Heterosis for Growth and Development Characteristics in Rice

B.K. Joshi[1], L.P. Subedi[2]

[1] *Agriculture Botany Division, NARC, Khumaltar, Lalitpur*

[2] *Institute of Agriculture and Animal Sciences, Tribhuvan University, Rampur, Chitwan*

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Abstract

Knowledge of the degree and direction of hybrid vigor is essential for its commercial exploitation. Heterosis, heterobeltiosis and standard heterosis were studied in 14 crosses of rice (*Oryza sativa* L.) cultivars with three wild aborted male sterile lines. These crosses showed marked variations in the expression of heterosis, heterobeltiosis and standard heterosis for plant height, days to flowering, days to maturity straw and grain yield. Heterosis ranging from –8.7 to 5.5% for days to flowering, -3.8 to 86.6% for plant height and 7.7 to 178.4% for straw yield, and –54.99 to 139.2% for grain yield was observed. Four hybrids showed negative significant heterobeltiosis for days to flowering, 11 hybrids were shorter in height than male parents and 13 hybrids expressed heterobeltiosis for straw yield. Most of the hybrids matured earlier and yielded higher grain and straw than the Masuli cultivar with appropriate choice of parental lines, it possible to develop F_1 rice hybrid possessing desired plant height, growth duration, straw, and grain yield.

Keywords: F_1, heterobeltiosis, *Oryza sativa*, Standard heterosis

Introduction

Heterosis (also called hybrid vigor) in rice was exploited commercially in China, India, Vietnam and the Philippines. Fifty five percent of the 32 million ha of rice area in China is under hybrid rice accounting for more than 66% of the total rice production (Ahmad *et al.* 1996). In India more than 60,000 ha were planted to hybrid rice in various part of the country (Ahmad 1996). Cultivation of F_1 hybrid was not started formaly in Nepal (S.P. Khatiwada, personal communication). Davis and Rutger (1976), and Virmani *et al.* (1981) reviewed on heterosis in various agronomic traits of rice. Virmani *et al.* (1981) reported a singnificant positive mid and high parent heterosis for yield ranging from 1.9 to 369% in rice. Standard heterosis for yield ranging from 16 to 63% was reported by Rutger and Shinjyo (1980) and from 29 to 45% by Yuan *et al.* (1994). Virmani *et al.* (1982) observed 54 and 34% heterosis for better parent and standard heterosis respectively. In China yield under the large scale production exceeded the best conventionally bred cultivars by 20 to 30% (Lin & Yuan 1980). Jennings (1967) found significant heterosis for vegetative growth to be negatively associated with yield in hybrids derived from tall parents. Virmani *et al.* (1981, 1982) observed significant standard heterosis for both vegetative growth and grain yield. Khaleque *et al.* (1977) and Mallick *et al.* (1978) observed the growth duration of rice hybrids to be shorter than the mid parent value. Most of the heterotic rice hybrids were late maturing than their parents (Lin & Yuan 1980). Jones (1926) observed hybrid vigor with respect to height of plants. Both positive and negative heterosis, and heterobeltiosis for plant height were observed by Anandakumar and Sree Rangasawmy (1986), Singh *et al.* (1980), Nijaguna and Mahadevappa (1983). Peng and Virmani (1996) reported positive and negative heterosis, hetrobeltiosis and standard heterosis for plant height and days to flowering. Nijaguna and Mahadevappa (1983) observed both positive and negative heterosis and heterobeltiosis for straw yield, biological yield and days to heading. Plant height of F_1 hybrids were taller than the parents and no heterosis was observed for days to flowering by Ponnuthurai *et al.* (1984). Singh *et al.* (1980) reported both positive and negative heterosis and heterobeltiosis for days to flowering and maturity.

It is important step to know the performance of F_1 hybrids before exploitation in commercial scale. For practical exploitation of hybrid vigor in rice, emasculation is major constraint but the use of male sterile lines increase the chance of identifying more heterotic hybrids. In addition, parents should be locally adopted and should perform well in hybrid combinations. Only the information on heterotic response for yield and yield components is not complete evidence for commercial exploitation of hybrid vigor. Equally, heterosis for plant height, days to flowering, days to maturity, straw, and grain yield are considered important for adapting the F_1 hybrid by farmers. Hence, male sterile lines were used for the estimates of heterosis, heterobeltiosis and standard heterosis for growth and development characters: plant height, days to flowering, days to maturity, straw, and grain yield.

