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Combining ability analysis for yield and its components in aerobic rice (*Oryza sativa* L.)

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Abstract
Line × tester analysis using a set of 4 females (lines) and 12 males (testers) having diverse genetic background was carried out to study the nature and magnitude of heterosis for yield and its components of rice under aerobic condition. Experimental material comprising 16 parents and their 48 hybrids were planted in a Randomized Block Design with three replications during *Kharif*- 2015 at the Main Rice Research Centre, Navsari Agricultural University, Navsari. Combining ability analysis revealed that both GCA (General Combining Ability) and SCA (Specific Combining Ability) variances were important for inheritance of various traits under study. However, the magnitude of SCA variance was higher than GCA variance for all characters which indicated the predominance of non-additive gene action. The estimates of GCA effects of parents indicated that four parents *viz.*, GR-7, CR DHAN 201, IET 23449 and NAUR-1 which had positive significant GCA effects for grain yield per plant and some of yield contributing characters. Crosses *viz.,* NAUR-1 × CR DHAN 201, Gurjari × GR-7 and GAR-13 × IET 23459 were found to be best specific combination for grain yield per plant and involved good × good, poor × poor and poor × good combining parents, respectively.

Keywords: Aerobic condition, gene action, GCA, line × testers, rice, SCA

Introduction

Rice (*Oryza sativa* L.) is diploid with a chromosome number of (2n = 24) and the world's second most important cereal crop belonging to the family Poaceae. It is the staple food for over one third of the world's population. Approximately 90 per cent of the world's rice is grown in the Asian continent and it ranks second in the grain production in India. Rice is placed on second position in cereal cultivation around globe and occupies an important position in the economy of India as an export item as well as staple food. India is the largest rice cultivator which accounts for almost 30 per cent of the world's rice area. Area under rice cultivation in India is 43.08 million hectares, production of 106.64 million tonnes with productivity of 2462.1 kg/ha. In Gujarat, rice is cultivated on an area of 8.08 lakh ha with total production as 16.36 lakh tonnes and productivity about 2076 kg/ha.

Aerobic rice refers to growing of rice germplasm in non-puddled and non-flooded condition. It is a new method of cultivating rice that requires less water than low land rice. It entails the growing of rice in aerobic soil, with the use of external inputs such as supplementary irrigation and fertilizers and aiming at high yields (Wang *et al.*, 2002) [19]. The water use of aerobic rice was about 60 per cent less than that of flooded rice and total water productivity was 1.6 to 1.9 times higher (Vijayakumar *et al.*, 2006) [18].

Hybrid rice technology had also shown increased yield, farmer profitability and better adaptability to stress environments such as water scarce and aerobic conditions. Considering all these issues, the main objective of this study is to develop rice hybrids with high yield potential for aerobic conditions to overcome the existing water crisis in India. The choice of parent is a matter of great concern to the plant breeders. In the past, the performance and adaptability of genetic stocks have been used as the main criteria in selection of parents for hybridization programme.

The concept of combining ability analysis has significant practical importance in plant breeding. It helps predicting relative efficiency of parents based on early generation performance and open the doors for comparative performance study of hybrid lines combinations. Without genetic direction, plant breeders face lack of rational basis to perform several tasks like choosing appropriate parents, in manipulating progenies and selection of superior parents. Combining ability analysis provides clue to use particular individuals as parents in hybridization programme along with that it helps in screening hybrids. The nature of gene action has a relevance on development of efficient breeding programme. General combining ability effects and additive × additive gene action is theoretically fixable. On the other hand, specific combining ability attributed to non-additive gene action, which can be due to dominance or epistasis or both and is not fixable. The presence of non-additive genetic variance is primary justification for initiating the hybrid programme (Cockerham, 1961). The success of hybrid programme based on the results of combining ability depends on the extent of genetic parameters, remain stable over environments.

Materials and Methods

The experimental material for present investigation consisted of 64 entries including 4 genotypes (NAUR-1, GNR-3, Gurjari and GAR-13) designated as females and 12 genotypes (IET 23467, IET 23445, IR-28, IET 22704, IET 23449, CR DHAN 201, IET 23459, GR-7, IET 23448, IET 23455, AAUDR-1 and IET 23471) designated as males. These parents were crossed to produce 48 F_1s according to Line × Testers mating design. The experiment was laid out in a Randomized Block Design with three replications at Main Rice Research Center, Navsari Agricultural University, Navsari during *Kharif* - 2015. Each entry was planted in a single row consist of ten plants in each row with a spacing 20 × 15 cm. The standard agronomical practices were followed to raise the good experimental crop. In this study, five competitive plants were randomly selected to record the observations on thirteen characters *viz.,* days to 50 per cent flowering, days to maturity, plant height (cm), number of productive tillers per plant, panicle length (cm), number of grains per panicle, panicle weight (g), 1000 grain weight (g), harvest index (%), grain yield per plant (g), straw yield per plant (g), amylose content (%) and protein content (%) and mean values over these five plants were subjected to statistical analysis.

Results and Discussion

Analysis of variance for combining ability

The genetic variances were estimated from the analysis of variances for combining ability for all 13 characters. The results are presented in Table 1. The variation present in hybrids was partitioned into portions attributable to lines, testers and line × tester sources.

