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Combining ability analysis and gene action for blast resistance in rice (*Oryza sativa* L.)

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Abstract
Ten rice genotypes were crossed in a line x tester mating design using five testers and six lines to produce 30 hybrids. Analysis of variance showed highly significant differences among genotypes for all the studied traits indicating a wide range of genetic diversity, different origin of these parents and prevalence of additive variance. However, mean sum of squares due to parents was significant for the studied traits except days to flowering, flag leaf length, flag leaf width and test weight. The highest GCV and PCV coupled in the character number of effective tiller. While for plant height, Shayamala, Jaldubi and Makdo exhibited highly significant negative GCA effects for short plant height. The best hybrids produced from different crosses were Mahamaya x Mehardhan, IGKV-R-1244 x Mehardhan and MTU- 1001 x IR-64. These crosses could be involved in the rice breeding program. The yield attributing character that is number of effective tiller is found significantly correlated with other characters like flag leaf width, panicle length and panicle weight. Significant phenotypic correlation of ET with FLW and PL shows that yield can be increase with improvements in above characters.

Keywords: Rice (*Oryza sativa* L), General combining ability, specific combining ability and heterosis analysis

Introduction
The cultivated species of rice (*Oryza sativa* L.) comes under family Poaceae. Cultivation of rice started back to 3000 B.C. Rice is the most valuable and primary food crop for more than 50% of the world's population [13]. Rice (*Oryza sativa* L; 2n=24; estimated genome size = 430Mb) is a major cultivated crop in the World [19]. The available information regarding genetic behavior of different agro-physiological traits of rice is limited. More than 90% of the world's rice is grown and consumed in Asia.

Line x tester analysis is one of the most powerful tools for estimating the general combining ability (GCA) of parents and selecting of desirable parents and crosses with high SCA for the exploitation of heterosis. Significant GCA and SCA for yield and yield components were also reported (Gnanamalar *et al*., 2015). Besides grain yield of hybrid rice their grain quality parameters have also been given special attention to increase their market value and consumer satisfaction. Therefore, rice plays an important role in providing food security, alleviating malnutrition and poverty in Asia and the World. (Sahu *et al*., 2016) [15].

Rice blast, caused by *Pyricularia oryzae* Cavara, is a devastating disease of rice (*Oryzae sativa* L.), which is a staple food for more than one-half of the world's population (Bouman *et al*. 2007; Talbot 2003). Identifying key genomic regions associated with blast resistance against a broad spectrum of isolates in backcross introgression lines have been developed through conventional breeding program (Korinsaka *et al*., 2011).

Material and Methods
The study was carried out at the Research-cum-Instructional Farm of S.G. College of Agriculture and Research Station, Jagdalpur, Bastar (C.G.) during the two growing season *kharif*-2019 and *rab*i-2020. Ten rice genotypes were used in this study; six belonged to improved rice varieties, four testers used were local varieties of Chhattisgarh (Table 1). The crossing used Line x Tester method, however the lines genotypes are namely: IGKV- R- 1244, Shayamala, Jaldubi, Bamleshwari, Mahamaya and MTU-1001, while the tester genotypes were Mehardhan, Assamchudi, Gandhak, Makdo and IR-64. Thirty F$_1$ was produced through crossing between line x tester during the growing season 2019, this hybridization was according to [11] and modified by [1]. In the growing season of 2020, all the ten parents and their thirty hybrids were grown in pots with two replications. 10 agronomic characters: Days to 50% flowering, Plant height (cm), Flag leaf width (cm), Flag leaf length (cm), No. of effective

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tillers, Panicle weight (g), Panicle length (cm), Yield per plant, Test weight (g), Harvest Index(%) were estimated for all rice genotypes under study.

Table 1: List of parents used in this experiment

Parents (lines)	Parents (testers)
IGKV- R- 1244	Mehardhan
Shayamala	Assamchudi
Jaldubi	Gandhak
Bamleshwari,	Makdo
Mahamaya	IR-64 (check)
MTU-1001	

Statistical analysis: Data recorded for plant traits were analyzed according to Analysis of Variance (ANOVA) technique as outlined by [18].

