International Journal of Agriculture, Environment and Biotechnology
Citation: IJAEB: 10(1): 1-10, February 2017
DOI: 10.5958/2230-732X.2017.00010.9

GENETICS AND PLANT BREEDING

Heterosis studies for yield & yield traits in rice (*Oryza Sativa* L.) under rainfed condition

Ravi Sahu, S.K. Singh, D.K. Singh, Prudhvi Raj Vennela*, S. Reddy Yerva, Dinesh Kumar, Monika Singh and N.D. Rathan

Department of Genetics & Plant Breeding, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, India

*Corresponding author email: vprudhviraj.2@gmail.com

Paper No. 546 Received: 21-01-2016 Accepted: 22-02-17

Abstract

Recognising the potential of hybrid rice to increase the productivity, the present investigation was conducted using three WA CMS lines (Pusa 6A, IR79156A and IR 68897A) and 31 male genotypes. The results manifested that the magnitude of heterosis for grain yield over better parent was significantly superior in eight hybrids with highest value of 60.83% in Pusa 6A x HUR-105. Sixteen hybrids showed significant positive heterosis over standard variety (NDR-97) with highest value of 116.48% in Pusa 6A x HUR-105. Twelve hybrids showed significant positive heterosis over standard hybrid (Arize-6444) with highest value of 85.69% in Pusa 6A x HUR-105. The top two high yielding heterotic crosses over the standard variety (NDR-97) were Pusa-6A x HUR-105 (116.48%) and Pusa-6A x Pantdhan-12 (114.74%). These two hybrids also exhibited significant positive heterosis for yield over standard hybrid (Arize 6444 Gold) i.e. 85.69% and 84.19% respectively. Hybrids Pusa-6A x HUR-105 and Pusa-6A x Pantdhan-12 showed significant positive standard heterosis for almost all the desirable yield attributing traits, apart from this Pusa-6A x Pantdhan-12 also showed significant negative standard heterosis over SH (Arize-6444) for days to 1st flowering, days to 50% flowering and days to maturity. The top heterotic crosses *viz.*, Pusa-6A x HUR-105, Pusa-6A x Pantdhan-12, Pusa-6A x URG-30, IR-79156A x Akshaydhan and Pusa-6A x NDR-359 and others which expressed higher standard heterosis for grain yield along with other desirable yield components should be tested in large scale under rainfed condition.

Highlights

- Hybrids, Pusa 6A × HUR-105 and Pusa 6A × Pantdhan-12 exhibited significant heterobeltiosis for yield and yield component traits.
- Hybrids, Pusa 6A × URG-30 and Pusa 6A × IET-22202 are short in their duration which is best suitable for rainfed condition. So, these hybrids may further be tested on large scale under rainfed conditions.
- IR 79156A × Akshaydhan may also be promoted in rainfed areas for large scale testing as these hybrids are much better than the standard checks NDR-97 and Arize-6444 Gold.

Keywords: Heterosis, Heterobeltiosis, Rice Hybrid, Standard Heterosis and WA-CMS

Rice (*Oryza sativa* L.) is one of the major staple food crops for about 65% of the world's population (Kumar *et al.* 2014). The productivity of rice has now stagnated. The present world rice area, production and productivity are 161.6 Mha, 480.7 Mt and 2.9 t/ha, respectively (USDA, Rice Outlook, 2015). In India, rice is grown in 44.0 Mha with the production of 106.0 Mt and productivity of 2.4 t/ha. It contributes 25% to agricultural GDP (USDA, Rice Outlook, 2015). In crop breeding, the use of hybrid vigour in first-generation seeds (or F_1) is well known. However, until about 30 years ago, its application in rice was limited because of the self-pollination character of the crop. In 1974, Chinese scientists successfully transferred the male sterility gene from wild rice to create the cytoplasmic genetic male-sterile (CMS) line and hybrid combination (Lin and Yuan, 1980). The first generations of hybrid rice varieties are three-line hybrids and given about 15 to 20 percent grain yield over the existing high-yielding varieties. In China, the area planted to hybrid rice is around 17.0 million hectares, which constitutes about 57% of the total rice area and has an average output capacity of 7.5 tonnes per hectare. At present India is growing hybrid rice in area of 2.50 mha, which is 5.70 % of total rice acreage and has an average output capacity of 4.79 t/ha (USDA Post, 2015). Even though hybrid rice programme was initiated in 1994 in India, the area and production of the hybrid varieties are slowly growing among the many states, which haven't even achieved 5 percent level of total rice cultivated area (FAO, 2014). It is expected that the area under hybrids in India will increase substantially and contribute towards increasing rice production. In about two decades of extensive efforts, India has so far released 78 rice hybrids by both public and private sectors for commercial cultivation (Directorate of Rice Development Report, 2015, Patna). These hybrids have yield advantage of 1.0-1.5 t/ha over the highest yielding inbred varieties. Most of the existing promising hybrids started giving low yield under biotic and abiotic stresses especially under drought stress. So, developing hybrid rice varieties with stable yield even under drought stress is essential to meet the increasing food demand for the growing population. Here in this study, we have initiated hybrid breeding program to achieve the goal of developing a best heterotic combinations under rainfed conditions.

