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Study on heterosis in relation to combining ability *per se* performance in temperate rice (*Oryza Sativa* L.)

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ABSTRACT

Thirty six (36) cross combinations developed by crossing 2 CMS lines with 18 testers in line x tester mating design were evaluated for to find out best heterotic combinations in terms of yield and yield components. Analysis of variance revealed significant differences among genotypes, crosses, lines, testers and line x tester interactions for all the traits studied. The 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 basis of *per se* performance will be effective. Assessment of heterosis based on standard checks (SR-1 and Jhelum) of effectively restored cross combinations showed that there was significant heterosis for all the traits except number of filled grains per panicle and the degree of heterosis varied from trait to trait. All combinations that showed superiority over standard checks for grain yield per plant also showed significant heterosis for majority of other traits. The average proportion of restorers, partial restorers, partial maintainers and maintainers were 16:22:33:27, respectively. The best cross combination in terms of grain yield was SKAU7A x K-08-61-2 and for early maturity SKAU11A x SR-2 over check SR-1 only. 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 for their commercialization under temperate conditions.

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Introduction

Rice is an important mono cereal crop and staple food of Kashmir. In Kashmir valley, rice occupies an area of 0.141 million ha with annual production of 0.34 million tons and average productivity 2.5t/ha (Anonymous, 2010). It is grown in both temperate and sub temperate zones of valley within an altitude of 1650m to 2200m amsl (above mean sea level) representing temperate region of the country. The rice crop in valley is frequently challenged by abiotic and biotic stresses more particularly by low temperature throughout the growing season. Though during past two and half decades, a few 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). To meet the demand of ever growing human population in valley, it is thus imperative to find alternative means for increasing the yield potential of rice cultivars in a sustainable manner. With limited resources in hand hybrid rice technology provides an opportunity to boost the yield of rice under valley conditions in a sustainable manner as hybrid rice varieties have a yield advantage of 15-20% over the conventional high yielding varieties (Virmani and Kumar, 2004). Though a good number of hybrids have been released in India but the initial evaluation of these hybrids and their parental lines has shown that hybrids developed from tropical and sub tropical areas as such were not suitable for cultivation under temperate condition of Kashmir (Sanghera *et al*., 2010). Therefore the present investigation was carried out to assess the extent of heterosis in experimental F1 hybrids developed by using CMS lines for yield and yield contributing traits under temperate conditions.

Materials and methods

The experimental material for present study was developed by crossing two temperate CMS lines (SKAU 7A & SKAU 11A) used as females and 8 testers (males) following Line x Tester mating design during the years 2010-2011 at Mountain Research Centre for Field Crops, Khudwani (34˚ N latitude and 74˚longitude) at an elevation of 1560 m amsl (above mean sea level). The mean temperature during the growing period ranges from 13^0 to 26^0C. The 36 cross combinations along with parents and 2 standard checks viz. SR-1 and Jhelum were evaluated in complete randomized block design in three replications during Kharif 2011. Thirty days old seedlings with single plant/hill were transplanted in a 5m long row with inter and intra row spacing of 20 and 15cm, respectively. Two lines of each entry were 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, ten plants were selected randomly from each replication and biometrical observations were recorded on pollen fertility (%), spikelet fertility (%), number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, panicle length (cm), number of tillers plant^{-1}, number of productive tillers plant^{-1}, plant height (cm), flag leaf area (cm^2), biological yield plant (g), grain yield plant (g), harvest index (%), grain length (mm), grain breadth (mm) and grain length/breadth ratio.

