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Research Article

Combining ability studies for lodging resistance and yield traits in rice

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Abstract
General and specific combining ability effects of parents and hybrids were studied for lodging resistance and for yield in rice. Twelve F_1 hybrids were developed by crossing four lines (lodging genotypes) with three testers (lodging resistant) in the L x T pattern. The analysis of variance was highly significant, indicating the genetic diversity of parents and the importance of both additive and non-additive gene actions in the inheritance of traits investigated. Significant *sca* effects for different traits indicated a preponderance of non-additive gene action. Among parents, lines *viz*., Ponmani, Uma and Gouri were found to be good combiner for grain yield per plant and lodging resistance. Among the hybrids *viz*., Ponmani x Uma, Prathyasha x Pournami and Prathyasha x Gouri were the best cross combinations. Thus, specific parents and crosses can be used effectively in crop improvement programs.

Key words: Combining ability, lodging resistance, rice, yield, *gca* and *sca*

INTRODUCTION

Rice is the most important food and second most widely cultivated cereal in the world and it provides 15 per cent of per capita protein and 21 per cent of global human per capita energy. Lodging of rice is one of the most important problems during growth and harvest of rice which affects yield and quality of grains. High yielding varieties with less culm strength cannot hold the weight of grains results in lodging during ripening. Also wind during maturity increases the severity of the problem in many high yielding varieties. Lodging is a complex trait having interactions between many agro-morphological traits such as, plant height (Yang *et al*., 2000), diameter and length of basal internode (Wan and Ma, 2003), type of panicle (Ma *et al.,* 2004), upper plant weight, lignin content, cellulose content, rate of nitrogen application (Yang *et al.,* 2009), silicon content (Ma and Yamaji, 2006) and yield and cultivation condition (Cuo *et al*., 2003). Seed yield is also a complex trait the expression of which depends upon various yield contributing traits such as test weight, number of seeds per panicle, panicle weight, number of panicles, number of tillers and lodging resistance (Keerthiraj *et al*., 2020 (a); Keerthiraj *et al*., 2020(c)). The knowledge on combining ability is useful in selecting the desirable parents and cross combinations at the same time elucidate the nature and magnitude of gene actions involved (Xiang *et al.,* 2016). The combining ability analysis provides information on the variance due to General Combining Ability (GCA) and Specific Combining Ability (SCA). Where, GCA is attributed to additive gene action (additive x additive epistasis) which, is theoretically fixable. SCA is attributed to non-additive gene action (dominance or epistasis or both) which is non-fixable. The presence of specific combining ability variance which, is due to non-additive genetic action is vital for pursuing the hybrid development programme (Cockerham, 1961). In this context, L × T analysis (Kempthorne, 1957) provides reliable information about the GCA and SCA of parents and their cross combinations, respectively. Hence, this investigation was carried out to identify the best combiner lines and hybrid combination for yield and lodging resistance.

MATERIALS AND METHODS

The present investigation was carried out in Department of Plant Breeding and Genetics (PBGN), College of Horticulture, Kerala Agricultural University (KAU) during summer and *Kharif*, 2019. The crossing was done between selected four highly lodging genotypes as lines and three highly lodging resistant genotypes as testers (Keerthiraj and Biju, 2020b) in the L x T pattern. The resulted twelve hybrids were evaluated in RBD with two replications along with parents. General agronomic practices were done uniformly. Observations consisted of quantitative and biochemical parameters recorded based on Standard Evaluation System- International Rice Research Institute (SES-IRRI, 2014).

For statistical analysis mean values of observation were recorded from ten randomly selected plants in each replication. For all the genotypes including crosses and parents, the test of significance among all were estimated and when found significant then Line × Tester analysis was performed. Combining ability analysis for various yield and lodging related traits was accomplished by the method suggested by Kempthorne (1957).