The nature and magnitude of estimates of genetic variance provide an idea about the relative role of fixable and non-fixable gene effects in the inheritance of character. This in turn helps in identifying suitable parents for hybridization as well as breeding method to be employed. The estimation of general combining ability (GCA) variances for lines (σ^2l) were highly significant for days to 50 per cent flowering, days to maturity and plant height. While, general combining ability (GCA) variance for testers (σ^2t) were found significant for days to maturity, panicle length, 1000 grain weight, harvest index and grain yield per plant. On the other hand, general combining ability (GCA) variances were highly significant for all characters except number of productive tillers per plant, number of grains per panicle, straw yield per plant, amylose content and protein content. The magnitude of SCA variance was higher than GCA variance for all characters except days to 50 per cent flowering and days to maturity, which indicated the predominance of non-additive gene action for all characters. This was further supported by low magnitude of σ^2gca/ σ^2sca ratios. The findings were in confirmation with reports of Dalvi and Patel (2006) [2], Kumar *et al.* (2008) [4], Saidaiah and Ramesha (2010) [11], Patil *et al.* (2012a) [9], Thakre *et al.* (2013) [14] and Utharasu and Anandakumar (2013) [17] in rice. For the choice of right breeding method, it is mandatory to include the nature and magnitude of gene effects. In view of this, it became evident that breeding for high yielding varieties in rice may become more effective by appropriate exploitation of additive gene effect along with non-additive gene effect.

General combining ability

Nature and magnitude of combining ability effects provide guideline to identify better parents and their utilization. General combining ability effects were estimated for parents and its character wise categorization has been presented in Table 2. In present investigation, negative general combining ability is desirable for characters *viz.,* days to 50 per cent flowering, days to maturity and plant height in which earliness and dwarfness are considered as desirable characters. In present study, it was observed that none of the parents was good general combiner for all the traits. These results were in agreement with the findings of Dalvi and Patel (2006) [2], Singh *et al*. (2007) [13], Tyagi *et al*. (2008) [16], Saidaiah and Ramesha (2010) [11], Saleem *et al.* (2010) [12], Malarvizhi *et al.* (2011) [5], Patil *et al.* (2012) [9], Utharasu and Anandakumar (2013) [17], Adilakshmi and Upendra (2014) [1], Nagaraju *et al.* (2015) [7] and Patel *et al.* (2015) [8].

Significant general combining ability in favourable direction was observed in parents, lines and testers. As shown in Table 2, for grain yield per plant, out of 16 parents only four parents indicated significant general combining effect in positive direction. Only two parents shown significant negative general combining ability effect for days to 50 per cent flowering. In case of days to maturity, only one parent revealed significant GCA effect in favourable direction. For plant height, only 3 parents shown significant negative GCA effect. In case of number of productive tillers per plant, total 6 parents indicated significant positive GCA effect. Likewise, for panicle length 4 parents, for number of grains per panicle total 8 parents, for panicle weight 8 parents, for 1000 grain weight 8 parents, for harvest index 3 parents, for straw yield per plant 1 parent, in case of amylose content 6 parents and for protein content total 8 parents revealed significant GCA effect in favourable direction.

The results of general combining ability effect of parents (Table 3) revealed that among parents, NAUR-1 followed by IET 23449, CR DHAN 201 and GR-7 were good general combiners for grain yield per plant and other yield related traits. For days to 50 per cent flowering, parents GNR-3 followed by Gurjari were found to be good general combiners. For days to maturity, only one parent AAUDR-1 was recognized as a good general combiner. Parents NAUR-1 followed by GAR-13 and IET 23449 were recognized as good general combiners for plant height. Parents NAUR-1 followed by IET 23449, CR DHAN 201, GR-7 and AAUDR-1 were found to be good general combiners for most of traits viz., number of productive tillers per plant, panicle length, number of grains per panicle, panicle weight and 1000 grains weight. Only three parents namely IET 23449 followed by CR DHAN 201 and GR-7 were recognized as good general combiners for harvest index. For straw yield per plant, only one parent IET 23459 was found to be a good general combiner. For amylose content, parent Gurjari followed by GAR-13, IET 22704, IET

23449, CR DHAN 201 and IET 23459 were revealed as good general combiners and for protein content, total eight parents namely GNR-3 followed by Gurjari, IET 23467, IET 23450, IR 28, GR-7, IET 23448 and AAUDR-1 were recognized as good general combiners.

Specific combining ability

A specific combining ability effect is the index to determine, usefulness of a particular cross combination in the exploitation of heterosis. In case of specific combining ability effects, none of the hybrid exhibited favourable SCA effects for all characters. In the present study, positive specific combining ability is desirable for all characters except days to 50 per cent flowering, days to maturity and plant height.

