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HETEROSIS IN RICE (*Oryza sativa* L.) UNDER TEMPERATE CONDITIONS OF KASHMIR

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ABSTRACT

Heterosis phenomena was studied for 30 inter-varietal (*indica* x *indica, japonica x japonica*) crosses and 15 inter-subspecific crosses generated through different mating designs in Kharif 2008 and evaluated for heterosis phenomena for various morpho-agronomic and other traits under different agro-ecologies of Kashmir. The basic experimental material comprized of 12 genotypes with six types belonging to each sub-specific group. For grain yield plant^{-1} only six inter-varietal crosses Jhelum x SK-382, Jhelum x China 1039, SK-382 x SR-1, SR-1 x Chenab, GS-504 x K-508 and Kohsar x K-508 and no inter-subspecific cross proved significantly superior over commercial check. For days to 50% flowering, an important economic character, only cross combinations Koshihikari x GS-508, Koshihikari x K-508 and Kohsar x K-508 flowered earlier as compared to better parent. The standard heterosis for early flowering was observed on GS-504 x K-508 and Kohsar x K-508. Negative heterosis was observed for grain yield plant^{-1} in inter-subspecific crosses, whileas heterosis for all economic characters was recorded in some inter-varietal crosses. Negative heterosis was pronounced for most of the cross combinations with respect to most important economic traits in case of inter-subspecific pool because of high magnitude of hybrid sterility. There was one to one correspondence between *per se* performance and heterotic estimates, but such was not the case with SCA effects. The crosses with high SCA effects viz-a-viz with high standard heterosis can be exploited to develop early desirable segregants for grain yield and other morpho-agronomic traits.

Keywords: Heterosis, inter-subspecific crosses, inter-varietal crosses, rice

INTRODUCTION

Heterosis is a widely demonstrated phenomenon in diploid organisms that undergo sexual reproduction. Although rice is naturally self-pollinated crop, heterosis is observed in their crosses with higher rate of manifestation in *indica*/ *japonica* crosses (the two sub-species of rice), followed by *indica*/ *indica* and *japonica*/ *japonica* crosses. Though heterosis has been observed for various morphological, physiological and biochemical characters in applied breeding programmes, the concern is primarily with the economic yield potential. During 1962-1967 a number of suggestions came from different parts of the world regarding commercial exploitation of heterosis as a major component of rice improvement programme at national and international level. China is the first country credited for exploiting the heterosis phenomena in rice. In India, more than 35 hybrids in rice have been released. However, these hybrids have been developed for tropical and sub-tropical conditions and are not suitable for temperate conditions of Kashmir which has a short growing season together with cold spells at seedling and maturity stages. Much work has been done on this aspect (Alam *et al*., 2004, Singh and Kumar, 2004, Shukla and Pandey, 2008) but were carried under different environmental conditions and on different kinds of experimental material. The cultivation of both the subspecies, i.e. *indica* and *japonica* are in vogue with former being popular in plain areas of Kashmir valley covering an altitude range of 1450-1850 m above mean sea level (amsl) and latter in areas at an altitude range of 1850-2250 m amsl because of their differential degrees of cold tolerance, maturity, adaptability and social acceptability. A novel attempt in this direction was made by carrying out intra- and inter-subspecific crosses in rice to study the nature and magnitude of heterosis in various inter-varietal and inter-subspecific crosses under temperate conditions of Kashmir.

