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Extent of heterosis in rice (*Oryza sativa* L.) under cold stress conditions – yield and its components*

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Summary. The nature and extent of heterosis for grain yield and its component characters was estimated in a seven-parent F_1-diallel cross in rice under the cold stress conditions of Palampur, representing sub-temperate climate of the mid hills of Himachal Pradesh. The highest heterotic effects for grain yield were observed in 'Himalaya 1'/'Phul Patas 72' and 'China 988'/'Himdhan' hybrids, which gave 60.36 and 32.48% heterosis, respectively, over mid parent, 38.76 and 26.86% heterosis, respectively, over high parent and 32.30 and 26.86% heterosis, respectively, over the best variety, 'Himdhan'. Heterosis for grain yield in these crosses was due to an increase in tiller number, panicle length, spikelets/panicle and 1,000-grain weight. Large number of crosses exhibited significant heterosis for high spikelet sterility and the majority of them had significant heterosis for late flowering, taking more than 120 days to flower, which resulted in lack of heterosis for grain yield in such crosses due to cold stress at the reproductive stage.

Key words: Heterosis – Yield – Yield components – Rice – Cold stress

Introduction

The successful development of hybrid maize in the 1930's provided an important impetus to the breeders of other crops, including self-pollinating cereals like wheat and rice, to utilize the principles of hybrid production. The basis of such genetic manipulation is the phenomenon of heterosis. A critical pre-requisite for the successful production of hybrid varieties is that sufficient hybrid vigor should be available through specific parental combinations so that the yields of the hybrids exceeds the best conventionally bred variety. The exploitation of hybrid vigor in rice appears to be an alternative for making a breakthrough in rice yields. The commercial hybrids of rice being grown at present have a longer growth duration and are not suitable for a subtemperate climate, where low temperatures further extend the growth duration of varieties. Under the subtemperate climate of the mid-hill areas of Himachal Pradesh, varieties taking more than 120 days to flower have very low yields. Hence, the present investigation was undertaken to assess the extent of heterosis in rice for grain yield and its components under cold stress conditions.

Materials and methods

Seven rice cultivars ['Himalaya 1', HPU 8020', 'China 988' (CH 988), 'Himdhan', 'Madhumalti' (MM), 'Paul Patas 72' (PP 72) and 'R 575'] were crossed in a diallel fashion (excluding reciprocals) during Kharif, 1981. 'Himalaya 1' and 'HPU 8020' are two high-yielding semi-dwarf indica varieties, of which the former is an early variety released for cultivation up to 1,800 m above m.s.l, while the latter is a late maturing mutant of the 'Bala' variety, proposed for release in the low altitude areas of H.P. Semi-dwarf varieties were introduced into H.P. only in the early 70's. All others are local tall indicas, except for 'Himdhan', which is an improved tall indica developed from the cross R575/TN1 and is suitable for cultivation up to an altitude of 1,500 m above m.s.l. The varieties represent a great diversity for morphological, physiological and quality traits and are being grown under varying agronomic situations. The 21 F_1's, along with seven parents, were

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Table 1. Magnitude of F_1 heterosis (%) over mid-parent (MP) and high-parent (HP) with respect to yield and its component characters in a 7-parent F_1 diallel in rice