Also, Analysis of Variance for line x tester crossing and combining ability analysis was done using line x tester design as describe by [12]. The genetic relationships were among individuals and populations measured by similarity of number of quantitative character.

Results and Discussion
Mean performance
The data on mean performance of parents and for grain yield and yield attributing ten characters are presented in table 2:-

Table 2: The data on mean performance of parents and for grain yield and yield attributing ten characters are presented

	Days to 50% flowering	Plant height (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Effective tillers	Panicle length (cm)	Panicle weight (g)	Yield per plant	Test weight(g)	Harvest index
L x T										
IGKV-R-1244 x MeharDhan	105.5	92	28.45	1.1	3.5	17.15	3.65	97	21	39.15
IGKV-R-1244 x Assamchudi	106	91	32.5	1.3	3	15.45	2.9	74	19.8	32.65
IGKV-R-1244 x Gndhak	98.5	98	29.95	1.35	5	16.95	2.6	82	22	36.7
IGKV-R-1244 x Makdo	102	93.7	25.5	1.35	1.5	17.6	3	77.5	21.4	26.2
IGKV-R-1244 x IR-64	104.5	88.5	24.5	1.15	4.5	14.5	2.6	72	20.15	26.45
Mahamaya x Mehardhan	103.5	78.5	23	1.45	3.5	12	2.65	76.5	21.3	27.7
Mahamaya x Assam chudi	106	77.5	25	1.25	3.5	11.8	2.1	69.5	22	26.6
Mahamaya x Gandhak	103.5	84	26	1.35	3	14	2.95	77	19	21.15
Mahamaya x Makdo	103	81.5	23	1.3	3.5	13	2.55	73	21.45	29.85
Mahamaya x IR-64	116	87	21.65	1.35	4.5	16.35	2.5	74	21	20.5
Shyamala x Mehardhan	103.5	83.5	24.5	1.4	3.5	16	3	77	21.85	29.45
Shyamala x Assam chudi	109	82.5	22	1.3	3.5	14.5	2.65	71.5	23.55	26.9
Shyamala x Gandhak	105	80.5	28	1.4	4.5	13.5	2.2	78	19.5	24.2
Shyamala x Makdo	103.5	84	18.5	1.3	3.5	15.5	2.05	76	19.7	29.4
Shyamala x IR-64	112.5	82	25.5	1.25	4.5	14.5	2.1	69	21	30.3
Jaldubi x Mehardhan	100.5	95.5	22.5	1.4	3.5	13	2.3	73.5	21	14.75
Jaldubi x Assam Chudi	95	98	23.5	1.15	4.5	13.5	2.45	81	23.1	26.95
Jaldubi x Gandhak	105.5	99	25	1.3	4.5	13.5	2	71	22.45	14.75
Jaldubi x Makdo	102.5	97	27	1.65	5.5	15.5	2.35	89	23.35	16.5
Jaldubi x IR- 64	118	89	27	1.4	4.5	15	2.45	84.5	21.5	21.75
Bamleshwari x Mehardhan	126	95.5	27.5	1.4	5.5	13	2.9	77	22.95	32
Bamleshwari x Assamchudi	111	88	25.5	1.25	6.5	13.5	2.7	77	22.15	19.85
Bamleshwari x Gandhak	108	91	29.5	1.4	4.5	13.5	2.45	79	21	23.35
Bamleshwari x Makdo	115	96.15	31.55	1.5	7.5	13.5	2.6	86	22.6	17.7
Bmleshwari x IR-64	119	96	29.5	1.35	6.5	12.5	2.55	88.5	24.05	35.75
MTU-1001 X Mehardhan	104.5	96	25.5	1.35	3.5	12.5	2.65	89	22.95	33.7
MTU -1001 x Assam chudi	105.5	96	31	1.05	6	14.5	2.35	82	20.95	19.95
MTU -1001 x Gandhak	110.5	91.5	29	1.15	2.5	14	2.1	81	21.95	20.65
MTU -1001 x Makdo	106	92.5	30.5	1.2	4	11.5	2.65	81	23.5	16.05
MTU -1001 x IR -64	107.5	85.5	32.3	1.25	3.5	13.5	2.25	79.5	23.4	35.8
IGKV-R-1244	95	82	20.5	1.35	22	15.5	4	77	20.8	37.1
Parents										
Mahamaya	102.5	70.5	22	1.2	11	18.5	3.25	85.5	24.4	27.85
Shayamala	98	77.5	28.5	1.4	6.5	14.5	2.7	88	22.25	33.9
Jaldubi	94	86.5	22	1.25	13	20.5	2.6	84.5	21.85	26.6
Bamleshwari	91.5	88.5	26.25	1.35	13.5	21	2.55	77	23.3	21.9
MTU – 1001	88	75	22.5	1.2	9.5	22	1.75	72.5	23.95	24.45
Mehar Dhan	97	100	26	1.3	8.5	15.5	2.25	126.5	23.5	20.25
Assam Chudi	103.5	108.5	31	1.25	12	16	2.05	106	20.1	27.15
Gandhak	96	102	27	1.55	16	17	3.45	128.5	22.2	22.3
Makdo	99	102	25.5	1.35	10.5	17.5	3.3	100.5	20.45	24.65
IR -64	101.5	74	34.5	1.8	17.5	13.5	2.25	111.5	16.15	28.4
Mean	104.38	88.84	26.55	1.33	6.78	15.00	2.58	84.09	21.58	26.18
C.V.	5.3253	5.6381	13.20	10.19	28.49	13.26	9.29	5.60	12.52	10.9
S.E.	3.9305	3.5419	2.47	0.09	1.36	1.40	0.17	3.33	1.91	2.02
C.D. 5%	11.22	10.11	7.08	0.27	3.90	4.02	0.48	9.51	-	5.77

