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Heterosis and Combining Ability Estimates using Line x Tester Analysis to Develop Rice Hybrids for Temperate Conditions

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Abstract

Heterosis and combining ability estimates were worked out through Line x Tester analysis of 36 hybrids developed by crossing 18 lines (Males) with two cytoplasmic male sterile (CMS) lines (Females) to know the genetic architecture of various agro-morphological traits in rice for development of hybrids under temperate conditions. Analysis of variance revealed significant differences among genotypes, crosses, lines, testers and line x tester interactions for all the studied traits. Preponderance of non-additive gene effects was realized by higher values of specific combining ability compared to general combining ability, ratio of variances of SCA to GCA and average degree of dominance. The proportional contribution of testers was observed to be lower than that of line x tester interactions thus higher estimates of SCA variances. The estimates of GCA effects indicated male parent 'K-08-61-2' was good general combiner for grain yield per plant and other yield contributing traits and among the female parent 'SKAU 11A' was observed to be good general combiner. Cross combinations 'SKAU 7A' x 'K-08-61-2', 'SKAU 7A' x 'SR-2', 'SKAU 11A' x 'K-08-60-2', 'SKAU 11A' x 'K-08-59-3' and 'SKAU 11A' x 'SKAU-389' were found to be good specific combinations for grain yield per plant and other desirable traits and needs to be tested on large scale.

Keywords: cytoplasmic male sterile lines, combining ability, rice, temperate conditions

Introduction

Rice (*Oryza sativa* L.) is an important cereal crop and staple food of Kashmir valley (India). It is cultivated within an altitude range of 1500-2200 m amsl (above mean sea level). At the current growth of population, rice requirement increases drastically, hence it is challenging task to ensure food and nutritional security to the people of valley. Though during past two and half decades, a number of high yielding rice varieties have been released, rice productivity in the valley has reached a plateau in the recent years and chances of further yield enhancement are scanty due to low genetic variability in hill rice cultivars (Sanghera and Wani, 2008). Therefore, enhancing productivity of rice through novel genetic approaches like hybrid rice was felt necessary. Hybrid rice technology will offer an opportunity to boost the yield of rice under temperate valley conditions and to break through the yield ceilings of semi dwarf varieties, as hybrid rice varieties have a yield advantage of 15-20% over the conventional high yielding varieties (Virmani, 1996). Rice being self pollinated crop, must involve use of an effective male sterility system to develop and produce F_1 hybrid varieties. For efficient hybrid rice breeding programme, availability of stable CMS lines, maintainers, identification of restorers and evaluation of parental lines and conversion of promising maintainer lines in to CMS lines forms an integral part of hybrid rice technology. Recently, (Sanghera *et al.*, 2010) have developed 'SKAU 7A' and 'SKAU 11A' cold tolerant CMS lines with better agro-morphological and floral characteristics that can be utilized for development of medium bold rice hybrids with good grain quality for temperate conditions of Kashmir (India). Thus, to exploit maximum heterosis using CMS system in the hybrid programme, one must know the combining ability of different male sterile and restorer lines. The knowledge of combining ability is useful to assess nicking ability among genotypes and at the same time elucidate the nature and magnitude of gene actions involved. Its role is important to decide parents, crosses and appropriate breeding procedures to be followed to select desirable segregants (Salgotra *et al.,* 2009). The general combining ability could identify superior parental genotypes where as specific combining ability helps in identification of good hybrid combinations which may ultimately lead to the development of hybrids (Saleem *et al.,* 2008). The presence of non-additive genetic variance is the primary justification for initiating the hybrid programme (Pradhan *et al.,* 2006). Line x Tester (Kempthorne, 1957) analysis is one of the most powerful tools for estimating the general combining ability (GCA) of parents and selection of desirable parents and crosses with high SCA for the exploitation of heterosis (Rashid *et al.*, 2007; Sarkar *et al.,* 2002).

Though a good quantum of research work has been documented on fertility restoration, heterosis and combining ability analysis in rice hybrids, but possibilities for

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exploitation of hybrid rice under temperate Kashmir conditions has not been explored yet. Therefore the present investigation was carried out to assess the combining ability of newly developed male sterile and identified restorer lines for the exploitation of maximum heterosis in F_1 for yield and yield contributing traits under temperate conditions.

Materials and methods

The present investigation was conducted during the years 2010-2011 at Mountain Research Centre for Field Crops, Khudwani (34°N latitude and 74°longitude) of Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (India). The experimental material used for study comprised of two newly developed and well adapted temperate CMS lines viz. 'SKAU 7A' and 'SKAU 11A' and eighteen males ('SKAU-405', 'Jhelum', 'K-08-60-2', 'SKAU-403', 'SKAU-407', 'K-08-59-3', 'China-1007', 'SR-1', 'SKAU-389', 'K-08-59-1', 'SKAU-292', 'SKAU-391', 'SKAU-354', 'SKAU-46', 'Chenab', 'SKAU-406', 'K-08-61-2' and 'SR-2') that were selected out of the elite germplasm collection maintained at Mountain Research Centre for Field Crops, Khudwani. Crosses were made in Line x Tester fashion by pollinating the two CMS lines 'SKAU 7A' and 'SKAU 11A' with aforementioned testers during the wet season 2010. The resulting 36 F_1 hybrid combinations along with 20 parents were grown in complete randomized block design in three replications during wet season 2011. Thirty days old seedlings with single plant/hill were transplanted in a 5 m long row with inter and intra row spacing of 20 and 15 cm, respectively. One line of each entry was planted in each replication. All the recommended agronomic and plant protection practices were uniformly followed throughout the crop growth period for raising ideal crop stand. In each entry, five plants were selected randomly from each replication and biometrical observations were recorded on pollen fertility (%), spikelet fertility (%), number of spikelets per panicle, number of filled grains per panicle, number of chaff seed per panicle, panicle length (cm), number of tillers per plant, number of productive tillers plant, plant height (cm), flag leaf area (cm^2), biological yield per plant (g), grain yield per plant (g), harvest index (%), grain length (mm), grain breadth (mm) and grain length/breadth ratio. Days to maturity and days to 50% flowering were recorded on plot basis. Combining ability analysis was carried out according to the standard given by Kempthorne (1957) through a computer generated programme WINDOW STAT.

Results and discussion

The analysis of variance revealed highly significant differences among the crosses, genotypes, parents, parent vs. crosses, crosses and lines x testers interaction for all the characters studied (Tab. 1), where as for testers, days to 50% flowering, pollen fertility percent, spikelet fertility percent, tillers per plant and productive tillers per plant were found significant. The significant difference of mean squares between parents and crosses for all the traits indicates that they are suitable for combining ability studies. Further, significant mean squares of parent vs. crosses revealed good scope for manifestation of heterosis in all the studied traits. These results coincide with the findings of (Jayasudha and Sharma, 2009; Rahimi *et al.,* 2010). They also found significant difference among parents vs. crosses. The significant differences between lines x testers interaction for these traits, indicated that specific combining ability attributed heavily in the expression of these traits and provide the importance of dominance or non additive variances for all the traits. Several researchers have reported the predominance of dominant gene action for a majority of the yield traits in rice (Faiz *et al.,* 2006; Satyanarayan *et al.,* 2000). The significant mean squares of lines and testers also revealed the prevalence of additive variances for the traits studied. Occurrence of both additive and non additive gene effects for yield and important yield component traits in rice has been reported in earlier studies (Bansal *et al.,* 2000; Rahimi *et al.,* 2010; Sukhpal *et al.,* 2005; Thirumeni *et al.,* 2000).