Materials and Methods

This experiment was conducted in screen house and in experiment farm at the Institute of Agriculture and Animal Sciences (IAAS), Rampur, (84^0 29' E and 27^0 37' N, and 224 masl) Nepal during the dry and wet seasons of 1998. Eight improved Nepalese cultivars, six landraces, and three wild aborted cytoplasmic-genetic male sterile (CMS) lines (Table 1 and 2) were used in the study. The improved cultivars were obtained from National Rice Research Program (NRRP), Hardinath, CMS lines from International Rice Research Institute (IRRI), the Philippines and the landraces were kindly provided by R. C. Sharma (Professor, IAAS, Rampur).

Table 1. Improved rice cultivars, landraces and CMS lines used in this study, Rampur, Nepal, 1999

A. Improved cultivars

Cultivar	Pedigree	Parentage	Origin	Grain type	Reaction to diseases[a]	
					Bl	BB
Bindesowari	IET1444	TN1/Co29	India	Medium	MR	MS
Chaite-6	NR274-7-3	NR6-5-46-50/IR28	Nepal	Medium	R	R
Janaki	BG90-2	Peta 3/TN//Renadja	Sri Lanka	Coarse	R	MR
Sabitri	IR2071-124-6-4	IR 1561/IR1737// CR94-13	IRRI .	Coarse	MR	MR
Radha-11	TCA80-4	Local selection	India	Medium	S	MR
Kanchan	IR39341-4-PL-P28	CR 126-42-5/IR 2061-21-3	IRRI	Medium	MR	-
Khumal-4	NR10068-76-1	IR 28/Pokhreli Masino	Nepal	Fine	R	-
Khumal-7	IR7167-33-2-2	Chaina1039DEFMUT/Ka18-361-1-8-6-10	IRRI	Coarse	R	-
Masuli	Mahsuri	Mayang Ebos80*2/ Taichumg65	Malaysia	Fine	S	MR

[a] Bl-Blast, BB-Bacterial blight, MR- Moderately resistant, R-Resistant, S- Susceptible
Source: NRRP, 1997

B. Landraces

Landraces	Origin	Remarks
Deharadune	Nepal	All landraces are popular local cultivars with intermediate statured of hilly area of Nepal. They mature earlier than Terai local cultivars and are field resistant to blast and bacterial leaf blight
Ratodhan	Nepal	
Gogi	Nepal	
Kature	Nepal	
Chiunde	Nepal	
IAR-97-34	Nepal	

C. CMS lines of wild aborted type

CMS line	Origin	Parentage	Remarks
IR58025A	IRRI	IR4843A/8*Pusa167-120	Stable in sterility, best combiner for yield, has aromatic long slender grains, developed more than 50 hybrids using this line in India
IR62829A	IRRI	IR46828A/8*IR29744-94	Stable in sterility, has functional male sterility, very good combiner, developed more than 20 hybrids using this line in India
IR68888A	IRRI	IR62829A/6*IR62844-15//IR629744-94	Stable in sterility, good combiner
Maintainer			
IR58025B	IRRI	IR48483A/8*Pusa167-120	
IR62829B	IRRI	IR46828A/8*IR29744-94	
IR68888B	IRRI	IR62829A/6*IR62844-15//IR629744-94	

Source: DRR, 1996

Table 2. Days to flowering and plant height of cultivars/lines used in this study Rampur, Nepal, 1999

Cultivar/line	Days to flowering	Plant height	Reference
Bindesowari	93	Semi dwarf	NRRP, 1997
Chaite-6	88	Semi dwarf	NRRP, 1997
Janaki	100	Semi dwarf	NRRP, 1997
Sabitri	105	Semi dwarf	NRRP, 1997
Radha-11	113	Intermediate	NRRP, 1997
Kanchan	108	Semi dwarf	NRRP, 1997
Khumal-4	109	Intermediate	NRRP, 1997
Khumal-7	111	Semi dwarf	NRRP, 1997
Deharadune	86	Intermediate	Field Book, 1998
Ratodhan	83	Intermediate	Field Book, 1998
Gogi	81	Intermediate	Field Book, 1998
Kature	95	Intermediate	Field Book, 1998
Chiunde	95	Intermediate	Field Book, 1998
IAR-97-34	101	Intermediate	Field Book, 1998
IR58025A	105	Semi dwarf	DRR, 1996
IR62829A	95	Semi dwarf	DRR, 1996
IR68888A	95	Semi dwarf	DRR, 1996