RESULTS AND DISCUSSION

The analysis of variance (**Table 1**) revealed a high significant difference among lines for days to 50 per cent flowering, flag leaf length, flag leaf width, tillers per plant, internodal length, culm wall thickness, days to maturity, panicles per plant, panicle length, panicle weight, seeds per panicle, test weight, silicon content and potassium content and significant difference for plant height, culm diameter, lodging per cent and seed yield per plant. Whereas, testers reported high significant difference for plant height, flag leaf length, flag leaf width, tillers per plant, culm wall thickness, panicles per plant, panicle weight, seeds per panicle, silicon content and potassium content. Significant difference was existed for lodging per cent, panicle length and test weight, indicating significant variation among parents used in this study in terms of general combining ability. L x T reported high significant difference for plant height, internodal length, culm diameter, culm wall thickness and panicle weight. Significant difference for flag leaf width, days to maturity, lodging per cent, panicle length, seed yield per plant and potassium content, as a direct test of presence of heterosis and predominance of non-additive gene action.

Table 1. Analysis of variance for combining ability for quantitative and biochemical characters

Source	df	Mean squares								
		Days to 50 per cent flowering	Plant height	Flag leaf length	Flag leaf width	Tillers per plant	Internodal length	Culm diameter	Culm wall thickness	Days to maturity
Lines	3	622.819 **	114.438 *	43.449 **	0.078 **	2.793 **	4.404 **	1.153 *	0.056 **	759.708 **
Testers	2	5.167	237.221 **	1.410 **	0.015 **	8.420 **	0.54	0.22	0.015 **	10.17
Line x Testers	6	4.944	12.206 **	0.113	0.001 *	0.193	0.169 **	0.229 **	0.000 **	4.500 *
Error	11	5.951	1.32	0.178	0	0.096	0.01	0	0	0.951
σ^2gca		44.15	23.4	3.1881	0.0064	0.773	0.33	0.07	0.005	54.35
σ^2sca		-0.503	5.47	-0.21	0.0005	0.044	0.08	0.11	0.0001	1.754
σ^2gca/ σ^2sca		-87.77	4.27	-15.15	12.80	17.66	4.32	0.58	50.00	30.98

Table 1. (…continued)

Source	df	Mean squares								
		Panicles per plant	Lodging	Panicle length	Panicle weight	Seeds per panicle	Test weight	Seed yield per plant	Silicon content	Potassium content
Lines	3	2.867 **	9.04*	4.768 **	8.647 **	1410.943 **	6.690 **	42.269 *	0.011 **	0.135 **
Testers	2	12.122 **	28.563 *	2.813 *	0.465 **	236.582 **	2.292 *	28.98	0.002 **	0.110 **
Line X Testers	6	0.048	3.827 *	0.382 *	0.040 **	15.84	0.22	7.647 *	0	0.007 *
Error	11	0.032	0.97	0.097	0.004	5.153	0.074	2.3	0	0.002
σ^2gca		1.0637	2.139	0.4869	0.6451	115.4	0.61	4	0.0009	0.017
σ^2sca		0.0135	1.495	0.1584	0.0173	5.973	0.085	2.57	0.0001	0.003
σ^2gca/ σ^2sca		78.79	1.43	3.07	37.29	19.32	7.11	1.55	9.00	6.11

*Significant at 5%; **significant at 1%

Apportioning of combining ability variance into fixable and non-fixable variance indicated that, both additive and non-additive gene actions played an important role in controlling the expression of the characters studied. Higher estimates of GCA variance over SCA variance for days to 50 per cent flowering, plant height, flag leaf length, flag leaf width, tillers per plant, inter-nodal length, culm wall thickness, days to maturity, panicles per plant, lodging per cent, panicle length, panicle weight, seeds per panicle, test weight, seed yield per plant, silicon content and potassium content pointed to be predominance of additive gene action, same results were reported for grain yield per plant with high GCA suggesting the predominance of additive gene action by Singh and Kumar (2004), Latha *et al*. (2013), Savita *et al.* (2015) and Kour *et al.* (2019). The magnitude of SCA variance was higher than GCA variance for culm diameter, indicating pre-ponderance of non-additive gene action i.e., dominance and epistatic gene action in the inheritance. Characters controlled by dominant gene action can be improved by exploiting heterosis. Simple selection cannot help in improving these traits.