Significant specific combining ability in favourable direction was observed in variable crosses. As revealed in Table 4, out of 48 crosses only five crosses had indicated positively significant specific combining ability effect in grain yield per plant. None of the cross had revealed significant SCA effect in favourable direction for days to 50 per cent flowering and days to maturity. In case of plant height out of 48 crosses, only three crosses had shown significant negative SCA effect. For number of productive tillers per plant, significant positive SCA effect was recorded in 13 crosses out of 48 crosses. Similarly, for panicle length only five crosses, for number of grains per panicle 17 crosses, for panicle weight 19 crosses, for 1000 grain weight 16 crosses, for harvest index 2 crosses, for straw yield per plant only 5 crosses, for amylose content 18 crosses and for protein content total 19 crosses respectively, revealed significant positive SCA effect. The results were in agreement with the findings of Dalvi and Patel (2006) [2], Singh *et al*. (2007) [13], Jayasudha and Sharma (2009), Saidaiah and Ramesha (2010) [11], Saleem *et al.* (2010) [12], Malarvizhi *et al.* (2011) [5], Mirarab *et al.* (2011) [6], Patil *et al.* (2012a) [9], Pratap *et al.* (2013) [10], Thakare *et al.* (2013) [14], Adilakshmi and Upendra (2014) [1], Tiwari and Jatav (2014) [15], Nagaraju *et al.* (2015) [7] and Patel *et al.* (2015) [8].

Some of the promising crosses with significant specific combining ability effects for several characters are illustrated in Table 5. Cross NAUR-1 × CR DHAN 201 followed by GAR-13 × IET 23459 and Gurjari × GR-7 were identified as best crosses with high significant SCA effect for grain yield. For days to 50 per cent flowering, cross GNR-3 × GR-7 followed by NAUR-1 × IET 23448 and GAR-13 × IET 23459 were recognized as best specific combiners among 48 crosses. Cross NAUR-1 × GR-7 followed by GAR-13 × IET 23450 and GAR-13 × IET 22704 were recognized as best specific combiners in case of days to maturity. For plant height cross GAR-13 × CR DHAN 201 followed by GNR-3 × IET 23448 and NAUR-1 × AAUDR-1, for number of productive tillers per plant cross NAUR-1 × CR DHAN 201 followed by Gurjari × GR-7 and GNR-3 × IET 23449, for panicle length cross GAR-13 × IET 23459 followed by GNR-3 × IET 23449 and Gurjari × GR-7, for number of grains per panicle cross NAUR-1 × CR DHAN 201 followed by NAUR-1 × IET 23467 and GNR-3 × AAUDR-1, for panicle weight cross GNR-3 × AAUDR-1 followed by GAR-13 × AAUDR-1 and GNR-3 × IET 23459, for 1000 grain weight cross Gurjari × IET 23450 followed by GNR-3 × IET 23459 and GAR-13 × IET 23459, for harvest index cross GAR-13 × IET 23459 followed by Gurjari × IET 23450 and GNR-3 × IET 22704, for straw yield per plant cross GAR-13 × IET 23455 followed by GAR-13 × IET 23450 and GAR-13 × IET 22704, for amylose content cross NAUR-1 × IET 23467 followed by Gurjari × IET 23471 and NAUR-1 × IET 23449 and cross NAUR-1 × IET 23467 followed by NAUR-1 × IET 23448 and NAUR-1 × IET 23471 respectively were recognized as best specific combiners for protein content as they had reported higher significant SCA effect in favourable direction.

By examining results, it can be seen that all crosses having best specific combination for grain yield per plant were obtained through good × good, poor × poor and poor × good GCA effects parental combinations. As revealed in Table 6, the best cross NAUR-1 × CR DHAN 201 recorded desirable significant SCA effect for traits like number of productive tillers per plant, panicle length, number of grains per panicle, panicle weight, 1000 grain weight, grain yield per plant and amylose content. The second-best cross GAR-13 × IET 23459 had significant SCA effect for number of productive tillers per plant, panicle length, panicle weight, 1000 grain weight, grain yield per plant and amylose content. Whereas, the third-best cross was Gurjari × GR-7, which had desirable significant SCA effect for panicle length, 1000 grain weight, harvest index and grain yield per plant.

A summarized account of the best parents *per se*, best general combiner and best specific combiner as presented in Table 5, revealed that best performing parent may or may not be a good general combiner. Therefore, parents should be selected on the basis of mean performance irrespective of their GCA effects. Further, the best general combiner or best parent *per se* may not always produce best specific combinations for all the characters. However, in some of the cross, high SCA effects of F_1 hybrids with high GCA effects of their parents, indicating the predominance of both additive and non-additive gene action. Therefore, it is more desirable to select crosses based on the *per se* performance rather than magnitude of SCA effects.

Table 1: Variance components of general and specific combining ability for yield and its components in Aerobic rice