Cross	Days to flower		Plant height		Tillers/plant		Panicle length		Spikelets/panicle	
	MP	HP	MP	HP	MP	HP	MP	HP	MP	HP
'Himalaya 1'/										
'HPU 8020'	−0.46	−7.76**	7.47	1.55	17.16	10.25	5.94	−1.42	1.82	−12.33
CH 988	−6.23**	−11.87**	−4.52	−22.46**	38.38**	14.89	0.70	−1.04	−2.22	−6.49
'Himdhan'	4.56*	−0.70	7.90*	−12.89**	48.26**	40.13**	13.15**	9.38**	29.01**	11.94
MM	4.38*	−4.34	5.76	−19.88**	7.47	6.19	4.89	0.59	2.78	2.42
PP 72	12.82**	5.05*	6.62*	−22.77**	25.80*	11.62	8.46**	−0.46	−5.81	−41.14**
'R 575'	14.34**	4.81*	10.03*	−12.51**	33.08	24.64	10.25**	2.55	28.34**	3.52
'HPU 8020'/										
CH 988	8.71**	7.07**	11.10**	−5.48	28.72**	12.56	13.75**	4.58	35.20**	12.14
'Himdhan'	1.15	−3.69	13.04**	−4.45	49.46**	48.77**	9.96**	−0.83	15.69	14.65
MM	26.15**	24.66**	−0.78	−21.67**	−4.74	−9.32	−1.54	−11.86**	20.42*	3.99
PP 72	28.98**	28.28**	−13.25**	−34.75**	30.27*	9.63	7.62*	−7.49*	−20.86**	−46.74**
'R 575'	18.73**	17.35**	−1.84	−18.37**	5.61	−6.52	2.30	−10.96**	2.22	−5.49
CH 988/										
'Himdhan'	3.02	1.90	8.73**	7.87*	25.51*	9.31	3.53	1.36	20.40	0.59
MM	29.45**	26.02**	−0.35	−9.07**	1.38	−15.35	−1.82	−4.73	20.28	14.63
PP 72	26.99**	25.75**	−17.70**	−29.27**	−0.92	−25.12*	−4.49	−11.29**	−29.12**	−56.48**
'R 575'	22.14**	18.91**	−3.60	−6.24	23.89*	−2.32	1.09	−4.82	20.91*	−5.72
'Himdhan'/										
MM	12.25**	8.11**	−2.11	−10.02**	14.75	9.72	2.68	1.83	−4.18	−16.61
PP 72	14.22**	11.88**	−1.03	−14.38**	1.30	−14.42	6.54*	0.95	−3.47	−35.33**
'R 575'	10.77**	6.70**	−1.07	−3.02	18.52	5.33	4.14	0.06	15.77	6.15
PP 72	13.45**	11.50**	−2.76	−9.02**	13.89	0.00	1.12	−3.43	−18.44**	−48.96**
'R 575'	13.64**	13.66**	−1.75	−8.00*	24.30	15.12	−2.28	−5.35	−7.59	−25.26**
PP 72/										
'R 575'	10.90**	8.53**	2.94	−9.39**	5.99	0.00	0.67	−0.78	−26.37**	−48.33**
SE±	2.22	2.57	3.13	3.62	1.25	1.44	0.69	0.80	16.33	18.86

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

continued overleaf

+ Standard parent

grown in a randomized complete block design with three replications during kharif, 1982 at Palampur (India). Each entry had two rows of 4.5 m length. The row to row and plant to plant spacing was kept at 20 and 30 cm, respectively. The data were recorded on 10 plants in each entry for days to flowering, plant height, tillers/plant, panicle length, spikelets/panicle, panicle density, sterility percent, 1,000-grain weight and yield/plant. The heterotic effects were computed as percentage increase or decrease in mean values over the mid and high parent for all the characters. Standard heterosis for yield was calculated over the highest yielding standard cultivar, 'Himdhan'.

Crops suffered cold temperature stress from flowering to maturity. The table below indicates the flowering pattern of varieties and crosses and the corresponding mean weekly maximum and minimum temperatures. A perusal of the data reveals that the mean minimum temperature dropped abruptly after the 38th week from 17.8 to 13.9°C, which coincided with the flowering period of those crosses taking more than 120 days to flower. Poor panicle exsertion, degeneration of apical spikelets and poor grain filling are the other manifestations of the cold stress which occur at the location.

Results and discussion

Under the sub-temperate conditions of Palampur, where low temperature at the reproductive stage from flowering to maturity is a limiting factor, the expression of heterosis is restricted and hybrids with long duration suffer from high sterility and consequently reduced yields. As such, identification of heterotic combinations of suitable duration for high yield under cold stress conditions should be done under such environmental conditions.