MATERIALS AND METHODS

The material for the present study comprized of 12 genetically diverse varieties of rice (*Oryza sativa* L.) belonging to 2 sub-specific groups, viz. *indica* and *japonica.* The six typical *japonica* types [Koshihikari, K-332, Kohsar, GS-503, GS-504 and K-508] and six typical *indica* varieties including one wide compatibility variety (WCV) [Jehlum, SK-382, Chenab, China-1039, Shalimar rice-1 and Dular (WCV)] were selected out of the germplasm collection maintained at Rice Research and Regional Station, Khudwani. Fifteen inter-varietal *indica* F_1 crosses were generated by putting 6 *indica* lines [Jhelum (P_1), SK-382 (P_2), Shalimar Rice-1 (P_3), China-1039 (P_4), Chenab (P_5) and Dular (P_6)] in half diallel (excluding reciprocals) in Kharif 2008 as per the procedure described by Griffing (1956). Similarly one more set of fifteen intervarietal *japonica* single crosses were generated in the same season by inter-mating all six *japonica* varieties [Koshihikari (P_7), K-332 (P_8), GS-503 (P_9), GS-504 (P_{10}), Kohsar (P_{11}) and K-508 (P_{12})] in all possible combinations by excluding reciprocals as per the procedure of Griffing (1956). In the same season varietal set of 5 *indica* varieties as lines [viz., Jhelum (L_1), SK-382 (L_2), Shalimar rice-1 (L_3), China-1039 (L_4) and Chenab (L_5)] were crossed with 3 typical *japonica* varieties as testers [Koshihikari (T_1), K-332 (T_2) and Kohsar (T_3)] in a line x tester fashion to generate 15 *indica*/*japonica* crosses as per line x tester mating design proposed by Kempthorne (1957). The materials were evaluated at 2 experimental farms situated under 2 agro-ecologies of Kashmir viz., Rice Research and Regional Station, Khudwani (1650 m amsl) and High Altitude Rice Research Sub-Station, Larnoo (2250 m amsl) during Kharif 2009. The F_1 experimental progenies were grown in a randomized complete block design with 2 replications. Each experimental progeny (F_1) was grown in 2 rows of 3 m length with intra- and inter-row spacing of 15 and 20 cm and recommended package of practices were followed to raise the good crop. The data was recorded on traits related to maturity on plot basis, while other morpho-agronomic traits were recorded on 5 randomly tagged plants from each experimental plot. The pooled data was used to estimate heterosis over better parent (heterobeltiosis) and standard checks (the most popular varieties in vogue under both agro-ecologies (standard heterosis). The varieties Jhelum and K-332 were used as standard checks for *indica* x *indica* and *japonica* x *japonica* crosses, respectively, to estimate standard heterosis. Variety Jhelum played the role of check variety for inter-subspecific crosses. The software Windostat was used to analyze the data.

RESULTS AND DISCUSSION

Among the intra-subspecific crosses none flowered earlier in comparison to better parent and standard check, except Koshihikari x GS-504 (-9.66%), Koshihikari x K-508 (-11.34%) and Kohsar x K-508 (-9.26%) revealing better parent heterosis and GS-504 x K-508 (-10.79%) and Kohsar x K-508 (-9.8%) demonstrating standard heterosis. Few intra-subspecific crosses were heterotic for the trait but in the positive direction. The crosses from inter-sub specific side which flowered earlier than better parent and standard check were China-1039 x K-332 (-10.91, -10.09%) and China-1039 x Kohsar (-8.18, -7.34%) [Table 1 and 2]. Heterotic study for days to maturity showed that most of the crosses were at par, while Kohsar x K-508 showed heterotic superiority of -14.37% over standard check K-332. The two test crosses of inter-subspecific pool depicted significant heterobeltiosis and standard heterosis for early maturity. Heterosis for spikelet sterility was highest in inter-subspecific crosses but in undesired direction and ranged between 592.8-1686.2% followed by inter-varietal (*I* x *i*) *indica* crosses 47.76 (Jhelum x Dular) -1198.1% (SK-382 x Dular) and inter-varietal *japonica* crosses 39.9 (Kohsar x K-508) - 201.86% (Koshihikari x K-332). For plant height, the trait determining the resistance to lodging in a genotype, most of the intra-subspecific crosses were at par with better parent and commercial variety. The inter-subspecific crosses, however, demonstrated taller stature when the different levels of heterosis were estimated. There were only a few crosses from the pool which could not prove heterotic rather were at par with the check genotype. The cross combinations Koshihikari x K-332, Koshihikari x GS-504 and China-1039 x Kohsar could be considered heterotically desirable because of the significant and negative estimate for the plant height.

