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Heterosis for Yield and Yield Components in Rice

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Abstract

It is important to know the degree and direction of hybrid vigor for its commercial exploitation. Heterobeltiosis and standard heterosis were studied in 14 crosses between rice (*Oryza sativa* L.) cultivars (improved and landraces) and three wild aborted male sterile parents. These crosses showed marked variations in the expression of heterobeltiosis and standard heterosis for yield and yield components. Grain yield manifested highly significant heterobeltiosis and standard heterosis in five crosses. Heterobeltiosis ranging from –55 to 139% and standard heterosis from –11 to 369% were observed. Highest heterotic effect among the yield components was for panicle number plant^{-1} followed by spikelet number and panicle length. With appropriate choice of parental lines, it is possible to develop F_1 rice hybrid possessing distinct yield superiority over the best-inbred lines.

Key words: F_1, heterobeltiosis, hybrid vigor, *Oryza sativa*, standard heterosis

Introduction

Rice is the most important crop in Nepal accounting for 50% of the total cropped area and production of the country (Upadhyaya, 1996). Efforts to improve rice productivity in Nepal have resulted in the introduction of a large number of improved cultivars with varying yield potentials. During the last 20 years, the productivity of rice remained nearly constant in spite of first priority given to the agricultural sector development during the same period by the HMG, Nepal (NARC, 1998). To meet the demand created by increasing population and rising incomes, increasing the yield potential of rice beyond that of semi dwarfing cultivars is an important strategy. Experience in China, India and Vietnam had established that hybrid rice offers an economically viable option to increase cultivars yield beyond the level of semi dwarf rice cultivars. Heterosis (also called hybrid vigor) in rice was exploited commercially in China, India, Vietnam and the Philippines. Davis and Rutger (1976), Virmani et al. (1981) reviewed on heterosis in various agronomic traits of rice. Virmani et al. (1981) reported a significant 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 and Yuan, 1980).

It is important to know the performance of F_1 hybrids before exploitation in commercial scale. For practical exploitation of hybrid vigor in rice, emasculation is a major constraint, however the use of male sterile lines increases the chance of identifying more heterotic hybrids. In addition, parents should be locally adopted and should perform well in hybrid combinations. Hence, male sterile lines were used for the estimates of heterobeltiosis and standard heterosis for yield and yield components.

Materials and Methods

This experiment was conducted in a screen house and in experiment farm at the Institute of Agriculture and Animal Sciences (IAAS),

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Rampur, during the dry and wet seasons of 1998. IAAS is located at 84°29' E and 27°37' N and 224 masl. Eight improved Nepalese cultivars, six landraces and three wild aborted cytoplasmic-genetic male sterile (CMS) lines (Table 1) were used in this 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 RC Sharma, IAAS, Rmapur.

Table 1. Improved rice cultivars, landraces and CMS lines used in the study†

A. Improved cultivars

Cultivar	Parentage	Origin	Grain type	Reaction to diseases‡	
				Bl	BB
Bindesowari	TN1/Co29	India	Medium	MR	MS
Chaite-6	NR6-5-46-50/IR28	Nepal	Medium	R	R
Janaki	Peta 3/TN//Renadja	Sri Lanka	Coarse	R	MR
Kanchan	CR 126-42-5/IR 2061-21-3	IRRI	Medium	MR	-
Khumal-7	Chaina1039DEFMUT/Ka18-361-1-8-6-10	IRRI	Coarse	R	-
Khumal-4	IR 28/Pokhreli Masino	Nepal	Fine	R	-
Masuli	Mayang Ebos80*2/ Taichumg65	Malaysia	Fine	S	MR
Radha-11	Local selection	India	Medium	S	MR
Sabitri	IR 1561/IR1737// CR94-13	IRRI	Coarse	MR	MR

B. Landraces

Landrace	Origin	Remarks
Chiunde	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
Deharadune	Nepal	
Gogi	Nepal	
IAR-97-34	Nepal	
Kature	Nepal	
Ratodhan	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

† Source: NRRP, 1997. ‡ Bl, Blast; BB, Bacterial blight; MR, Moderately resistant; R, Resistant; S, Susceptible.
§ Source: DRR, 1996.

