolam was good general combiner for panicle length, productive tillers plant^{-1}, grain yield plant^{-1}, straw yield plant^{-1}, kernel length and L: B ratio.

In case of specific combining ability effects, none of the hybrid exhibited favourable SCA effects for all the characters (Table 3a and 3b). Jayasudha and Sharma (2010) [8] reported that, the cross combinations, which expressed high sca effects for grain yield, have invariable positive sca effects for one or more exhibited yield related traits also. Secondly to get best specific combination for yield it would be important to give due weightage to yield related traits. In the present study positive specific combining ability is desirable for all the characters except days to 50 per cent flowering, days to maturity, plant height and kernel breadth. Significant specific combining ability in desirable direction was observed in various traits and crosses, for days to 50 per cent flowering (7), days to maturity (7), plant height (4), panicle length (8), number of productive tillers plant^{-1} (4), number of spikelets panicle^{-1} (4), spikelets fertility per cent (9), grain yield plant^{-1} (8), straw yield plant^{-1} (7), harvest index (7), test weight (12), kernel length (6), kernel breadth (6) and L:B ratio (3).

Significant specific combining ability in desirable direction indicated dominance gene effect. Gopikannan and Ganesh, (2013) reported that since, predominance of dominant gene action involved in the inheritance of complex trait like yield, one or two cycles of inter mating among selected segregants in the segregating generations followed by recombination breeding in advanced generations would be an ideal approach to get superior segregants/cultures through breaking up of undesirable linkages and allowing favourable genes to recombine. As a whole, on perusal of data for hybrids based on *per se*, sca effects and standard heterosis. These results are in agreement with findings of Bineeta devi *et al.*, (2015), Sonu kumar *et al.*, (2016), Thorat *et al.*, (2017), Sudeepthi *et al.*, (2018) and Singh *et al.*, (2019) [3, 17, 20, 19].

High SCA effects denotes undoubtedly a high heterotic response, but this may be due to poor performance of the parents in comparison with their hybrids. With the same amount of heterotic effect, the SCA effect may be less, where the mean performance of the parents was higher but this estimate may also be biased (Ziauddin *et al.*, 1979) [22]. This suggested that the selection of cross combination based on heterotic response would be more realistic rather than on the basis of SCA effects. Therefore, comparative study of first three best specific combinations along with their mean performance and general combining ability effects of the parents in the specific crosses was made and could be summarized as follows.

General combining ability effects were estimated for parents and specific combining ability effects were estimated for hybrids. The character wise categorization of general combining ability effects of the parents has been presented in Table 4. In present study it was observed that none of the parents was good general combiner for all the traits. These results are in agreement with the findings of Jayasudha and Sharma (2010), Tiwari *et al.*, (2011), Hasan *et al.*, (2013), Sonu kumar *et al.*, (2016), Thorat *et al.*, (2017), Sudeepthi *et al.* (2018) and Singh *et al.*, (2019) [8, 17, 20, 19, 21, 7].

By examining the summary from Table 4a and 4b, it is revealed that the best specific combination Karjat 9 x Munga recorded the desirable significant SCA effects for grain yield plant^{-1} as well as plant height and panicle length. The second best specific combination Ratnagiri 6 x Bela showed desirable significant sca effects for the characters days to maturity and number of spikelets panicle^{-1}. Whereas the third best cross combination Ratnagiri 6 x Munga had desirable significant sca effects for number of productive tillers plant^{-1} and test weight. Chethri *et al.,* (2018) reported that the SCA effects and *per se* performance of the crosses were not closely related. The crosses with high *per se* performance need not be the one with high SCA effects and vice versa. An ideal combination to be explored is one where high magnitude of SCA is present, in addition to high GCA effect in both or at least one of the parents.

A closer look at the general combining ability of these crosses parentage revealed that at least one of the parent was a good general combiner. This clearly signifies the importance of computing general combining ability of parents and specific combining ability of hybrids (Gahtyari *et al.,* 2017) [5]. In the present study, on the basis of combining ability, the most promising parents for yield and yield attributing traits were Ratnagiri 6, Karjat 9, Munga, and Valai. Whereas, most promising hybrids were Karjat 9 x Munga, Ratnagiri 6 x Munga, Ratnagiri 6 x Bela and Ratnagir 5 x Valai.

The high positive or negative specific combining ability effects showed by the crosses involved either good x good, good x average and average x poor combining parents. Therefore, information of general combining ability effects alone may not be sufficient to predict the magnitude of heterosis. Hence information on general combining ability effects of the parents needs to be supplemented by that of specific combining ability effects and hybrid performance. The result is in accordance with Sonu kumar *et al.,* (2016) and Sudeepthi *et al.,* (2018) [17, 19].