Many factors such as wind, insect pest, rainfall etc., make the crossing difficult in the field, therefore in this experiment, F_1 seeds were produced in the screen house. Before crossing, pollen sterility was tested on each plant of CMS lines. This was determined by staining pollen grains in 1% potassium iodide-iodine (I-KI) solution. The CMS plants showing completely sterility were used for crossing. Approach method (Erickson 1970) was used for pollinating the seed parents. Field experiment, consisting of 14 F_1's, 14 pollen parents, three CMS lines, and one check, Masuli (also called Mahasuli in Malaysia) was conducted to estimate the heterosis, heterobeltiosis and standard heterosis. Dormancy of F_1 seeds was broken by keeping them at 50 ^{0}C for four days for growing in the field during the wet season of 1999. For rising seedlings, trays of 30 cm x 20 cm size each were filled with soil and compost in the ratio of 2:1. The pre-germinated seeds were seeded in a spacing of 10 cm between solid seeded rows of 30 cm long in tray. Irrigation and weeding in trays were done as necessary.

Field layout and analytical procedures

The field was laid out in a randomized complete block with three replications. The pollen parent was planted beside their F_1 and CMS line planted after the pollen parent. Masuli was planted in six replications for getting more accurate data. Field was fertilized at the rate of 120, 60 and 60 kg N, P, K ha^{-1} respectively. Half of the nitrogenous fertilizer was applied as a basal dose and half top-dressed after one month of transplanting. Twenty-one days old seedlings were transplanted in the field in two rows in each plot with 10 hills per row at spacing of 20 cm x 20 cm. Single seedling was planted to each hill. Rouging was carried out at both vegetative and flowering stages. All other standard agronomic practices were followed.

Following characters from the two rows of each plot were recorded according to IRRI (1980), and Ba Bang and Swaminathan (1995).

- Days to flowering: number of days from seeding to the day of 50% plants showed panicle exertion.
- Days to maturity: number of days from seeding to the day of 80% plants matured.
- Plant height including panicle length: in cm, from the ground to the tip of the main panicle at maturity.
- Grain yield: weight of dried grains (g m^{-2}).
- Straw yield: Biological yield minus grain yield (g m^{-2}).

Grain and straw weight were adjusted at 14%

moisture as suggested by Gomez (1972). F_1 hybrid performance was evaluated on the basis of the estimates of heterosis (Matzinger & Cockerham 1962), heterobeltiosis (Fonseca & Patterson 1968) and standard heterosis (Virmani *et al.* 1982) as follows:

$$\text{Heterosis} = \frac{F_1\text{-MP}}{\text{MP}} \times 100$$

$$\text{Heterobeltiosis} = \frac{F_1\text{- BP}}{\text{BP}} \times 100$$

$$\text{Standard heterosis} = \frac{F_1\text{- CC}}{\text{CC}} \times 100$$

where, F_1 is the average performance of the F_1 hybrid; MP, the average performance of mid parent, BP, the average performance of better parent, and CC, average performance of commercial cultivar. Thus, heterosis is expressed as percent increase of the F_1 hybrids above the MP, BP and CC.

The analysis of the variance was performed following Gomez and Gomez (1984). The square for the interaction of blocks by entries was used to test the significance of the mean square for entries. The F test was used to test the significance of mean squares. Least significant difference test was used to compare the means. MSTAT (1986) software was used to analyze the data.