Screen house experiment

F_1 seeds were produced in the screen house. Seeding interval (SI) for making synchronized flowering was determined from the days to 50% flowering. After determining SI between the parental lines, the seeding sequence was worked out. Three seeds of each parental line were placed over the moistened filter paper in petri dishes and were incubated for two days at 37°C. The CMS seeds were fumigated with Phostoxin whereas seeds of other cultivars were used without treatment. Three pre-germinated seeds were seeded in each five liter capacity plastic bucket filled two-third with soils and farmyard manure (FYM) in the ratio of 2:1. One seedling was removed after a month. The pollen parents were seeded thrice to ensure continuous supply of pollen to the female parent during the period of flowering whereas the CMS lines were seeded only once. There were altogether 22 plastic buckets including 18 buckets for male parent and four for seed parent (Fig. 1). Buckets were filled with water after a week of transplanting. This condition was maintained up to the time of grain filling stage. Weeds were removed when observed in the buckets.

Bamboo pole

Plastic sheet

2.5m

Pole adjustment point

Bucket

Fig. 1. Crossing chamber for crossing seed parent (A) and pollen parent (T).

Construction of crossing chamber: Four bamboo poles each of 3 m long were pegged in four corner of the crossing block in which 22 plastic buckets were easily accommodated (Fig. 1). Plastic sheet of 2.5 m width was used to make cylinder shaped crossing chamber. Top portion of chamber was left open. Fourteen crossing chambers were constructed before the extrusion of panicles.

Crossing: Pollen sterility was tested on each plant of CMS lines before crossing. This was determined by staining of pollen grains in 1% potassium iodide-iodine (I-KI) solution (Chaudhary et al., 1981). At heading, about 10 spikelets from each plant were collected in the morning just before their blooming and fixed in 70% alcohol. All the anthers from six spikelets were taken out with the help of forceps and placed in the stain and observed in microscope (10x). The CMS plants that showed complete sterility were used in crossing program. Approach method (Erickson, 1970) was used for pollinating the seed parents. Spikelets of CMS lines were cut one third from the tip of the floret to facilitate crossing and bagged with label at the time when the upper florets begin to exert anthers. The cutting procedure was carried out before 10.00 hrs and/or after 15.00 hrs. The panicles of female and pollen parents were bagged with a narrow glassine bag. Panicles with similar height were maintained by placing bricks under respective pots. The panicles of parental lines were left for 2 to 3 days and tapped gently to disperse the pollen. Shaking of the pollen parent was repeated 3 to 4 times during the day at an interval of 30 minutes. The process was repeated for 3 to 5 days as a supplementary pollination. The seed parents were harvested separately at 21 to 25 days after pollination. The seeds were sun-dried for 2 to 3 days, bagged and labeled.

Field experiment

Field experiment, consisting of 14 F_1's, 14 pollen parents, three CMS lines and one check, Masuli was conducted to estimate the heterobeltiosis and standard heterosis. Dormancy of F_1 seeds was broken by keeping them at 50^oC for four days to grow in the field during the wet season of 1999. After breaking the dormancy, seeds were germinated in incubator as described earlier. For raising seedlings, trays of 30- × 20-cm size were filled with soil and FYM in the ratio of 2:1. The pre-germinated seeds were seeded in a 30 cm row spaced at 10 cm apart. Irrigation and weeding in nursery were done as needed.

Field layout and analytical procedures

The field was laid out in a randomized complete block with three replications. The F_1 was planted in the middle of the pollen parent and CMS line. Masuli was planted as a check variety in six replications. Field was fertilized at the rate of 120:60:60 kg $NP_2O_5K_2O$ ha^{-1}. Half of the nitrogen fertilizer was applied as a basal dose and half was top-dressed at one month after transplanting. Twenty-one day old seedlings were transplanted in the field in four rows of each plot with 10 hills per row at a spacing of 20- × 20-cm. Single seedling was planted in each hill. Irrigation was applied as necessary. Field was weeded twice at one-month interval after transplanting. Rouging was carried out at both vegetative and flowering stages. Gundhibug (*Leptocorisa oratorius* F.) was controlled by sprayings insecticide (Roger). All other standard agronomical practices were followed.

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

- Panicle number $plant^{-1}$: average from 20 hills $plot^{-1}$ at maturity.
- Number of filled grains $panicle^{-1}$: average from five panicles $plot^{-1}$.
- 1000-grain weight: randomly collected from seed lot of each plot.
- Grain yield: weight of clean and dry grains, g m^{-2}.
- Panicle length: average from five panicles $plot^{-1}$, measured from panicle base to tip.
- Spikelet fertility: number of seed set divided by total spikelet.