The mean performance for days to 50% flowering revealed that parents flowered earlier than crosses, however those were statistically at par. The results showed that three lines (MTU-1001, Jaldubi and IGKV-R-1244) of early maturity gave 88, 94and 95 days and Mahamaya, MTU-1001and Shyamala of short stature gave. While, Shaymala recorded high value in grain yield per plant, Mahamaya for test weight and IGKV-R-1244 for panicle weight. In tester genotypes the variety Gandhak was of short duration and, highly yielding IR-64 short suture. While crosses Mahamaya x Mehardhan, IGKV – R- 1244 x Mehardhan, MTU-1001 x IR – 64 had short duration for 50% flowering.Also, these crosses were of high values for test weight (g), panicle length (cm), no. of effective tillers/plant and yield/plant and less value for flag leaf length and width.

Analysis of variance
The recorded data on different agronomic and maturity parameters were subjected to Analysis of Variance (ANOVA)

to confirm the differences among rice genotypes. Mean squares from analysis of variance of the studied traits of rice are presented in table 3. The results depicted highly significant differences among rice genotypes for all the studied characters indicating overall differences among these genotypes. Sum of squares of rice genotypes for these traits was further portioned into parents, crosses and parents vs. crosses which revealed highly significant differences among themselves.

These results indicated that these genotypes interacted and produced markedly different combining ability effects and this might be due to the difference in wide genetic diversity and different origin of these parents. Also, highly significance of lines and testers indicated a prevalence of additive variance. However, mean sum of squares due to line x tester was also significant for all the studied traits except plant height indicating the importance of both additive and non-additive variance. These results are similar to those obtained by earlier researchers [7, 5, 16, 17, 2].

Table 3: Analysis of variance (ANOVA) for line x tester for yield and yield attributing traits in rice (*Oryza sativa* L.)