The parents were characterized for their ability to transmit desirable traits to their progenies. Information regarding the general combining ability effects of parents is of at most importance in plant breeding programmes as it helps in the successful prediction of genetic potential of individuals to yield desirable progenies in segregating population. General combining ability effects (*gca*) of parents and specific combining ability effects (*sca*) of hybrids for quantitative and biochemical characters are given in **Table 2 and 3,** respectively.

Table 2. General combining ability effects (*gca*) for lines and testers for quantitative and biochemical characters

Parents	Days to 50 per cent flowering	Plant height	Flag leaf length	Flag leaf width	Tillers per plant	Internodal length	Culm diameter	Culm wall thickness	Days to maturity
Lines									
Swetha	2.458*	-0.45	1.468**	-0.052**	-0.75**	-0.207**	0.125**	-0.053**	1.458**
Prathyasha	-10.208**	-3.817**	-0.488	-0.105**	0.883**	-0.493**	-0.52**	-0.086**	-12.542**
Vaisakh	-5.375**	6.217**	2.58**	0.158**	-0.217	1.264**	-0.128**	0.005	-3.375**
Ponmani	13.125**	-1.95**	-3.56**	0.001	0.083	-0.564**	0.523**	0.134**	14.458**
± SE (Lines)	0.8948	0.4589	0.2982	0.0076	0.1328	0.0522	0.0255	0.0051	0.4065
Testers									
Uma	-0.583	3.088**	-0.291	-0.025**	1.05**	-0.029*	0.133**	0.046**	1.167**
Gouri	0.917	3.2**	-0.19	-0.026**	-0.05	0.273**	0.052*	-0.006	-0.083
Pournami	-0.333	-6.287**	0.481*	0.05**	-1**	-0.244**	-0.185**	-0.04**	-1.083**
± SE (Tester)	0.7749	0.3974	0.2583	0.0066	0.115	0.0452	0.0221	0.0044	0.352

*Significant at 5%; **significant at 1%

Table 2. (……continued.)

Parents	Panicles per plant	Lodging	Panicle length	Panicle weight	Seeds per panicle	Test weight	Seed yield per plant	Silicon content	Potassium content
Lines									
Swetha	-0.7**	1.823**	0.565**	0.788**	11.167**	-1.071**	2.156**	-0.046**	-0.03
Prathyasha	0.933**	-0.687	-0.9**	-0.924**	-16.05**	0.171	1.191	0.007	-0.047*
Vaisakh	-0.267**	-0.367	-0.607**	-1.124**	-10.033**	1.389**	-3.849**	-0.016*	0.213**
Ponmani	0.033	-0.769*	0.942**	1.26**	14.917**	-0.489**	0.503	0.054**	-0.137**
± SE (Lines)	0.0596	0.3734	0.1041	0.0312	0.8058	0.09	0.6455	0.0052	0.0159
Testers									
Uma	1.042**	-2.025**	-0.447**	0.232**	-5.108**	0.569**	-1.74**	0.001	-0.091**
Gouri	0.317**	0.308	0.673**	-0.25**	5.717**	-0.075	-0.293	0.014**	0.133**
Pournami	-1.358**	-1.717**	-0.225*	0.018	-0.608	-0.494**	2.033**	-0.015**	-0.041**
± SE (Tester)	0.0516	0.3233	0.0901	0.027	0.6978	0.0779	0.5591	0.0045	0.0137

*Significant at 5%; **significant at 1%

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Table 3. Specific combining ability effects (*sca*) for lines and testers for quantitative and biochemical characters