As a result of the ceiling imposed by cold temperatures on flowering duration, only two out of 21 crosses, viz. 'Himalaya 1'/PP 72 and CH 988/'Himdhan' in the present study, exhibited significant heterosis for yield over the high parent and standard parent. In addition, four other crosses, viz. 'Himalaya 1'/'HPU 8020', 'HPU 8020'/CH 988, 'HPU 8020'/'Himdhan' and

Table 1 (continued)

Cross	Panicle density		Sterility percent		1,000-grain weight		Yield/plant		
	MP	HP	MP	HP	MP	HP	MP	HP	SP+
'Himalaya 1'/									
'HPU 8020'	− 5.82	− 23.64**	− 12.36	− 44.96**	1.09	0.99	31.49*	27.78	− 5.67
CH 988	− 3.39	− 8.03	384.89**	226.99**	3.64	− 3.53	− 64.73**	− 68.94**	− 71.58**
'Himdhan'	14.51	2.44	264.83**	145.22**	5.08*	− 6.21*	13.01	− 4.13	− 4.13
MM	− 2.28	− 5.94	115.01**	50.52*	7.43**	− 1.29	7.66	3.43	− 21.82
PP 72	− 8.59*	− 40.06**	46.90*	− 11.34	9.96**	8.01*	60.36**	38.76**	32.30**
'R 575'	17.56*	0.74	142.52**	41.47**	12.27**	− 4.60	− 29.95*	− 31.53	− 51.31**
'HPU 8020'/									
CH 988	14.91*	− 10.27	13.48	− 1.56	1.80	− 4.99	28.60*	16.16	6.32
'Himdhan'	4.07	− 6.99	58.40**	38.16*	7.42**	− 4.04	25.47*	9.05	9.05
MM	18.21*	− 6.91	174.59**	125.24**	− 28.58**	− 34.31**	− 72.77**	− 73.09**	− 79.66**
PP 72	− 45.96**	− 59.97**	62.73**	47.13**	− 0.07	− 1.94	− 86.00**	− 87.58**	− 88.16**
'R 575'	− 1.01	− 7.41	127.67**	87.89**	− 4.56	− 18.83**	− 85.58**	− 86.29**	− 89.88**
CH 988/									
'Himdhan'	16.56	− 0.13	35.04	34.19	2.90	− 1.67	32.48**	26.86*	26.86**
MM	21.59*	20.27	197.79**	178.66**	− 23.73**	− 24.79**	− 57.30**	− 61.02**	− 64.32**
PP 72	− 23.50**	− 51.64**	155.21**	103.40**	− 29.80**	− 35.73**	− 82.63**	− 82.98**	− 83.77**
'R 575'	21.54**	− 0.01	97.06**	45.64**	− 18.59**	− 26.25**	− 49.45**	− 56.36**	− 60.05**
'Himdhan'/									
MM	− 7.34	− 19.84	182.39**	162.70**	3.68	0.43	− 19.19	− 29.05*	− 29.05**
PP 72	− 7.17	− 35.98**	89.25**	51.55**	8.08**	− 5.04	− 50.74**	− 51.89**	− 51.89**
'R 575'	10.38	5.11	73.00**	28.39**	3.77	− 1.89	− 35.45**	− 46.26**	− 46.26**
MM/									
PP 72	− 7.98	− 41.21**	83.17**	39.00**	− 5.74*	− 14.80**	− 37.90**	− 44.33*	− 46.92**
'R 575'	− 4.56	− 20.77**	13.06	− 19.91	− 13.37**	− 20.51**	− 7.17	− 12.74	− 34.04**
PP 72/									
'R 575'	− 26.06**	− 47.53**	4.68	− 13.98	4.79*	− 12.25**	28.22*	8.83	3.76
SE±	0.54	0.63	4.08	4.72	0.63	0.73	2.46	2.84	2.84