Gene action studies gives the insight view of the expression of the genes in a genetic population. The knowledge of gene action helps in studies of desirable parental lines used in hybridization programme and choice of the appropriate breeding procedure. General combining ability effects and additive x additive gene action are theoretically fixable. On the other hand, specific combining ability attributed to non-additive gene action may be due to dominance or epistasis or both and are not fixable. The presence of non-additive genetic variance is primary justification for initiating the hybrid programme. The success of hybrid programme based on the results of combining ability depends on the extent of genetic parameters remaining stable over environments. In present studies all parents showed significant positive expression in all the traits under study.

Combining ability analysis revealed that both GCA and SCA variances were important for inheritance of various studied traits with additive and non-additive nature of gene action. The SCA variances were higher than the corresponding GCA variances for almost all the traits (Saidaiah *et al*., 2012), indicated preponderance of non-additive gene effects. The estimates of average degree of dominance varied from greater to unity and emphasized predominance of non-additive gene effects (Table 5). The lesser than unity value of predictability ratio also suggested prevalence of non-additive gene effects. The importance of additive as well as non-additive gene effects with predominance of non-additive gene effects in inheritance of grain yield and yield components of rice were agreement with earlier findings of Kannan *et al.,* (2016), Archana devi *et al.*, (2017) and Paranthaman *et al.,* (2019).

The ratio of σ^2 gca/σ^2 sca is less than unity for a character indicated preponderance of non-additive gene effect. It suggested greater importance of non-additive gene action in their expression and indicated very good prospect for the exploitation of non-additive genetic variation for grain and its component characters through hybrid breeding (Pratap *et al.,* 2013).

Table 1: Analysis of variance for combining ability for fourteen characters in rice.

Source of variation	DF	Characters													
		Days to 50 per cent flowering	Plant height (cm)	Panicle length (cm)	No. of productive panicles plant^{-1}	No. of spikelets panicle^{-1}	Spikelet fertility (%)	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Harvest index (%)	Days to maturity	Test weight (g)	Kernel length (mm)	Kernel breadth (mm)	L:B ratio
Replication	2	10.76	29.16	0.23	0.29	75.43	5.88	0.47	1.45	0.10	11.79	0.02	0.002	0.002	0.002
Line	5	65.08	241.42	25.31	1.23	241.36	40.84	40.85	125.45	4.78	91.17	17.50	0.133	0.032	0.021
Tester	3	353.83**	2,990.68*	252.14**	13.83**	1,528.70	152.48	349.03**	1,013.61**	18.40**	501.65**	32.51**	0.97**	0.037	0.046
Line x tester	15	64.78**	276.01**	28.80**	1.95**	503.79**	96.26**	40.84**	71.08**	3.15**	86.72**	31.62**	0.11**	0.015**	0.021**
Error	46	5.23	24.76	2.06	0.30	131.18	4.07	3.38	6.83	0.08	5.10	0.06	0.008	0.001	0.003

DF: Degree of freedom

*Significant at 5% level of significance, **Significant at 1% level of significance

Table 2: Estimation of General Combining Ability (GCA) effects of parents for fourteen quantitative characters.

Parents		Characters													
		Days to 50 per cent flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers plant^{-1}	No. of spikelets panicle^{-1}	Spikelet fertility (%)	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)	Harvest index (%)	Days to maturity	Test weight (g)	Kernel length (mm)	Kernel breadth (mm)	L:B ratio
Females	Karjat 4	-2.93**	-7.81**	-2.27**	-0.40*	-1.53	-3.02**	-2.88**	-5.58**	1.18**	-3.67**	-1.31**	-0.07*	-0.03**	0.00
	Karjat 9	0.82	0.77	0.13	-0.18	-7.44*	-0.90	-0.03	-0.37	0.09	1.00	1.66**	0.06*	0.04**	-0.02
	Palghar 1	0.65	6.04**	0.87*	0.32	1.47	2.32**	1.46**	2.33**	-0.14	0.83	1.07**	0.09**	0.06**	-0.03
	Ratnagiri 5	-2.85**	-0.18	-1.23**	0.04	0.31	-0.04	-1.50**	-1.46	-0.28**	-3.08**	-0.26**	-0.18**	-0.07**	0.01
	Ratnagiri 6	1.99**	-0.35	1.25**	-0.20	0.89	1.25*	1.56**	2.09**	-0.15	1.67*	-1.27**	0.00	0.03**	-0.04*
	TKK	2.32**	1.54	1.25**	0.42**	6.31	0.40	1.39*	3.00**	-0.69**	3.25**	0.10	0.09**	-0.03**	0.08**
Males	Bela	-1.15*	-3.77**	-2.44**	0.57**	6.61*	0.38	-2.80**	-4.93**	0.68**	-1.58**	-3.09**	-0.20**	-0.04**	-0.04**
	Munga	3.96**	7.26**	2.26**	0.92**	9.00**	1.37**	2.48**	4.83**	-0.93**	4.81**	2.54**	0.21**	0.04**	0.05**
	Valai	2.96**	12.84**	4.03**	-0.72**	-5.78*	2.44**	4.86**	7.83**	-0.80**	3.53**	3.63**	0.19**	0.04**	0.04**
	Kudai	-5.76**	-16.33**	-3.84**	-0.78**	-9.83**	-4.18**	-4.53**	-7.74**	1.05**	-6.75**	-3.08**	-0.20**	-0.04**	-0.04**