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Days to maturity and days to 50% flowering were recorded on plot basis. Pollen fertility was observed under a light microscope using Iodine potassium iodide (1KI) [0.1%] staining method at flowering stage. It was then calculated as the mean percentage of fertile pollen grains to the total number of pollen grains in three random microscopic fields. Unstained, half stained, shriveled and empty yellow pollen grains were classified as sterile while well filled, stained and dark round pollen grains were recorded as fertile. For spikelet fertility / sterility, 5 panicles of each testcross were covered with butter paper bags to avoid foreign pollen contamination and at maturity were harvested. The percent spikelet fertility was then calculated. Combining ability analysis was carried out according to the standard given by Kempthorne (1957) through a computer generated programme WINDOW STAT. Based on pooled values, standard heterosis was calculated and interpretations were made accordingly.

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 (Table 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. 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 (Rahimi *et al.,* 2010 and Jayasudha and Sharma, 2009). 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.

The best crosses in respect of *per se* performance, GCA effects and SCA effects for different traits studied are presented in Table 2. 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 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, SKAU7A x SKAU-389 and SKAU7A x SR-2 for number of filled grains per panicle, SKAU7A 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 and positive allells 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 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) and 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 from poor combiners (Dubey, 1975). Such combinations in present study were observed in most crosses as evident from Table 2. 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 (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 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 and Tiwari *et al.,* 2011).

In present study, among 36 cross combinations 6 effective restorers, 8 partial restorers, 12 partial maintainers and 10 maintainers cross combinations were categorized on the basis of pollen fertility and spikelet fertility (Table 3). The cross combinations which observed highest restoration ability was SKAU 7A x K-08-61-2 (93%), and minimum restoration ability was shown by SKAU7A x K-08-60-2 (88%). Regarding the restoration ability of elite lines towards the newly developed CMS lines (based on WA cytosterility) only three lines were found to be effective restorers namely K-08-61-2, K-08-60-2 and SR-2. Most of the lines behaved either partial restorers or partial maintainers and frequency of restorers, partial restorers, partial maintainers and maintainers were 16%, 22 %, 33 % and 27%, respectively. The frequency of restorers was much low than the frequency of maintainers because the material used was having tropical japonica background, that lack fertility restoration system to WA cytoplasm. The low frequency of restoration has been reflected in various studies. The lines SKAU-405, Jhelum, SKAU-407, China-1007 and SKAU-391 were categorized as effective maintainers and thus can be used for the development new CMS lines as they are locally adapted genotypes. The variations in behavior of fertility restoration indicate that either the fertility restoring genes are different or that their penetrance and expressivity varied with the genotypes of the parents or the modifiers of female background. Standard heterosis over checks (SR-1 and Jhelum) was computed for six fully restored cross combinations for eighteen traits revealed that heterosis varied from character to character and from cross to cross and none of the cross combination recorded significant heterosis for all the traits simultaneously (Table 3). All the effectively restored combinations out yield the standard checks SR-1 and Jhelum by 25.88% to 55.70%, respectively. Among these the best cross combinations was SKAU 7A x K-08-60-2 (44.70% over SR-1 and 55.70% over Jhelum) and SKAU 7A x K-08-60-2 (25.88% over SR-1 and 35.45% over Jhelum) revealed minimum heterosis. Tiwari *et al*., (2011) also reported more than 25% yield increase over standard variety in rice. Cross combinations SKAU 7A x K-08-61-2, SKAU 11A x K-08-61-2, SKAU 7A x SR-2 and SKAU 11A x SR-2 recorded significant heterosis for the biological yield over both the checks. Earlier rice workers (Tiwari *et al*., 2011; Faiz *et al.*, 2006; Bagheri and Jeoldar 2010)) have also reported significant heterosis for this trait. The percent of heterosis for these combinations ranged from (8.9% to 13.14%) over check SR-1 and (10.14% to 14.33%) over check Jhelum. The most desirable cross combination SKAU 7A x K-08-061-2 for yield also revealed significant standard heterosis for pollen fertility, spikelet fertility, number of tillers plant^{-1}, number of productive tillers per plant^{-1}, panicle length, flag leaf area, biological yield, harvest index, grain length and grain length/breadth ratio. Negative heterosis is desirable for breeding early matured hybrids and varieties. Two cross combinations SKAU 7A x SR-2 and SKAU 11A x SR-2 manifested superiority for days to 50% flowering (6.58% and 7.23%) and days early maturity(9.49% and 9.89%) over the check SR-1. Thus, suggesting the possibility of developing early maturity hybrids from these cross combinations that is a desperate need under temperate condition. Heterosis for early maturity and other important yield components were both in positive and negative direction.