Major role of non-additive gene effects in the manifestation of all the traits was observed by higher value of specific combining ability variance (σ^2SCA) than the general combining ability variance (σ^2GCA), ratio of σ^2GCA/σ^2SCA being less than one, and degree of dominance $(\sigma^2A/\sigma^2D)^{1/2}$ being greater than one (Tab. 2). Importance of non-additive genes for expression of yield and its components have also been reported (Dalvi and Patel, 2009; Malani *et al.,* 2006; Saidaiah *et al.,* 2010; Silvaraj *et al.,* 2011; Swamy *et al.,* 2003). The present results indicate the preponderance of non-additive gene action in the expression of all the traits studied and a very good prospect for the exploitation of non-additive genetic variation for traits through hybrid breeding. In present study, grain parameters like grain length, grain breadth and their ratio recorded higher SCA variance than GCA variance. Vanaja *et al.* (2003) and Thakare *et al.* (2010) also reported higher estimates of SCA variances than GCA variances for these grain quality parameters. Furthermore, based on the present study all the eighteen (18) traits revealed low narrow sense heritability (15.07 to 29.97%) although the highest specific heritability was calculated for flag leaf area (29.97%). Similar results were obtained by Mirarab *et al.* (2011) that showed low narrow sense heritability for different traits studied thus indicating that non-additive effects play an important role in controlling the traits. Ahmadikhah (2008) also reported a low specific heritability for yield-related traits and Wu *et al.* (1986) reported a low specific heritability for tiller number and grain yield of rice. Therefore, it seems that hybridization must be a choice for utilizing the putative heterosis in special crosses.

Tab. 1. Analysis of variance for various agro-morphological traits in rice (*Oryza sativa* L.)

Source of variation	df	Days to 50% flowering	Days to maturity	Pollen fertility (%)	Spikelet fertility (%)	No of spikelets panicle^{-1}	No of filled grains panicle^{-1}	No of chaff seed panicle^{-1}	Panicle length (cm)	No of tillers plant^{-1}	No of productive tillers plant^{-1}	Plant height (cm)	Flag leaf area (cm^2)	Biological yield plant^{-1} (g)	Grain yield plant^{-1} (g)	Harvest index (%)	Grain length (mm)	Grain breadth (mm)	Grain L/B ratio
Replication	2	3.58	5.64	1.08	1.83	2.54	4.57	10.63	0.86	8.06	5.19	0.287	6.91	3.613	0.21	0.78	0.03	0.02	0.01
Genotypes	55	84.19**	46.35**	4889.78**	4959.00**	1082.54**	19795.09**	18837.88**	8.87**	19.59**	17.52**	300.19**	118.96**	687.86**	439.68**	399.71**	0.53**	0.15**	0.14**
Parents	19	42.06**	63.68**	2534.44**	2422.57**	1224.43**	9806.77**	5535.76**	3.04**	5.49**	5.06**	231.65**	94.75**	877.17**	144.22**	17.06**	0.53**	0.13**	0.12**
Parents vs. Crosses	1	2888.48**	382.27**	83587.42**	86382.52**	5629.97**	296363.40**	384529.50**	144.08**	368.19**	272.34**	1489.60**	720.66**	1210.40**	6219.37**	6888.99**	1.26**	0.32**	0.04**
Crosses	35	26.93**	27.34**	3919.34**	4009.54**	864.73**	17315.37**	15610.69**	8.06**	17.29**	17.01**	303.41**	114.91**	570.16**	434.94**	422.03**	0.52**	0.16**	0.17**
Lines	17	50.83**	54.12**	8059.64**	8243.83**	1703.90**	35576.10**	32066.04**	14.32**	30.91**	30.53**	614.39**	221.10**	1170.27**	892.80**	866.31**	1.06**	0.32**	0.35**
Testers	1	22.23*	0.48*	3.34	28.41	6.75	124.59	57.78	2.83	27.20**	15.71**	3.20	38.00	1.12	6.75	4.21	0.00	0.01	0.000
Line x tester	17	3.30**	3.15**	9.40**	9.43**	76.04**	65.86**	70.21**	2.11**	3.09**	3.56**	10.08**	13.24**	3.53**	2.27**	2.33**	0.11**	0.09**	0.08 **
Error	110	0.82	0.47	1.71	0.50	1.37	1.78	2.30	0.50	0.80	0.63	1.29	1.14	1.32	1.02	1.10	0.06	0.03	0.03

*, ** Significant at 5 and 1 percent level, respectively

Tab. 2. Estimates of genetic components of variance, degree of dominance and heritability for various agro-morphological traits in rice

Components of variance	Days to 50% flowering	Days to maturity	Pollen fertility (%)	Spikelet fertility (%)	No of spikelets panicle^{-1}	No of filled grains panicle^{-1}	No of chaff seed panicle^{-1}	Panicle length (cm)	No of tillers plant^{-1}	No of productive tillers plant^{-1}	Plant height (cm)	Flag leaf area (cm^2)	Biological yield plant^{-1}(g)	Grain yield plant^{-1}(g)	Harvest index (%)	Grain length (mm)	Grain breadth (mm)	Grain L/B ratio
σ^2 lines	8.31*	8.77*	1343.02*	1373.90*	283.82*	5929.03*	5344.10*	2.31*	5.0016*	4.96*	102.17*	36.65*	104.82*	98.63*	104.22*	0.09*	0.07*	0.08*
σ^2 testers	0.39	-0.01	0.03	0.51	0.10	2.27	1.03	0.04	0.7279	0.27	0.03	0.68	-0.00	0.10	0.06	-0.01	0.01	-0.01
σ^2 GCA	1.18*	0.86*	134.33*	137.85*	20.47*	29.49*	235.33*	0.27*	0.7279*	0.74*	10.24*	4.27*	2.47*	1.25*	1.37*	0.02*	0.01*	0.09*
σ^2 sca(lines x testers)	2.77**	1.83*	360.09*	301.32*	45.00*	613.27*	527.53*	1.55*	1.9348*	1.94*	29.05*	9.32*	4.74*	3.42*	2.46*	0.05*	0.03*	0.26 *
σ^2 E	0.32	0.48	0.52	0.13	0.33	0.62	0.65	0.15	0.3021	0.24	0.45	0.39	0.43	0.33	0.31	0.00	0.01	0.01
Variance ratio (σ^2 GCA/σ^2 SCA)	0.43	0.47	0.38	0.48	0.46	0.48	0.44	0.18	0.38	0.39	0.36	0.46	0.46	0.37	0.47	0.49	0.49	0.37
Degree of dominance $(\sigma^2A/\sigma^2D)^{1/2}$	1.08	1.06	1.15	1.04	31.20	1.01	1.08	2.39	1.1528	1.14	1.19	1.04	1.05	0.11	1.03	1.01	1.01	1.15
Heritability (h^2ns) (%)	23.23	22.51	20.84	25.87		28.18	20.86	20.41	23.5673	21.66	15.90	29.92	15.06	15.52	17.37	25.85	28.86	25.63

* Significant at 5 percent level, respectively

Tab. 3. Percent contribution of different components (lines, testers and lines x testers) towards the hybrid sum of squares for various agro-morphological traits in rice

Characters	Contribution of line %	Contribution of tester %	Contribution of line x tester %
Days to 50% flowering	91.67	2.35	5.96
Days to maturity	96.11	0.04	3.83
Pollen fertility (%)	99.88	0.02	0.11
Spikelet fertility (%)	99.86	0.02	0.11
No of spikelets panicle^{-1}	95.70	0.02	4.27
No of filled grains panicle^{-1}	99.79	0.02	0.18
No of chaff seed panicle^{-1}	99.77	0.01	0.21
Panicle length (cm)	86.24	1.04	12.75
No of tillers plant^{-1}	86.82	45.49	8.67
No of productive tillers plant^{-1}	87.17	2.63	10.18
Plant height (cm)	98.35	0.03	1.61
Flag leaf area(cm^2)	93.45	0.94	5.59
Biological yield plant^{-1} (g)	99.69	0.05	0.30
Grain yield plant^{-1} (g)	99.70	0.04	0.25
Harvest index (%)	99.70	0.02	0.26
Grain length (mm)	99.01	0.00	0.98
Grain breadth (mm)	97.40	0.02	2.56
Grain L/B ratio	97.83	0.04	2.16

The proportional contribution of lines, testers and their interaction to the total variance showed that lines played an important role towards the trait indicating predominant lines influence for traits (Tab. 3). The greater contributions of lines x testers interaction than testers for all the characters except number of tillers per plant indicates higher estimates of specific combining ability variance effects. These results are in agreement with the findings of Rashid *et al.* (2007).