Source of variations	d.f.	Characters: Days to 50 per cent flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	No. of grains per panicle	Panicle weight (g)	1000 grain weight (g)	Harvest index (%)	Grain yield per plant (g)	Straw yield per plant (g)	Amylose content (%)	Protein content (%)
Replications	2	17.51	2.09	11.27	0.00	0.53	3.74	0.00	2.86	20.43	1.01	16.63	0.46	0.01
Hybrids	47	35.16*	44.11	322.11**	15.09**	19.58**	3030.82**	3.63**	37.86**	78.06**	55.27**	52.75**	28.11**	2.49**
Line effect	3	329.47**	230.15**	1704.11**	11.15	20.99	1690.56	3.77	24.16	79.41	62.76	26.23	14.30	1.06
Tester effect	11	12.11	55.77*	217.32	16.39	41.90**	3969.08	4.91	68.58*	172.85**	119.30**	44.79	25.36	3.27
Line × Tester effect	33	16.09	23.30	231.39**	15.02**	12.02**	2839.91**	3.19**	28.86**	46.34*	33.24**	57.81**	30.29**	2.36**
Error	94	21.34	34.92	117.86	0.93	4.60	85.95	0.04	1.70	26.06	14.88	18.67	0.86	0.02
$\sigma^2 l$		8.70**	5.74**	40.91**	-0.10	0.25	-31.93	0.02	-0.13	0.92	0.82	-0.88	-0.44	-0.04
$\sigma^2 t$		-0.33	2.71*	-1.17	0.11	2.49**	94.10	0.14	3.31*	10.54**	7.17**	-1.08	-0.41	0.08
$\sigma^2 gca$		0.27**	0.29**	1.27**	0.00	0.10**	2.67	0.006*	0.12**	0.44**	0.31**	-0.07	-0.03	0.002
$\sigma^2 sca$		-0.43	-3.68	35.58*	4.70**	2.67**	914.65**	1.05**	9.08**	7.27**	6.42**	13.34**	9.83**	0.78**
$\sigma^2 gca / \sigma^2 sca$		-0.63	-0.08	0.03	0.00	0.03	0.002	0.005	0.013	0.06	0.05	-0.005	-0.003	0.002

* and ** shows significance at 5 per cent and 1 per cent levels of probability, respectively.

Table 2: Estimation of General combining ability (GCA) effects of parents for yield and its components in Aerobic rice

Parents	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	No. of Productive tillers per plant	Panicle length (cm)	No. of grains per panicle	Panicle weight (g)	1000 grain weight (g)	Harvest index (%)	Grain yield per plant (g)	Straw yield per plant (g)	Amylose content (%)	Protein content (%)
Lines													
NAUR-1	0.063	-0.944	-3.789*	0.741**	0.671*	6.899**	0.317**	-0.876**	1.563	1.742**	-0.052	-0.618**	-0.093**
GNR-3	-2.188**	-1.389	3.615	0.100	0.213	3.515*	0.234**	1.056**	0.140	-0.215	-0.563	-0.424**	0.115**
Gurjari	-2.132**	-1.444	7.656**	-0.329*	-1.099**	-1.553	-0.212**	0.150	0.312	-0.061	-0.608	0.729**	0.171**
GAR-13	4.257**	3.778**	-7.481**	-0.512**	0.215	-8.861**	-0.338**	-0.329	-2.015*	-1.465*	1.223	0.313*	-0.192**
S.E. (g_i)	0.69	0.98	1.86	0.16	0.33	1.63	0.03	0.21	0.82	0.62	0.70	0.15	0.03
S.E. (g_i- g_j)	0.98	1.38	2.63	0.23	0.47	2.31	0.05	0.30	1.17	0.88	0.99	0.21	0.04
Testers													
IET 23467	-0.410	3.222	8.034*	0.563*	0.269	-3.267	0.447**	1.546**	0.999	1.913	1.410	-3.026**	0.607**
IET 23450	-0.243	-1.528	-1.103	-1.978**	-3.933**	-39.653**	-1.487**	-6.288**	-3.782**	-4.382**	-1.379	0.254	0.469**
IR 28	0.174	-3.111	-1.452	-1.003**	0.146	-2.772	0.196**	-0.200	1.866	0.469	-1.958	0.135	0.159**
IET 22704	-1.910	2.889	-0.193	-0.798**	-0.035	-20.780**	-0.791**	-0.863*	-1.455	-3.166**	-2.383	1.584**	-0.286**
IET 23449	0.257	1.556	-8.059*	0.782**	1.876**	17.223**	0.049	2.313**	3.604*	3.075**	-0.652	1.157**	-0.110*
CR DHAN 201	1.340	0.639	-1.759	0.590*	0.374	10.478**	0.674**	1.763**	2.874*	3.867**	0.806	1.495**	-0.618**
IET 23459	-1.243	0.222	-4.351	-0.588*	-2.800**	-7.311*	-0.463**	-2.663**	-4.881**	-2.288*	3.552**	1.532**	-1.046**
GR-7	-0.076	-0.111	-0.563	2.363**	2.212**	15.605**	0.639**	1.042**	7.797**	5.187**	-3.059*	-0.501	0.572**
IET 23448	-0.493	0.306	1.327	-0.383	-0.098	15.373**	-0.061	0.213	-3.518*	-2.653*	0.905	0.224	0.135**
IET 23455	1.590	-1.028	-0.581	-0.328	0.487	-14.086**	0.105	0.838*	1.612	1.429	0.407	-2.202**	-0.382**
AAUDR 1	1.007	-3.944*	2.922	1.314**	2.344**	19.681**	0.560**	1.413**	-1.213	-0.197	1.833	-0.656*	0.567**
IET 23471	0.007	0.889	5.777	-0.536	-0.843	9.508**	0.132*	0.887*	-3.903**	-3.253**	0.517	0.003	-0.067
S.E. (g_j)	1.20	1.69	3.22	0.28	0.58	2.83	0.06	0.37	1.43	1.08	1.22	0.26	0.05
S.E. (g_i- g_j)	1.70	2.39	4.56	0.39	0.82	4.00	0.08	0.52	2.02	1.52	1.72	0.37	0.07

* and ** shows significance at 5 and 1 per cent levels of probability, respectively.