For yield component traits like number of panicles plant^{-1}, nine inter-varietal crosses proved significantly superior (Jhelum x Chenab, SK-382 x China 1039, SK-382 x Dular, China 1039 x Chenab, China 1039 x Dular, Koshihikari x GS-503, Koshihikari x GS-504, Koshihikari x Kohsar and Kohsar x K-508 over better parent and check parent. The test cross combinations from *indica* x *japonica* pool that revealed heterobeltiosis and standard heterosis to an appreciable extent were Jhelum x K-332, China 1039 x K-332and Chenab x Kohsar. Significant heterobeltiosis and superiority over commercial check was recorded for 7 inter-varietal *indica* (i x i) crosses and ranged between 6.36- 15.96 and 7.44-17.13%, respectively. Among the inter-varietal *japonica* (j x j) crosses, Koshihikari x GS-503 and K-332 x GS-504 revealed 29.23% superiority in the form of more panicles against the standard check. Heterobeltiosis of good margin was observed only in two inter-varietal *japonica* crosses (Koshihikari x GS-503 and Koshihikari x GS-504). The heterotic estimate for number of panicles plant^{-1} either over better parent or check parent or both were recorded for 12 of 15 inter-subspecific crosses. Significant heterotic estimate for panicle length in case of *indica x indica* crosses ranged between 6.36-15.96 and 7.44-17.33%, respectively, over better parent and standard check. Superiority over better parent for inter-varietal *japonica* crosses ranged between 5.00 to 29.88%, whereas only one cross combination, Koshihikari x GS-503, displayed standard heterosis (10.34%) in the desired direction. Most of the cross combinations of inter-subspecific pool (9 out of 15) showed superiority in the form of longer panicle when compared to check variety K-332.

For the most important economic trait i.e., grain yield plant^{-1}, six inter-varietal (*i x i* and *j* x *j*) crosses [(Jhelum x SK-382), (Jhelum x China 1039), (SK-382 x SR-1), (SR-1 x Chenab), (GS-504 x K-508) and (Kohsar x K-508)] and no inter-subspecific cross proved significantly superior over commercial check variety. The magnitude of heterobeltiosis was highest for Koshihikari x GS-504 (215.4%) followed by GS-503 x GS-504 (207.6%) and Koshihikari x GS-503 (207.4%). The heterotic estimate of 12.46 and 13.67% over check 'Jhelum' was noticed on cross combinations Jhelum x China 1039 and SK-382 x SR-1, respectively. The cross combination GS-504 x K-508 exhibited the superiority over check K-332 by a magnitude of 29.57%. All the 15 inter-subspecific crosses displayed highly significant but negative heterosis over both levels of heterosis. Most of the cross combinations of *indica x indica* type and six crosses of *japonica x japonica* type and all test crosses of inter-subspecific pool realized positive and significant heterotic estimate for biological yield plant^{-1}. Superiority over better parent for biological yield plant^{-1} was highest for cross combinations SR-1 x Dular (196.41%) followed by Koshihikari x GS-503 (104.8%), China 1039 x Dular (87.2%) and Koshihikari x Kohsar (83.9%). Similarly, superiority for the trait over check Jhelum varied in magnitude with highest in SR-1 x Dular (280.9%) followed by SK-382 x China 1039 (140.6%), SK-382 x Dular (121.7%) and so on. The noteworthy hybrid for biological yield among *japonica x japonica* crosses was Koshihikari x Kohsar that recorded standard heterosis of 70.5% over check 'K-332' followed by Koshihikari x GS-504 (51.2%). The 100-grain weight was high for 8 crosses of *indica* x *indica* type, 7 crosses of *japonica* x *japonica* type and all combinations of inter-subspecific pool. Magnitude of desired heterobeltiosis ranged between 3.69-24.76%, while as, significant positive standard heterosis over standard check (Jhelum) ranged between 3.28-22.71% in case of inter-varietal *indica* (i x i) crosses. Inter-subspecific

Table 1: Estimates of heterotic effects for various morpho-agronomic and other traits in inter-varietal crosses of rice