Grain yield and 1000-grain weight were adjusted at 14% moisture as suggested by Gomez (1972). F_1 hybrid performance was evaluated on the basis of the estimates of heterobeltiosis (Fonseca and Patterson, 1968) and standard heterosis (Virmani et al., 1982; Subedi, 1982) as follows:

Heterobeltiosis = $\{(F_1\text{-BP/BP})\} \times 100$
Standard heterosis = $\{(F_1\text{-CC})/\text{CC}\} \times 100$

Heterosis is expressed as percent increase of the F_1 hybrids above the BP and CC, where F_1 is the average performance of the $F_{1;}$ BP, the average performance of better parent and CC, average performance of commercial cultivar.

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 (LSD) was used to compare the means. MSTATC (1986) software was used to analyze the data.

Results and Discussion

Significant positive heterobeltiosis and standard heterosis for yield were noticed in IR68888A/Radha-11, IR62829A/Ratodhan, IR62829A/Kature, IR58025A/Kanchan and IR58025A/Sabitri (Table 2). Five hybrids showed highly significant increase in yield with a standard heterosis from 67.92 to 369.27%. Three hybrids showed negative standard heterosis but the values were not significant. On an average hybrid showed superiority over inbred line in yield and yield components (data not shown). In four crosses, most of the spikelets were sterile. Therefore, heterobeltiosis and standard heterosis for yield, grain number panicle^{-1}, spikelet fertility and 1000-grain weight were not estimated. It indicated that pollen parents of these sterile hybrids might not have restorer gene(s).

Table 2. Heterobeltiosis and standard heterosis for yield and yield components in 14 crosses of rice

SN	Hybrid	Yield, g m^{-2}	Panicle no. plant^{-1}	Spikelet no. panicle^{-1}	Grain no. panicle^{-1}	Spikelet fertility, %	1000-grain wt, g	Panicle length, cm
1	IR68888A/Radha-11							
	Heterobeltiosis	139.20**	80.53**	30.85*	35.31**	3.41	-2.04	10.5
	Standard heterosis	369.27**	98.10**	42.48**	46.86**	3.07	25.05*	14.91*
2	IR58025A/Janaki							
	Heterobeltiosis	-54.99**	0.00	13.1	-50.48**	-56.22**	-20.36**	4.15
	Standard heterosis	-20.87	-7.32	-4.6	-62.64**	-60.84**	45.55**	15.47*
3	IR58025A/Kanchan							
	Heterobeltiosis	55.64*	0	14.06	5.53	-7.48	3.41	9.88
	Standard heterosis	67.92**	7.32	16.66	-6.29	-19.67**	25.70*	12.03
4	IR58025A/Khumal-4							
	Heterobeltiosis	-37.13**	-10.87	36.12*	-12.34	-35.60**	0.29	-5
	Standard heterosis	56.68*	7.32	41.01**	-4.13	-32.01**	22.74*	14.31*
5	IR58025A/Sabitri							
	Heterobeltiosis	37.29**	-6.52	36.17*	33.15**	-2.22	0.35	9.47
	Standard heterosis	144.62**	4.83	17.16	17.44	0.23	34.53**	19.17**
6	IR58025A/Chaite-6							
	Heterobeltiosis	-42.50**	-9.82	38.71*	-7.21	-33.11**	-3.24	15.34*
	Standard heterosis	-3.15	12.14	13.14	-22.72*	-31.69**	23.81*	18.61**
7	IR68888A/Bindesowri							
	Heterobeltiosis	!	2.41	11.35	!	!	!	4.04
	Standard heterosis	!	2.41	4.67	!	!	!	17.45*
8	IR68888A/Khumal-7							
	Heterobeltiosis	!	17.65	21.43	!	!	!	5.69
	Standard heterosis	!	-2.49	2.74	!	!	!	11.73
9	IR62829A/Deharadune							
	Heterobeltiosis	!	31.32*	6.3	!	!	!	11.15
	Standard heterosis	!	2.41	11.56	!	!	!	5.41
10	IR62829A/Ratodhan							
	Heterobeltiosis	57.39**	40.55**	11.14	11.96	0.74	6.75	-1.02
	Standard heterosis	127.30**	26.77*	0.66	-5.92	-6.53	38.62**	13.15
11	IR68888A/Gogi							
	Heterobeltiosis	-25.92	48.02*	9.93	-57.09**	-60.97**	-7.88	7.77
	Standard heterosis	-8.93	-9.8	23.58*	-61.64**	-68.96**	58.64**	38.93**
12	IR62829A/Kature							
	Heterobeltiosis	42.39*	44.42**	29.08*	-0.34	-22.80**	4.67	-8.64
	Standard heterosis	92.25**	26.77*	14.96	-7.85	-19.84**	39.39**	27.20**
13	IR68888A/Chiunde							
	Heterobeltiosis	!	32.05	18.82*	!	!	!	12.27
	Standard heterosis	!	-19.53	45.69**	!	!	!	25.78**
14	IR58025A/IAR-97-34							
	Heterobeltiosis	-33.91*	17.9	9.30**	-40.45**	-45.52**	5.28	31.57**
	Standard heterosis	11.49	-19.53	48.55**	-12.99	-41.43**	27.36**	19.43**