The close examination of results revealed that none of the parents showed significant GCA effects simultaneously in the desired direction for all the traits studied (Tab. 4). However, to find the good parent for subsequent hybrid rice development, variation in GCA effects was estimated among lines and testers for all the traits. Among the lines 'K-08-61-2', 'K-08-60-2', 'SR-2', 'Jhelum', 'SKAU-403', 'K-08-59-3', 'SKAU-389' and 'K-08-59-1' had favorable genes for grain yield per plant due to significant positive GCA effects. The relative magnitude of GCA effects revealed that the *per se* performance for grain yield were generally related to GCA effects (Tab. 5). In general, higher *per se* performance for all the traits was associated with higher GCA effects except for days to 50% flowering, number of productive tillers per plant and number of filled grains per panicle. Correspondence between *per se* performance and GCA effects for most of the traits in rice has been observed by Rossaman and Vijaykumar (2005) and Sharma *et al.* (2005). Furthermore, 'SR-2', 'SKAU-389', 'Jhelum' and 'SKAU-292' were the top most performers and identified as desirable parents for early maturity. 'K-08-61-2' was observed to have GCA effects in desirable direction for maximum traits including spikelet fertility percent, pollen fertility percent, grain yield per plant, number of spikelets per panicle, number of filled grains per panicle, number of chaff seed per panicle, panicle length, harvest index and flag leaf area. Singh *et al.* (1996) and Bagheri and Jeoldar (2010) also observed good general combiner male parents for yield and various yield components in rice. Lines 'K-08-61-2' for spikelet fertility percent, pollen fertility percent, chaff seed per panicle, panicle length, flag leaf area and grain yield per plant, 'K-08-59-3' for more number of spikelets per panicle, and number of filled grains panicle, 'SR-1' for more number of tillers per plant, 'Jhelum' for number of productive tillers per plant, 'SKAU-391' for plant height, 'SKAU-407' for biological yield per plant, 'K-08-60-2' for harvest index (%) Grain L/B ratio and grain length and 'SKAU-389' for grain breadth were found as desirable parents with highest and significant GCA effects. The female parent 'SKAU 11A' was found to be a good combiner for number of productive tillers per plant, number of tillers per plant, number of filled grains per panicle and number of chaff seed per panicle. Similar results have been reported by earlier workers (Sao and Motiramani, 2006; Sarkar *et al.,* 2002) in rice, who observed female parents to be significant for some of the yield contributing traits. 'SKAU 11A' was found to be a good general combiner for flag leaf area and days to 50% flowering due to high GCA effects. Based on the present results, it was observed that for plant height maximum parents fourteen (14) exhibited significant and desirable GCA effects towards the trait, closely

Tab. 4. General Combining Ability (GCA) effects of lines and testers for various agro-morphological traits in rice

Parents	Days to 50% flowering	Days to maturity	Pollen fertility (%)	Spikelet fertility (%)	No of spikelets panicle^{-1}	No of filled grains panicle^{-1}	No of chaff seed panicle^{-1}	Panicle length (cm)	No of tillers plant^{-1}	No of productive tillers plant^{-1}
Lines										
'SKAU-405'	-0.546	0.565	-31.398**	-34.015**	-6.398**	-70.611**	64.120**	0.681*	1.320**	1.211**
'Jhelum'	-0.213	-4.102**	-33.231**	33.215**	13.102**	-68.444**	81.120**	-1.036**	4.704**	5.718**
'K-08-60-2'	6.287**	1.731**	52.435**	49.002**	-21.231**	79.889**	-101.213**	2.564**	-3.963**	-3.456**
'SKAU-403'	-2.880**	2.231**	3.769**	4.769**	24.769**	18.056**	6.620**	1.581**	-0.046	-0.139
'SKAU-407'	-0.213	-0.102	-35.231**	-35.481**	-18.065**	-73.444**	55.287**	0.064	-1.796**	-1.289*
'K-08-59-3'	-0.880*	1.231*	54.102**	59.769**	25.102**	134.22**	-109.213**	-0.603*	-1.746**	-1.489**
'China-1007'	0.287**	-1.435**	-38.231**	-35.481**	5.102**	-73.444**	78.454**	-2.109**	0.504	0.728
'SR-1'	4.713**	2.231**	-6.565**	-5.165**	20.102**	-5.944**	25.954**	1.286**	4.854**	4.311**
'SKAU-389'	-1.880**	-5.435**	23.435**	23.119**	9.602**	51.056**	-41.546**	0.064	-0.996*	-0.889*
'K-08-59-1'	1.620**	1.231*	43.602**	45.235**	10.769**	98.722**	-88.046**	-0.269	0.570	1.061**
'SKAU-292'	-2.213**	-1.602**	-26.231**	-30.131**	0.602	-62.444**	62.954**	-0.253	-0.796	-0.206
'SKAU-391'	2.454**	2.565**	-34.565**	32.915**	-23.731**	-68.944**	45.120**	0.764*	0.537	0.611
'SKAU-354'	0.954*	-0.269	-17.565**	-20.265**	-12.231**	-44.444**	32.120**	-0.486	-1.446**	-0.772*
'SKAU-46'	-1.213**	0.398	-34.731**	-35.481**	1.769**	-73.444**	75.120**	-0.919**	0.887*	1.544**
'Chenab'	0.954**	2.065**	-20.398**	-19.565**	-33.898**	-46.444**	14.454**	-1.619**	0.254	0.278
'SKAU-406'	-0.546	3.898**	-8.731**	-8.331**	5.769**	-16.778**	22.454**	-0.453	-3.146**	-3.206**
'K-08-61-2'	6.287**	3.065**	54.935**	60.302**	5.898**	114.889**	-120.880**	4.264**	-1.030*	-0.856*
'SR-2'	-3.546**	-7.269**	54.102**	51.852**	4.769**	107.556**	-102.880**	-1.036**	1.337**	-2.622**
Testers										
'SKAU 7A'	-0.304*	-0.365*	-0.171	0.613	0.250	1.074*	-0.731**	0.162	0.502**	0.381*
'SKAU 11A'	0.403*	0.331*	0.163	-0.811	-0.152	-1.172**	0.842**	-0.151	-0.643**	-0.385*
'S.E'(g_i)Lines	0.4040	0.4392	0.5121	0.2581	0.4117	0.5606	0.5713	0.2750	0.3886	0.3487
'S.E' (g_i-g_j) Lines	0.5713	0.6974	0.7242	0.3650	0.5823	0.7928	0.8080	0.3889	0.5496	0.4931
'S.E' (g_i) Testers	0.1347	0.1644	0.1707	0.0860	0.1372	0.1869	0.1904	0.0917	0.1295	0.1162
'S.E' (g_i-g_j)Testers	0.1904	0.2325	0.2414	0.3217	0.1941	0.2643	0.2693	0.1296	0.1832	0.1644
No of parents with desirable GCA effects	7	6	7	9	11	8	7	6	6	6

*, ** Significant at 5 and 1 percent level, respectively

followed by biological yield per plant (11) and number of spikelets per plant (11).