Results and Discussion

Heterosis, heterobeltiosis and standard heterosis for five characters were given in Table 3. There were wide variations in heterosis, heterobeltiosis and standard heterosis for plant height, days to flowering, days to maturity, straw, and grain yield. On an average hybrid showed superiority over inbred lines in all the traits. Significant positive heterobeltiosis and standard heterosis for yield were noticed in IR68888A/Radha-11, IR62829A/Ratodhan, IR62829A/Kature, IR58025A/Kanchan, and IR58025A/Sabitri (Table 3). Five hybrids showed highly significant increase in yield with a standard heterosis from 56.68 to 369.27%. Three hybrids showed negative standard heterosis but, the values were statistically non significant. On an average hybrid showed superiority over inbred line in yield.

According to Swaminathan *et al.* (1972) heterobeltiosis of, 20% over better parent could offset the cost of hybrid seed. Thus, the crosses showing more than 20% of heterobeltiosis viz., IR68888A/Radha-11, IR58025A/Khumal-4, IR62829A/Ratodhan, IR62829A/Kature, IR58025A/Kanchan, and IR58025A/Sabitri may be exploited for hybrid rice production.

Maximum positive heterosis, heterobeltiosis for plant height was expressed by the hybrid IR58025A/Kanchan, to the extent of 62.6 per cent and 39.57 per cent respectively and IR68888A/Gogi with 35.26% was the maximum positive standard heterosis. IR62829A/Kature showed maximum negative values for heterosis (-3.28%) and heterobeltiosis (-33.33%) but maximum negative standard heterosis (-22.25%) was observed in IR58025A/Janaki. In all, seven crosses showed significant heterosis, two crosses showed significant heterobeltiosis and two crosses expressed significant standard heterosis for plant height. The results are similar to those obtained by Anandakumar and Sree Rangaswamy (1986), Singh *et al.* (1980), Ponnuthurai *et al.* (1984). Semi dwarf plant height is essential to get high yield in rice varieties, tall plant are usually susceptible to lodging and show low harvest index. On the other hand, very dwarf plants are related with low dry matter and low grain production. The tendency that hybrids were taller than the parents is very obvious for seven hybrids which showed 21.6 to 62.6 % significant positive heterosis and only one hybrid was significantly taller than the male parent 39.57% and two hybrids were significantly taller than the check (115.33 cm) by 2.88 to 35.26%. No hybrid was shorter than the mean height of the parent as well as than the shorter parents. Almost all crosses produced hybrids taller than the mean of the two parents.

Negative heterosis for days to flowering is usually desirable, because this will cause the hybrids to mature earlier as compared to the parent, thereby increasing their productivity per day per unit area. Mid parent heterosis for this trait was ranged from –8.68 to 5.52 % with a mean of –0.4% and standard error of 1.13. Seven hybrids had negative heterosis for days to flowering with a margin of –8.68 to –0.69% indicating the growth duration of most hybrids was shorter than that of the mid parent though there were seven hybrids which showed positive heterosis ranging from 0.37 to 5.52%. As compared with the male parents, seven hybrids showed earlier maturity and seven hybrids were later maturing (heterobeltiosis of 0.77 to 7%). Seven hybrids had no significant difference when compared to male parent. In comparison with the check in present study, which took 104 days to flower, all 14 hybrids showed negative heterosis ranging from –24.68 to –6.09%. The early flowering tendency of the hybrids has also been reported by Mallick *et al.* (1978), and Virmani *et al.* (1981, 1982). Therefore, F_1 rice hybrids are useful not only for their high grain yield per cropping season but also for their higher productivity brought about by their earlier maturity. The results thus

Table 3. Heterosis, heterobeltiosis, and standard heterosis (%) for growth and development characteristics in 14 crosses of rice. Rampur, 1999