Table 3: Classification of parents with respect to general combining ability (GCA) for yield and its components in Aerobic rice

Parents	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	No. of grains per panicle	Panicle weight (g)	1000 grain weight (g)	Harvest index (%)	Grain yield per plant (g)	Straw yield per plant (g)	Amylose content (%)	Protein content (%)
Lines													
NAUR -1	P	A	G	G	G	G	G	P	A	G	P	P	P
GNR-3	G	A	P	A	A	G	G	G	A	P	P	P	G
Gurjari	G	A	P	P	P	P	P	A	A	P	P	G	G
GAR-13	P	P	G	P	A	P	P	P	P	P	A	G	P
Testers													
IET 23467	A	P	P	G	A	P	G	G	A	A	A	P	G
IET 23450	A	A	A	P	P	P	P	P	P	P	P	A	G
IR 28	P	A	A	P	A	P	G	P	A	A	P	A	G
IET 22704	A	P	A	P	P	P	P	P	P	P	P	G	P
IET 23449	P	P	G	G	G	G	A	G	G	G	P	G	P
CR DHAN 201	P	P	A	G	A	G	G	G	G	G	A	G	P
IET 23459	A	P	A	P	P	P	P	P	P	P	G	G	P
GR-7	A	A	A	G	G	G	G	G	G	G	P	P	G
IET 23448	A	P	P	P	P	G	P	A	P	P	A	A	G
IET 23455	P	A	A	P	A	P	A	G	A	A	A	P	P
AAUDR-1	P	G	P	G	G	G	G	G	P	P	A	P	G
IET 23471	P	P	P	P	P	G	G	G	P	P	A	A	P

G = Good general combiner having significant GCA effects in desirable direction
A = Average general combiner having either positive or negative but non-significant GCA effects in undesirable direction
P = Poor general combiner having significant GCA effects in undesirable direction

Table 4: Estimation of Specific combining ability (SCA) effects of hybrids for various characters in Aerobic rice

Sr. No	Crosses	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	No. of grain per panicle
1	NAUR-1 × IET 23467	0.521	-0.056	-3.145	1.317*	2.059	43.599**
2	NAUR-1 × IET 23450	-0.646	1.028	3.288	-0.902	-0.586	-8.742
3	NAUR-1 × IR 28	0.271	-1.389	-5.299	0.803	-1.151	29.834**
4	NAUR-1 × IET 22704	0.354	3.944	5.618	-1.645**	1.393	-19.141**
5	NAUR-1 × IET 23449	-0.146	0.611	3.272	-2.545**	-2.011	-20.667**
6	NAUR-1 × CR DHAN 201	5.104*	-0.806	1.675	5.341**	2.497*	45.674**
7	NAUR-1 × IET 23459	-0.313	0.611	-0.033	0.625	-0.949	5.979
8	NAUR-1 × GR-7	1.521	-6.056	5.355	-0.103	0.499	36.480**
9	NAUR-1 × IET 23448	-4.063	-0.806	5.899	-0.83	-1.408	-1.221
10	NAUR-1 × IET 23455	-0.146	1.528	-0.67	-0.072	0.184	-26.849**
11	NAUR-1 × AAUDR-1	-0.229	-0.222	-13.526*	-0.977	-1.546	-61.572**
12	NAUR-1 × IET 23471	-2.229	1.611	-2.435	-1.013	1.018	-23.373**
13	GNR-3 × IET 23467	-1.229	0.389	6.788	0.308	-0.406	-33.634**