Materials and methods

The parental material comprises of three Wild Abortive (WA) CMS lines *viz*., Pusa 6A, IR79156A and IR 68897A crossed with 31 male genotypes in *kharif* - 2014. Only 56 cross combinations could be made perfectly. Hence, the experiment was conducted in *Kharif* - 2015 with 56 experimental hybrids, parents and two checks, NDR-97(inbred variety) and Arise-6444Gold (popular hybrid) in a single row of 3 mt. plot length with spacing of 15x20 cm^2 in R.B.D. design and 3 replications at Agriculture farm, IAS, BHU, Varanasi. All the recommended agronomic practices were adopted to raise the crop under rainfed condition. No irrigation was provided to the crop after transplanting for posing water stress. Out of 56 hybrids, only 17 were found as complete restorers as per the classification of Virmani *et al.* (1997). Observations were recorded on five randomly selected plants for estimation of magnitude of heterosis with respect to fifteen quantitative traits *viz.,* days to 1^{st} flowering, days to 50% flowering, days to maturity, tillers/plant, effective tillers/plant, plant height (cm), panicle length (cm), spikelets/panicle, grains/panicle, sterile spikelets/panicle, pollen fertility(%), spikelet fertility (%), grain weight/ panicle (g), 1000- grain weight (g) and grain yield/plant (g). The character means of each replication was subjected for analysis of variance (Panse and Sukhatme, 1967) and estimation of heterosis over better parent, standard variety and standard hybrid was done.

Results and discussion

The analysis of variance (Table 1) for 33 entries (2 female lines; 2 check varieties;12 male lines and 17 full fertile crosses) was done for fifteen characters *viz.,* days to 1^{st} flowering, days to 50 per cent flowering, days to maturity, plant height (cm), number of tillers/plant, number of effective tillers/plant, panicle length(cm), number of spikelets/panicle, number of grains/panicle, sterile spikelet/panicle, pollen fertility(%), spikelet fertility (%),grain weight/panicle,1000- grain weight(g), grain yield / plant(g). Analysis of variance for the treatments revealed that all the genotypes expressed significant differences for all traits.

For days to 1^{st} flowering, negative value of heterosis is desirable as early flowering is usually associated with early maturity which enhances the productivity per day per unit area. Out of 17 hybrids, 13 crosses showed significant negative heterosis over SH (Arize-6444 Gold). Pusa-6A × Danteshwari (-13.07%) exhibited highest negative significant heterosis for days to 1^{st} flowering over SH (Arize-6444 Gold) (Table 2**).** Viraktamath (1987) and Sen and Singh (2011) also reported negative heterosis for earliness in rice hybrids. For days to 50 percent flowering, 14 crosses showed significant negative heterosis over SH (Arize-6444 Gold). Pusa-6A × Danteshwari (-14.43%) exhibited highest negative significant heterosis over SH (Arize-6444 Gold) for this trait (Table 2). These results were in the agreement of Patel *et al.* (1994), Lingaraju *et al.* (1999), Viraktamath (1987), Young and Virmani (1990), Patil *et al.* (2003), Sen and Singh (2011), Sharma *et al.* (2013) and Singh *et al.* (2013). The negative value of heterosis

Table 1: ANOVA of combining ability (Line x Tester mating design) for different characters in rice

Source of Variations	df	Days to 1st Flowering	Days to 50% Flowering	Days to Maturity	Plant Height (cm)	Tillers $Plant^{-1}$	Effective Tillers $Plant^{-1}$	Panicle Length (cm)	Spikelets $Panicle^{-1}$	Grains $Panicle^{-1}$	Sterile Spikelets $Panicle^{-1}$	Grain Weight $Panicle^{-1}$ (g)	1000 Grain Weight	Grain Yield $Plant^{-1}$ (g)	Grain Yield $Plot^{-1}$ (g)
Replicates	2	4.31	5.28	0.92	17.16	0.49	1.38	1.20	153.22	119.30	1.47	0.04	0.29	5.97	1463.05
Treatments	32	208.54***	219.93***	216.83***	410.71***	7.35***	6.09***	27.55***	6838.08***	4495.65***	650.30***	2.03***	16.71***	100.70***	36345.93***
Hybrids	16	64.77***	70.13***	75.00***	418.25***	7.74***	7.43***	13.66***	6782.23***	4416.82***	616.66***	1.54***	7.56***	83.88***	31446.99***
Parents	13	383.69***	397.81***	387.82***	280.57***	7.01***	3.64***	31.24***	3002.41***	2479.55***	503.81***	1.54***	30.79***	43.13***	14660.39***
Hybrids vs. Parents	1	0.17	1.23	9.54*	1933.81***	14.12*	15.95***	199.16***	44967.00***	26200.80***	2518.37***	13.16***	7.19***	1193.78***	424690.81***
Checks	1	560.66***	661.50***	620.17***	495.77***	2.67	11.56***	7.55**	9949.52***	7118.07***	236.38***	3.53***	0.03	10.64*	3332.30
Checks vs. Hybrids	1	82.57***	73.29***	53.83***	809.52***	0.999	0.04	100.08***	29256.23***	14541.64***	2545.31***	6.98***	9.01***	324.59***	115910.37***
Checks vs. Parents	1	84.02***	81.05***	76.20***	51.01	7.74	4.44**	9.96**	4611.14***	1761.53***	672.49***	0.77***	2.85***	1.75	652.45
Error	64	2.05	2.21	2.36	13.37	2.09	0.51	0.93	102.86	129.86	16.01	0.06	0.19	2.53	1035.15
Total	98	69.52	73.36	72.36	143.19	3.77	2.35	9.63	2303.14	1555.21	222.83	0.70	5.59	34.66	12573.93

** Significant at 5% level, ** significant at 1% level and *** significant at 0.1% level*

Table 2: Estimates of *per se* performance, heterobeltosis and standard heterosis for yield and yield components in 17 hybrids of rice.