Source of variation	df	Days to 50% flowering	Plant height (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Effective tillers	Panicle length (cm)	Panicle weight (g)	Yield per plant	Test weight(g)	Harvest index
Replication	1	24.695	108.45*	31.34	0.00	3.52	6.67	0.001	0.597	8.56	27.51
Treatments	40	4612.80**	150.73**	26.52*	0.03*	41.07	11.75**	0.43**	379.41**	5.23	82.00**
Parents	10	445.81	355.20**	35.86*	0.06*	39.13**	15.58**	0.93**	785.50**	10.89	51.52**
Parents (Lines)	5	254.66	96	18.78	0.01	55.48**	18.93*	1.14**	74.15	3.73	66.80**
Parents (Testers)	4	77.4	359.9**	29.65	0.10**	28.35**	4.85	0.87**	308.60**	15.48	22.57
Parents (L v/s T)	1	113.75	1632.49**	146.07*	0.13*	0.54	41.75*	0.12	6249.94*	28.31	90.94*
Parents v/s Crosses	1	1710.30*	53.98	4.34	0.04	1156.83**	168.19**	0.63*	4856.73*	0.00	12.67
Crosses	29	2456.68*	83.56*	24.07	0.03*	3.26	5.04	0.25**	84.99**	3.46	94.90**
Line Effect	5	986.28*	360.84*	70.90*	0.05	9.43*	14.99*	0.54	136.30	6.73	188.31
Tester Effect	4	521.76	18.06	11.62	0.04	1.41	0.78	0.43	63.14	2.08	107.73
Line * Tester Effect	20	948.63	27.34	14.86	0.02	2.09	3.40	0.14*	76.53**	2.92	68.97**
Error	40	1234.80	25.32	12.19	0.01	3.74	3.82	0.05	21.22	7.33	8.12
Total	81	5872.30	88.28	19.51	0.02	22.17	7.77	0.24	197.85	6.31	44.84

* Significant at p=0.05% level   ** Significant p=0.01% level

General combining ability effects (GCA): Variation in general combining ability (GCA) effects was estimated among lines and testers for ten agronomic traits to identify the best parent. The results of the general combining ability effects of lines and testers are presented in table 4. High positive values of (GCA) effects would be of interest in most of traits under investigation {flag leaf length (5 crosses), flag

leaf width (6 crosses), no. of effective tillers/plant (3 crosses), panicle length (4 crosses), panicle weight (3 crosses), grain yield/plant (5 crosses), test weight (6 crosses) and harvest index (3 crosses)}. High negative values for days to flowering (8 crosses) and plant height (3 crosses) would be useful from the breeder's point of view.

Table 4: General combining ability (GCA) for yield and its component traits in Rice (*Oryza sativa* L.)

Parents	Days to 50% flowering	Plant height (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Effective tillers	Panicle length (cm)	Panicle weight (g)	Yield per plant	Test weight(g)	Harvest index
IGKV – R - 1244	-3.91*	2.94	1.68	-0.06	-0.75	2.15**	0.40**	1.73	-0.85	6.34 **
Shayamala	-0.81	-7.99**	-2.76 *	0.02	-0.65	-0.74	0.00	-4.7 **	-0.77	-0.73
Jaldubi	-0.51	-7.19 **	-2.79*	0.01	-0.35	0.62	-0.14	-4.46 **	-0.60	2.16 *
Bamleshwari	-2.91	6.00**	-1.49	0.06	0.25	-0.07	-0.23**	1.03	0.56	-6.95**
Mahamaya	8.58 **	3.63 *	2.21	0.06	1.85**	-0.97	0.09	2.73	0.83	-0.16
MTU - 1001	-0.41	2.60	3.16**	-0.11 *	-0.35	-0.97	-0.14	3.73 *	0.83	-0.66
Mehar Dhan	0.03	0.47	-1.25	0.03	-0.41	-0.23	0.31**	2.90*	0.12	3.56**
Assam Chudi	-1.80	-0.86	0.08	-0.09*	0.25	-0.30	-0.01	-2.93*	0.20	-0.40
IR -64	-2.05	0.97	1.41	0.01	-0.25	0.06	-0.15*	-0.76	-0.73	-2.42**
Gandhak	-1.88	1.11	-0.48	0.07	-0.14	0.25	-0.08	1.65	0.28	-3.27**
Makdo	5.70**	-1.69	0.24	-0.02	0.41	0.21	-0.13	-0.85	0.13	2.53 **
h^2 (NS)	50.48	68.57	41.56	36.51	22.50	30.26	52.13	27.16	-57.22	42.44
GA at 5%	7.19	9.31	3.05	0.09	0.53	0.97	0.41	4.05	-1.13	6.76