Cross	Days to 50% flowering		Days to maturity		Spikelet sterility (%)		Plant height (cm)		No. of panicles plant^{-1}		Panicle length (cm)		Biological yield (g plant^{-1})		Grain yield (g plant^{-1})		100-grain weight (g)	
	BP#	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum
Inter-varietal (j xj)□ crosses																		
P_1 x P_2	-5.19	-6.51	5.17	5.17	98.2**	124.3**	4.32	5.83	-32.7**	0.9	-1.69	-0.69	32.61	71.08*	7.96	12.64**	5.32**	8.08**
P_1 x P_3	-4.00	0.47	-3.61	1.38	29.8**	104.7**	3.85	5.87	-32.8**	0.7	0.04	1.06	47.73	89.86**	-14.75**	-12.06**	12.45**	22.57**
P_1 x P_4	-0.46	-2.40	-3.10	-3.10	248.5**	279.3**	-3.53	-3.98	-16.2**	24.6**	-9.37**	-8.45**	31.01	28.11	9.12*	12.46**	-0.20	11.14**
P_1 x p_5	-4.63	-4.19	0.00	1.72	90.2**	175.4**	5.65	4.44	20.2**	80.4**	10.75**	11.88**	0.08	20.28	-7.74	-3.58	3.69**	22.71**
P_1 x p_6	4.72	3.26	3.79	3.79	127.6**	47.7**	10.16*	8.88*	-29.7**	5.4	10.37**	11.49**	47.50	42.17	-28.82**	-26.64**	23.30**	10.92**
P_2 x P_3	-5.33	-0.93	-2.62	-4.41	67.1**	210.7**	2.48	4.48	-24.2**	8.0*	-3.41	-2.44	24.53	60.04*	10.20*	13.67**	7.83**	17.25**
P_2 x P_4	-0.46	1.40	6.25	5.52	293.4**	328.2**	2.18	3.46	51.3**	47.3**	15.96**	17.13**	87.27**	140.66**	-11.12*	-8.40*	-39.80**	-32.97**
P_2 x P_5	-0.46	0.00	1.69	3.45	254.1**	412.6**	0.35	1.60	-3.3	-5.9	-3.03	-2.05	9.38	40.56	-29.32**	-26.13**	-33.58**	-21.40**
P_2 x P_6	4.25	2.79	1.04	-1.72	1092.6**	1198.1**	-6.80	-5.64	94.4**	52.8**	-8.81**	-7.89**	72.50*	121.69**	-54.24**	-52.83**	11.89**	0.66
P_3 x P_4	0.00	4.19	-3.29	1.38	111.5**	245.3**	6.30	8.48	-29.4**	0.9	7.72**	8.81**	23.91	59.24*	1.09	4.18	5.69**	17.69**
P_3 x P_5	-2.23	1.86	-8.55*	-4.14	85.2**	202.3**	3.50	5.62	6.1	51.6**	9.99**	10.91**	29.06	65.86*	3.89	8.58*	-12.73**	3.28**
P_3 x P_6	0.00	4.19	-6.58	-2.07	512.3**	899.7**	0.89	2.95	3.1	47.3**	8.26**	9.35**	196.41**	280.92**	-56.32**	-54.99**	24.76**	12.23**
P_4 x P_5	-2.27	0.00	0.00	1.72	71.8**	148.7**	-1.25	-1.61	8.0*	8.0*	2.41	3.45	-1.67	18.17	-19.43**	-15.79**	-15.00**	11.35**
P_4 x P_6	-5.45	-3.26	6.34	4.14	117.9**	134.1**	7.57	7.18	63.2**	63.5**	6.36**	7.44**	105.31**	102.01**	-8.69*	-11.43*	-17.83**	7.64**