Sr. No	Crosses	Days to 50 per cent flowering	Days to maturity	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	No. of grain per panicle
14	GNR-3 × IET 23450	-1.063	3.472	8.251	-0.624	-1.591	-10.715
15	GNR-3 × IR 28	2.521	1.722	-5.57	-0.646	-0.073	-23.186**
16	GNR-3 × IET 22704	0.271	2.056	5.211	1.269*	1.335	5.679
17	GNR-3 × IET 23449	-0.229	-1.611	-7.339	4.569**	3.204**	37.397**
18	GNR-3 × CR DHAN 201	-2.979	1.306	11.298	-2.682**	-0.011	-36.683**
19	GNR-3 × IET 23459	-1.729	-1.278	5.866	1.419*	-0.42	37.573**
20	GNR-3 × GR-7	-0.896	1.389	2.398	-3.025**	-3.463**	-41.356**
21	GNR-3 × IET 23448	-0.146	-1.694	-13.542*	-0.036	0.224	23.920**
22	GNR-3 × IET 23455	3.104	-0.361	0.669	-1.424*	-1.805	13.655*
23	GNR-3 × AAUDR-1	-0.313	-4.444	-2.63	2.287**	1.992	43.528**
24	GNR-3 × IET 23471	2.688	-0.944	-11.399	-1.416*	1.016	-16.179**
25	Gurjari × IET 23467	0.049	-0.556	1.40	-0.556	-0.134	15.550**
26	Gurjari × IET 23450	1.215	1.528	-10.573	1.394*	2.614*	12.806*
27	Gurjari × IR 28	-0.868	-2.556	3.753	0.299	1.086	-11.085
28	Gurjari × IET 22704	0.882	-0.556	-9.763	-0.896	-2.174	-17.766**
29	Gurjari × IET 23449	-0.285	-2.222	3.677	-2.366**	1.082	5.251
30	Gurjari × CR DHAN 201	-1.368	0.694	7.013	-1.470**	-2.413*	16.269**
31	Gurjari × IET 23459	4.215	1.444	-9.462	-1.936**	-3.005*	-40.452**
32	Gurjari × GR-7	-4.618	0.111	0.407	5.117**	3.179**	4.685
33	Gurjari × IET 23448	1.799	0.694	-4.899	-0.987	0.416	0.128
34	Gurjari × IET 23455	-0.951	-0.306	-4.558	2.364**	0.207	12.086*
35	Gurjari × AAUDR-1	0.632	0.944	9.009	-2.417**	-0.553	-15.831**
36	Gurjari × IET 23471	-0.701	0.778	13.997*	1.453*	-0.305	18.359**
37	GAR-13 × IET 23467	0.66	0.222	-5.043	-1.069	-1.518	-25.515**
38	GAR-13 × IET 23450	0.493	-6.028	-0.966	0.132	-0.437	6.651
39	GAR-13 × IR 28	-1.924	2.222	7.116	-0.457	0.138	4.437
40	GAR-13 × IET 22704	-1.507	-5.444	-1.066	1.272*	-0.554	31.229**
41	GAR-13 × IET 23449	0.66	3.222	0.391	0.342	-2.275	-21.981**
42	GAR-13 × CR DHAN 201	-0.757	-1.194	-19.986**	-1.189*	-0.073	-25.260**
43	GAR-13 × IET 23459	-2.174	-0.778	3.629	-0.108	4.374**	-3.101
44	GAR-13 × GR-7	3.993	4.556	-8.159	-1.989**	-0.215	0.19
45	GAR-13 × IET 23448	2.41	1.806	12.541	1.853**	0.768	-22.827**
46	GAR-13 × IET 23455	-2.007	-0.861	4.559	-0.868	1.413	1.108
47	GAR-13 × AAUDR-1	-0.09	3.722	7.146	1.107*	0.107	33.874**
48	GAR-13 × IET 23471	0.243	-1.444	-0.163	0.977	-1.729	21.194**
	S.E. (S_{ij})	2.41	3.38	6.45	0.55	1.15	5.65
	S.E. (S_{ij}- S_{kl})	3.40	4.78	9.12	0.78	1.63	8.00

* and ** shows significance at 5 and 1 per cent levels of probability, respectively.

Sr. No	Crosses	Panicle weight (g)	1000 grain weight (g)	Harvest index (%)	Grain yield per plant (g)	Straw yield per plant (g)	Amylose content (%)	Protein content (%)
1	NAUR-1 × IET 23467	1.075**	2.739**	0.234	1.97	2.655	6.448**	1.357**
2	NAUR-1 × IET 23450	-0.278*	-0.211	-0.815	-3.135	-3.716	1.966**	-0.129
3	NAUR-1 × IR 28	0.756**	-0.749	-1.993	-2.943	-0.913	0.651	-1.029**
4	NAUR-1 × IET 22704	-0.724**	0.764	-0.475	-0.864	-0.522	2.029**	-0.821**
5	NAUR-1 × IET 23449	-0.457**	0.989	-2.988	-2.542	0.831	3.736**	0.133
6	NAUR-1 × CR DHAN 201	1.001**	2.639**	5.259	7.629**	1.569	1.168*	0.012
7	NAUR-1 × IET 23459	0.021	-0.186	0.964	-0.882	-2.433	-1.126*	-1.094**
8	NAUR-1 × GR-7	0.963**	3.260**	-2.791	-0.891	2.238	-2.043**	0.198*
9	NAUR-1 × IET 23448	0.579**	-1.461*	2.484	1.509	-0.829	-5.092**	1.122**
10	NAUR-1 × IET 23455	0.717**	-3.086**	-0.015	-1.243	-1.815	-2.218**	0.566**
11	NAUR-1 × AAUDR-1	-2.075**	-3.361**	-0.967	-0.743	0.549	-0.968	-1.433**
12	NAUR-1 × IET 23471	-1.577**	-1.336	1.102	2.136	2.385	-4.550**	1.120**
13	GNR-3 × IET 23467	-1.379**	-3.676**	-2.506	-2.057	0.453	-4.376**	-1.558**
14	GNR-3 × IET 23450	-0.625**	-3.343**	-0.339	-1.599	-2.551	0.131	-0.037
15	GNR-3 × IR 28	-1.025**	1.169	2.257	2.703	0.538	3.373**	-0.177
16	GNR-3 × IET 22704	0.525**	2.782**	5.565	1.866	-4.324	-0.975	-1.099**
17	GNR-3 × IET 23449	1.122**	1.907*	1.425	4.474*	3.699	0.451	0.942**
18	GNR-3 × CR DHAN 201	0.094	-0.743	-2.058	1.286	5.584*	-2.680**	0.374**
19	GNR-3 × IET 23459	1.264**	4.282**	-3.85	-2.516	1.878	2.266**	0.348**
20	GNR-3 × GR-7	-0.701**	-0.972	-1.281	-0.991	0.032	-0.601	0.187
21	GNR-3 × IET 23448	0.772**	-2.393**	0.44	0.466	-0.171	2.367**	0.574**
22	GNR-3 × IET 23455	-1.034**	-0.768	4.758	0.12	-6.210*	-3.519**	-0.012
23	GNR-3 × AAUDR-1	1.308**	2.074**	-7.010*	-2.954	6.180*	1.994**	0.365**
24	GNR-3 × IET 23471	-0.321**	-0.318	2.599	-0.798	-5.107*	1.569**	0.092
25	Gurjari × IET 23467	0.007	1.029	-2.209	-2.16	0.265	-4.819**	-0.125
26	Gurjari × IET 23450	0.840**	4.563**	5.962*	4.948*	-0.699	-1.329*	0.830**

