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Research Article

Studies on combining ability for grain yield and related traits in advanced breeding lines in rice (*Oryza sativa* L.)

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Abstract
The present investigation was undertaken to study the combining ability using 10 lines and 3 testers crossed in Line × Tester mating design. Resulting 30 $F_{1's}$ were evaluated along with their parents in a replicated trial using randomized block design during Kharif season 2016-17 at Norman E. Borlaug Crop Research Centre Pantnagar, Uttarakhand, India. Genotypes were evaluated for grain yield per plant and its contributing characters. Among the lines UPR3912-21-2-1 and tester NDR359 exhibited a high general combining ability (GCA) for most of the characters under the study. The per se performance and specific combining ability (SCA) effects were in agreement with each other for seven hybrids namely Pant Sugandh Dhan17×NDR359, PD26×NDR359, PR113×NDR359, PD26×NDR359, PD26×PD24, Pant Sugandh Dhan17×PD24, PR113×PD24 for days to 50% flowering, the number of tillers, dwarfness, the number of panicles, panicle length, grain length and 1000 grain weight respectively. Cross PD26×NDR359 exhibited high SCA for number of panicles and both the parents were good general combiner for this character.

Keywords
General combining ability, Specific combining ability, per se performance.

INTRODUCTION

Rice is a monocot plant belonging to the family Gramineae. After wheat, rice is the most important cereal crop (Rajamoorthy *et al*., 2015). It is the predominant staple food for at least 33 developing countries of the world, providing 27%, 20% and 3% of their dietary energy, protein and fat supply respectively (Kennedy *et al*., *2002*). The world population is expected to reach 8 billion by 2030 and the rice production must be increased by 50% in order to meet the growing demand (Khush and Brar, 2002). The success of any plant breeding programs fundamentally depends not only on the selection of parents but also in the breeding methods (Torres and Geraldi, 2007). The estimates of GCA helps in the selection of suitable parents for hybridization. The SCA values helps to report superior cross combinations which may be utilized for exploitation of heterosis. Combining ability analysis is useful as it provides clear understanding of gene action involved in the inheritance of various quantitative characters and also helps in deciding the most appropriate breeding procedure for genetic improvement of traits. If the estimates of GCA variance is higher than the estimates of SCA variance, it is inferred that there is a dominance of additive gene action and hence progeny selection will be the appropriate breeding procedure for the genetic improvement of such traits. If SCA variances are higher than GCA variances, it means that there is predominance of non additive, and thus heterosis breeding may be rewarding. Equal magnitude of SCA and GCA variance indicate equal importance of additive and non additive gene in the inheritance of character, reciprocal selection will be effective in such situation.

MATERIAL AND METHODS

The present study was conducted at Norman E. Borlaug Crop Research Centre, Pantnagar, Uttarakhand, India. The basic experimental material comprised of ten lines *viz.,* PR113, Pant Sugandh Dhan 17, UPR 3912-21-2-1, UPR 3654-5-1-2, UPRI 2015-2, UPR 3037-2-2-1-3, UPR 3905-22-2-2-1, UPR 2760-10-1-2, UPR 2015-5 and Pant Dhan 26 (PD 26) and three testers *viz.*HKR 47, Pant Dhan

24 (PD 24) and NDR 359. The Line × tester mating design was used to generate thirty crosses during kharif 2015-16. The experimental materials consisted of 43 genotypes i.e.,10 lines, 3 testers, 30 F1's. The experiment was conducted under irrigated timely transplanted condition. Observations were recorded on five randomly competitive plants from each row. The experimental material was laid out in a Randomized Block Design (RBD) with three replications. Observations were recorded on the whole plot basis in respect of days to 50 per cent flowering, days to maturity, however, plant height, the number of tillers per plant, the number of panicles, panicle length, the number of grains per panicle, grain length, grain width, 1000 grain weight and grain yield per plant were recorded on the basis of five randomly selected competitive plants from the F1 crosses, lines and the testers. Analysis of variance was carried out as per Panse and Sukhatme (1985). The GCA and SCA values were determined according to Singh and Chaudary (1977). This method was calculated by following model:

$$Xij = u + gi + gj + sij + eijk$$

where, u=the population mean, gi=the general combining ability effect of the ith parent, gj=the GCA effect of the jth parent, sij=the SCA effect of the cross between ith and jth parents such that sij=sji and eijk the environmental effect associated with ijkth observation.