Based on the estimates of SCA effects none of the cross combinations exhibited significant and desirable SCA effect for all the parameters studied (Tab. 6) indicating that no specific combination was desirable for all the traits studied. These results are in complete agreement with earlier findings (Ghosh, 1993; Subramanian and Rathinam, 1984; Tiwari *et al.,* 2011). Since, yield per plant is ultimate goal of rice breeding and hybrid development programme. For this trait, eleven hybrid combinations viz. 'SKAU 11A' x 'K-08-60-2', 'SKAU 11A' x 'SKAU-403', 'SKAU 11A' x 'K-08-59-3', 'SKAU 11A' x 'SR-1', 'SKAU 7A' x 'SKAU-389', 'SKAU 7A' x 'K-08-59-1', 'SKAU 11A' x 'SKAU-391', 'SKAU 7A' x 'SKAU-354', 'SKAU 7A' x 'SKAU-46', 'SKAU 7A' x 'K-08-61-2' and 'SKAU 7A' x 'SR-2' were found good specific combinations based on high and significant SCA effects. High SCA effects for grain yield using line x tester analysis have earlier been reported (Gansen and Rangasamy, 1998; Roy and Mandal, 2001; Singh and Kumar, 2004). The cross combination 'SKAU 11A' x 'K-08-60-2' was one of the top best specific combination for acceptable and significant SCA effects for grain yield per plant and other desirable characters like pollen fertility percent, spikelet fertility percent, less number of chaff seed per panicle, number of filled grains per panicle, panicle length, flag leaf area, biological yield per plant, harvest index and grain breadth. In addition, significant SCA effect for grain yield per plant was also observed in the cross combinations 'SKAU 7A' x 'K-08-61-2', 'SKAU 7A' x 'SR-2', 'SKAU 11A' x 'K-08-60-2', 'SKAU 11A' x 'K-08-59-3' and 'SKAU 7A' x 'SKAU-389'. The best crosses in respect of *per se* performance, GCA effects and SCA effects for different traits studied are presented in Tab. 7. The perusal of SCA effects along with *per se* performance revealed that some of the crosses showing desirable SCA effects were also having superior *per se* performance for most of the traits thus indicating the selection of these crosses on the

Tab. 4. General Combining Ability (GCA) effects of lines and testers for various agro-morphological traits in rice (continuous)

Parents	Plant height (cm)	Flag leaf area(cm^2)	Biological yield $plant^{-1}$(g)	Grain yield $plant^{-1}$(g)	Harvest index (%)	Grain length (mm)	Grain breadth (mm)	Grain L/B ratio
Lines								
‘SKAU-405’	-6.461**	2.989**	16.898**	-6.602**	-8.504**	-0.432**	0.209**	-0.312**
‘Jhelum’	-4.061**	-6.444**	14.731**	9.769**	-10.937**	-0.242**	-0.108**	-0.012
‘K-08-60-2’	-19.806**	-3.861**	8.269**	18.565**	20.546**	0.933**	-0.215**	0.524**
‘SKAU-403’	-4.944**	3.159**	16.931**	1.769**	-4.437**	-0.192**	-0.130**	0.026
‘SKAU-407’	-9.611**	0.256	17.398**	-9.602	-10.979**	-0.102**	0.215**	-0.212**
‘K-08-59-3’	-5.094**	-10.594**	-22.269**	11.898**	15.363**	0.382**	0.259**	-0.079**
‘China-1007’	-7.801*	-2.461**	3.898**	-11.935**	-11.989**	-0.533**	-0.286**	0.041
‘SR-1’	-5.944**	7.756**	1.102*	-0.602	-0.721	-0.140**	-0.141**	0.058*
‘SKAU-389’	-2.628**	8.232**	9.565**	5.231**	2.563**	-0.092**	0.334**	-0.287**
‘K-08-59-1’	2.722**	1.973**	16.231**	11.065**	14.388**	0.350**	0.050	0.063*
‘SKAU-292’	3.706**	1.839**	-3.435**	-12.269**	-11.737**	0.173**	0.180**	-0.096**
‘SKAU-391’	19.88*	2.506**	-12.435**	-12.435**	-11.121**	0.272**	0.149**	-0.039
‘SKAU-354’	-5.761**	-5.828**	-11.935**	-5.769**	-4.009**	-0.272**	-0.510**	0.378**
‘SKAU-46’	-5.894**	-8.451**	5.565**	-10.269**	-10.591**	-0.530**	-0.146**	-0.081**
‘Chenab’	-2.261**	-1.444**	-21.269**	-3.269**	0.758	-0.097**	-0.026	-0.026
‘SKAU-406’	-2.411**	3.2294**	-22.102**	-8.769**	-5.622**	-0.338**	0.110**	-0.217**
‘K-08-61-2’	-23.22**	12.139**	4.898*8	19.731**	16.736**	0.822**	-0.215**	0.479**
‘SR-2’	4.411**	-5.061	-2.602**	16.565**	16.296**	0.035	0.274**	-0.207**
Testers								
‘SKAU 7A’	0.172	-0.593**	0.102	0.250	0.198	0.001	0.004	0.000
‘SKAU 11A’	-0.271	0.661**	-0.112	-0.388	-0.191	0.002	-0.031	-0.001
‘S.E’ (g_i) Lines	0.4780	0.4428	0.4666	0.4079	0.3993	0.0287	0.0246	0.0028
‘S.E’ (g_i-g_j) Lines	0.6759	0.6263	0.6598	0.5768	0.5647	0.0405	0.0348	0.0322
‘S.E’ (g_i) Testers	0.1593	0.1476	0.1555	0.1360	0.1331	0.0096	0.0082	0.0076
‘S.E’ (g_i-g_j)Tester	0.2253	0.2088	0.2199	0.1923	0.1882	0.0135	0.0116	0.0107
No of parents with desirable GCA effects	4	10	11	8	6	6	8	5

*, ** Significant at 5 and 1 percent level, respectively

basis of *per se* performance will be effective. These results are in line with those of Petchiammal and Kumar (2007); Saleem *et al.* (2010) and Selvaraj *et al.* (2011) who reported several promising specific combiners based on high *per se* performance and SCA effects for grain yield per plant. Similarly for other traits, sets of good specific combinations were identified based on high mean performance and SCA effects. In this regard, ‘SKAU 7A’ x ‘SR-2’ for days to 50% flowering and days to maturity, ‘SKAU 11A’ x ‘K-08-61-2’, ‘SKAU 11A’ x ‘SR-2’ and ‘SKAU 11A’ x ‘K-08-60-2’ for spikelet fertility percent, ‘SKAU 7A’ x ‘Jhelum’ for number of tillers per plant and number of productive tillers per plant and ‘SKAU 11A’ x ‘SKAU-389’ for flag leaf area were promising ones. The significant SCA effects compared with *per se* performance for different traits in rice have also been reported by Saidaiah *et al.* (2010).

Furthermore, the majority of cross combinations were involved with high/low or average/low type of gene interactions which substantiate the operation of non-additive gene action for expression of these traits. These results are supported with the findings of Bagheri and Jeoldar (2010) and Saidaiah *et al.* (2010). Besides these interactions, involvement of high x high, low x low and average x average were also found in different cross combinations for various traits i.e. ‘SKAU 7A’ x ‘SR-2’ for early maturity, ‘SKAU 7A’ x ‘SKAU-389’ and SKAU7A x ‘SR-2’ for number of filled grains per panicle, ‘SKAU 7A’ x ‘Jhelum’ for number of productive tillers per plant and SKAU11A x ‘SKAU-389’ for flag leaf area had high mean performance and highly significant SCA effects that involve high x high GCA effects of parents. Saidaiah *et al.* (2010) and Salgotra *et al.* (2009) also reported about interaction between positive alleles in crosses involving high x high combiners which can be fixed in subsequent generations for effective selection, if no repulsion phase linkages are involved.