P_5 x P_6	-0.93	-0.47	-2.36	-0.34	363.9**	531.2**	9.21*	4.43	-7.7	-6.6	-1.24	-0.24	-16.83	0.20	-61.26**	-60.08**	-16.33**	9.61**
Inter-varietal (i x i)± crosses																		
P_7 x P_8	-6.30	3.72	-6.80	7.51	-39.7**	201.8**	-20.70*	-19.30*	-11.9**	10.2**	-17.58**	-22.48**	-15.55	-10.74	-36.58**	-36.58**	6.52**	6.29**
P_7 x P_9	-7.98	1.86	-4.44	10.24	-79.6**	10.3	12.11	-0.06	40.0**	29.2**	5.15*	10.34**	104.86**	-4.36	207.38**	-27.57**	10.49**	16.49**
P_7 x P_{10}	-9.66*	0.00	-4.14	10.58	-84.8**	-9.4	14.25	-16.77*	37.5**	12.8**	25.56**	-13.70**	41.55**	51.26**	215.38**	-25.68**	28.60**	37.53**
P_7 x p_{11}	-6.30	3.72	-3.85	10.92	-53.2**	134.1**	1.08	-1.47	13.3**	31.3**	-0.85	-9.04**	83.89**	70.49**	-46.50**	-42.95**	11.68**	32.75**
P_7 x p_{12}	-11.30'	-1.86	-6.21	8.19	-40.4**	198.6**	-7.08	-1.03	-21.4**	-5.6	1.20	-13.18**	-14.62	-21.48	-27.28**	-37.55**	-6.65**	0.43
P_8 x P_9	-4.15	-3.26	-6.10	5.12	-83.3**	-9.4	-3.79	-1.80	-45.0**	-32.3**	3.89	-3.36	-29.39*	-24.84*	-23.97**	-23.86**	4.32**	9.98**
P_8 x P_{10}	-2.33	-2.33	-2.84	5.12	-83.2**	0.1	-0.34	1.70	5.0	29.2**	6.94**	-0.52	-13.59*	-7.66	-13.88*	-13.76*	-4.06**	2.60**
P_8 x P_{11}	-3.23	-2.33	0.33	2.73	-11.3	0.2	13.16	15.48	-37.9**	-23.6**	5.56*	-1.81	22.02*	29.88*	3.95	10.75	-8.39**	8.89**
P_8 x P_{12}	2.91	-1.40	4.56	9.56	-11.9*	-0.4	-6.16	0.41	-18.3**	0.5	-7.78**	-14.21**	-37.02**	-32.96**	-32.82**	-32.72**	-10.89**	-4.12**
P_9 x P_{10}	2.31	2.79	-0.30	11.60	-60.4**	136.4**	10.79	-1.23	-13.3**	-20.0**	-2.20	-19.38**	18.65	26.80*	207.66**	-38.47**	18.86**	27.11**
P_9 x P_{11}	-0.46	0.47	-4.57	6.83	-54.7**	148.5**	14.56	11.67	-33.2**	-22.5**	5.35*	-3.36	39.78**	29.60*	-29.28**	-24.65**	-2.55**	15.84**
P_9 x P_{12}	-2.78	-2.33	-2.44	9.22	84.2**	-13.2*	-1.97	4.87	-10.2**	-7.7*	2.41	-12.14**	1.42	-6.72	-14.29*	-8.69	-31.39**	-18.44**
P_{10} x P_{11}	-1.84	-0.93	-0.63	7.27	-78.6**	27.5**	14.44	11.55	-25.6**	-13.8**	-0.28	-8.53**	5.18	11.95	-12.08*	6.33	6.20**	26.25**
P_{10} x P_{12}	-3.24	-10.79*	-5.70	1.71	-72.6**	63.8**	-11.29	-5.10	8.2*	0.5	29.88**	2.84	22.54*	30.44*	21.62**	29.57**	0.73	19.74**
P_{11} x P_{12}	-9.26*	-9.84*	-3.26	-14.37*	-32.2**	-39.9**	5.92	13.31	8.4*	10.8*	5.00*	2.33	3.00	-3.83	6.47	13.43*	-5.47**	12.36**