Estimation of general combining ability effect

a) For lines:

$$g_i = \frac{Xi...}{tr} - \frac{X...}{ltr}$$

b)For testers:

$$g_j = \frac{X.j.}{lr} - \frac{X...}{ltr}$$

Estimation of specific combining ability effect

$$S_{ij} = (X_{ij.}/r) - (X_{i..}/tr) - (X_{.j.}/lr) - (X_{...}/ltr)$$

Where, g_i = GCA of i^{th} line, $X_{...}$ = Grand total (Sum of all the crosses over all the replication),$X_{i..}$ = Performance of i^{th} line crossed with the testers over all the replications, g_j= GCA of j^{th} tester, $X_{.j.}$ = Performance of j^{th} tester crossed with the lines over all the replication, S_{ij} = SCA of the cross between i^{th} line and j^{th} tester, X_{ij} = Total of $(ij)^{th}$ combination over all replications, r=Number of replications, l=Number of lines, t=Number of testers.

Table 1. Estimates of componenet of variation for different traits in rice

Sl no.	Characters	Mean sum of square			gm	gcv	pcv	ecv
		Replication	Treatment	Error				
	df	2	42	84				
1	Days to 50% flowering	3.223837	4.517857*	2.828004	85.953	0.872	2.142	1.956
2	Days to maturity	1.39895	8.848214**	3.014431	126.18	1.105	1.764	1.375
3	Number of tillers per plant	26.84575	150.6715**	10.12272	28.147	24.317	26.814	11.303
4	Plant height(cm)	238.6584	520.0446**	12.73730	125.68	10.34	10.75	2.8395
5	Number of panicles per plant	13.03198	150.0694**	6.300828	25.503	27.144	28.873	9.8425
6	Panicle length (cm)	10.77471	56.82986**	4.960224	34.855	11.919	13.533	6.389
7	Number of grains per panicle	456.3779	2846.813**	62.43548	165.16	18.445	19.0558	4.784
8	Grain length (cm)	0.0018622	.6499256**	0.001594	9.433	4.928	4.946	0.423
9	Grain width (cm)	0.00144568	0.0351741**	0.000590	2.366	4.53	4.652	1.027
10	1000 grain weight (gm)	1.525345	5.136347**	1.288831	25.648	4.416	6.251	4.426
11	Grain yield per plant (gm)	168.8387	4308.326**	30.04160	108.42	34.829	35.194	5.054

df= degree of freedom, gm = general mean, pcv = phenotypic coefficient of variation, gcv = genotypic coefficient of variation, ecv = environment coefficient of variation.

RESULT AND DISCUSSION

Existence of variability is a prerequisite to achieve crop improvement through selection. In the present investigation estimates of genotypic, phenotypic and environmental coefficient of variation have been given in **table 1**. Variability occurs due to difference in the genetic constitution of the individuals of the population or due to difference in the environment in which they are grown. Presence of high magnitude of genetic variability is of foremost importance to a plant breeder to start any breeding program. The results on analysis of variance revealed the presence of significant variability among

the genotypes for all the eleven characters under study. Since, grain yield per plant followed by the number of panicles per plant, the number of tillers per plant and the number of grains per panicle showed high genetic coefficient of variation therefore, they can be used as main centre for selection criteria. Similar findings also reported by (Nuruzzaman *et al*. (2002), Kumar and Verma (2015)).

Analysis of variance for combining ability of eleven characters under study are represented in **table 2**. Results indicated significant differences among crosses for all the character under study. Significant differences were observed among the lines for days to maturity, the number of tillers per plant, plant height, the number of panicles per plant, panicle length, the number of grains per panicle, grain yield per plant. Line×tester showed significant difference for all the character under study except days to maturity.

The estimates of variance due to GCA (σ^2gca) and variance due to SCA (σ^2sca) for various character are given in **table 3**. Results revealed that SCA variance is higher than GCA variance for all the characters under study indicating predominance of non additive gene action in the inheritance for all the characters under study (Tiwari and Singh (2016), Sahu *et al.* (2016), Rahaman (2016))

Table 2. Analysis of variance for combining ability for various characters in rice

Source of variation	d.f.	Days to 50% flowering	Days to maturity	Number of tillers per plant	Plant height	Number of panicles per plant	Panicle length	Number of grains per panicle	Grain length	Grain width	1000 grain weight	Grain yield per plant
Replication	2	3.222	1.331	26.845	238.408	13.031	10.798	456.377	0.0018	0.0009	1.552	168.838
Treatment	42	4.517*	8.845**	150.671**	520.032**	150.069**	56.830**	2846.813**	0.649**	0.035**	5.137**	4308.326**
Crosses	29	5.277*	7.774**	178.749**	394.262**	171.367**	62.624**	3235.210**	0.381**	0.039**	3.753**	5114.868**
Lines	9	4.584	14.359**	340.661**	584.896*	329.566**	99.672*	5772.676**	0.312	0.047	4.311	9686.185**
Tester	2	8.220	1.762	122.699	450.512	97.543	59.404	3373.442	0.069	0.002	3.420	5317.200
Line×tester	18	5.296*	5.149	104.021**	292.696**	100.470**	44.457**	1951.118**	0.451**	0.039**	3.512**	2806.728**
Error	84	2.828	3.015	10.122	12.741	6.300	4.959	62.435	0.0015	0.0006	1.288	30.041