Standard week	Mean weekly temperature °C		Crosses/varieties which flowered during the week
	Maximum	Minimum	
34	26.6	19.1 (18.0–20.0)	'Himalaya 1', 'Himalaya 1'/CH 988
35	26.3	17.8 (16.9–18.5)	
36	27.4	18.8 (17.4–19.9)	CH 988, 'Himdhan', 'Himalaya I'/'HPU 8020', 'Himalaya 1'/'Himdhan', 'Himalaya 1'/MM, 'HPU 8020'/Himdhan'
37	27.3	17.4 (15.5–18.0)	MM, PP72, R 575, 'HPU 8020', 'Himalaya 1'/PP 72, CH 988/Himdhan
38	26.7	17.8 (17.0–18.8)	'Himalaya 1'/'R 575', 'HPU 8020'/CH 988, 'Himdhan'/MM, 'Himdhan'/PP 72, 'Himdhan'/ 'R 575', PP 72/'R 575'
39	25.3	13.9 (12.0–17.9)	MM/PP 72, MM/'R 575'
40	25.9	14.7 (13.9–15.5)	'HPU 8020'/'R 575', CH 988/'R 575'
41	24.2	14.4 (13.0–15.2)	'HPU 8020/MM', HPU 8020'/PP 72, CH 988/MM CH 988/PP 72

PP 72/'R 575', displayed heterosis over the mid parent only (Table 1).

The cross 'Himalaya 1'/PP 72 exhibited the highest heterosis for grain yield over mid parent (60.36%), high parent (38.76%) and standard parent (32.30%) and was simultaneously found to have significant heterosis for tillers/plant and panicle length over mid parent and for 1,000-grain weight over both mid and high parents. However, there was high negative heterosis for spikelets/panicle over the high parent, PP 72, which had an exceptionally high spikelet number of 539 (range 331 to 665).

The cross CH 988/'Himdhan' also showed significant heterosis for grain yield over the mid parent (32.48%), high parent (26.86%) and standard parent (26.86%). This cross exhibited significant heterosis for tillers/plant over mid and high parents.

The cross 'Himalaya 1'/'HPU 8020', involving two semi-dwarfs, exhibited heterosis for yield over the mid parent (31.49%) only. This was the only cross which had significant heterosis for early flowering and low spikelet sterility over the high parent, 'HPU 8020'.

In the cross 'HPU 8020'/CH 988, high heterosis over mid parent (28.60%) for yield was accompanied by significant heterosis for plant height, tillers/plant, panicle length, spikelets/panicle and panicle density over mid parent.

In the cross 'HPU 8020'/'Himdhan', high heterosis for yield over mid parent (25.47%) was accompanied by significant heterosis over mid parent for 1,000-grain weight, plant height and panicle length, and over both mid and high parents for tillers/plant.

The cross PP 72/'R 575', involving the tall local varieties, also exhibited significant heterosis over the mid parent (28.22%) and displayed simultaneous heterosis for 1,000-grain weight ober the mid parent.

A large number of crosses exhibited highly significant heterosis for high spikelet sterility over both mid and high parents and the majority of them also had heterosis for late flowering and took more than 120 days to flower. These crosses flowered at a time which coincided with low temperatures. Hence, cold temperatures, coupled with such other genetic causes as genetic diversity among the parents, resulted in high sterility and contributed to the lack of heterosis for grain yield in these crosses. Crosses of 'Himalaya-1' with CH 988, 'Himdhan' and 'Madhumalti' and the cross 'HPU 8020'/'Himdhan', though showing high heterosis for spikelet sterility in an undesirable direction, were early flowering. Hence, high sterility can be attributed mainly to genetic causes.