Table 2. Continued…

SN	Hybrid	Yield, g m^{-2}	Panicle no. $plant^{-1}$	Spikelet no. $panicle^{-1}$	Grain no. $panicle^{-1}$	Spikelet fertility, %	1000-grain wt, g	Panicle length, cm
Range								
	Heterobeltiosis	-54.9 to 139	-10.8 to 80.5	6.3 to 38.7	-57 to 35.3	-60.9 to 3.4	-20.4 to 6.8	-8.6 to 31.6
	Standard heterosis	-10.9 to 369	-19.5 to 98.1	-4.7 to 48.6	-63 to 46.9	-68.9 to 3.07	22.7 to 59	5.4 to 38.9
Mean								
	Heterobeltiosis	13.75	20.54	20.45	-8.14	-25.98	-1.28	7.65
	Standard heterosis	83.66	7.79	19.88	-11.99	-27.77	34.14	18.12
SE								
	Heterobeltiosis	19.75	7.19	3.07	10.27	7.57	2.54	2.58
	Standard heterosis	36.59	7.79	4.75	10.34	7.69	3.67	2.19

* Statistically significant at 5%; ** Significant at 1%. ! All sterile spikelets. SE, Standard error.

Nine hybrids showed higher tillering capacity than check cultivar, but only three crosses manifested significant heterobeltiosis and standard heterosis for panicle number. Increase in panicle number was earlier observed by Singh et al. (1980), Anandakumar and Sree Rangasamy (1986) whereas Virmani et al. (1981, 1982), Jennings (1967) reported the negative heterosis for panicle number in the hybrids.

Hybrid vigor for panicle length was noticed in 14 crosses but only ten crosses showed significant standard heterosis. Singh et al. (1980) reported similar results. There were no positive significant heterobeltiosis and standard heterosis for spikelet fertility percentage. Six crosses showed highly negative significant heterobeltiosis and standard heterosis for spikelet fertility. Non significant positive or negative heterosis for this trait was reported by Virmani et al. (1981).

It appeared that hybrid vigor in yield were due to significantly high yield components eg tiller number, panicle length, spikelet number and 1000-grain weight. Grafius (1959) suggested that there is no separate gene system for yield per se and that the yield is an end product of the multiplication interaction between the yield components. This was confirmed by the present investigation where none showed hybrid vigor for yield alone. In five crosses, the heterotic effect in yield was along with hybrid vigor for panicle number, 1000-grain weight, spikelet number and panicle length thus, it is obvious that hybrid vigor for yield is the result of interaction of simultaneous increase in the expression of yield components. Among the yield components highest heterosis effect was for panicle number followed by spikelet number and panicle length. Similar result was observed by Mandal (1982). The major yield components in rice are number of panicles $plant^{-1}$, spikelet number $panicle^{-1}$, spikelet fertility percentage and 1000-grain weight (Virmani and Edwards, 1983). There are many reports showing evidence of significant positive high parent heterosis and standard heterosis for yield and yield components. Although the hybrids had fewer effective panicles per square meter, they had significantly more filled grains per panicles and larger seeds (Virmani et al., 1981). Significant positive mid parent, high parent and standard heterosis were observed for one or more of yield components in a number of crosses (Carnahan et al., 1972; Mohanty and Mohapatra, 1973; Saini and Kumar 1973; Mallick et al., 1978; Virmani et al., 1982; Luat et al., 1985; Peng and Virmani, 1994). Virmani et al. (1981) observed negative heterosis for panicle number per square meter. Most crosses showing significant standard heterosis for yield were found to be possessing heterosis for more than one component (Maurya and Sing, 1978; Virmani et al., 1982). Results obtained in China and at IRRI indicate that heterotic F_1 combinations usually show an increased sink size through an increase in spikelet per panicle, spikelet fertility percentage and 1000-grain weight (Virmani and Edwards, 1983).

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

Maximum variation was observed in heterobeltiosis and standard heterosis for yield among hybrids followed by grain number panicle^{-1}. 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. Yield components should be considered to increase the yield through selections.

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