Table 3. General and specific combining ability variances for various characters in rice

Sl no.	Characters	σ^2gca	σ^2sca	σ^2gca/ σ^2sca	$(\sigma^2sca/\ \sigma^2gca)^{1/2}$ Mean degree of dominance
1	Days to 50% flowering	-0.0003	0.822	0.0003	52.34
2	Days to maturity	0.049	0.711	0.068	3.80
3	Number of tillers per plant	1.397	31.299	0.044	4.73
4	Plant height	1.899	93.318	0.020	7.009
5	Number of panicles per plant	1.325	31.389	0.042	4.867
6	Panicle length	0.339	13.165	0.025	6.231
7	Number of grains per panicle	24.009	629.560	0.038	5.120
8	Grain length	-0.0013	0.149	0.0087	10.70
9	Grain width	0.0000001	0.012	0.000008	346.410
10	1000 grain weight	0.0045	0.741	0.006	12.83
11	Grain yield per plant	43.156	925.562	0.046	4.630

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

The estimates of GCA effect serves as basis of selection of parents in breeding program. In the present investigation none of the parent was found as good general combiner for all the 11 traits. Performance of parents in respect of GCA effects is given in **table 4**. The significant positive and negative SCA effects were observed in F_1 generation for various traits under investigation as given in **table 5**. For days to 50% flowering among the lines UPR 2015-2 exhibited a significant positive GCA effect and the cross combination Pant sugandh dhan 17 × NDR 359 showed a significant positive SCA effect. Lines UPR-3905-22-2-2-1 exhibited a significant negative GCA effect and among the F_1s UPRI 2015-2×Pant dhan 24 showed a significant negative SCA effect for days to maturity (Deshmukh *et al*. (2016), Kumar *et al*. (2016)). For the number of tillers per plant lines UPR 3912-21-2-1, UPR2760-10-1-2 and PR 113 and among the testers NDR 359 exhibited a significant positive GCA effect whereas the significant

Table 4. GCA effects of parents for different character in rice

Particulars	Days to 50% flowering	Days to maturity	Number of tillers per plant	Plant height	Number of panicles per plant	Panicle length	Number of grains per panicle	Grain length	Grain width	1000 grain weight	Grain yield per plant
Lines											
PR113	-0.644	-3.322**	-6.466**	-9.344**	-7.011**	-3.016**	-23.966**	0.333**	-0.132**	-0.229	-46.474**
Pant Sugandh Dhan 17	-0.644	0.788	-1.911	3.960**	-2.566**	1.803*	17.811**	-0.166**	-0.030*	0.540	-.106
UPR 3912-21-2-1	1.022	0.677	5.977**	-4.765**	5.100**	-3.927**	-28.188**	0.095**	0.021	-1.61**	-6.236**
UPR 3654-5-1-2	-0.200	0.677	-8.133**	1.893	-7.344**	-0.956	-9.411**	0.139**	-0.043**	-0.283	-37.584**
UPRI 2015-2	-0.422	1.011	-6.911**	15.169**	-6.122**	4.647**	32.477**	-0.038**	0.091**	0.744*	-9.399**
UPR 3037-2-2-1-3	-0.422	-0.211	8.866**	8.214**	8.877**	3.361**	26.588**	-0.155**	-0.078**	0.641	64.911**
UPR 3905-22-2-2-1	-0.755	0.677	-1.800	3.001*	-2.233**	3.930**	26.700**	0.017	0.080**	0.145	5.888**
UPR 2760-10-1-2	1.133*	-0.433	1.088	-9.096**	1.100	-0.383	0.477	0.280**	0.015	0.049	4.614
UPR 2015-5	0.577	0.099	7.755**	-0.945	8.211**	-0.783	-3.633	-0.121**	0.003	0.385	38.835**
Pant Dhan 26	0.355	0.233	1.533	-8.087**	1.988*	-4.677**	-38.855**	-0.158**	0.072**	-0.381	-14.447**
$SE^{+}(g_i)\pm$	0.5605	0.578	1.060	1.189	0.836	0.742	2.633	0.0131	0.008	0.378	1.827
$SE^{++}(g - g_j)\pm$	0.7926	0.818	1.499	1.682	1.183	1.049	3.724	0.018	0.011	0.534	2.583
Testers											
HKR 47	0.366	-0.266	-0.799	-3.262**	-0.922*	-1.152**	-5.322**	-0.0549**	-0.0064	0.386	-5.056**
NDR 359	-0.600	0.200	-1.500**	4.284**	1.155*	-0.415	-6.888**	0.0263**	0.010*	-0.152	-10.044**
Pant Dhan 24	0.233	0.666*	2.300**	-1.022	2.077**	1.568**	12.211**	0.0286**	-0.003	-0.234	15.100**
$SE(g_j)\pm$	0.307	0.317	0.580	0.651	0.458	0.406	1.442	0.0071	0.004	0.207	1.0006
$SE(g - {}_ig_j)\pm$	0.434	0.448	0.821	0.921	0.648	0.574	2.039	0.0101	0.006	0.293	1.414