S. No.	Characters	Days to 1st Flowering				Days to 50% Flowering				Days to Maturity				Plant Height(cm)			
	Crosses	Mean	BP	NDR-97	Arize 6444	Mean	BP	NDR-97	Arize 6444	Mean	BP	NDR-97	Arize 6444	Mean	BP	NDR-97	Arize 6444
1	IR-79156A x Akshaydhan	94.33	17.43**	25.78**	0.00	99.00	19.28**	26.38**	-0.34	125.00	13.29**	18.30**	-0.79	122.15	19.74**	40.14**	15.96**
2	IR-79156A x IR-36	86.33	7.47**	15.11**	-8.48**	91.33	10.04**	16.60**	-8.05**	117.33	6.34**	11.04**	-6.88**	97.66	5.45	12.04**	-7.29*
3	IR-79156A x URG-42	87.33	8.71**	16.44**	-7.42**	91.33	10.04**	16.60**	-8.05**	118.67	7.55**	12.30**	-5.82**	118.13	17.00**	35.53**	12.14**
4	IR-79156A x Danteshwari	83.33	3.73*	11.11**	-11.66**	87.00	4.82**	11.06**	-12.42**	114.67	3.93**	8.52**	-8.99**	88.41	3.69	1.43	-16.07**
5	IR-79156A x URG-30	84.00	7.69**	12.00**	-10.95**	88.33	7.72**	12.77**	-11.07**	113.67	3.02**	7.57**	-9.79**	102.79	2.08	17.94**	-2.42
6	IR-79156A x BPT-5204	90.00	12.03**	20.00**	-4.59**	94.33	13.65**	20.43**	-5.03**	120.00	8.76**	13.56**	-4.76**	108.94	27.66**	24.99**	3.42
7	Pusa-6A x Akshaydhan	98.33	26.07**	31.11**	4.24**	102.33	24.80**	30.64**	3.02*	128.33	18.83**	21.45**	1.85	121.82	20.65**	39.76**	15.64**
8	Pusa-6A x IR-36	84.67	8.55**	12.89**	-10.25**	88.00	7.32**	12.34**	-11.41**	111.00	2.78*	5.05**	-11.90**	100.47	8.49*	15.27**	-4.62
9	Pusa-6A x URG-42	93.33	19.66**	24.44**	-1.06	96.67	17.89**	23.40**	-2.68*	123.33	14.20**	16.72**	-2.12*	105.48	4.47	21.01**	0.13
10	Pusa-6A x Danteshwari	82.00	5.13**	9.33**	-13.07**	85.00	3.66*	8.51**	-14.43**	112.67	4.32**	6.62**	-10.58**	87.06	2.11	-0.12	-17.36**
11	Pusa-6A x URG-30	83.33	6.84**	11.11**	-11.66**	86.00	4.88**	9.79**	-13.42**	112.33	4.01**	6.31**	-10.85**	114.25	13.46**	31.08**	8.46**
12	Pusa-6A x HUR-105	94.00	20.51**	25.33**	-0.35	98.00	19.51**	25.11**	-1.34	125.00	15.74**	18.30**	-0.79	116.84	21.78**	34.05**	10.92**
13	Pusa-6A x IET-22202	88.33	18.30**	17.78**	-6.36**	93.00	18.22**	18.72**	-6.38**	118.67	9.88**	12.30**	-5.82**	125.94	24.73**	44.49**	19.55**
14	Pusa-6A x Susksamarat	91.33	17.09**	21.78**	-3.18*	95.33	16.26**	21.70**	-4.03**	122.33	13.27**	15.77**	-2.91**	120.35	19.20**	38.08**	14.25**
15	Pusa-6A x IR-64	85.67	9.83**	14.22**	-9.19**	90.67	10.57**	15.74**	-8.72**	118.67	9.88**	12.30**	-5.82**	96.79	6.60*	11.05**	-8.12**
16	Pusa-6A x NDR-359	91.00	16.67**	21.33**	-3.53**	94.33	15.04**	20.43**	-5.03**	122.33	13.27**	15.77**	-2.91**	110.02	11.63**	26.23**	4.45
17	Pusa-6A x Pantdhan-12	88.67	13.68**	18.22**	-6.01**	92.33	12.60**	17.87**	-7.05**	119.00	10.19**	12.62**	-5.56**	107.91	8.06**	23.81**	2.44
	Mean	88.59	12.91	18.12	-6.09	92.53	12.72	18.12	-6.85	119.00	9.37	12.62	-5.56	108.53	12.75	24.52	3.03
	Range	82.00 to 98.33	3.73 to 26.07	9.33 to 31.11	-13.07 to 4.24	85.00 to 102.33	3.66 to 24.80	8.51 to 30.64	-14.43 to 3.02	111.00 to 128.33	2.78 to 18.83	5.05 to 21.45	-11.90 to 1.85	87.06 to 125.94	2.08 to 27.66	-0.12 to 44.49	-17.36 to 19.55

Contd.