Taller plant height is desirable and needed phenotypic acceptability of the hybrid genotypes in valley. In the present study, 4 cross combinations SKAU 7A x K-08-60-2, SKAU 11A x K-08-60-2, SKAU 7A x K-08-61-2 and SKAU 11A x K-08-61-2 were found desirable for taller height in rice genotypes. The heterosis in these cross combinations ranged from (23.53% to 28.71%) over check SR-1 and (26.83% to 32.15%) over check Jhelum. Generally, large panicle length is associated with high number of grains per panicle thus results into higher product, therefore positive heterosis for panicle length is desirable (Saidaiah *et al*., 2010). In the present study, all cross combinations were found to have significant heterosis in this trait except SKAU 7A x SR-2 and SKAU 11A x SR-2 over check SR-1. The spectrum of variation for heterotic combinations was 16.66% to 30.15% over SR-1 and 3.11% t0 38.23% over Jhelum. Pollen fertility and spikelet fertility are the important traits which directly influence the ultimate product i.e. grain yield. For these traits SKAU 7A x K-08-61-2 (5.27% over SR-1and 6.20% over Jhelum) and SKAU 11A x K-08-61-2 (4.38% over SR-1 and 4.45% over Jhelum) were the desirable heterotic combinations.

Positive heterosis for number of spikelets panicle^{-1}, they concluded that standard heterosis in yield was primarily due to increased number of spikelets panicle^{-1}. This is in justification with our findings as the superior cross combinations were SKAU 7A x K-08-60-2 (12.07% over SR-1 and 9.56% over Jhelum), SKAU 11A x K-08-60-2 (10.6% over SR-1 and 8.31% over Jhelum) and SKAU11A x SR-2 (3.15% over SR-1 and 5.446% over Jhelum) revealed desirable heterosis for this trait. Furthermore, panicle bearing tillers per plant is believed to be closely associated with high yield potential. Desirable combination for this trait was SKAU 7A x K-08-61-2 (21.20% over SR-1 and 29.03% over Jhelum). Besides these yield contributing traits, heterosis was manifested by entire cross combinations for grain length. The range of heterosis was 3.77% to 18.91% over SR-1 and 4.85% to 20.14% over Jhelum. Harvest index is not directly a yield contributing trait but is considered important parameter for genetic improvement of genotypes. Heterosis for this trait ranged from -1.75% to 14.45% over check SR-1 and 12.75% to 31.77% over check Jhelum. The acceptable amount of heterosis for yield and other yield contributing traits indicates that hybrids can be commercially exploited in present conditions after screening of F_1's in various locations and seasons.

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

Source of variation	df	DF	DM	PF	SF	SPP	FGP	CSP	PL	TP	PTP	PH	FLA	BY	GY	HI	GL	GB	L:B
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; df – degree of freedom; DF– Days to 50% flowering; DM– Days to maturity; PF– Pollen fertility (%); SF– Spikelet fertility (%); SPP– No. of spikelets panicle^{-1}; FGP– No. of filled grains panicle^{-1}; CSP– No. of chaff seed panicle^{-1}; PL– Panicle length (cm); TP– No. of tillers plant^{-1}; PTP– No. of productive tillers plant^{-1}; PH– Plant height (cm); FLA– Flag leaf area (cm^2); BY– Biological yield plant^{-1} (g); GY– Grain yield plant^{-1} (g); HI– Harvest index (%); GL– Grain length (mm); GB– Grain breadth (mm); L:B– Grain L/B ratio

Table-2: 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
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