Level of significance: *p<0.05 and **P<0.01, +Standard error of GCA effect of *i*th inbred line; ++Difference between GCA effects of *i*th and *j*th inbred lines.

SCA effect was exhibited by cross combinations PD 26× NDR 359, Pant Sugandh Dhan 17×NDR 359, UPR-3905-22-2-2-1×HKR 47 and UPRI 2015-5×HKR. For plant height among the lines UPR-3905-22-2-2-1, UPRI 2015-2, Pant Dhan 26 and PR 113 and among the testers HKR 47 emerged as good general combiner, while among the F_{1s} significant negative SCA effects was shown by UPRI 2015-5×HKR47, PR113×NDR 359, UPRI 2015-5×NDR 359, UPRI 2015-5×PD 24, Pant Sugandh Dhan 17× HKR47, UPRI 2015-2×PD 24, UPR-3905-22-2-2-1×NDR 359, PD 26×HKR47 and UPRI 2015-2× NDR 359 (Sala *et al.* (2016), Gade *et al.* (2016), Singh *et al.* (2015)). For the number of panicles per plant among the lines UPR 3912-21-2-1, UPR 2760-10-1-2, PR 113 and Pant Dhan 26 and among the testers NDR 359 exhibited a significant positive GCA effect. Among the various cross combinations studied PD 26× NDR 359, Pant Sugandh Dhan 17×NDR 359, UPR-3905-22-2-2-1×HKR 47, UPRI 2015 -5×HKR47, UPR3912-21-2-1×HKR47, UPRI 2015-5×NDR 359 and UPRI 2015-2×HKR47 exhibited a significant positive SCA effect. The significant positive GCA effect for panicle length was exhibited by line UPRI 2015-5, UPR 3654-5-1-2, UPR 3912-21-2-1, Pant Sugandh Dhan 17 and tester NDR 359 whereas F_{1s} Pant Sugandh Dhan 17×PD 24, PD 26×PD 24, UPRI 2015-5×NDR 359, UPR3037-2-2-1-3×PD 24, UPR 3654-5-1-2×PD 24, Pant Sugandh Dhan 17× HKR47 exhibited a significant positive SCA effect (Montazeri*et al.* (2014)). For the number of grains per panicle lines UPRI 2015 -5, UPR 3654-5-1-2, UPR 3912-21-2-1, Pant sugandh Dhan 17 and tester NDR 359 exhibited a significant positive GCA effect and among the crosses Pant Sugandh Dhan 17×PD 24, UPRI 2015-5×NDR 359, PD 26×PD 24, UPR3037-2-2-1-3×PD 24, UPR 3654-5-1-2×PD 24, Pant Sugandh Dhan 17×HKR47, PR113×HKR47, Pant Sugandh Dhan 17×NDR 359, UPR3037-2-2-1-3×NDR 359 exhibited a significant SCA effect. For gain length among the lines UPR 3905-22-2-2-1, UPRI 2015-2, UPR 3037-2-2-1-3, PR 113 and NDR 359 and Pant Dhan 24 among the testers exhibited significant positive GCA effect. Significant positive SCA effect for this character was shown by cross combinations UPRI 2015-2× NDR 359, Pant Sugandh Dhan 17×PD 24, Pant Sugandh Dhan 17×NDR 359, Pant Sugandh Dhan 17×HKR47, UPR3037-2-2-1-3×HKR47, UPR3912-21-2-1×PD 24, UPR 3654-5-1-2×NDR 359, UPRI 2015-2×HKR47, PD 26×PD 24, UPR3912-21-2-1×HKR47, UPR 2760-10-1-2×NDR 359, UPR-3905-22-2-2-1×NDR359. Significant positive SCA effect for grain width was shown by line UPRI 2015-5, UPR 3654-5-1-2, Pant Dhan 26 and testers Pant Dhan 24. Ten