Involvement of both the poor combiners also produced superior specific combining hybrids as evident from the combinations ‘SKAU 11A’ x ‘SKAU-406’, ‘SKAU

Tab. 5. Best parents identified on the basis of GCA and *per se* performance for different traits in rice

Traits	Parent GCA effect		Parent *per se* performance	
Days to 50% flowering	'SR-2'	-3.546	'Jhelum'	100.677
	'SKAU-403'	-2.880	'SKAU-403'	101.667
	'SKAU-292'	-1.213	'SR-2'	105.000
Days to maturity	'SR-2'	-7.269	'Jhelum'	136.000
	'SKAU-389'	-5.435	'SKAU-403'	137.002
	'Jhelum'	-4.102	'SKAU-389'	137.677
Pollen fertility (%)	'K-08-61-2'	54.935	'K-08-61-2'	97.677
	'SR-2'	54.102	'SR-2'	96.000
	'K-08-60-2'	52.435	'K-08-60-2'	95.204
Spikelet fertility (%)	'K-08-61-2'	60.302	'K-08-61-2'	92.000
	'SR-2'	51.852	'SR-2'	89.333
	'K-08-60-2'	50.002	'K-08-60-2'	91.433
No of spikelets plant^{-1}	'K-08-59-3'	25.102	'SKAU-403'	207.900
	'SKAU-403'	24.769	'K-08-59-3'	205.000
	'SR-1'	20.102	'SR-2'	194.000
No of filled grains panicle^{-1}	'K-08-59-3'	134.220	'SKAU-403'	207.900
	'K-08-61-2'	114.889	'K-08-59-3'	205.000
	'SR-2'	107.556	'SR-2'	194.000
No of chaff seed panicle^{-1}	'K-08-61-2'	-120.880	'K-08-61-2'	8.667
	'K-08-59-3'	-109.213	'SR-1'	8.677
	'SR-2'	-102.880	'SR-2'	10.643
Panicle length (cm)	'K-08-61-2'	4.264	'SKAU-403'	22.033
	'K-08-60-2'	2.564	'K-08-60-2'	21.113
	'SKAU-403'	1.581	'K-08-61-2'	21.031
No of tillers plant^{-1}	'SR-1'	4.854	'SR-1'	11.004
	'Jhelum'	4.704	'Jhelum'	10.667
	'SR-2'	1.337	'SR-2'	10.126
No of productive tillers plant^{-1}	'Jhelum'	5.718	'SKAU-403'	11.400
	'SR-1'	4.311	'SR-1'	11.000
	'SKAU-46'	1.544	'SKAU-391'	11.000
Plant height (cm)	'SKAU-391'	19.889	'SR-2'	135.00
	'SR-2'	4.411	'SKAU-391'	112.677
	'SKAU-292'	3.706	'SKAU-292'	108.333
Flag leaf area (cm^2)	'K-08-61-2'	12.139	'SKAU-292'	44.067
	'SKAU-389'	8.232	'SR-1'	42.767
	'SR-1'	7.756	'K-08-61-2'	42.433
Biological yield plant^{-1} (g)	'SKAU-407'	17.398	'SKAU-407'	120.333
	'SKAU-403'	16.931	'SR-1'	115.330
	'SKAU-405'	16.898	'SKAU-403'	110.000
Grain yield plant^{-1} (g)	'K-08-61-2'	19.731	'K-08-61-2'	33.333
	'K-08-60-2'	18.565	'SR-2'	31.333
	'SR-2'	16.565	'K-08-60-2'	30.002
Harvest index (%)	'K-08-60-2'	2.546	K-08-060-2	30.431
	'K-08-61-2'	16.736	'SR-2'	29.001
	'SR-2'	16.296	'SKAU-403'	25.455
Grain length (mm)	'K-08-60-2'	0.933	'K-08-61-2'	7.533
	'K-08-61-2'	0.822	'K-08-60-2'	7.433
	'K-08-59-3'	0.382	'SKAU-391'	7.083
Grain breadth (mm)	'SKAU-389'	0.334	'SKAU-405'	2.967
	'SR-2'	0.254	'SR-2'	2.917
	'K-08-59-3'	0.209	'K-08-59-3'	2.901
Grain L/B ratio	'K-08-60-2'	0.524	'K-08-60-2'	2.873
	'K-08-61-2'	0.479	'K-08-61-2'	2.293
	'SKAU-354'	0.378	'SKAU-354'	2.820

Tab. 6. Specific Combining Ability (SCA) effects of lines and testers for various agro-morphological traits in rice