Hybrids	Days to 50 per cent flowering	Plant height	Flag leaf length	Flag leaf width	Tillers per plant	Internodal length	Culm diameter	Culm wall thickness	Days to maturity
Swetha x Uma	0.917	1.212	0.018	0.025	0.15	-0.178	-0.045	-0.005	1.167
Swetha x Gouri	0.917	-1.3	-0.253	-0.034*	-0.35	0.19	-0.024	-0.007	-0.083
Swetha x Pournami	-1.833	0.088	0.235	0.01	0.2	-0.013	0.069	0.012	-1.083
Prathyasha x Uma	1.083	-1.571	-0.08	-0.012	0.317	0.008	-0.47**	0.004	0.667
Prathyasha x Gouri	-1.417	2.867**	0.213	0.004	-0.083	-0.195	0.241**	-0.004	-1.583*
Prathyasha x Pournami	0.333	-1.296	-0.133	0.008	-0.233	0.187	0.229**	0.001	0.917
Vaishakh x Uma	-0.25	0.396	0.026	0.005	-0.183	0.036	0.043	-0.013	0.001
Vaishakh x Gouri	-0.75	-3.067**	0.21	0.026	0.117	0.313**	0.05	0.005	-0.25
Vaishakh x Pournami	1	2.671**	-0.236	-0.03*	0.067	-0.349**	-0.093	0.008	0.25
Ponmani x Uma	-1.75	-0.037	0.036	-0.017	-0.283	0.134	0.472**	0.014	-1.833*
Ponmani x Gouri	1.25	1.5	-0.17	0.004	0.317	-0.308**	-0.267**	0.006	1.917*
Ponmani x Pournami	0.5	-1.463	0.134	0.013	-0.033	0.174	-0.205**	-0.02*	-0.083
± SE (Hybrids)	1.5499	0.7948	0.5165	0.0132	0.23	0.0904	0.0441	0.0088	0.704

*Significant at 5%; **significant at 1%

Table 3. (……continued)

Hybrids	Panicles per plant	Lodging	Panicle length	Panicle weight	Seeds per panicle	Test weight	Seed yield per plant	Silicon content	Potassium content
Swetha x Uma	0.225	1.927*	0.168	0.123*	-2.592	-0.09	2.548*	0.001	0.001
Swetha x Gouri	-0.05	-0.165	-0.343	-0.13*	3.583*	0.133	-0.928	-0.004	0.022
Swetha x Pournami	-0.175	-1.762*	0.175	0.007	-0.992	-0.043	-1.62	0.005	-0.024
Prathyasha x Uma	-0.108	0.372	-0.273	-0.16*	-0.325	0.413*	-0.432	-0.004	-0.027
Prathyasha x Gouri	0.117	-0.405	-0.172	0.171**	1.75	-0.078	0.917	0.002	-0.036
Prathyasha x Pournami	-0.008	0.033	0.445*	-0.011	-1.425	-0.335	-0.485	0.001	0.063*
Vaishakh x Uma	-0.008	-1.208	-0.281	-0.015	1.558	-0.43*	-1.072	0.005	-0.042
Vaishakh x Gouri	-0.083	0.24	0.394	-0.089	-3.017	0.128	-1.333	0.006	0.064*
Vaishakh x Pournami	0.092	0.968	-0.113	0.104	1.458	0.302	2.405	-0.01	-0.022
Ponmani x Uma	-0.108	-1.091	0.386	0.052	1.358	0.108	-1.044	0.001	0.068*
Ponmani x Gouri	0.017	0.331	0.121	0.048	-2.317	-0.183	1.345	-0.004	-0.051
Ponmani x Pournami	0.092	0.76	-0.507*	-0.1	0.958	0.075	-0.301	0.005	-0.017
± SE (Hybrids)	0.1032	0.6467	0.1803	0.054	1.3956	0.1559	1.1181	0.009	0.0275

*Significant at 5%; **significant at 1%

The general combining ability effects were significant for days to 50 per cent flowering, flag leaf length, internodal length, culm diameter, days to maturity, panicle length and panicle weight in all the lines. However, Significant and negative *gca* effects was observed in Prathyasa and Vaisakh for days to 50 per cent flowering, culm diameter, days to maturity, panicle length, panicle weight and seeds per panicle. Indicating that crosses involving these parents can result in reduction in these characters. Prathyasa and Vaisakh can be utilised as parents to reduce duration of hybrids. However, they may result in a reduction in favourable traits *viz.,* culm diameter, panicle length and weight and seeds per panicle. Negative and significant *gca* effects were observed for flag leaf length in Prathyasa and Ponmani and for internodal length in Swetha, Prathyasa and Ponmani. Reduction in internodal length can reduce lodging in rice (Detang *et al*., 1997).