Table 5. SCA Effects of crosses for different characters in rice

S NO.	CROSSES	DFF	DM	NTP	PH	NPP	PL	NGP	GL	GW	TGW	GY
1.	UPR-3905-22-2-2-1×HKR 47	0.744	-1.511	4.800**	0.876	4.811**	-4.68**	-31.90**	-0.391**	0.0120	0.942**	0.630
2.	Pant Sugandh Dhan 17× HKR47	0.711	-0.311	0.166	-8.663**	1.044	2.643*	16.333**	0.720**	-0.111**	-0.0049	17.181**
3.	PR113×HKR47	-1.455	1.822	-4.966**	7.786**	-5.855**	2.043	15.566**	-0.328**	0.0993**	-0.936**	-17.81**
4.	UPR 3037-2-2-1-3×HKR47	-0.255	-0.288	-7.755**	8.575**	-7.300**	0.827	4.322	0.154**	0.1075**	0.748**	-33.28**
5.	UPRI 2015-5×HKR47	1.044	0.9111	4.611*	-13.38**	4.266**	-0.773	-2.777	-0.216**	-0.012	-1.418**	14.245**
6.	UPR3912-21-2-1×HKR47	-0.788	-0.622	3.144	4.812*	3.033*	-0.053	-1.544	0.0613**	-0.095**	0.669**	19.041**
7.	UPR 3654-5-1-2×HKR47	-0.588	-0.511	-0.311	4.804*	-0.633	0.5851	3.655	-0.096**	0.0920**	-0.936**	-3.533
8.	UPRI 2015-2×HKR47	0.377	1.022	2.388	-2.085	2.933*	0.037	3.222	0.0892**	-0.051**	1.656**	19.607**
9.	UPR 2760-10-1-2×HKR 47	0.211	-0.511	-2.077	-2.718	-2.300	-0.622	-6.877	0.0068	-0.040**	-0.719**	-16.07**
10	PD 26×HKR47	-0.033	0.488	1.466	-4.547*	1.477	-2.872*	-24.12**	-0.440**	0.143**	-0.576**	-5.681
11	UPR-3905-22-2-2-1×PD 24	-0.066	-0.644	1.166	1.702	1.044	-2.760*	-12.88**	-0.328**	0.0364**	0.599**	1.978
12	Pant Sugandh Dhan 17×PD 24	0.100	0.1555	-2.633	2.845	-2.522	5.633**	37.011**	0.769**	-0.179**	-0.0225	3.703
13	PR113×PD 24	-0.811	-0.177	0.244	-2.743	0.588	-0.435	-1.344	-0.032	-0.087**	1.508**	6.755*
14	UPR 3037-2-2-1-3×PD 24	1.155	-0.311	1.277	11.806**	1.155	3.779**	19.888**	0.0074	0.1086**	0.161**	16.470**
15	UPRI 2015-5×PD 24	-0.344	0.4888	-1.522	-9.063**	-1.744	-3.34**	-18.54**	0.0402	-0.0206	-1.670**	-23.22**
16	UPR3912-21-2-1×PD 24	1.855	1.711	-0.533	-3.535	-1.077	0.809	5.544	0.153**	-0.047**	-0.854**	-8.542**
17	UPR 3654-5-1-2×PD 24	-1.844	0.577	-1.500	11.231**	-1.177	2.731*	19.111**	-0.027	0.0453**	-0.108**	6.838*
18	UPRI 2015-2×PD 24	-0.011	-2.28*	2.033	-7.695**	2.255	-3.54**	-24.65**	-0.126**	0.0026	0.962**	1.703
19	UPR 2760-10-1-2×PD 24	-0.477	-0.511	2.133	-0.685	2.366	-1.235	-6.566	0.0161	0.0164	0.287**	8.297*
20	PD 26×PD 24	-1.177	-0.644	0.833	6.947**	0.266	5.596**	33.666**	0.0618**	-0.0302*	0.0838**	19.795**
21	UPR-3905-22-2-2-1×NDR 359	1.655	1.155	-2.966	-6.261**	-2.633	-4.36**	-27.10**	0.0457*	0.0137	-0.371**	-28.09**
22	Pant Sugandh Dhan 17×NDR 359	1.966*	-0.066	4.911**	11.522**	5.033**	2.195	14.988**	0.728**	-0.242**	-1.120**	26.541**
23	PR113×NDR 359	-1.733	0.7999	1.611	-18.25**	0.599	-3.98**	-28.77**	-0.253**	0.0575**	0.636**	-13.24**
24	UPR 3037-2-2-1-3×NDR 359	-0.233	-0.733	-6.522**	6.729**	-5.633**	1.790	13.788**	-0.475**	0.1848**	0.484**	-13.29**
25	UPRI 2015-5×NDR 359	-1.477	1.933	3.577	-9.785**	3.255*	4.958**	35.766**	-0.169**	-0.0035	0.0008	41.810**
26	UPR3912-21-2-1× NDR 359	1.488	-0.866	-4.055*	2.654	-3.844**	-5.49**	-40.66**	0.0325	-0.0268	-0.812**	-53.96**
27	UPR 3654-5-1-2× NDR 359	-0.011	-1.066	0.477	7.131**	0.588	0.537	4.900	0.136**	0.0304*	0.811**	12.153**
28	UPRI 2015-2× NDR 359	-0.922	-1.066	-8.533**	-4.480*	-8.522**	-0.144	-0.344	0.0772**	0.0108	0.00088	-32.99**
29	UPR 2760-10-1-2×NDR 359	0.0444	-0.533	-6.500**	8.046**	-6.288**	-1.772	-7.111	0.0525*	-0.0157	-0.792**	-28.90**
30	PD 26× NDR 359	0.8777	1.599	15.033**	-3.566	14.811**	1.917	7.455	-0.129**	0.0048	0.791**	61.896**
	$SE(S_{ij})$	0.970	1.002	1.836	2.060	1.449	1.285	4.561	0.0227	0.01416	0.0141	3.164
	$SE(S_{ij}-S_{kl})$	1.37	1.417	2.5973	2.914	2.049	1.818	6.450	0.0321	0.02002	0.02002	4.474