S. No.	Characters / Crosses	Tillers Plant^{-1}				Effective Tillers Plant^{-1}				Panicle length (cm)				Spikelets panicle^{-1}			
		Mean	BP	BPT 5204	Arize 6444	Mean	BP	BPT 5204	Arize 6444	Mean	BP	BPT 5204	Arize 6444	Mean	BP	BPT 5204	Arize 6444
1	IR-79156A x Akshaydhan	9.00	-15.63	-10.00	3.85	7.00	-16.00*	-17.09*	23.53*	33.67	6.61*	36.98**	25.53**	248.00	43.26**	168.27**	42.62**
2	IR-79156A x IR-36	10.00	-6.25	0.00	15.38	8.00	-4.00	-5.25	41.18**	25.24	-16.52**	2.69	-5.90*	149.00	-16.71**	61.18**	-14.31**
3	IR-79156A x URG-42	7.33	-31.25**	-26.67*	-15.38	5.33	-36.00**	-36.83**	-5.88	30.38	0.50	23.61**	13.27**	210.00	21.54**	127.17**	20.77**
4	IR-79156A x Danteshwari	7.33	-31.25**	-26.67*	-15.38	5.33	-36.00**	-36.83**	-5.88	28.71	-5.03	16.82**	7.05*	217.00	26.65**	134.74**	24.79**
5	IR-79156A x URG-30	8.67	-18.75	-13.33	0.00	6.00	-28.00**	-28.94**	5.88	28.10	-7.07**	14.31**	4.75	187.00	9.14	102.29**	7.54
6	IR-79156A x BPT-5204	7.33	-31.25**	-26.67*	-15.38	5.33	-36.00**	-36.83**	-5.88	29.76	-1.55	21.09**	10.96**	339.00	61.17**	266.71**	94.95**
7	Pusa-6A x Akshaydhan	8.33	-13.79	-16.67	-3.85	6.67	-9.09	-21.04**	17.65	31.98	1.27	30.12**	19.24**	224.67	29.78**	143.03**	29.20**
8	Pusa-6A x IR-36	8.00	-17.24	-20.00	-7.69	6.33	-13.64	-24.99**	11.76	29.74	5.75*	20.99**	10.87**	194.56	8.76	110.46**	11.89*
9	Pusa-6A x URG-42	8.00	-17.24	-20.00	-7.69	5.33	-27.27**	-36.83**	-5.88	29.09	3.44	18.35**	8.45**	226.67	31.19**	145.20**	30.35**
10	Pusa-6A x Danteshwari	8.00	-17.24	-20.00	-7.69	6.00	-18.18*	-28.94**	5.88	26.86	-4.48	9.29**	0.15	209.00	22.46**	126.08**	20.19**
11	Pusa-6A x URG-30	10.00	0.00	0.00	15.38	8.33	8.70	-1.30	47.06**	28.80	2.42	17.18**	7.38*	192.00	12.50*	107.69**	10.42*
12	Pusa-6A x HUR-105	10.00	3.45	0.00	15.38	8.00	9.09	-5.25	41.18**	31.86	13.29**	29.62**	18.78**	246.67	39.62**	166.83**	41.85**
13	Pusa-6A x IET-22202	6.67	-31.03*	-33.33**	-23.08	5.67	-22.73**	-32.89**	0.00	32.06	4.34	30.44**	19.54**	229.33	23.52**	148.08**	31.89**
14	Pusa-6A x Susksamarat	8.00	-17.24	-20.00	-7.69	6.44	-12.14	-23.69**	13.71	31.95	13.61**	29.98**	19.11**	191.11	11.98*	106.73**	9.90*
15	Pusa-6A x IR-64	11.00	13.79	10.00	26.92	9.00	22.73**	6.59	58.82**	29.71	5.64*	20.87**	10.76**	137.22	-19.60**	48.44**	-21.08**
16	Pusa-6A x NDR-359	11.67	20.69	16.67	34.62*	9.67	31.82**	14.49*	70.59**	31.77	10.68**	29.25**	18.44**	147.22	-25.64**	59.26**	-15.33**
17	Pusa-6A x Pantdhan-12	12.00	24.14	20.00	38.46**	10.00	36.36**	18.44*	76.47**	30.63	-0.08	24.61**	14.19**	170.33	-0.20	84.26**	-2.04
	Mean	8.90	-10.95	-10.98	2.72	6.97	-8.84	-17.48	22.95	30.02	1.93	22.13	11.92	206.99	16.44	123.91	19.04
	Range	6.67 to 12.00	-31.25 to 24.14	-33.33 to 20.00	-23.08 to 38.46	5.33 to 10.00	-36.00 to 36.36	-36.83 to 18.44	-5.88 to 76.47	25.24 to 33.67	-16.52 to 13.61	2.69 to 36.98	-5.90 to 25.53	137.22 to 339.00	-25.64 to 61.17	48.44 to 266.71	-21.08 to 94.95