*Significant at 5% level of significance, **Significant at 1% level of significance

Table 3a: Estimation of Specific Combining Ability (SCA) Effects of hybrids for fourteen characters.

Sr. No.	Characters Crosses	Days to 50 per cent flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers plant^{-1}	No. of spikelets panicle^{-1}	Spikelet fertility (%)	Grain yield plant^{-1} (g)
1	Karjat 4 x Bela	-1.51	2.97	-0.95	-0.02	14.97*	7.75**	-1.34
2	Karjat 4 x Munga	6.71**	-4.16	-0.65	-0.11	-17.42*	-4.91**	-0.46
3	Karjat 4 x Valai	-0.96	-4.31	2.91**	1.20**	-2.97	-2.58*	3.40**
4	Karjat 4 x Kudai	-4.24**	5.50	-1.32	-1.07**	5.42	-0.26	-1.60
5	Karjat 9 x Bela	-2.93*	12.29**	0.32	-0.52	6.22	-6.37**	0.44
6	Karjat 9 x Munga	-2.71*	-15.27**	4.62**	-0.09	0.50	3.84**	5.19**
7	Karjat 9 x Valai	3.63**	-1.85	-4.82**	-0.39	-5.72	-5.33**	-5.66**
8	Karjat 9 x Kudai	2.01	4.82	-0.12	1.01**	-1.00	7.86**	0.03
9	Palghar 1 x Bela	0.57	-5.02	2.18*	-0.07	-16.69*	2.78*	3.03**
10	Palghar 1 x Munga	-3.21*	-5.91*	-2.66**	-0.62	0.58	2.92*	-3.46**

11	Palghar 1 x Valai	-1.87	-1.32	2.34**	0.22	18.69**	0.15	2.72*
12	Palghar 1 x Kudai	4.51**	12.25**	-1.86*	0.47	-2.58	-5.85**	-2.28*
13	Ratnagiri 5 x Bela	4.40**	-5.53	-0.86	1.27**	-15.53*	-4.69**	-1.05
14	Ratnagiri 5 x Munga	-1.04	0.08	-2.66**	-0.32	17.42*	3.05*	-2.95**
15	Ratnagiri 5 x Valai	-5.71**	10.07**	2.91**	-0.44	-2.81	3.95**	3.23**
16	Ratnagiri 5 x Kudai	2.35	-4.63	0.61	-0.51	0.92	-2.30	0.76
17	Ratnagiri 6 x Bela	-6.10**	-3.26	-0.40	-0.64*	19.22**	0.71	-0.69
18	Ratnagiri 6 x Munga	-0.21	10.95**	-1.33	1.37**	-0.17	2.93*	-1.58
19	Ratnagiri 6 x Valai	4.79**	2.30	2.00*	-0.35	-8.06	1.76	2.70*
20	Ratnagiri 6 x Kudai	1.51	-9.99**	-0.27	-0.37	-11.00	-5.39**	-0.43
21	TKK x Bela	5.57**	-1.45	-0.30	-0.01	-8.19	-0.18	-0.39
22	TKK x Munga	0.46	14.29**	2.67**	-0.23	-0.92	-7.83**	3.26**
23	TKK x Valai	0.13	-4.89	-5.34**	-0.24	0.86	2.05	-6.38**
24	TKK x Kudai	-6.15**	-7.95**	2.96**	0.47	8.25	5.96**	3.51**

*Significant at 5% level of significance, **Significant at 1% level of significance

Table 3b: Estimation of Specific Combining Ability (SCA) Effects of hybrids for fourteen characters.