Sr. No	Crosses	Panicle weight (g)	1000 grain weight (g)	Harvest index (%)	Grain yield per plant (g)	Straw yield per plant (g)	Amylose content (%)	Protein content (%)
27	Gurjari × IR 28	0.125	-0.175	-0.399	0.683	1.873	-3.270**	0.220*
28	Gurjari × IET 22704	-0.339**	-5.913**	-1.292	-1.938	-2.072	-2.389**	0.891**
29	Gurjari × IET 23449	-0.292*	-0.038	3.869	-0.606	-5.469*	-0.252	-1.131**
30	Gurjari × CR DHAN 201	0.440**	0.612	-4.377	-2.581	3.619	2.500**	-0.720**
31	Gurjari × IET 23459	-1.287**	-7.713**	-5.229	-3.926	1.743	0.223	1.025**
32	Gurjari × GR-7	0.878**	1.933**	3.033	5.209*	1.251	3.406**	-0.13
33	Gurjari × IET 23448	-0.889**	2.863**	-1.749	-1.628	-0.062	-0.189	-0.460**
34	Gurjari × IET 23455	0.145	2.038**	-0.435	-0.107	-0.112	2.157**	-0.649**
35	Gurjari × AAUDR-1	-0.516**	-0.888	4.773	1.496	-4.757	-0.789	0.832**
36	Gurjari × IET 23471	0.888**	1.688*	-1.947	0.609	4.418	4.752**	-0.585**
37	GAR-13 × IET 23467	0.297*	-0.092	4.481	2.247	-3.373	2.747**	-0.663**
38	GAR-13 × IET 23450	0.063	-1.008	-4.808	-0.215	6.966**	-0.769	0.987**
39	GAR-13 × IR 28	0.144	-0.246	0.135	-0.443	-1.498	-0.754	1.028**
40	GAR-13 × IET 22704	0.537**	2.367**	-3.798	0.936	6.917**	1.335*	0.056
41	GAR-13 × IET 23449	-0.373**	-2.858**	-2.307	-1.325	0.939	-3.935**	0.334**
42	GAR-13 × CR DHAN 201	-1.534**	-2.508**	1.176	-6.334**	-10.772**	-0.987	-0.278**
43	GAR-13 × IET 23459	0.002	3.617**	8.115**	7.325**	-1.188	-1.364*	-0.256*
44	GAR-13 × GR-7	-1.139**	-4.221**	1.04	-3.327	-3.521	-0.761	-1.236**
45	GAR-13 × IET 23448	-0.463**	0.992	-1.175	-0.347	1.063	2.914**	0.095
46	GAR-13 × IET 23455	0.172	1.817*	-4.308	1.23	8.137**	3.581**	0.236*
47	GAR-13 × AAUDR-1	1.283**	2.175**	3.204	2.2	-1.972	-0.236	-0.628**
48	GAR-13 × IET 23471	1.011**	-0.033	-1.754	-1.947	-1.697	-1.771**	-0.663**
	S.E. (S_{ij})	0.12	0.73	2.86	2.16	2.43	0.52	0.10
	S.E. (S_{ij}- S_{kl})	0.17	1.04	4.04	3.05	3.44	0.73	0.14

* and ** shows significance at 5 and 1 per cent levels of probability, respectively.

Table 5: Promising parents and F1s based on *per se* performance, general combining ability and specific combining ability effects