S.N.	Parent Hybrid	Flowering	Days to maturity	Days to height, cm	Plant yield, g m^{-2}	Straw Grain yield, g m^{-2}
1	IR58025A	91	112	71	781.8	!
	Janaki	97	134	91	768.6	740.2
	IR58025A/Janaki					
	Heterosis	+3.90	+8.92**	+11.16	+22.16	!
	Heterobeltiosis	+0.69	0.00	-1.10	+23.21	-54.99**
	Standard Heterosis	-6.09**	-2.66	-22.25	-4.21	-20.87
2	Kanchan	88	121	99	632.7	454.3
	IR58025A/Kanchan					
	Heterosis	+0.37	+3.85*	+62.60**	+7.74	!
	Heterobeltiosis	+2.28	0.00	+39.53**	+20.43	+55.64*
	Standard Heterosis	-13.78**	-12.08**	+19.37	-22.93	+67.92**
3	Khumal-4	95	128	139	1114.4	1049.2
	IR58025A/Khumal-4					
	Heterosis	-8.68*	-3.57*	+28.34**	+33.10**	!
	Heterobeltiosis	-10.68**	-9.57**	-3.25	+13.24	-37.13**
	Standard Heterosis	-18.27**	-15.94**	+16.77	+27.64*	+56.68*
4	Sabitri	103	137	107	1191.1	750.2
	IR58025A/Sabitri					
	Heterosis	-0.69	+9.78**	+19.92	+8.42	!
	Heterobeltiosis	-6.48**	00	-0.32	-10.21	+37.29**
	Standard Heterosis	-7.38**	-0.96	-7.80	+8.18	+144.62**
5	Chaite-6	83	114	96	647.3	709.2
	IR58025A/Chaite-6					
	Heterosis	-1.34	+0.88	+27.05*	+29.73	!
	Heterobeltiosis	+3.63*	+0.29	+10.45	+43.20*	-42.50**
	Standard Heterosis	-17.63**	-17.39**	-8.38	-6.24	-3.15
6	IAR-97-34	93	129	125	794.2	710.3
	IR58025A/IAR-97-34					
	Heterosis	+1.26	+12.71**	+25.93*	+36.64*	!
	Heterobeltiosis	0.00	+5.43**	-1.34	+35.57*	-33.91*
	Standard Heterosis	-10.26**	-1.45	+6.65	+8.91	+11.49
7	IR62829A	83	108	77	823.7	!
	Deharadune	85	110	132	729.9	650.6
	IR62829A/Deharadune					
	Heterosis	-1.38	-0.61	+12.92	+22.95	!
	Heterobeltiosis	-2.35	- 1.22	-10.83	+30.85	!
	Standard Heterosis	-20.19**	-21.50**	+2.32	-3.40	!
8	Ratodhan	81	109	132	673.3	608.1
	IR62829A/Ratodhan					
	Heterosis	+5.48	+14.42**	+17.39	+9.21	!
	Heterobeltiosis	+7.00**	+14.06**	-7.30	+21.41	+57.39**
	Standard Heterosis	-16.66**	-9.91**	+6.36	-17.31	+127.30**

9	Kature	92	124	199	974.0	568.5
	IR62829A/Kature					
	Heterosis	+5.52	+10.47**	-3.75	+30.97*	!
	Heterobeltiosis	+0.72	+3.49**	-33.33**	+20.86	+42.39*
	Standard Heterosis	-11.22**	-7.01**	+15.04	+19.07	+92.25**
10	IR68888A	86	110	72	682.8	!
	Raddha-11	103	132	116	1144.2	826.0
	IR68888A/Radha-11					
	Heterosis	+1.36	+5.84**	+33.90**	+125.18**	!
	Heterobeltiosis	-7.14**	-2.87	+8.58	+79.78**	+139.20**
	Standard Heterosis	-7.74**	-7.32**	+9.52	+108.07**	+369.27**
11	Bindesowri	84	112	107	641.5	597.1
	IR68888A/Bindesowri					
	Heterosis	-4.32	-2.85	+2.60	+56.74**	!
	Heterobeltiosis	-3.18	-3.85*	-14.02	+61.78**	!
	Standard Heterosis	-21.80**	-21.74**	-20.23	+4.98	!
12	Khumal-7	80	109	127	597.3	650.9
	IR68888A/Khumal-7					
	Heterosis	-5.81	-1.37	+12.71	+88.83**	!
	Heterobeltiosis	-2.49	-0.92	-11.55	+102.35**	!
	Standard Heterosis	-24.68**	-21.74**	-2.60	+22.25	!
13	Gogi	85	112	166	703.8	517.7
	IR68888A/Gogi					
	Heterosis	-4.09	-2.26	+30.91**	+87.69**	!
	Heterobeltiosis	-3.53*	-2.99	-6.02	+84.89**	-25.92
	Standard Heterosis	-21.15**	-21.50**	+35.26**	+31.62*	-8.93*
14	Chiunde	83	110	168	539.9	438.7
	IR68888A/Chiunde					
	Heterosis	+2.77	+1.82	+21.61*	+128.35**	!
	Heterobeltiosis	+4.84**	+1.82	-13.07	+158.56**	!
	Standard Heterosis	+16.66**	-18.84**	+26.88*	+41.20**	!
15	Masuli	104	138	115	988.6	421.0
	Range					
	Heterosis	-9-+220	-4-+14	-4-+63	+8-+128	!
	Heterobeltiosis	-11-+116	-10-+14	-33-+40	-10-+159	-55-+139
	Standard Heterosis	-25—6	-22—6	-23-+35	-23-+108	-21-+369
	Mean					
	Heterosis	-0.40	+4.14	+21.67	+49.12	!
	Heterobeltiosis	-1.19	+0.26	-3.11	+48.99	+13.75
	Standard Heterosis	-15.25	-12.86	+5.49	+15.56	+83.66
	SE					
	Heterosis	+1.13	+1.65	+4.26	+11.16	!
	Heterobeltiosis	+1.31	+1.42	+4.35	+11.86	+19.75
	Standard Heterosis	+1.59	+2.13	+4.48	+8.67	+36.59