Contd…

S. No.	Characters Crosses	Grains panicle^{-1}				Sterile spikelets panicle^{-1}				Grain Weight Panicle^{-1} (g)				1000- Grain Weight (g)				Grain Yield Plant^{-1} (g)			
		Mean	BP	NDR-97	Arize 6444	Mean	BP	NDR-97	Arize 6444	Mean	BP	NDR-97	Arize 6444	Mean	BP	NDR-97	Arize 6444	Mean	BP	NDR-97	Arize 6444
1	IR-79156A x Akshaydhan	203.00	28.21**	149.93**	35.23**	31.26	40.19**	94.67**	66.98**	45.00	204.47**	300.95**	89.26**	4.58	7.93	137.72**	32.37**	23.20	-7.75**	5.45**	6.18**
2	IR-79156A x IR-36	118.00	-22.54**	45.28**	-21.39**	22.18	3.77	38.11**	18.46**	31.00	16.75	176.21**	30.38*	2.83	-28.56**	46.71**	-18.30**	24.03	-6.30**	9.24**	9.99**
3	IR-79156A x URG-42	197.00	25.74**	142.54**	31.24**	20.79	-1.55	29.43**	11.02	13.00	-19.32	15.83	-45.32**	3.96	11.88*	105.36**	14.35*	20.37	-11.58**	-7.42**	-6.79**
4	IR-79156A x Danteshwari	170.00	28.46**	109.30**	13.25*	20.31	-3.82	26.44**	8.46	47.00	143.10**	318.77**	97.67**	3.85	40.46**	100.00**	11.37	22.67	-8.72**	3.03	3.74*
5	IR-79156A x URG-30	146.00	10.33	79.75**	-2.74	17.26	-18.23**	7.49	-7.80	41.00	442.57**	265.31**	72.44**	2.96	11.28	53.63**	-14.45*	20.57	-10.71**	-6.52**-	-5.87**
6	IR-79156A x BPT-5204	262.00	34.90**	222.57**	74.54**	25.72	21.83**	60.17**	37.39**	77.00	377.87**	586.07**	223.85**	4.97	83.17**	157.96**	43.64**	20.13	-12.59**	-8.48**	-7.86**
7	Pusa-6A x Akshaydhan	190.44	20.28**	134.47**	26.87**	27.37	22.72**	70.40**	46.16**	34.22	131.55**	204.93**	43.94**	4.51	6.28	134.08**	30.35**	21.95	-12.72**	-0.23	0.46
8	Pusa-6A x IR-36	153.33	0.66	88.78**	2.15	22.32	3.27	39.00**	19.23**	41.22	55.25**	267.30**	73.38**	3.73	-5.81	93.43**	7.71	24.30	-5.26**	10.45**	11.21**
9	Pusa-6A x URG-42	196.67	25.53**	142.13**	31.02**	20.78	-3.89	29.37**	10.97	30.00	86.18**	167.30**	26.17	4.36	23.19**	126.12**	25.92**	22.85	9.86**	3.86*	4.58**
10	Pusa-6A x Danteshwari	157.33	17.12*	93.70**	4.81	22.49	4.04	40.04**	20.12**	51.67	167.24**	360.35**	117.30**	3.83	22.52**	98.62**	10.60	24.00	-3.36*	9.09**	9.84**
11	Pusa-6A x URG-30	162.00	20.60**	99.45**	7.92	31.56	45.98**	96.49**	68.54**	30.00	297.00**	167.30**	26.17	3.81	21.88**	97.58**	10.02	23.83	17.21**	8.33**	9.08**
12	Pusa-6A x HUR-105	192.33	42.82**	136.80**	28.13**	34.77	60.83**	116.48**	85.69**	54.33	49.54**	384.11**	128.52**	4.35	39.27**	125.78**	25.72**	23.85	19.05**	8.41**	9.15**
13	Pusa-6A x IET-22202	185.89	38.03**	128.86**	23.83**	26.16	21.00**	62.87**	39.70**	43.44	19.57*	287.08**	82.71**	4.86	35.66**	152.08**	40.37**	24.90	-3.30*	13.18**	13.96**
14	Pusa-6A x Susksamarat	146.44	9.01	80.30**	-2.44	20.23	-6.43	25.94**	8.03	44.67	35.35**	297.98**	87.86**	3.57	14.30*	85.29**	3.18	24.20	-5.84**	10.00**	10.76**
15	Pusa-6A x IR-64	108.44	-19.27**	33.51**	-27.76**	22.73	5.15	41.53**	21.40**	28.78	19.90	156.40**	21.03	2.56	-17.93**	33.04**	-25.92**	24.25	8.99**	10.23**	10.98**
16	Pusa-6A x NDR-359	118.22	-23.34**	45.55**	-21.24**	27.44	21.75**	70.88**	46.57**	29.00	-20.18*	158.39**	21.97	2.98	-26.05**	54.67**	-13.87*	25.25	3.91*	14.77**	15.56**
17	Pusa-6A x Pantdhan-12	144.00	7.20	77.29**	-4.07	34.49	59.54**	114.74**	84.19**	26.33	-22.30*	134.63**	10.75	3.48	11.31	80.45**	0.48	24.40	-2.98*	10.91**	11.67**
	Mean	167.71	14.34	106.48	11.73	25.17	16.24	56.71	34.42	39.27	116.74	249.94	65.18	3.83	14.75	98.97	10.80	23.22	-1.89	5.55	6.27
	Range	108.44 to 262.00	-23.34 to 42.82	33.51 to 222.57	-27.76 to 74.54	17.26 to 34.77	-18.23 to 60.83	7.49 to 116.48	-7.80 to 85.69	13.00 to 77.00	-22.30 to 442.57	15.83 to 586.07	-45.32 to 223.85	2.56 to 4.97	-28.56 to 83.17	33.04 to 157.96	-25.92 to 43.64	20.13 to 25.25	-12.72 to 19.05	-8.48 to 14.77	-7.86 to 15.56