Table 5: List of top three best combiners of the experiment

Characters	GCA combiners	
	Lines	**Testers**
Days to 50% flowering	IGKV – R- 1244, Bamleshwari, shyamala	IR – 64, Gandhak, Assamchudi
Plant height	Shyamala, Jaldubi,	Makdo
Flag leaf length	MTU-1001, IGKV – R- 1244, Mahamaya	IR – 64
Flag leaf width	Mahamaya	Gandhak
Effective tiller	Mahamaya	Assamchudi
Panicle length	IGKV – R- 1244	Gandhak
Panicle weight	IGKV – R- 1244	Meherdhan
Yield per plant	MTU-1001, Mahamaya	Meherdhan
Test weight	Mahamaya	Gandhak
Harvest index	IGKV – R- 1244, Jaldubi	Meherdhan

Specific combining ability effect (SCA): The estimates of specific combining ability effects of twenty-four rice hybrids are presented in table 6. fifteent out of the thirty cross combinations studied showed highly significant negative SCA effects for duration. Also, fourteen crosses were found to be highly significant heavily negative SCA effects in plant height, seventeen and fifteen crosses were found to be highly significant positive SCA effects in flag leaf length and flag leaf width respectively, while no. of tiller/plant sixteen crosses gave highly significant positive SCA effects Panicle length with seventeen and Panicle weight thirteen cross combinations also found highly significant positive SCA effect. Thirteen cross combinations for grain yield per plant, eighteen cross combinations for test weight and thirteen cross combinations harvest index showed highly positive significant SCA effect.

Table 6: Specific combing ability in cross combinations

F_1	Days to 50% flowering	Plant height (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Effective tillers	Panicle length (cm)	Panicle weight (g)	Yield per plant	Test weight(g)	Harvest index
IGKV – R - 1244 x MeharDhan	2.16	-1.11	1.52	-0.18	0.41	1.05	0.38 *	13.60**	0.08	3.35
IGKV – R - 1244 x Assamchudi	4.50	-0.77	4.23	0.14	-0.75	-0.57	-0.03	-3.56	-1.27	0.82
IGKV – R - 1244 x Gndhak	-2.75	4.38	0.35	0.08	1.75	0.55	-0.19	2.26	1.86	6.89**
IGKV – R - 1244 x Makdo	0.58	-0.05	-2.19	0.03	-2.00	1.01	0.05	-4.65	0.25	-2.75
IGKV – R - 1244 x IR-64	-4.50	-2.44	-3.92	-0.07	0.58	-2.04	-0.21	-7.65 *	-0.85	-8.31**
Mahamaya x Mehardhan	-2.93	-3.67	0.52	0.07	0.31	-1.19	-0.21	-0.40	0.22	-1.02
Mahamaya x Assam chudi	1.40	-3.33	1.18	0.00	-0.35	-1.32	-0.43*	-1.56	0.84	1.84
Mahamaya x Gandhak	-0.85	1.32	0.85	-0.02	-0.35	0.50	0.55**	3.76	-1.21	-1.58
Mahamaya x Makdo	-1.51	-1.31	-0.24	-0.11	-0.10	-0.68	0.008	-2.65	0.22	7.96**
Mahamaya x IR-64	3.90	6.99	-2.32	0.03	0.48	2.70	0.08	0.85	-0.08	-7.19**
Shyamala x Mehardhan	-3.23	0.52	2.05	0.03	0.01	1.43	0.28	-0.20	0.60	-2.16
Shyamala x Assam chudi	4.10	0.86	-1.78	0.06	-0.65	0.00	0.26	0.13	2.22	-0.74
Shyamala x Gandhak	0.35	-2.97	2.88	0.05	0.85	-1.36	-0.042	4.46	-0.88	-1.42
Shyamala x Makdo	-1.31	0.38	-4.71	-0.10	-0.40	0.44	-0.34	0.05	-1.70	4.62*
Shyamala x IR-64	0.10	1.19	1.55	-0.05	0.18	-0.51	-0.16	-4.45	-0.25	-0.28
Jaldubi x Mehardhan	-3.83	-0.67	-1.24	-0.01	-0.58	-0.86	-0.327	-9.20**	-1.40	-7.75 *
Jaldubi x Assam Chudi	-7.50	3.16	-1.58	-0.13	-0.25	-0.29	0.157	4.13	0.61	8.41**
Jaldubi x Gandhak	3.25	2.32	-1.41	-0.09	0.25	-0.66	-0.152	-8.03*	0.90	-1.76
Jaldubi x Makdo	0.08	0.18	2.48	0.20 *	1.00	1.14	0.048	7.55*	0.79	0.83
Jaldubi x IR- 64	-3.23	0.52	2.05	0.03	0.01	1.43	0.283	-0.20	0.60	-2.16
Bamleshwari x Mehardhan	10.16 *	1.69	0.04	-0.01	-0.18	0.03	-0.05	-7.40*	0.27	2.70
Bamleshwari x Assamchudi	-3.00	-4.46	-3.29	-0.03	0.15	0.60	0.07	-1.56	-0.60	-5.47*
Bamleshwari x Gandhak	-5.75	-3.30	-0.62	0.008	-1.35	0.23	-0.03	-1.73	-0.81	0.04
Bamleshwari x Makdo	1.08	1.70	3.32	0.05	1.40	0.04	-0.03	2.85	-0.23	-4.75 *
Bmleshwari x IR-64	-2.50	4.36	0.54	-0.008	-0.01	-0.91	0.04	7.85*	1.37	7.48**
MTU-1001 X Mehardhan	-2.33	3.22	-2.90	0.11	0.01	-0.46	-0.06	3.60	0.27	4.90*
MTU -1001 x Assam chudi	0.50	4.56	1.25	-0.05	1.85	1.60	-0.03	2.43	-1.80	-4.87*
MTU -1001 x Gandhak	5.75	-1.77	-2.07	-0.06	-1.15	0.73	-0.14	-0.73	0.13	-2.15
MTU -1001 x Makdo	1.08	-0.91	1.32	-0.07	0.10	-1.95	0.25	-3.15	0.67	-5.90**
MTU -1001 x IR -64	-5.00	-5.10	2.39	0.07	-0.81	0.08	-0.01	-2.15	0.72	8.03**