Crosses	Days to 50% flowering	Days to maturity	Pollen fertility (%)	Spikelet fertility (%)	No of spikelets panicle^{-1}	No of filled grains panicle^{-1}	No of chaff seed panicle^{-1}	Panicle length (cm)	No of tillers plant^{-1}
'SKAU 7A' x 'SKAU-405'	0.954**	-0.769*	0.657	0.154	-3.917**	1.759*	-5.769**	0.571	-0.199
'SKAU 11A' x 'SKAU-405'	-0.851**	0.879*	-0.667	0.354	3.211**	-1.590*	5.688**	-0.554	0.156
'SKAU 7A' x 'Jhelum'	0.751**	0.595*	0.824	0.454	5.583**	3.926**	1.231	0.588*	1.498*
'SKAU 11A' x 'Jhelum'	-0.821**	-0.666*	-0.676	-0.355	-4.976**	-3.116**	-1.321	-0.676*	-1.432*
'SKAU 7A' x 'K-08-60-2'	-0.413	-0.302	-2.843**	-1.896*	2.917**	-2.074*	1.765*	-0.579*	1.298*
'SKAU 11A' x 'K-08-60-2'	0.313	0.301	2.743**	1.799*	-2.891**	2.077*	-1.635*	0.676*	-1.267*
'SKAU 7A' x 'SKAU-403'	0.387	0.498	-0.509	-0.863	-0.417	-2.907**	1.731**	-0.129	1.815**
'SKAU 11A' x 'SKAU-403'	-0.281	-0.391	0.645	0.933	0.421	2.866**	-1.765**	0.321	-1.765**
'SKAU 7A' x 'SKAU-407'	-0.913*	0.595*	-1.576 *	-0.513	-4.250**	1.077	-3.269**	0.955*	-0.469
'SKAU 11A' x 'SKAU-407'	0.813*	-0.672*	1.567*	-0.551	3.245**	-1.103	3.240**	-0.865*	0.437
'SKAU 7A' x 'K-08-59-3'	-0.380	-0.102	-0.176	-1.204*	1.250*	-1.926*	-0.769	-0.879*	-1.319*
'SKAU 11A' x 'K-08-59-3'	0.465	-0.104	0.167	1.432*	-1.231*	1.921*	0.372	0.888*	1.321*
'SKAU 7A' x 'China-1007'	0.120	-0.103	-0.716	-0.513	2.917**	-1.074	-3.898**	-0.229	0.431
'SKAU 11A' x 'China-1007'	-0.131	0.101	0.563	0.432	-2.654**	1.001	3.988**	0.243	-0.455
'SKAU 7A' x 'SR-1'	-0.213	0.432	-1.157	0.904*	-2.417**	1.426	-3.935**	-0.620*	0.415
'SKAU 11A' x 'SR-1'	-0.322	-0.331	1.161	-0.881*	2.421**	-1.431	3.876**	0.587*	-0.325
'SKAU 7A' x 'SKAU-389'	0.287	0.203	0.324	-1.287**	7.750**	7.426**	-0.231	-0.945*	-0.335
'SKAU 11A' x 'SKAU-389'	-0.327	-0.102	-0.341	1.183**	-6.550**	-7.343**	0.322	0.897*	0.435
'SKAU 7A' x 'K-08-59-1'	-0.846**	0.398	-1.643*	-0.730	-2.417**	-3.241**	-0.731	-0.245	-1.235*
'SKAU 11A' x 'K-08-59-1'	0.871**	-0.399	1.543*	0.571	2.327**	3.211**	0.342	0.345	1.324*
'SKAU 7A' x 'SKAU-292'	-0.046	-0.269	-1.509**	-1.063**	-1.917*	-3.074**	1.065	0.371	-0.469
'SKAU 11A' x 'SKAU-292'	0.076	0.226	1.450*	1.041**	1.791*	3.077**	1.234	-0.321	0.544
'SKAU 7A' x 'SKAU-391'	-1.046**	0.065	1.157	0.054	-4.917**	3.426**	-8.345**	-0.745*	-0.335
'SKAU 11A' x 'SKAU-391'	1.112**	-0.067	-1.221	-0.113	3.441**	-3.454**	8.324**	0.675*	0.443
'SKAU 7A' x 'SKAU-354'	0.787**	-0.435	1.505*	-0.906**	0.250	-2.074**	2.231*	-0.195	0.781
'SKAU 11A' x 'SKAU-354'	-0.877**	0.543	-1.877*	0.878**	-0.321	-2.154	-2.341*	-0.231	-0.987
'SKAU 7A' x 'SKAU-46'	-0.713	-0.269	0.991	-0.513	-0.417	-1.074	0.565	0.105	-0.585
'SKAU 11A' x 'SKAU-46'	0.654	0.389	-0.898	-0.651	0.432	1.032	0.435	-0.210	0.453
'SKAU 7A' x 'Chenab'	-1.546**	0.925**	1.324	-0.204	4.250**	4.259**	1.898*	0.805*	1.448*
'SKAU 11A' x 'Chenab'	1.667**	-0.931**	-1.241	0.209	-4.220**	-4.654**	-1.765*	-0.866*	-1.554*
'SKAU 7A' x 'SKAU-406'	1.287**	0.932**	0.657	0.270	0.917	0.926	-0.102	0.305	-0.952
'SKAU 11A' x 'SKAU-406'	-1.277**	-0.952**	-0.541	-0.287	-0.875	-0.897	0.112	-0.322	0.876
'SKAU 7A' x 'K-08-61-2'	-0.454	-0.262	1.454*	-1.830*	-2.750**	-4.074**	1.631*	0.655*	1.698**
'SKAU 11A' x 'K-08-61-2'	-0.551	0.361	-1.561*	1.965*	2.434**	4.987**	-1.723*	-0.766*	-1.876**
'SKAU 7A' x 'SR-2'	-1.620**	-1.066*	1.824*	-1.213**	-2.417**	4.407**	1.898*	0.421	-1.669**
'SKAU 11A' x 'SR-2'	-1.631**	1.064*	-1.543*	1.321**	2.321**	-4.442**	-1.876*	-0.322	1.779**
'S.E.' (S_{ij})	0.3713	0.2974	0.7242	0.3650	0.5823	0.7928	0.8080	0.2889	0.5496
$S_{ij}-S_{kl}$	0.6079	0.9863	1.0242	0.4161	0.8235	1.1212	1.1426	0.5500	0.7773
$S_{ij}-S_{ik}$	2.4902	2.0401	2.1569	1.5908	2.538	2.4558	2.5219	1.6951	2.3957
No of crosses with desirable SCA effects	10	6	7	8	14	12	11	9	8

*,** Significant at 5 and 1 percent level, respectively

11A' x 'SKAU-405' and 'SKAU 11A' x 'Chenab' for Days to maturity, 'SKAU 11A' x 'SKAU-391' for number of spikelets per panicle, 'SKAU 7A' x 'Chenab' for flag leaf area, 'SKAU 11A' x 'SKAU-391' for biological yield per plant and 'SKAU 11A' x 'K-08-60-2', 'SKAU 11A' x K-08-61 for grain breadth. Involvement of both the combiners with low GCA has been attributed to Dominance x Dominance interaction, which have also been suggested by Singh *et al.* (2005), Dalvi and Patel (2009) in rice.

However, the desirable performance of combination like high x low may be ascribed to the interaction between dominant alleles from good combiners and recessive alleles

Tab. 6. Specific Combining Ability (SCA) effects of lines and testers for various agro-morphological traits in rice (continuous)

Crosses	No of productive tillers plant^{-1}	Plant height (cm)	Flag leaf area(cm^2)	Biological yield plant^{-1}(g)	Grain yield plant^{-1}(g)	Harvest index (%)	Grain length (mm)	Grain breadth (mm)	Grain L/B ratio
'SKAU 7A' x 'SKAU-405'	-0.681	-0.289	0.510	0.565	0.583	0.436	-0.053	0.006	-0.023
'SKAU 11A' x 'SKAU-405'	0.583	0.339	-0.550	-0.589	-0.598	-0.531	0.012	-0.005	0.029
'SKAU 7A' x 'Jhelum'	1.519**	-0.756	0.277	0.398	-0.250	-0.231	0.017	0.040	-0.030
'SKAU 11A' x 'Jhelum'	-1.432**	0.761	-0.298	-0.410	0.276	0.278	-0.043	-0.043	0.021
'SKAU 7A' x 'K-08-60-2'	0.985*	0.656	-1.267*	0.865*	-0.917*	-0.914*	0.042	-0.054*	0.070*
'SKAU 11A' x 'K-08-60-2'	-0.855*	-0.699	1.298*	-0.810*	0.936*	0.976*	-0.032	0.065*	-0.081*
'SKAU 7A' x 'SKAU-403'	0.202	0.861	-1.270*	-0.769*	-0.850*	-0.098	-0.090*	-0.059*	0.015
'SKAU 11A' x 'SKAU-403'	-0.211	-0.821	1.261*	0.799*	0.829*	0.121	0.101*	0.061*	-0.023
'SKAU 7A' x 'SKAU-407'	-0.181	-1.339	-0.423	-0.269	-0.417	-0.306	0.043	0.030	-0.010
'SKAU 11A' x 'SKAU-407'	0.177	1.398	0.435	0.354	0.435	0.365	-0.021	-0.021	0.013
'SKAU 7A' x 'K-08-59-3'	-0.048	-0.122	1.273**	1.065*	-0.717*	0.056	0.032	0.036	0.030
'SKAU 11A' x 'K-08-59-3'	0.122	0.144	-1.210**	-1.086*	0.833*	-0.088	-0.023	-0.027	-0.022
'SKAU 7A' x 'China-1007'	0.669	-1.622*	-0.007	-0.102	-0.415	-0.349	-0.018	0.008	-0.016
'SKAU 11A' x 'China-1007'	-0.765	1.989*	0.076	0.134	0.432	0-387	0.012	-0.002	0.012
'SKAU 7A' x 'SR-1'	-0.215	0.794	-1.390*	-0.102	-0.750*	-0.681	-0.028	0.003	0.017
'SKAU 11A' x 'SR-1'	0.230	-0.843	1.401*	0.138	0.788*	0.731	0.034*	-0.007	-0.014
'SKAU 7A' x 'SKAU-389'	-0.681	-1.722*	-2.247**	-0.121	0.830*	0.369	-0.023*	0.038	-0.035
'SKAU 11A' x 'SKAU-389'	-0.699	1.876*	2.341**	0.132	-0.945*	-0.397	0.034	-0.041	0.041
'SKAU 7A' x 'K-08-59-1'	-0.998*	1.328	0.427	-0.769*	0.783*	0.677	-0.002	-0.005	0.002
'SKAU 11A' x 'K-08-59-1'	0.776*	-1.398	-0.487	0.807*	-0.899*	-0.682	0.009	0.007	-0.005
'SKAU 7A' x 'SKAU-292'	-0.465	1.611*	-1.073	0.231	0.083	-0.064	0.028	0.008	0.004
'SKAU 11A' x 'SKAU-292'	0.231	-1.756*	1.121	-0.287	-0.121	0.031	-0.037	-0.010	-0.006
'SKAU 7A' x 'SKAU-391'	-0.515	2.161**	-0.007	-1.435**	-0.750*	0.986*	0.077*	-0.004	0.027
'SKAU 11A' x 'SKAU-391'	0.554	-2.222**	0.098	1.555**	0.777*	-0.943*	-0.078*	0.007	-0.021
'SKAU 7A' x 'SKAU-354'	0.902*	-1.489*	-0.840	1.065*	0.740*	0.781*	-0.017	-0.029	0.034
'SKAU 11A' x 'SKAU-354'	-0.887*	1.587*	0.870	-1.066*	-0.765*	-0.730*	0.023	0.035	-0.038
'SKAU 7A' x 'SKAU-46'	-0.448	-1.622*	0.437	-0.769*	0.777*	-0.791*	-0.005	0.085**	-0.071**
'SKAU 11A' x 'SKAU-46'	0.321	1.765*	-0.489	0.788*	-0.765*	0.820*	0.001	-0.088**	0.081**
'SKAU 7A' x 'Chenab'	0.789*	0.011	3.510**	0.065	0.420	-0.726*	-0.025	-0.022	0.024
'SKAU 11A' x 'Chenab'	-0.795*	-0.121	-3.567**	-0.102	-0.455	0.810*	0.045*	0.029	-0.019
'SKAU 7A' x 'SKAU-406'	-0.865*	1.861*	0.048	1.231*	-0.417	-1.426**	0.043*	-0.032	0.005
'SKAU 11A' x 'SKAU-406'	0.902*	-1.891*	-0.108	-1.276*	0.656	1.567**	-0.055	0.045	-0.002
'SKAU 7A' x 'K-08-61-2'	1.285*	1.161	2.727**	-1.102**	1.250**	0.999*	-0.030	-0.054*	0.069**
'SKAU 11A' x 'K-08-61-2'	-1.986*	-1.261	-2.810**	1.139**	-1.265**	-0.832*	0.040	0.065*	-0.078**
'SKAU 7A' x 'SR-2'	-0.788**	-0.172	1.793**	0.731*	1.083**	-0.802*	-0.050	0.005	-0.021
'SKAU 11A' x 'SR-2'	0.796**	0.179	-1.820**	-0.745*	-1.113**	0.899*	0.056	-0.009	0.028
'S.E.' (S_{ij})	0.3931	0.6759	0.6263	0.6598	0.3468	0.3647	0.0205	0.0248	0.0222
S_{ij}-S_{kl}	0.6974	0.9559	0.8857	0.9331	0.8157	0.7986	0.0573	0.0492	0.0455
S_{ij}-S_{ik}	2.1496	2.9463	2.7299	2.8761	2.5143	2.4613	0.1766	0.1517	0.1403
No of crosses with desirable SCA effects	7	7	8	10	10	8	5	4	3