Sr. No.	Characters Crosses	Straw yield plant^{-1} (g)	Harvest Index (%)	Days to maturity	Test weight (g)	Kernel length (mm)	Kernel breadth (mm)	L:B ratio
1	Karjat 4 x Bela	-1.44	-0.02	-1.33	1.67**	0.05	0.00	0.02
2	Karjat 4 x Munga	-1.45	0.27	7.28**	-4.25**	-0.29**	-0.05**	-0.07*
3	Karjat 4 x Valai	4.24**	-0.05	-3.11*	2.48**	0.22**	0.07**	0.01
4	Karjat 4 x Kudai	-1.34	-0.20	-2.83*	0.10	0.02	-0.02	0.03
5	Karjat 9 x Bela	-0.26	0.68**	-3.00*	-3.01**	0.04	-0.07**	0.10**
6	Karjat 9 x Munga	5.44**	1.00**	-3.06*	2.05**	0.20**	0.11**	-0.03
7	Karjat 9 x Valai	-6.63**	-0.69**	5.56**	-1.00**	0.02	-0.02	0.03
8	Karjat 9 x Kudai	1.45	-0.98**	0.50	1.96**	-0.25**	-0.01	-0.09**
9	Palghar 1 x Bela	4.01*	-0.07	-0.50	-0.99**	-0.05	-0.08**	0.07*
10	Palghar 1 x Munga	-5.27**	0.18	-2.56	1.28**	0.03	-0.02	0.03
11	Palghar 1 x Valai	4.99**	-0.46**	-1.94	0.07	0.02	0.10**	-0.10**
12	Palghar 1 x Kudai	-3.73*	0.35*	5.00**	-0.36*	-0.01	0.00	0.00
13	Ratnagiri 5 x Bela	-2.30	0.49**	5.75**	3.98**	-0.27**	0.05**	-0.18**
14	Ratnagiri 5 x Munga	-3.91*	-0.35*	0.03	-5.05**	-0.11*	-0.08**	0.05
15	Ratnagiri 5 x Valai	6.28**	-0.82**	-7.03**	2.04**	0.17**	-0.03	0.11**
16	Ratnagiri 5 x Kudai	-0.07	0.68**	1.25	-0.97**	0.21**	0.06**	0.02
17	Ratnagiri 6 x Bela	1.56	-1.60**	-7.67**	0.91**	0.14**	0.00	0.06
18	Ratnagiri 6 x Munga	-0.07	-0.98**	-1.06	4.01**	0.02	0.02	-0.02
19	Ratnagiri 6 x Valai	-1.01	2.59**	6.22**	-5.53**	-0.26**	-0.04**	-0.07*
20	Ratnagiri 6 x Kudai	-0.47	-0.01	2.50	0.60**	0.10	0.01	0.03
21	TKK x Bela	-1.56	0.53**	6.75**	-2.57**	0.08	0.09**	-0.06
22	TKK x Munga	5.26**	-0.11	-0.64	1.96**	0.15**	0.03	0.03
23	TKK x Valai	-7.87**	-0.57**	0.31	1.94**	-0.16**	-0.08**	0.02
24	TKK x Kudai	4.17**	0.16	-6.42**	-1.33**	-0.07	-0.03	0.01

*Significant at 5% level of significance, **Significant at 1% level of significance

Table 4a: Best crosses with high SCA effect, *per se* performance and GCA effect of parents for grain yield and in components traits.

Characters	Promising cross	SCA effect	Mean performance	GCA effect	
				Female	Male
Days to 50 percent flowering	TKK x Kudai	-6.15**	89	2.32**	-5.76**
	Ratnagiri 6 x Bela	-6.10**	94	1.99**	-1.15**
	Ratnagiri 5 x Valai	-5.71**	93	-2.85**	2.96**
Plant height (cm)	Karjat 9 x Munga	-15.27**	116.67	0.77	7.26**
	Ratnagiri 6 x Kudai	-9.99**	97.23	-0.35	-16.33**
	TKK x Kudai	-7.95**	101.17	1.54	-16.33**
Panicle length (cm)	Karjat 9 x Munga	4.62**	31.17	0.13	2.26**
	TKK x Kudai	2.96**	24.53	1.25**	-3.84**
	Karjat 4 x Valai	2.91**	28.83	-2.27**	4.03**
Number of productive tillers plant^{-1}	Ratnagiri 6 x Munga	1.37**	14.0	-0.20	0.92**
	Ratnagiri 5 x Bela	1.27**	13.8	0.04	0.57**
	Karjat 4 x Valai	1.20**	12.0	-0.40*	-0.72**
Number of spikelets panicle^{-1}	Ratnagiri 6 x Bela	19.22**	240	0.89	6.61*
	Palghar 1 x Valai	18.69**	228	1.47	-5.78*
	Ratnagiri 5 x Munga	17.42*	240	0.31	9.00**
Spikelets fertility per cent	Karjat 9 x Kudai	7.86**	91.33	-0.90	-4.18**
	Karjat 4 x Bela	7.75**	93.67	-3.02	0.38
	TKK x Kudai	5.96**	90.74	0.40	-4.18**
Grain yield plant^{-1} (g)	Karjat 9 x Munga	5.19**	35.89	-0.03	2.48**
	TKK x Kudai	3.51**	28.62	1.39*	-4.53**
	Karjat 4 x Valai	3.40**	33.64	-2.88**	4.86**
Straw yield plant^{-1} (g)	Ratnagiri 5 x Valai	6.28**	51.57	-1.46	7.83**
	Karjat 9 x Munga	5.44**	48.82	-0.37	4.83**
	TKK x Munga	5.26**	52.02	3.00**	4.83**