Table 7: Best specific combiner for yield and yield attributing traits in rice

Characters	SCA combiners
Days to 50% flowering	Bamleshwari x Meahrdhan, IGKV – R- 1244 x Assamchudi IGKV – R- 1244 x Mehardhan
Plant height	Mahamaya x Mehardhan, MTU-1001 x IR – 64, Bamleshwari xGandhak
Flag leaf length	IGKV – R- 1244 x Assamchudi, Jaldubi x Mehardhan, Jaldubi x IR – 64
Flag leaf width	Mahamaya x Mehardhan, MTU-1001 x IR – 64, Shyamala x Assamchudi
Effective tiller	Shyamala x Gandhak, Mahamaya x IR – 64, IGKV – R- 1244 x Mehardhan
Panicle length	Mahamaya x IR – 64, IGKV – R- 1244 x Mehardhan, IGKV – R- 1244 x Makdo
Panicle weight	Mahamaya x Gandhak, IGKV – R- 1244 x Mehardhan, Shyamala x Mehardhan
Yield per plant	IGKV – R- 1244 x Mehardhan, Bamleshwari x IR – 64, Jaldubi x Makdo
Test weight	Shyamala x Assamchudi, IGKV – R- 1244 x Gandhak,
Harvest index	Jaldubi x Assamchudi, MTU-1001 x IR – 64, IGKV – R- 1244 x Gandhak

Generally, the results obtained from general and specific combining ability effects could indicate that the excellent hybrid combinations were obtained from crossing good x good, good x low and low general combiners. Consequently, it could be concluded that GCA effects of the parental lines were general unrelated to the specific combining ability effects of their respective crosses. This conclusion was also drawn by earlier researchers [16, 2, 17].

Table 8: Reaction of rice entries in ivt-b kharif-2019 under blast screening nursery (Student Trials).

Name	Entry number	Disease score
Gandhak	IVTB - 69	7
Assamchudi	IVTB - 70	6
Makdo	IVTB - 34	5
Mehardhan	IVTB - 66	3
IGKV – R- 1244	IVTB - 14	3
IR - 64	IVTB - 21	0

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