*,** Significant at 5 and 1 percent level, respectively

from poor combiners (Dubey, 1975). Such combinations in present study were observed in most crosses as evident from Tab. 7. Generally, such cross combinations involving at least one low general combiner indicates both additive and non-additive gene action, which infers the exploitation of heterosis in F_1 generation, similar findings have been reported by Kumar *et al.* (2007), Faiz *et al.* (2006); Bagheri and Jeoldar (2010) in rice, as their high yielding potential would be unfixable in succeeding generations (Peng and Virmani, 1990). Furthermore, hybrid combinations which show non-significant SCA effects (average effects) but originated from parents having high GCA

Tab. 7. Top ranking of specific cross combinations for different traits on the basis of SCA, *per se*, and GCA of parents involved in rice

Trait	Per se performance	SCA effect	GCA effect of parents
Days to 50% flowering	'SKAU 7A' x 'SR-2'	'SKAU 7A' x 'SR-2'	High x High
	'SKAU 11A' x 'SR-2'	'SKAU 7A' x 'Chenab'	High x Low
	'SKAU 7A' x 'SKAU-403'	'SKAU 11A' x 'SKAU-406'	Low x Average
	'SKAU 11A' x 'SKAU-403'	'SKAU 7A' x 'SKAU-391'	High x Low
	'SKAU 7A' x 'SKAU-389'	'SKAU 7A' x 'SKAU-407'	High x Average
Days to maturity	'SKAU 7A' x 'SR-2'	'SKAU 7A' x 'SR-2'	High x High
	'SKAU 11A' x 'SR-2'	'SKAU 11A' x 'SKAU-406'	Low x Low
	'SKAU 7A' x 'SKAU-389'	'SKAU 11A' x 'Chenab'	Low x Low
	'SKAU 11A' x 'SKAU-389'	'SKAU 11A' x 'SKAU-405'	Low x Low
	'SKAU 11A' x 'Jhelum'	'SKAU 11A' x 'SKAU-407'	Low x Average
Pollen fertility (%)	'SKAU 7A' x 'K-08-61-2'	'SKAU 11A' x 'K-08-60-2'	Average x High
	'SKAU 7A' x 'SR-2'	'SKAU 7A' x 'SR-2'	Low x High
	'SKAU 11A' x 'K-08-60-2'	'SKAU 11A' x 'SKAU-407'	Average x Low
	'SKAU 7A' x 'K-08-59-3'	'SKAU 11A' x 'K-08-59-1'	Average x High
	'SKAU 11A' x 'K-08-61-2'	'SKAU 7A' x 'SKAU-354'	Low x High
Spikelet fertility (%)	'SKAU 11A' x 'K-08-61-2'	'SKAU 11A' x K-08-61	Low x High
	'SKAU 11A' x 'K-08-60-2'	'SKAU 11A' x K-08-60	Low x High
	'SKAU 7A' x 'K-08-59-1'	'SKAU 11A' x 'K-08-59-3'	Low x High
	'SKAU 11A' x 'K-08-59-3'	'SKAU 11A' x 'SR-2'	Low x High
	'SKAU 11A' x 'SR-2'	'SKAU 11A' x 'SKAU-389'	Low x High
Number of spikelets panicle^{-1}	'SKAU 7A' x 'SR-1'	'SKAU 7A' x 'SKAU-389'	Average x High
	'SKAU 7A' x 'SR-2'	'SKAU 7A' x 'Jhelum'	Average x High
	'SKAU 11A' x 'SKAU-407'	'SKAU 7A' x 'Chenab'	Average x Low
	'SKAU 7A' x 'SKAU-403'	'SKAU 11A' x 'SKAU-391'	Low x Low
	'SKAU 7A' x 'K-08-59-3'	'SKAU 11A' x 'SKAU-407'	Low x Average
Number of filled grains pancle^{-1}	'SKAU 7A' x 'K-08-59-3'	'SKAU 7A' x 'SKAU-389'	High x High
	'SKAU 11A' x 'K-08-59-3'	'SKAU 11A' x 'K-08-61-2'	Low x High
	'SKAU 7A' x 'K-08-60-2'	SKAU7 A x 'SR-2'	High x High
	'SKAU 11A' x 'K-08-60-2'	'SKAU 7A' x 'Chenab'	High X Low
	'SKAU 11A' x 'SR-2'	'SKAU 11A' x 'Jhelum'	Low X Low
Number of chaff seed pancle^{-1}	'SKAU 7A' x 'K-08-60-2'	'SKAU 7A' x 'SKAU-391'	High x Low
	'SKAU 11A' x 'K-08-61-2'	'SKAU 7A' x 'SKAU-405'	High x Low
	'SKAU 11A' x 'SR-2'	'SKAU 11A' x 'SKAU-403'	High x Low
	'SKAU 11A' x 'K-08-61-2'	'SKAU 7A' x 'SR-1'	High x Low
	'SKAU 7A' x 'K-08-59-3'	'SKAU 7A' x 'China-1007'	High x Low
Panicle length (cm)	'SKAU 7A' x 'K-08-61-2'	'SKAU 7A' x 'SKAU-407'	Average x Average
	'SKAU 11A' x 'K-08-61-2'	'SKAU 11A' x 'SKAU-389'	Low x Average
	'SKAU 7A' x 'SKAU-403'	'SKAU 11A' x 'K-08-59-3'	Low x Low
	'SKAU 7A' x 'SKAU-405'	'SKAU 7A' x 'Chenab'	Average x Low
	'SKAU 11A' x 'SKAU-407'	'SKAU 11A' x 'K-08-60-2'	Low x Average
Number of tillers plant^{-1}	'SKAU 7A' x 'Jhelum'	'SKAU 7A' x 'SKAU-403'	Low x High
	'SKAU 7A' x 'SR-1'	'SKAU 11A' x 'SR-2'	High x Low
	'SKAU 11A' x 'SR-1'	'SKAU 7A' x 'K-08-61-2'	High x High
	'SKAU 11A' x 'Chenab'	'SKAU 7A' x 'Jhelum'	High x Average
	'SKAU 11A' x 'SR-2'	'SKAU 7A' x 'Chenab'	High x Low
Number of productive tillers plant^{-1}	'SKAU 7A' x 'Jhelum'	'SKAU 7A' x 'Jhelum'	High x High
	'SKAU 7A' x 'SR-1'	'SKAU 7A' x 'K-08-61-2'	High x Low
	'SKAU 11A' x 'SR-1'	'SKAU 7A' x 'K-08-60-2'	High x Low
	'SKAU 7A' x 'K-08-61-2'	'SKAU 7A' x 'SKAU-354'	High x Low
	'SKAU 11A' x 'SKAU-403'	'SKAU 11A' x 'SKAU-406'	Low x Low
Plant height (cm)	'SKAU 7A' x 'SKAU-407'	'SKAU 7A' x 'SKAU-391'	Low x Low
	'SKAU 7A' x 'SKAU-354'	'SKAU 11A' x 'SKAU-406'	Average x High
	'SKAU 7A' x 'SKAU-46'	'SKAU 11A' x 'SKAU-292'	Average x Low
	'SKAU 7A' x 'SKAU-405'	'SKAU 7A' x 'SKAU-389'	Low x High
	'SKAU 11A' x 'SKAU-407'	'SKAU 7A' x 'SKAU-46'	Low x High