DFF= Days to 50% flowering, DM= Days to maturity, NTP=Numbers of tillers per plant, PH= Plant height, NPP= Number of panicles per plant, PL= Panicle length, NGP= Number of grains per panicle, GL= Grain length, GW= Grain width, TGW= Thousand grain weight, GY= Grain yield per plant. *, **Significant at 5% and 1% level of significance, respectively.

cross combinations namely UPR3037-2-213×NDR359, PD26×HKR47, UPR3037-2-2-1-3×PUPR3037-2-2-3×HKR47,PR113×HKR47, UPR 3654-5-1-2×HKR 47, UPR 3654-5-1-2×PD 24, UPR-3905-22-2-2-1×PD 24, UPR 3654-5-1-2×NDR359 exhibited a significant positive SCA effect for this character (Thakare *et al*. (2010), Patil *et al.* (2012)). For 1000 grain weight, line UPRI 2015-5 exhibited a significant positive GCA effect and significant positive SCA effect was exhibited by cross combination UPRI 2015-2×HKR47, PR113×PD 24, UPRI 2015-2×PD 24, UPR-3905-22-2-2-1×HKR 47, UPR 3654-5-1-2× NDR 359, PD 26× NDR 359, UPR3037-2-2-1-3×HKR47, UPR3912-21-2-1×HKR47, PR113×NDR 359,UPR-3905-22-2-2-1×PD24,UPR3037-2-2-1-3×NDR 359, UPR 2760-10-1-2×PD 24, UPR3037-2-2-1-3×PD 24 and PD 26×PD 24. For grain yield per plant among the lines UPR 3912-21-2-1, UPR 2760-10-1-2, UPR 3654-5-1-2 and NDR 359 among the testers exhibited significant positive GCA effect. Thirteen cross combinations showed significant positive SCA effects namely Pant Dhan 26×NDR 359, UPRI 2015-5×NDR 359, Pant Sugandh Dhan 17×NDR 359, PD 26×PD 24, UPRI 2015-2×HKR47, UPR3912-21-2-1×HKR47, Pant Sugandh Dhan 17× HKR47, UPR3037-2-2-1-3×PD 24, UPRI 2015-5×HKR47, UPR 3654-5-1-2× NDR 359, UPR 2760-10-1-2×PD 24, UPR 3654-5-1-2×PD 24 and UPR3037-2-2-1-3×PD 24 (Pradhan and Singh (2008),Rashid *et al.* (2007)).