Sr. No.	Characters	***per se* performance**		**Combining ability effects**	
		Parents	**F1s**	**GCA**	**SCA**
1.	Days to 50 per cent flowering	AAUDR-1	Gurjari × GR-7	GNR-3	GNR-3 × GR-7
		IET 23450	GNR-3 × IET 23459	Gurjari	NAUR-1 × IET 23448
		IET 23455	NAUR-1 × IET 23448	IET 22704	GAR-13 × IET 23459
2.	Days to maturity	AAUDR-1	GNR-3 × AAUDR-1	AAUDR-1	NAUR-1 × GR-7
		IR 28	NAUR-1 × GR-7	IR 28	GAR-13 × IET 23450
		IET 23455	Gurjari × IR 28	IET 23450	GAR-13 × IET 22704
3.	Plant height (cm)	IET 23455	GAR-13 × CR DHAN 201	IET 23449	GAR-13 × CR DHAN 201
		IR 28	GAR-13 × GR-7	GAR-13	GNR-3 × IET 23448
		IET 22704	GAR-13 × IET 23449	NAUR-1	NAUR-1 × AAUDR-1
4.	No. of productive tillers per plant	GR-7	Gurjari × GR-7	GR-7	NAUR-1 × CR DHAN 201
		NAUR-1	NAUR-1 X CR DHAN 201	AAUDR-1	Gurjari × GR-7
		CR DHAN 201	GNR-3 × IET 23449	IET 23449	GNR-3 × IET 23449
5.	Panicle length (cm)	IET 23448	GNR-3 × IET 23449	AAUDR-1	GAR-13 × IET 23459
		GNR-3	GNR-3 × AAUDR-1	GR-7	GNR-3 × IET 23449
		NAUR-1	Gurjari × GR-7	IET 23449	Gurjari × GR-7
6.	No. of grains per panicle	GAR-13	GNR-3 × AAUDR-1	AAUDR-1	NAUR-1 × CR DHAN 201
		IR 28	NAUR-1 × CR DHAN 201	IET 23449	NAUR-1 × IET 23467
		IET 23449	NAUR-1 × GR-7	IET 23448	GNR-3 × AAUDR-1
7.	Panicle weight (g)	GNR-3	GNR-3 × AAUDR-1	CR DHAN 201	GNR-3 × AAUDR-1
		IET 23467	NAUR-1 × CR DHAN 201	GR-7	GAR-13 × AAUDR-1
		CR DHAN 201	NAUR-1 × GR-7	AAUDR-1	GNR-3 × IET 23459
8.	1000 grain weight (g)	IET 23467	GNR-3 × IET 23449	IET 23449	Gurjari × IET 23450
		IET 23455	GNR-3 × AAUDR-1	CR DHAN 201	GNR-3 × IET 23459
		GR-7	NAUR-1 × CR DHAN 201	IET 23467	GAR-13 × IET 23459
9.	Harvest index (%)	IR 28	Gurjari × GR-7	GR-7	GAR-13 × IET 23459
		AAUDR-1	NAUR-1 × CR DHAN 201	IET 23449	Gurjari × IET 23450
		IET 23449	Gurjari × IET 23449	CR DHAN 201	GNR-3 × IET 22704
10.	Grain yield per plant (g)	NAUR-1	NAUR-1 × CR DHAN 201	GR-7	NAUR-1 × CR DHAN 201
		CR DHAN 201	Gurjari × GR-7	CR DHAN 201	GAR-13 × IET 23459
		GR-7	GNR-3 × IET 23449	IET 23449	Gurjari × GR-7
11.	Straw yield per plant (g)	NAUR-1	GAR-13 × IET 23455	IET 23459	GAR-13 × IET 23455
		IET 23448	GNR-3 × AAUDR-1	AAUDR-1	GAR-13 × IET 23450
		GNR-3	GAR-13 × IET 23450	IET 23467	GAR-13 × IET 22704
12.	Amylose content (%)	NAUR-1	Gurjari × IET 23471	IET 22704	NAUR-1 × IET 23467

		IET 23459	Gurjari × CR DHAN 201	IET 23459	Gurjari × IET 23471
		GNR-3	NAUR-1 × IET 23449	CR DHAN 201	NAUR-1 × IET 23449
13.	Protein content (%)	GAR-13	NAUR-1 × IET 23467	IET 23467	NAUR-1 × IET 23467
		Gurjari	Gurjari × AAUDR-1	GR-7	NAUR-1 × IET 23448
		IET 23455	Gurjari × IET 23450	AAUDR-1	NAUR-1 × IET 23471

Table 6: Best crosses based on SCA effects and their performance for general and specific combining ability for grain yield per plant

Sr. No.	Best crosses based on SCA effects	Mean yield (g)	GCA effects		SCA effects	Other traits revealing significant SCA effects
			P_1	P_2		
1.	NAUR-1 × CR DHAN 201	36.40	1.742**	3.867**	7.629**	PTP, PL, GPP, PW, GW, AC
2.	GAR-13 × IET 23459	26.74	-1.465*	-2.288*	7.325**	PTP, PL, PW, GW, AC
3.	Gurjari × GR 7	33.50	-0.061	5.187**	5.209*	PL, GW, HI

(**Note:** Where, PTP= Number of productive tillers per plant; PL= Panicle length; GP= Number of grains per panicle; PW= Panicle weight; GW= 1000 grain weight; HI= Harvest index; GYP= Grain yield per plant; SYP= Straw yield per plant; AC= Amylose content; PC= Protein content)

Conclusion

From the above research, it is concluded that best performing parent may not be a good general combiner. Therefore, parents should be selected on the basis of mean performance irrespective of their GCA effects. Furthermore, the best general combiner or best parent *per se* may not always produce best specific combinations for all the characters. The magnitude of SCA variance was higher than GCA variance for all characters except days to 50 per cent flowering and days to maturity, which indicated the predominance of non-additive gene action for those characters. This was further supported by low magnitude of σ^2gca/ σ^2sca ratios. So, these characters could be exploited by heterosis breeding. Simple selection has been suggested for the improvement of the characters which are mainly governed by additive gene action. The cross combinations involving good × good, poor × poor and poor × good general combining parents with highest significant SCA effects may be obtained for different traits. Crosses having both the parents, as poor general combiners may involve dominance x dominance or epistatic interaction. Such crosses may not give good transgressive segregants in later generation.

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