Tab. 7. Top ranking of specific cross combinations for different traits on the basis of SCA, *per se*, and GCA of parents involved in rice (continuous)

Trait	Per se performance	SCA effect	GCA effect of parents
Flag leaf area (cm^2)	'SKAU 7A' x 'K-08-61-2'	'SKAU 7A' x 'Chenab'	Low x Low
	'SKAU 11A' x 'K-08-61-2'	'SKAU 7A' x 'K-08-61-2'	Low x High
	'SKAU 11A' x 'SKAU-389'	'SKAU 11A' x 'SKAU-389'	High x High
	'SKAU 11A' x 'SR-1'	'SKAU 7A' x 'SR-2'	Low x Low
	'SKAU 7A' x 'SR-1'	'SKAU 11A' x 'SR-1'	High x High
Biological yield $plant^{-1}$ (g)	'SKAU 7A' x 'SKAU-405'	'SKAU 11A' x 'SKAU-391'	Low x Low
	'SKAU 11A' x 'SKAU-407'	'SKAU 7A' x 'SKAU-406'	Average x Low
	'SKAU 7A' x 'SKAU-407'	'SKAU 11A' x 'K-08-61-2'	Low x High
	'SKAU 11A' x 'SKAU-403'	'SKAU 7A' x 'K-08-59-3'	Average x Low
	'SKAU 7A' x 'Jhelum'	'SKAU 7A' x 'SKAU-354'	Average x Low
Grain yield $plant^{-1}$ (g)	'SKAU 7A' x 'K-08-61-2'	'SKAU 7A' x 'K-08-61-2'	Average x High
	'SKAU 11A' x 'K-08-60-2'	'SKAU 7A' x 'SR-2'	Average x High
	'SKAU 11A' x 'SKAU-389'	'SKAU 11A' x 'K-08-60-2'	Low x High
	'SKAU 7A' x 'SR-2'	'SKAU 11A' x 'K-08-59-3'	Low x High
	'SKAU 11A' x 'SR-2'	'SKAU 7A' x 'SKAU-389'	Low x High
Harvest index (%)	'SKAU 11A' x 'SKAU-389'	'SKAU 11A' x 'SKAU-406'	Low x Low
	'SKAU 7A' x 'SKAU-354'	'SKAU 7A' x 'K-08-61-2'	Average x High
	'SKAU 7A' x 'SKAU-292'	'SKAU 7A' x 'SKAU-391'	Average x Low
	'SKAU 7A' x 'SR-2'	'SKAU 11A' x 'K-08-60-2'	Low x High
	'SKAU 11A' x 'K-08-61-2'	'SKAU 11A' x 'SR-2'	Low x High
Grain length (mm)	'SKAU 7A' x 'K-08-60-2'	'SKAU 11A' x 'SKAU-403'	Average x Low
	'SKAU 11A' x 'K-08-60-2'	'SKAU 7A' x 'SKAU-391'	Average x Average
	'SKAU 7A' x 'K-08-61-2'	'SKAU 7A' x 'SKAU-406'	Average x Low
	'SKAU 11A' x 'K-08-61-2'	'SKAU 11A' x 'Chenab'	Average x Low
	'SKAU 7A' x 'SKAU-391'	'SKAU 11A' x 'SR-1'	Average x Low
Grain breadth (mm)	'SKAU 7A' x 'SKAU-389'	'SKAU 7A' x 'SKAU-46'	Average x Low
	'SKAU 7A' x 'SR-2'	'SKAU 11A' x 'K-08-60-2'	Low x Low
	'SKAU 11A' x 'SR-2'	'SKAU 11A' x 'K-08-61-2'	Low x Low
	'SKAU 7A' x 'SKAU-403'	'SKAU 11A' x 'SKAU-403'	Low x Low
	'SKAU 7A' x 'SKAU-405'		
Grain L/B ratio	'SKAU 7A' x 'K-08-60-2'	'SKAU 11A' x 'SKAU-46'	Low x Low
	'SKAU 7A' x 'K-08-61-2'	'SKAU 7A' x 'K-08-60-2'	Average x High
	'SKAU 11A' x 'K-08-60-2'	'SKAU 7A' x 'K-08-61-2'	Average x High

effects (additive gene effects) can be used for recombination breeding with easy selection of desirable segregates particularly for developing high yielding pure lines due to presence of additive gene action (Saleem *et al.,* 2010; Tiwari *et al.,* 2011).

Thus present study on combining ability using CMS system revealed presence of both additive and non-additive variances with preponderance of non-additive variances (σ^2 SCA) for all the traits studied thus indicating the ample scope of hybrid rice breeding programme under temperate conditions and needs to be exploited following appropriate breeding procedures. Further, based on results of the nature and magnitude of gene action simultaneously with combining ability we could not identify any parent/cross suitable for all the desirable attributes. Thus hybridization of parents with good GCA effects has an ample scope of throwing promising transgressive segregants in the segregating generations to be used as commercial varieties. The promising crosses with desirable SCA effects for most of the characters and involving good/good or average/good as combinations will be advanced to next generations at the agro ecologies (research stations) to derive super segregants for most of the traits having favorable attributes from restored cross combinations.

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