Among the lines, a significant positive *gca* effect for plant height was observed in Vaisakh, while it was negative in Prathyasa and Pournami. Flag leaf length had positive *gca* effects in Swetha and Vaisakh, while it was negative in Ponmani. A positive *gca* effect was observed in Vaisakh for flag leaf width however, Swetha and Prathyasa had negative *gca* effects. A positive *gca* effects for tillers per plant was observed in Prathyasa, while it was negative in Swetha, Culm wall thickness had positive *gca* effects in Pournami wherein it was negative in Swetha and Prathyasa. Positive *gca* effect was observed for panicles per plant in Prathyasa. However, Swetha and Vaisakh had negative effects. A positive *gca* effect for lodging was recorded by Swetha, while it was negative in Pournami. Vaisakh and Ponmani had positive *gca* effects for test weight, while it was negative in Swetha. Positive *gca* effects for seed yield per plant was showed by Swetha, while it was negative in Vaisakh. Ponmani had a positive *gca* effect for silicon content wherein Swetha and Vaisakh had a negative effects. A positive *gca* effects were exhibited by Vaisakh for potassium content, while it was negative in Prathyasa and Ponmani.

Significant *gca* effects were observed for plant height, flag leaf width, internodal length, culm diameter, panicles/plant, panicle length, and potassium content in all testers. It was negative in Pournami for plant height, Uma and Gouri for flag leaf length, Uma and Pournami for internodal length, panicle length and potassium content, Pournami for culm diameter and panicles per plant, hence Pournami can be considered as a good parent to transfer earliness and reduced internodal length which can help in reduction in lodging, however, it can result in reduction in characters like culm diameter, number and length of panicles and potassium content which may have a negative effect on lodging resistance and yield. Among the testers positive *gca* effects for flag leaf length was showed by Pournami. Uma had a positive *gca* effects for tillers per plant, culm wall thickness, days to maturity, panicle weight, and test weight. Negative *gca* effects for tillers per plant, culm wall thickness, days to maturity, lodging, test weight and silicon content was seen in Pournami. Uma had a negative *gca* effect for lodging, seeds per panicle and seed yield per plant. A positive *gca* effects was observed in Pournami for flag leaf length and seed yield per plant. Gouri had a positive *gca* effects for seeds per panicle and silicon content, while it had a negative effect for panicle weight.

The *sca* effects of hybrids for days to 50 % flowering varied from -1.83 (Swetha x Uma) to 1.25 (Ponmani x Gouri). For plant height the *sca* effects of hybrids varied from--3.07 (Vaisakh x Gouri) to 2.87 (Prathyasha x Gouri) and Prathyasha x Gouri, Vaisakh x Gouri and Vaisakh x Pournami reported a significant response. The *sca* effects for flag leaf width of hybrids varied from -0.03 (Swetha x Gouri) to 0.03 (Vaisakh x Gouri) and Swetha x Gouri and Vaisakh x Pournami reported a significant response.

The *sca* effects for internodal length of hybrids varied from -0.35 (Vaisakh x Pournami) to 0.31 (Vaisakh x Gouri) in which Vaisakh x Gouri, Vaisakh x Pournami and Ponmani x Gouri reported significant response among hybrids. In case of culm diameter the *sca* effects of hybrids varied from -0.47 (Prathyasha x Uma) to 0.47 (Ponmani x Uma) and Prathyasha x Uma, Prathyasha x Gouri, Prathyasha x Pournami, Ponmani x Uma, Ponmani x Gouri and Ponmani x Pournami reported significant response among hybrids. Among hybrids, the *sca* effects varied from -0.02 (Ponmani x Pournami) to 0.01 (Vaisakh x Pournami) and Ponmani x Pournami reported a significant response among hybrids