for days to maturity is desirable because short duration varieties are generally preferable and become important at the time of drought. Out of 17 hybrids, 14 crosses showed significant negative heterosis over SH (Arize-6444 Gold). Pusa-6A × IR-36 (-11.90%) showed highest negative significant heterosis over SH (Arize-6444 Gold) for days to maturity (Table 2). The hybrids showing negative heterosis for days to maturity using CMS lines have also been reported by Singh *et al.* (1994), Sharma *et al.* (2013) and Singh *et al.* (2013).

The negative significant heterosis for plant height is desirable because dwarf plant stature is essential to develop semi-dwarf high yielding hybrid which is believed to be lodging resistant. The results manifested that four crosses showed significant negative heterosis over SH (Arize-6444 Gold). Among them, Pusa-6A × Danteshwari (-17.36%) (Table 2) showed highest negative magnitude of heterosis for this trait. These results were similar to the earlier reports of Khoyumthem *et al.* (2005), Sharma *et al.* (2013) and Singh *et al.* (2013). Higher number of tillers per plant contributes to higher grain yield. In present study, Pusa-6A × Pantdhan-12 (38.46%) and Pusa-6A × NDR-359 (34.62%) showed positive and significant heterosis over SH (Arize-6444 Gold) (Table 2). These observations were in agreement with the reports of Patil *et al.* (2003), Sharma *et al.* (2013) and Singh *et al.* (2013). Higher number of effective tillers per plant contributes to higher grain yield. Out of 17 hybrids, 3 hybrids possess the significant positive heterosis over BP, 2 over SV (NDR-97) and 7 over SH (Arize-6444 Gold). The crosses Pusa-6A × Pantdhan-12 (76.47%), Pusa-6A × NDR-359 (70.59%) and Pusa-6A × IR-64 (58.82%) were the top heterotic hybrids over SH (Arize-6444 Gold) (Table 2) for number of effective tiller per plant. Sarawgi *et al.* (2000), Vaithiyalingam and Nadarajan (2010), Sharma *et al.* (2013) and Singh *et al.* (2013) also observed highest significant heterosis for effective tiller per plant increases the yield.

Panicle length with positive and significant heterosis may contribute to enhance the number of spikelets / panicle, subsequently boost the grain yield / plant. Out of 17 hybrids, 6 hybrids showed the significant positive heterosis over BP, 16 over SV (NDR-97) and 14 over SH (Arize-6444 Gold). The heterotic hybrids, Pusa-6A × Susksamarat (13.61%), Pusa-6A × HUR-105 (13.29%) and Pusa-6A × NDR-359 (10.68%) over BP, IR-79156A × Akshaydhan (SV=36.98% and SH=25.53%), Pusa-6A × IET-22202 (SV=30.44% and SH=19.54%) and Pusa-6A × Akshaydhan (SV=30.12% and SH=19.24%) over SV (NDR-97) and SH (Arize-6444 Gold) respectively were the best hybrids for panicle length (Table 2). Roy *et al.* (2009), Sharma *et al.* (2013) and Singh *et al.* (2013) have also obtained highly significant positive heterosis for panicle length. Hybrids with positive heterosis for number of spikelets per panicle is desirable. Out of 17 hybrids, 11 hybrids over BP, all 17 over SV (NDR-97) and 12 over SH (Arize-6444 Gold) showed significant positive heterosis. The heterotic hybrid, IR-79156A × BPT-5204 (BP=61.17%, SV=266.71% and SH=94.95%) (Table 2) was the best hybrid for this trait. These results were in close agreement with earlier reports of Thirumeni and Subramaniam (2000), Sharma *et al.* (2013) and Singh *et al.* (2013).

Number of grains per panicle is the major yield attributing character, hence significant positive heterobeltiosis and standard heterosis is desirable. Out of 17 hybrids, 10 hybrids showed the significant positive heterosis over BP, all 17 over SV (NDR-97) and 8 over SH (Arize-6444 Gold). The heterotic hybrid, Pusa-6A × HUR-105 (42.82%) over BP, IR-79156A × BPT-5204 (SV=222.57% and SH=74.54%) over SV (NDR-97) and SH (Arize 6444 Gold) (Table 2) was found to be the best hybrid for this trait. Similar findings were also reported by Saravanan *et al.* (2008), Sharma *et al.* (2012) and Singh *et al.* (2013). Number of sterile spikelets per panicle is one of the important traits which contribute directly to the yield reduction. The hybrids with negative heterosis are desirable for this trait. Out of 17 hybrids, 2 hybrid, Pusa-6A × Pantdhan-12 (-22.30%) and Pusa-6A × NDR-359 (-20.18%) showed negative significant heterosis over BP, and IR-79156A × URG-42 (-45.32%) hybrid showed negative significant heterosis over SH (Arize-6444 Gold) (Table 2). Similar finding were also reported by Saravanan *et al.* (2008) and Sharma *et al.* (2013).