As GCA effects are mainly due to additive gene effect or additive × additive gene interaction therefore, these

good general combiners can be used in specific breeding program for improving grain yield of rice. They can also be utilized for hybrid rice breeding program. The parental line UPR3912-21-2-1 combines well with the maximum number of characters followed by UPRI 2015-5, PR113 and UPR 3654-5-1-2 and among the testers NDR 359 combines well for most of the character under study and hence these parents can be used in crossing program in the improvement of rice crop. Our findings indicated that UPR3912-21-2-1 may be exploited for grain yield and its component characters like the number of tillers per plant, the number of panicles per plant, panicle length, the number of grains per panicle whereas PR113 can be used for dwarfness, the number of tillers per plant, the number of panicles per plant and grain length. UPRI 2015-5 and UPR 3654-5-1-2 may be exploited for panicle length, the number of grains per panicle, grain width. UPRI 2015-5 had a significant GCA for thousand grain weight and UPR 3654-5-1-2 for grain yield per plant similar findings were also reported by Devi and Lal (2015), Bhati *et al.* (2015). The SCA effect of a cross is the estimation of non-additive gene action for a trait, therefore it can serve as the basis for the selection of hybrid combinations. A highly significant SCA effect is desirable for successful hybrid breeding program. Out of 30 crosses, 1 cross each for days to 50% flowering and days to maturity, 4 crosses for the number of tillers per plant, 9 crosses for plant height, 7 crosses for the number of panicles per plant, 6 crosses for panicle length, 9 crosses for the number of grains per panicle, 12 crosses for grain length, 10 crosses for grain width 14 crosses for thousand grain weight and 13 crosses for grain yield per plant exhibited a significant and desirable SCA effect. A close evaluation of crosses on the basis of SCA effect and per se performance revealed agreement in the performance of Pant Sugandh Dhan 17×NDR 359, PD 26× NDR 359, PR113×NDR 359, PD 26× NDR 359, PD 26×PD 24, Pant Sugandh Dhan 17×PD 24, PR113×PD 24 for days to 50% flowering, the number of tillers per plant, plant height, the number of panicles per plant, panicle length, grain length and1000 grain weight, respectively. The cross PD 26× NDR 359 exhibited high SCA for the number of panicles per plant and both the parents were good general combiner for the same character indicating the presence of additive component of genetic variance. Therefore, this cross is expected to produce better progenies in later generation. Similar findings were earlier reported by Roy and Senapati (2012), Devi and Lal (2015). The $F_{1's}$ with best mean phenotypic performance and highest SCA effect are given in **table 6**.

Table 6. Crosses with highest mean and sca effects for various characters in rice

Sl no	Characters	Best F_1 mean performance	Best specific cross combination
1	Days to 50% flowering	Pant Sugandh Dhan 17×NDR 359 (84.666)	Pant Sugandh Dhan 17×NDR 359 (1.966)
2	Days to maturity	PD 26× NDR 359 (128), UPRI 2015-5×NDR 359 (127.666), UPRI 2015-5×PD 24 (127.666)	UPRI 2015-2×PD 24 (-2.288)
3	Number of tillers per plant	PD 26× NDR 359 (46)	PD 26× NDR 359 (15.033)
4	Plant height	PR113×NDR 359 (106.44)	PR113×NDR 359 (-18.251)
5	Number of panicles per plant	PD 26× NDR 359 (43.33)	PD 26× NDR 359 (14.811)
6	Panicle length	PD 26×PD 24 (44.496)	PD 26×PD 24 (5.596)
7	Number of grains per panicle	PD 26×PD 24 (223. 66)	Pant Sugandh Dhan 17×PD 24 (37.011)
8	Grain length	Pant Sugandh Dhan 17× HKR47 (10.476), Pant Sugandh Dhan 17×PD 24 (10.33), Pant Sugandh Dhan 17×NDR 359 (10.35)	Pant Sugandh Dhan 17×PD 24 (0.769)
9	Grain width	UPR 3037-2-2-1-3×PD 24 (2.573)	UPR 3037-2-2-1-3×NDR 359 (0.1848)
10	1000 grain weight	PR113×PD 24 (28.516)	UPRI 2015-2×HKR47 (1.656), PR113×PD 24 (1.508)
11	Grain yield per plant	UPRI 2015-2×PD 24 (189.98)	PD 26× NDR 359 (61.896)

REFERENCES

Bhati, S., Pandey, D.P. and Singh, D. 2015. Combining ability and heterosis for yiels and its component traits in rice [*Oryza sativa* (L.)]. *Electronic journal of plant breeding*, **6**(1): 12-18

Deshmukh, U.C., Koshta, N, and Sharma, D. 2016. Combining Ability and Gene Action Analysis to Develop Hybrid Rice in Chhattisgarh. *Advances in Life Sciences*,**5**(3): 174-180

Devi, B. and Lal, G.M. 2015. Combining ability analysis for yield and yield components in rice (*Oryza sativa* L.). *Electronic journal of plant breeding*, **6**(2): 360-365.