±*Indica* varieties: P_1 = Jehlum, P_2 = SK-382, P_3 = Chenab, P_4 = China-1039, P_5 = Shalimar rice-1 and P_6 = Dular; □ *Japonica* varieties: P_7 = Koshihikari, P_8 = K-332, P_9 = Kohsar, P_{10} = GS-503, P_{11} = GS-504 and 12 = K-508; #BP = better parent; *,** Significant at 5 and 1% level, respectively

Table 2: Estimates of heterotic effects for various morpho-agronomic and other traits in inter-subspecific (i x j) crosses[a] of rice

Cross[±]	Days to 50% flowering		Days to maturity		Spikelet sterility (%)		Plant height (cm)		No. of panicles $plant^{-1}$		Panicle length (cm)		Biological yield (g $plant^{-1}$)		Grain yield (g $plant^{-1}$)		100-grain weight (g)	
	BP[#]	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum	BP	Jhelum
L_1 x T_1	9.63**	9.00**	2.33	6.23*	606.2**	1184.3**	11.17**	11.02**	-20.3**	-19.1**	15.05**	14.00**	66.4**	79.5**	-52.3**	-52.3**	3.74**	39.27**
L_1 x T_2	4.13	4.02	-4.15	4.02	250.5**	383.0**	-9.78**	-9.70**	13.5**	12.5**	-15.41**	-13.10**	76.4**	76.0**	-77.1**	-77.1**	-2.21	31.28**
L_1 x T_3	4.13	3.98	-1.73	-1.35	1301.9**	1448.1**	7.20**	7.11*	-17.1**	-17.0**	2.84	2.60	76.3**	72.3**	-61.2**	-61.2**	9.69**	47.26**
L_2 x T_1	1.42	-1.83	2.33	6.23*	434.0**	871.3**	10.35**	7.29*	-29.8**	-42.7**	13.23**	2.93	5.0	54.0**	-41.5**	-41.0**	79.43**	87.21**
L_2 x T_2	-4.27	-7.34*	1.39	0.69	924.3**	1311.6**	21.55**	18.19**	-11.7**	-27.8**	14.08**	3.70	117.6**	219.2**	-59.2**	-58.8**	49.41**	44.98**
L_2 x T_3	2.84	-0.46	-2.44	-3.11	1152.5**	1350.1**	0.59	-2.2	60.0**	-3.0	6.80*	-2.91	174.1**	302.1**	-38.2**	-37.6**	17.36**	35.84**
L_3 x T_1	5.80*	8.72**	-0.65	5.54*	721.5**	1394.1**	10.05**	14.83**	1.6	-17.1	11.62**	14.20**	68.9**	156.1**	-71.0**	-65.6**	19.52**	36.99**
L_3 x T_2	0.89	3.67	-7.82**	-2.08	813.4**	1435.1**	-1.16	3.13	-5.2	-22.4**	6.89*	9.36**	2.4	55.3**	-77.6**	-73.5**	18.13**	35.39**
L_3 x T_3	-5.36	-2.75	-14.3**	-9.00**	582.8**	1047.4**	13.54**	18.48**	9.4**	-11.2**	7.91*	10.41**	39.8**	112.0**	-52.1**	-43.3**	10.06**	27.40**
L_4 x T_1	6.36*	7.34*	-6.00*	-2.42	280.9**	592.8**	22.11**	24.69**	-22.7**	-36.9**	25.65**	29.27**	202.1**	226.0**	-68.7**	-79.9**	11.73**	28.31**
L_4 x T_2	-10.91**	-10.09**	-4.79*	-3.81	1316.1*	1851.5**	4.89	7.11*	125.8**	84.7**	11.55**	14.77**	153.0**	153.0**	-63.9**	-90.6**	19.28**	36.99**
L_4 x T_3	-8.18**	-7.34*	5.82*	6.92**	1517.5**	1686.2**	-8.49**	-6.55*	-0.1	27.7**	-6.27*	-3.57	36.0**	36.0**	-80.0**	-88.3**	11.24**	28.77**
L_5 x T_1	9.77**	8.26**	-2.00	1.73	706.6**	1367.0**	15.57**	16.46**	-6.2*	-23.5**	5.67*	6.80*	28.3**	58.4**	-54.9**	-52.3**	14.95**	40.41**
L_5 x T_2	5.12	3.67	-5.76*	-3.81	1151.6**	1624.9**	-0.44	0.33	-9.6**	-26.1**	27.57**	28.93**	45.6**	79.7**	-75.6**	-74.3**	6.54**	30.14**
L_5 x T_3	5.12	9.67	-6.78*	-4.84*	937.3**	1318.6**	1.14	1.91	74.6**	21.2**	5.96*	7.09*	1.4	25.2**	-69.1**	-67.4**	4.67**	27.85**

[±] Five *indica* varieties as lines: L_1 = Jhelum, L_2 = SK-382, L_3 = Shalimar rice-1, L_4 = China-1039 and L_5 = Chenab]; three *japonica* varieties as testers: T_1 = Koshihikari, T_2 = K-332 and T_3 = Kohsar

[#] BP = Better parent, L = line, T = tester

*,** = significant at 5 and 1% level, respectively

crosses displayed heterotic range of 3.7-79.43 and 27.40-87.21% over better parent and check (Jhelum), respectively. Heterosis/ superiority over better parent and standard check were observed in so many cases in rice for maturity traits (Reddy *et al*., 1998, Sarawgi *et al*., 2000, Singh and Kumar, 2004), yield components (Reddy *et al*., 1998, Sarkar *et al*., 2001, Saravanan *et al*., 2006), grain yield (Bisne and Motiramani, 2006) , spikelet fertility (Rashid *et al.*, 2007), plant height (Fu *et al.*, 2007) and for other morpho-agronomic traits (Alam *et al*., 2004, Saleem and Mirza, 2008). Significant heterosis for yield and yield components has been reported from several countries ranging from 2–369% in rice (Virmani *et al*., 1981)