The hybrids with positive heterosis for pollen fertility are desirable. In the present study, only IR-79156A × URG-42 (SV=6.64% and SH=5.78%) hybrid showed positive significant heterosis over SV (NDR-97) and SH (Arize-6444 Gold) (Table 2). This is because for the study of heterosis only those hybrids were selected which were exhibiting full fertility. These results were in close agreement

Table 3: Standard Heterosis (%) of top five high yielding hybrids for yield and yield traits in rice

S. No.	Hybrids	Days to maturity		Plant height		Effective tillers per plants		Panicle length		Grain weight per panicle		1000 Grain weight		Grain Yield per plant	
		(NDR -97)	(Arize -6444 Gold)	(NDR-97)	(Arize -6444 Gold)	(NDR-97)	(Arize -6444 Gold)	(NDR-97)	(Arize -6444 Gold)	(NDR -97)	(Arize -6444 Gold)	(NDR-97)	(Arize -6444 Gold)	(NDR -97)	(Arize -6444 Gold)
1.	Pusa-6A × HUR-105	18.30**	-0.79	34.05**	10.92**	-5.25	41.18**	29.62**	18.78**	125.78**	25.72**	8.41**	9.15**	116.48**	85.69**
2.	Pusa-6A × Pantdhan-12	12.62**	-5.56**	23.81**	2.44	18.44*	76.47**	24.61**	14.19**	80.45**	0.48	10.91**	11.67**	114.74**	84.19**
3.	Pusa-6A × URG-30	6.31**	-10.85**	31.08**	8.46**	-1.30	47.06**	17.18**	7.38*	97.58**	10.02	8.33**	9.08**	96.49**	68.54**
4.	IR-79156A × Akshaydhan	18.30**	-0.79	40.14**	15.96**	-17.09*	23.53*	36.98**	25.53**	137.72**	32.37**	5.45**	6.18**	94.67**	66.98**
5.	Pusa-6A × NDR-359	15.77**	-2.91**	26.23**	4.45	14.49*	70.59**	29.25**	18.44**	54.67**	-13.87*	14.77**	15.56**	70.88**	46.57**

**, **: significant at 5% and 1% respectively* with the reports of Thirumeni and Subramaniam (2000), Sharma *et al.* (2013) and Singh *et al.* (2013). In general, hybrids obtained by using CMS lines may not be having better fertility as the normal inbreds. For spikelet fertility positive heterosis is desirable. Among all the hybrids, Pusa-6A × Pantdhan-12 (7.28%) over BP, IR-79156A × URG-42 (SV=6.77% and SH=8.66%) over both SV (NDR-97) and SH (Arize-6444 Gold) showed positive significant heterosis (Table 2). This is very similar to the result observed for the pollen fertility. These finding were also reported by Thirumeni and Subramaniam (2000), Sharma *et al.* (2013) and Singh *et al.* (2013).

The hybrids with positive heterosis are desirable for grain weight per panicle. Out of 17 hybrids, 9 hybrids showed the significant positive heterosis over BP, all 17 over SV (NDR-97) and 7 over SH (Arize-6444 Gold). The heterotic hybrid, IR-79156A × BPT-5204 (83.17%, SV=157.96% and SH=43.64%) was found to be best over BP, SV (NDR-97) and SH (Arize-6444 Gold) (Table 2). Similar findings were also reported by Virmani *et al.* (1981), Tseng and Huang (1987) and Sharma *et al.* (2013). For 1000-Grain weight positive heterosis is desirable. In the present study, 5 hybrids showed the significant positive heterosis over BP, 12 over SV (NDR-97) and 13 over SH (Arize-6444 Gold). The hybrids Pusa-6A × HUR-105 (19.05%) over BP and Pusa-6A × NDR-359 (SV=14.77% and SH=15.56%) over SV and SH were the best hybrids for this trait (Table 2). Tiwari *et al.* (2011), Gopalakrishnan and Kumar (2013), Sharma *et al.* (2013) and Singh *et al.* (2013) also reported highly significant positive heterosis for 1000 grain weight.

Heterosis for grain yield/plant in positive direction is desirable as higher grain yield is the main objective for almost all the breeding programmes. Virmani *et al.* (1981) suggested that the yield advantage of 20% to 30% over best available standard variety should be sufficient to encourage farmers for adapting the hybrid rice varieties. In the present investigation, Out of 17 hybrids, 8 hybrids showed the significant positive heterosis over BP, 16 over SV (NDR-97) and 12 over SH (Arize-6444 Gold).

The heterotic hybrids Pusa-6A × HUR-105 (BP=60.83%, SV=116.48% and SH=85.69%), Pusa-6A × Pantdhan-12 (BP=59.54%, SV=114.74% and SH=84.19%), Pusa-6A × URG-30 (BP=45.98%, SV=96.49% and SH=68.54%), IR-79156A × Akshaydhan (BP=40.19%, SV=94.67% and SH=66.98%) and Pusa-6A × NDR-359 (BP=21.75%, SV=70.88% and SH=46.57%) (Table 3) were the best five hybrids for grain yield/plant. The results obtained from present study indicated that the yield heterosis was mainly influenced by number of effective tiller / plant, panicle length, number of spikelets /panicle, number of grains/panicle, and 1000-grain weight. These results were in agreement of earlier results of Bhave *et al.* (2002), Singh *et al.* (2013) and Latha *et al.* (2013) observed the similar results.