* Statistically significant at 5%, ** significant at 1%. ! all sterile spikelets.

suggest that one can expect to develop heterotic hybrids from the parents (CMS and restorers) possessing semi-dwarf plant height and medium maturity under well managed irrigated condition. The results on days to maturity were similar to days to flowering. Six hybrids showed highly significant positive heterosis for days to maturity and five hybrids matured earlier than mid parent values. Heterobeltiosis ranged from –9.6 to 14%. Only two hybrids matured significantly earlier than the pollen parents. All hybrids showed negative standard heterosis out of which 11 hybrids were highly significantly different from the Masuli for days to maturity. Heterosis, heteobeltiosis and standard heterosis in IR58025/Khumal, IR68888A/ Bindesowari, IR68888A/Khumal-7, IR62829A/ Deharadune and IR68888A/Gogi crosses were all negative. Similar results were reported by Singh*et al.* (1980). To develop the short duration cultivar and to increase the productivity with respect to time, the hybrids showing negative heterosis, heterobeltiosis and standard heterosis are useful.

The plant with shorter culm withstands lodging at high fertilizer levels but, produces less straw. Hence information on straw yield is useful. Heterosis, heterobeltiosis and standard heterosis of straw yield ranged from 7.74 to 128.35, -10.21 to 158.56 and –22.93 to 108.07 %, respectively. Mallick *et al.* (1978) reported a negative heterosis for plant height, a component of straw yield in several rice hybrids. Three hybrids expressssed significantly positive heterosis, heterobeltiosis and standard heterosis for straw yield. All hybrids produced more straw than their mid parents value, nine hybrids than male parents and 13 hybrids than Masuli. Nijaguna and Mahadevappa (1980) reported the similar results. Moderated increase in height becomes beneficial to hybrids. This may be due to the improvement in distribution of light interception.

IR68888A/Radha-11 showed highly positive significant heterosis, heterobeltiosis and standard heterosis for biological yield. Significant positive heterosis was observed in nine crosses, heterobeltiosis in seven crosses and standard heterosis in four crosses. Significant negative heterobeltiosis was noticed in three hybrids and standard heterosis in four. Nijaguna and Mahadevappa (1983) reported similar result. All CMS lines were shorter than male parents. This dwarfness character of CMS affected the mid parent values on yield and plant height.

Summary

Maximum variation was observed in heterobeltiosis and standard heterosis for yield among hybrids followed by straw yield. F_1 rice hybrids are useful not only for their high grain yield per cropping season. The results indicated the possibility of obtaining more heterotic hybrids only in specific cross combinations. With appropriate choice of parental lines it appears possible to develop F_1 rice hybrid possessing distinct yield superiority over the best-inbred lines. Crossing Nepalese landraces and cultivars with CMS lines expressed heterosis, heterobeltioss, and standard heterosis on days to flowering, days to maturity, plant height, straw and grain yield. Wide variation observed on hybrids for these characters suggested that F_1 could be developed with desired characteristics on rice.

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