For tillers per plant, only two crosses, viz. 'Himalaya 1'/'Himdhan' and 'HPU 8020'/'Himdhan', exhibited heterosis of 40.13% and 48.77% respectively, over high parent. Seven other crosses exhibited heterosis over

Table 2. Mean performance of hybrids showing heterosis for yield over high and standard parents

Parent/cross	Days to flower	Plant height (cm)	Tillers/ plant	Panicle length (cm)	Spikelets/ panicle	Panicle density	Sterility %	1,000-grain weight (g)	Yield/ plant (g)	Grain length (mm)	L/B ratio	Protein (%)
'Himalaya 1'	94.0	61.2	9.5	22.8	135	5.9	7.9	22.1	16.9	6.3	2.9	8.8
'Phul Patas 72' (PP 72)	109.0	136.3	7.3	27.3	539	19.6	38.1	21.4	23.1	6.8	3.0	7.8
'Himalaya 1'/PP 72	115.0	105.3	10.6	27.2	317	11.7	33.8	23.9	32.1	6.8	2.9	7.9
'China 988' (CH 988)	107.0	98.0	14.3	23.4	123	5.3	22.6	25.7	22.2	6.1	2.3	7.8
'Himdhan'	105.0	99.5	10.6	24.5	183	7.4	22.9	28.2	24.3	6.0	2.1	8.3
CH 988/'Himdhan'	109.0	107.4	15.7	24.8	184	7.4	30.8	27.7	30.8	6.1	2.2	9.0

mid parent only and four of them involved 'China 988' as one of the parents. For panicle length, only 'Himalaya 1'/'Himdhan' displayed significant heterosis over the high parent. Among other crosses exhibiting heterosis over mid parent only, three crosses involved PP 72 as one of the parents. PP 72 had the longest panicles (27.34 cm). For spikelets/panicle, crosses of 'R 575' with 'Himalaya 1' and CH 988, crosses of 'HPU 8020' with CH 988 and 'Madhumalti' and cross 'Himalaya 1'/'Himdhan' exhibited heterosis over mid parent only. Crosses of PP 72 (539 spikelets/panicle) had spikelet numbers ranging from 235 in the cross CH 988/PP 72 to 348 spikelets in cross 'Himdhan'/ PP 72. For 1,000-grain weight, out of the seven crosses showing heterosis over mid parent, four involved 'Himalaya 1' as one of the parents and one of them, 'Himalaya 1'/PP 72, also displayed heterosis over high parent.

In general, the expression of heterosis for yield and yield contributing characters in the desirable direction was exhibited in the cross combinations involving a semi-dwarf and a tall variety, suggesting the presence of diverse genes with positive effects in these combinations.

From the point of view of commercial exploitation of hybrid vigour, crosses 'Himalaya 1'/PP 72 and CH 988/'Himdhan', with 32.30% and 26.86% standard heterosis, appeared to be promising. Studies at IRRI during 1980/81 have shown heterosis levels as high as 73, 59 and 34% over mid, high and standard parents, respectively (Virmani et al. 1982). Panwar et al. (1983) reported as high as 42.44% heterosis for yield over high parent and check in the cross 'IR 8'/'Sona'. They reported that the heterosis for grain yield in heterotic crosses was due to an increase in one or more components of yield. In the present case also in the cross 'Himalaya 1'/PP 72, heterosis for yield was due to increased tiller number (10.6), panicle length (27.2 cm), spikelets/panicle (317 nos) and 1,000-grain weight (23.9 g), and in CH 988/'Himdhan', it was accompanied by an increase in tiller number (15.7), panicle length (24.8 cm), spikelets/panicle (184 nos) and 1,000-grain weight (27.7 g). 'Himalaya 1'/PP 72 had a grain length of 6.8 mm, L/B ratio of 2.9 and protein content of 7.9%, whereas CH 988/'Himdhan' had a grain length of 6.1 mm, L/B ratio of 2.2 and protein content of 9.0%. The cross CH 988/'Himdhan' was a week earlier in flowering than 'Himalaya-1'/PP 72, which took 115 days to flower (Table 2).

The other crosses, showing heterosis for yield over mid parent only, can not suite the heterosis breeding program but can be exploited for the development of pure line varieties through conventional breeding methods.

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