The breeding for high grain yield is an important objective in rice improvement, and the first and foremost breeding objective under temperate conditions of Kashmir. The standard checks used in the present study were very high yielding pure-line varieties in vogue and as a result a few crosses reported heterosis for different traits. The hybrid sterility is a genetic impediment influencing the *indica/ japonica* crosses, as a result most of the spikelets could not get converted into filled seeds. Thus the *per se* performance (mean values) of inter-subspecific crosses were very low. As a result no cross from such pool could display desirable heterosis for the grain yield. The second important economic trait was early flowering because the crop suffers most due to cold stress at early and later stages of growth. Similarly, lodging nature determined by the plant height is also given due consideration. Breeding for more panicles plant^{-1} is also an important objective because of the restrain exerted on the trait by cold stress particularly to *japonica* varieties in vogue under high altitude ecologies. Biological yield (total biomass) is also a due priority because of the high live stock population and long spell of lean season which is solely met out by the rice crop straw. This was the rationale behind of taking the above mentioned and other aspects into consideration in the present study.

The results revealed that all the heterotic crosses had close correspondence with *per se* performance, which suggested that *per se* performance (mean over locations) of hybrids could be considered for judging heterosis for grain yield and other economic traits. The cross combinations showing high standard heterosis for grain yield plant^{-1} were superior in terms of earlier to flower (Table 2). Under temperate Kashmir conditions delay of one week in flowering some time makes the crop to coincide with early cold spell meaning severe repercussion to crop maturity. This often results in a high level of spikelet sterility so a drastic reduction in grain yield. Similarly all cross combinations with heterotic grain yield also reported heterotic estimate for 100-grain weight. The heterotic estimate for important yield component, i.e., number of panicles was associated with 2 out of 6 crosses that depicted standard heterosis for grain yield. High biological yield and early maturity were also observed to be associated in 2 out of 6 crosses regarding standard heterosis for grain yield. This fact elucidates that early flowering, high 100-grain weight, more number of panicles and high biological yield have a very good association with high grain yield plant^{-1}. The only cross combination, Kohsar x K-508, showed significant heterosis over standard check for more than one yield component i.e., fertile spikelets, number of panicles plant^{-1} and 100-grain weight. Rest of the crosses depicting standard heterosis for grain yield simultaneously displayed superiority for only one yield component. The crosses observed to be heterotic for one yield component were either at par or undesirably heterotic for other component trait. All the component characters are responsible for sum total of metabolic substances produced by the plant but the conditions which favour the development of one component could possibly have adverse effect on the other.

Vegetative heterosis was pronounced for most of the cross combinations of inter-subspecific pool because of high degree of spikelet sterility. No inter-subspecific cross combination was found heterotic for grain yield plant^{-1}. Similarly, most of the cross combinations of such pool were inferior for traits like spikelet sterility resulting in undesirable heterotic magnitude. However, economic heterosis was pronounced for traits like plant height, number of panicles, panicle length and biological yield plant^{-1} suggesting the predominance of vegetative heterosis in comparison to other cross groups. The main reason for this seems to be hybrid sterility i.e. partial failure of spikelets to get converted into seed a major barrier for putting together the characters across the two sub-species. Hybrid sterility is most important phenomenon studied in rice for last two decades (Siddiq and Singh, 2006). High heterosis for other morphological traits might be due to more diversity between the two sub-species. Similar sort of information were gathered by Ikehashi (1982) and Yuan *et al.* (1987). The other explanation for vegetative heterosis may be more and more accumulation of photosynthates and their non-diversion towards the sink (grains). This might be the reason for high 100-grain weight. Moreover, it seems that a few seeds which developed did not experience any sort of competition for metabolites. The differential expression of heterotic estimates within and among crossing blocks may be due to different experimental material, evaluation under different agroecologies, differential expressions of hybrid sterility and differential degrees of cold tolerance.