Table 3 Estimation of heterosis (%) for fully restored cross combinations over standard checks for various agro-morphological traits in rice under temperate condition

Crosses/ Traits	Standard check	SKAU 7A x K-08-60-2	SKAU11A x K-08-60-2	SKAU 7A x K-08-61-2	SKAU11A x K-08-61-2	SKAU 7A x SR-2	SKAU 11A x SR-2
Days to 50% flowering	SR-1 Jhelum	2.975** 0.95	3.29** 0.32	5.26** -1.32	3.61** 1.13	-6.58** 1.24	-7.23** 1.41
Days to maturity	SR-1 Jhelum	5.09** 0.24	2.77** 2.68**	2.54** 1.93	2.08** 1.47	-9.49* 2.40**	-9.81* 2.01*
Pollen fertility (%)	SR-1 Jhelum	1.10 1.29	1.14 1.56	4.81** 4.93**	4.72** 4.83**	1.44 0.56	-0.725 0.36
Spikelet fertility (%)	SR-1 Jhelum	-12.15* -12.09*	-11.35* -11.28*	5.27** 6.20**	4.38** 4.45**	-9.50* -9.44*	-8.04* -7.97*
Spikelets panicle^{-1}	SR-1 Jhelum	12.07* 9.56*	10.60* 8.13*	-7.17* -7.60*	-5.05** -7.71*	-1.91 0.32	3.15** 5.446**
Filled grains panicle^{-1}	SR-1 Jhelum	-22.14* -22.83*	-21.12* -22.83*	-5.28* -7.33**	-2.21 -2.33	-9.19* -11.16*	-5.79** -7.83**
Panicle length (cm)	SR-1 Jhelum	16.6* 23.8*	20.45* 27.94*	30.15* 38.23*	22.61* 30.23*	1.61 3.11**	-0.77 4.39**
No. of tillers plant^{-1}	SR-1 Jhelum	-9.09* -6.25*	-23.63* -21.25*	21.20* 24.99*	0.60 2.49	30.30* 34.36*	33.33* 37.49*
No. productive tillers plant^{-1}	SR-1 Jhelum	-9.97** -3.87	-28.01* -20.06*	21.20* 29.03*	-9.09** -3.221	-13.33* -7.74**	-6.66** -0.63
Plant height (cm)	SR-1 Jhelum	23.53* 26.83*	24.48* 27.48*	28.71* 32.15*	26.07* 29.44*	-0.03 -2.71	-0.03 -2.91
Flag leaf area (cm^2)	SR-1 Jhelum	29.96* 33.36*	5.13** 7.13**	29.00* 20.29*	21.13* 25.23*	1.80 1.55	1.52 1.77
Biological yield plant^{-1} (g)	SR-1 Jhelum	0.69 1.74	0.34 1.39	13.14* 14.33*	15.22* 16.43*	7.26** 8.39**	8.99** 10.14*
Grain yield plant^{-1} (g)	SR-1 Jhelum	25.88* 35.45*	27.06* 36.72*	44.70* 55.70*	41.17* 51.19*	36.47* 46.84*	27.06* 36.72*
Harvest index (%)	SR-1 Jhelum	10.83* 27.20*	14.81* 31.77*	14.45* 19.88*	11.02* 14.80*	2.79 19.12*	-1.75 12.75*
Grain length (mm)	SR-1 Jhelum	18.91* 20.14*	17.62* 18.22*	17.01* 18.22*	16.10* 17.30*	3.77** 4.85**	5.30** 6.39**
Grain breadth (mm)	SR-1 Jhelum	-2.96** -2.34**	0.74 1.37	-2.96** -2.34**	0.74 1.37	17.29* 18.03*	16.66* 17.40*
Grain L/B ratio	SR-1 Jhelum	22.58** 23.09**	16.79* 17.28*	20.18* 21.18*	15.49* 15.00*	-11.46* -11.09*	-9.68* -9.30*

*,** Significant at 5 and 1 per cent level, respectively