Table 4b: Best crosses with high SCA effect, *per se* performance and GCA effect of parents for grain yield and in components traits.

Characters	Promising cross	SCA effect	Mean performance	GCA effect	
				Female	Male
Harvest index%	Ratnagiri 6 x Valai	2.59**	43.86	-0.69**	-0.80
	Ratnagiri 6 x Munga	1.00**	40.16	-0.15	-0.93**
	Karjat 9 x Bela	0.68**	43.67	0.09	0.68**
Days to maturity	Ratnagiri 6 x Bela	-7.67**	122	1.67*	-1.58**
	Ratnagiri 5 x Valai	-7.03**	123	-3.08**	3.53**
	TKK x Kudai	-6.42**	119	3.25**	-6.75**
Test weight (g)	Ratnagiri 6 x Munga	4.01**	26.76	-1.27**	2.54**
	Ratnagiri 5 x Bela	3.98**	22.11	-0.26**	-3.09**
	Karjat 4 x Valai	2.48**	26.28	-1.31**	3.63**
Kernel length (mm)	Karjat 4 x Valai	0.22**	6.34	-0.07*	0.19**
	Ratnagiri 5 x Kudai	0.21**	5.84	-0.18**	-0.20**
	Karjat 9 x Munga	0.20**	6.47	0.06*	0.21**
Kernel breadth (mm)	TKK x Valai	-0.08**	2.21	-0.03**	0.04**
	Ratnagiri 5 x Munga	-0.08**	2.17	-0.07**	0.04**
	Palghar 1 x Bela	-0.08**	2.23	0.06**	-0.04**
Length breadth ratio	Ratnagiri 5 x Valai	0.11**	2.78	0.01	0.04**
	Karjat 9 x Bela	0.10**	2.66	-0.02	-0.04**
	Palghar 1 x Bela	0.07*	2.62	-0.03	-0.04**

Table 5: Estimates of general and specific combining ability variances and proportionate gene action in rice for the characters under study.

Sr. No.	Characters	σ^2GCA	σ^2SCA	σ^2GCA/ σ^2SCA	Nature of gene action	Degree of dominance
						$\sqrt{\frac{\sigma^2 SCA}{2\sigma^2 GCA}}$
1	Days to 50 per cent flowering	9.645	19.852	0.486	Non additive	1.014
2	Plant height (cm)	89.336	83.749	1.067	Additive	0.685
3	Panicle length (cm)	7.328	8.916	0.822	Non additive	0.780
4	Number of productive panicles plant^{-1}	0.371	0.549	0.677	Non additive	0.860
5	Number of spikelets panicle^{-1}	25.416	124.203	0.205	Non additive	1.563
6	Spikelet fertility (%)	0.028	30.728	0.001	Non additive	23.240
7	Grain yield plant^{-1} (g)	10.275	12.488	0.823	Non additive	0.780
8	Straw yield plant^{-1} (g)	33.223	21.418	1.551	Additive	0.568
9	Harvest index (%)	0.563	1.023	0.550	Non additive	0.953
10	Days to maturity	13.980	27.206	0.514	Non additive	0.986
11	Test weight (g)	6.225	10.521	0.592	Non additive	0.919

12	Kernel length (mm)	0.029	0.035	0.838	Non additive	0.772
13	Kernel breadth (mm)	0.001	0.005	0.296	Non additive	1.299
14	L:B ratio	0.001	0.006	0.126	Non additive	1.996

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