For culm wall thickness, *sca* effects among the hybrids varied from -0.02 (Ponmani x Pournami) to 0.01 (Vaisakh x Pournami) and Ponmani x Pournami reported significant response among hybrids. The *sca* effects for days to maturity of hybrids varied from -1.83 (Ponmani x Uma) to 1.92 (Ponmani x Gouri) and Prathyasha x Gouri, Ponmani x Uma and Ponmani x Gouri reported significant response among hybrids. The *sca* effects for panicle length of hybrids varied from -0.51 (Ponmani x Pournami) to 0.44 (Prathyasha x Pournami) and both recorded significant responses among hybrids. For panicle weight the *sca* effects among the hybrids varied from -0.16 (Prathyasha x Uma) to 0.17 (Prathyasha x Gouri) and Swetha x Uma, Swetha x Gouri, Prathyasha x Uma and Prathyasha x Gouri recorded significant responses among hybrids. The *sca* effects for seeds per panicle of hybrids varied from -3.01 (Vaishakh x Gouri) to 3.58 (Prathyasha x Gouri) and Swetha x Gouri recorded significant responses among hybrids. For test weight the *sca* effects of hybrids varied from -0.43 (Vaishakh x Uma) to 0.41 (Prathyasha x Uma) and both reported significant response among hybrids. The *sca* effects among the hybrids varied from -1.33 (Vaishakh x Gouri) to 2.55 (Swetha x Uma) and Swetha x Uma recorded a significant response among hybrids for seed yield per plant. In case of lodging the *sca* effects of hybrids varied from -1.76 (Swetha x Pournami) to 1.92 (Swetha x Uma) and both reported positive significant response. For silicon content the *sca* effects of hybrids varied from -0.01 (Vaishakh x Pournami) to 0.006 (Vaishakh x Gouri). The *sca* effects for potassium content of hybrids varied from -0.051 (Ponmani x Gouri) to 0.068 (Ponmani x Umas) and Prathyasha x Pournami, Vaishakh x Gouri and Ponmani x Uma reported significant response among hybrids.

Results from *gca* effects of parents indicated that Swetha and Pournami were better combiners for grain yield per plant and seeds per panicle. Ponmani, Uma and Pournami were better combiners for reduced lodging indicating scope for further utilization of these lines in plant breeding programmes for reduced lodging. When all the characters were considered, Ponmani, Uma and Gouri recorded as better combiner.

Specific combining ability studied among the cross combinations indicated that Swetha x Uma recorded a high response to seed yield per panicle and all other hybrids reported moderate response to the same. Out of the twelve hybrids, Swetha x Pournam) recorded high response and except Swetha x Um), remaining hybrids exhibited a moderate response for lodging resistance. Based on all the eighteen characters, Ponmani x Uma, (Prathyasha x Pournami, Prathyasha x Gouri, Swetha x Pournami, Vaisakh x Gouri and (Swetha x Uma were better cross combination among the twelve hybrids.

The present study identified that Pournami and Swetha were found to be better combiner for grain yield per plant. Ponmani, Uma and Pournami were recorded to be better combiner for reduced lodging, indicating scope for further utilization of these lines in plant breeding programmes for reduced lodging in addition Pournami is good for reduced internode length and plant height which will have added advantage to lodging resistance. Ponmani, Uma and Gouri identified as better combiners for yield and reduced lodging. Hybrids, Swetha x Pournami recorded high *sca* effect for reduced lodging and except Swetha x Uma remaining hybrids exhibited a moderate response for reduced lodging per cent. When all the traits were considered together, Ponmani x Uma, Prathyasha x Pournami, Prathyasha x Gouri, (Swetha x Pournami, Vaisakh x Gouri and Swetha x Uma recorded as better cross combinations among the twelve hybrids for higher yield and reduced lodging. It was clear that crosses exhibiting high *sca* effects did not always involve parents with high *gca* effect. The hybrids with high *sca* effects *viz.,* Prathyasha x Pournami was a low/high cross combination and Prathyasha x Gouri was a high/low cross combination. It clearly revealed that crosses that resulted from high/poor or poor/high could be exploited for getting desirable recombination from the segregating population.

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