Gade, P.M.S., Senguttuvel, P. and Subramanyam, D. 2016. Combining Ability Analysis for Grain Yield and its Component Traits in Aerobic Rice (*Oryza sativa* L.) Cultivars. *Research Journal of Agricultural Sciences,* **7**(2): 237-240.

Kennedy, G., B. Burlingame, V.N. Nguyen 2002. Nutritional Contribution of Rice: Impact of Biotechnology and Biodiversity in Rice Consuming Countries. A paper presented at the International Rice Commission Workshop. 20th Session. Bangkok, Thailand, 23 – 26 July

Khush G.S. and Brar D.S. 2002. Biotechnology for rice breeding:progress and impact. In: Sustainable rice production for food security. Proceedings of the 20th Session of the International Rice Commission (23-26 July, 2002). Bangkok, Thailand, 2002.

Kumar, S., Chauhan, M.P., Srivastava, K., Singh, S.B., Kumar, B., Kumar, N., Kumar, R. and Shivani. 2016. Studies on combining ability for yield and yield attributes in rice (*Oryza sativa* L.). *Res. Environ. Life Sci.,* **9**(2): 231-236

Kumar, A. and Verma, O.P. 2015. Genetic variability, heritability and genetic advance studies in rice (*Oryza sativa* L.) under sodic soil. *Res. Environ. Life Sci.*, **9**(2): 149-151

Montazeri, Z., Jelodar, N.B. and Bagheri, N. 2014. Genetic Dissection of Some Important Agronomic Traits in Rice Using Line × Tester Method. *International Journal of Advanced Biological and Biomedical Research*, **2**(1): 181-191

Nuruzzaman, M., Alam, M.F., Ahmed, M.G., Shohael, A.M., Biswas, M.K., Amin, M.R. and Hosaain, M.M. 2002. Studies on parental variability and heterosis in rice. *Pakistan journal on biological sciences,* **5**(10): 1006-1009. [Cross Ref]

Patil, P.R., Surve, V.H. and Mehta, H.D. 2012. Line×Tester analysis in rice (*Oryza sativa* L.). *Madras Agriculture Journal*, **99**(4): 210-213

Pradhan, S.K. and Singh, S. 2008. Combining ability and gene action analysis for morphological and quality traits in basmati rice. *ORYZA- An International Journal on Rice*, **45**(3): 193-197.

Rahaman, M.A. 2016. Study of nature and magnitude of gene action in hybrid rice (*Oryza sativa* L.) through experiment of line x tester mating design. *International Journal of Applied Research*, **2**(2): 405-410.

Rajamoorthy, Y., Rahim, K.B.A., Munusamy, S. 2015. Rice industry in malaysia : Challenges, Policies and Implications. *Procedia Economics and Finance*, **31**: 861-867. [Cross Ref]

Rashid, M., Cheema, A.A., and Ashraf, M. 2007. Line ×Tester Analysis In Basmati Rice. *Pak. J. Bot.*, **39**(6): 2035-2042

Roy, S.K. and Senapati, B.K. 2012. Combining ability analysis for grain yield and quality characters in rice (*Oryza sativa*). *Indian journal of agriculture science*, **82**(4): 293-303.

Sahu, K.P., Sharma, D., Singh, S. and Sahu, P. 2016. gene action and combining ability analysis in cms based hybrid rice for grain yield and quality attributing traits. *International Journal of Agriculture Sciences*, **8**(48): 2024-2029.

Sala, M., Shanthi, P. and Selvi, B. 2016. Combining ability studies for yield and yield contributing traits in rice (*Oryza sativa* L.). *Agricultural Research Journal,* **53**(1): 13-18. [Cross Ref]

Thakare, I.S., Patel, A.L. and Mehta, A.M. 2010. Line × Tester Analysis Using CMS System in Rice (O*ryza sativa* L.). *The Bioscan*, **8**(4): 1379-1381.

Tiwari, G.C. and Singh, S.S. 2016. Diallel Analysis for Yield and Yield Components in Rice (*Oryza sativa* L.). *Advances in Life Sciences,* **5**(8): 3196-3202.

Torres, E.A. and I.O. Geraldi 2007. Partial diallel analysis of agronomic characters in rice (*Oryza sativa* L.).*Gen. Mol. Biol.* **30**(3): 605-613. [Cross Ref]