Table 3: The crosses showing standard and desirable heterosis for grain yield plant^{-1} simultaneously for other morpho-agronomic traits

Crosses showing standard heterosis for grain yield plant^{-1}	Other morpo-agronomic traits reporting heterosis
Jhelum x SK-382	DFF*, np, SS, 100-gw, By
Jhelum x China 1039	DFF,np, 100-gw
SK-382 x SR-1	DFF, DM, FS, ph, pl, 100-gw, By
SR-1 x Chenab	DFF, pl, 100-gw
GS-504 x K-508	DFF, SS, 100-gw, By
Kohsar x K-508	DFF, DM, FS,np, 100-gw, ph, By

*DFF = days to 50% flowering, DM = days to maturity, SS = spikelet sterility, FS = fertile spikelets panicle^{-1}, np = number of panicles plant^{-1}, ph = plant height, pl = panicle length, gw = grain weight, By = biological yield plant^{-1}

There was no one-to-one correspondence of the standard heterotic crosses with their corresponding favourable SCA effects (Table 4). Among the 6 crosses which depicted standard heterosis for grain yield plant^{-1}, only 4 crosses showed highly significant positive SCA effects for the trait; however, there was a very good correspondence between high *per se* performance (mean) and heterotic estimates. Significant and desirable SCA effects for grain yield did not correspond simultaneously with significant and desirable SCA effect for all the component traits, suggesting that desirable SCA effects of just one or two agronomic traits could result in significant SCA effects for grain yield. Similar suggestions have been given by Ramalingam *et al.* (1993) and Parihar and Pathak (2008). Besides, any sort of combination on the basis of GCA effects (good, average and poor) were reported that resulted into favourable SCA effects, irrespective of *per se* performance for grain yield and other morpho-agronomic traits.

Table 4: The crosses showing standard heterosis for grain yield along with SCA effects and *per se* performance *viz-a-viz* respective morpho-agronomic traits with desirable SCA effects

Standard heterotic crosses for grain yield plant^{-1} (g)	SCA effects	*per se* performance (g plant^{-1})	Traits with significant and desirable SCA effects
Jhelum x SK-382	3.84*	19.36	DFF (-5.02**), np (3.56*), Pl (1.98*), 100 gw (0.38*)
Jhelum x China 1039	1.18	20.22	DM (-6.60**), Ph (-7.99**)
SK-382 x SR-1	2.46	18.96	-
SR-1 x Chenab	3.65*	20.28	DM (-8.35**), np (3.77*)
GS-504 x K-508	5.34*	20.24	DM (-6.44*), Pl (2.97*), By (11.30*), 100 gw (7.83**)
Kohsar x K-508	5.30*	19.18	DFF (-5.69**), np (3.00*)

DFF = days to 50% flowering, DM = days to maturity, SS = spikelet sterility, FS = fertile spike-lets panicle^{-1}, Np = number of panicles plant^{-1}, ph = plant height, pl = panicle length, gw = grain weight, By = biological yield plant^{-1}.
*,** = Significant at 5 and 1% level, respectively

The nature and extent of heterotic effects over better parent and standard check(s) revealed that it was of appreciable magnitude for yield, yield components, besides for the traits related to maturity for some cross combinations suggesting the possibility of their improvement through exploitation of heterosis. Although more than 40 hybrids have been developed for different environmental conditions in India but none has been found suitable under Kashmir agroclimatic conditions. Hence, the only way out is to develop a hybrid by using indigenous germplasm of Kashmir, which is highly adapted to such agro-ecology. The heterotic estimate observed in the present study has shown potential of some hybrids for yield and early maturity but no standardized CMS system is available under Kashmir conditions for economic seed production. Both inter-varietal and inter-subspecific hybrids need to be developed for different agroecologies of Kashmir; and by the time CMS system is developed into our indigenous lines/ varieties, the crosses having high SCA effects for grain yield viz-a-viz high standard heterosis over check may be exploited to obtain early desirable segregants for grain yield and other morph-agronomic traits by resorting to pedigree breeding technique. Hybridization of parent with good GCA effects has ample scope for producing promising transgressive segregants in segregating generations to be used as varieties. The F_2 material of all the crosses is under evaluation at two rice research stations covering different agro-ecologies of Kashmir for making selections for important economic traits for two regions of Kashmir valley. Besides, opportunity of deriving super-lines or ideotypes having desirable features from both sub-species can be very high whose potential may be exploited worldwide under equivalent ecologies (1600-2250 m amsl).

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