Among the top five hybrids for yield, the hybrids namely, Pusa-6A × HUR-105 was highest yielder (85.69%), and exhibited significant and desirable heterosis for days to maturity (-0.79%), panicle length (18.78%), grains weight per panicle (25.72%) and 1000 grain weight (9.15%) (Table 3). Remaining four promising hybrids recorded significant and desirable standard heterosis for yield components namely, days to maturity, plant height (cm), number of tillers per plant, 1000 grain weight, panicle length (cm) and grain weight/ panicle. It is observed that the standard heterosis in the present set of desirable hybrids was highly influenced by traits like number of effective tillers per plant, 1000 grain weight, grains /panicle and panicle length (cm). Grain yield *per se* is a complex heritable character which is an end product of multiplicative interaction of various yield components and hence heterosis for yield may be attributed to heterosis of individual yield components or alternatively due to multiplicative effects of component characters.

Conclusion

On the basis of objective to identify best suitable hybrids for the rainfed condition it may be concluded that the hybrids which have given higher yield should posses short maturity duration *viz.*, Pusa 6A × URG-30 and Pusa 6A × IET-22202 may further be tested on large scale. However, the highest yielding hybrids in the rainfed condition of present investigation having not more than 125 days to maturity viz., Pusa 6A × HUR-105 (125 days maturity and 34.77 g per plant yield), Pusa 6A × Pantdhan-12 (119 days maturity and 34.49 g per plant yield) and IR 79156A × Akshaydhan (125 days maturity and 31.26 g per plant yield) may also be promoted in rainfed areas for large scale testing as these hybrids are much better than the standard checks NDR-97 (16.06 g per plant yield) and Arize-6444 Gold (18.72 g per plant yield). It may be concluded that the findings of the present investigation are much helpful to enhance the production and productivity of rice in drought affected areas of eastern Uttar Pradesh.

Acknowledgement

Authors express their gratitude to UPCAR (Uttar Pradesh Council of Agricultural Research,) for supporting this project.

References

Bhave S G, Dhonukshe B L, Bendale V W 2002 Heterosis in hybrid rice. *J. Soils and Crops*, 12(2): 183-186.

Directorate of Rice Development Report, 2015, Patna.

FAO, 2014.

Gopalkrishnan M, Ganpaty S 1996 Heterosis in rice. *Crop Research* (Hisar), 11(3): 323-326.

Khoyumthem P, Sharma P R, Singh N B, Singh M R K 2005 Heterosis for grain yield and its component characters in rice (*Oryza sativa* L.). *Environment and Ecology*, 23 (Special 4): 687-691.

Latha S, Sharma D, Sanghera G S 2013 Combining ability and heterosis for grain yield and its component trait in rice (*Oryza sativa* L.). *Not Science Biol*., 5(1): 90-97.

Lin S C, Yuan L P 1980 Hybrid rice breeding in China. In: Innovative approaches to rice breeding. International rice research institute, Manila, Philippines, 35-51.

Lingaraju S, Vidyachandra B, Shridhara S, Chikkalingaiah 1999. Heterosis breeding in rice (*Oryza sativa* L.) for higher yields. *Mysore J. of Agril. Science*, 33(4): 328-332.

Panse V G, Sukhatme P V 1967 Statistical Methods for Agricultural Workers, 2nd Ed., Indian Council of Agricultural Research, New Delhi.

Patel S R, Desai N M, Kukadia M U 1994 Heterosis for yield and yield contributing characters in upland rice. *Gujrat Agril. Uni. Research J.*, 20(1): 163-162.

Patil D V, Thiyagarajan K, Pushpa Kamble 2003 Combining ability of parents for yield and yield contributing traits in two line hybrid rice (*Oryza sativa* L.). *Crop Research*, 25(3): 520-524.

Roy S K, Senapati B K, Sinhamahapatra S P, Sarkar K K 2009 Heterosis for yield and quality traits in rice. Oryza, 46(2): 87-93.

Saravanan K, Sabesan T, Kumar S T 2008 Heterosis for yield and yield components in rice (*Oryza sativa* L.). *Advances in Plant Sciences*, 21(1): 119-121.

Sarawgi A K, Rastogi N K, Munhot M K 2000 Heterosis among line x tester crosses for grain yield and quality components in rice. *Tropical Agril. Research and Extension*, 3(2): 2000.

Sen C, Singh R P 2011 Study on heterosis in Boro X High yielding rice hybrids. *International J. of Plant Breeding and Genet.*, 5(2): 141-149.

Sharma S K, Singh S K, Nandan R, Amita Sharma, Ravinder Kumar, Kumar V, Singh M K 2013 Estimation of heterosis and inbreeding depression for yield and yield related traits in rice (Oryza sativa L.). Mol. Plant Bre., 29(4): 238-246. https://doi.org/10.5376/mpb.2013.04.0029

Singh S K, Haque M F 1999 Heterosis for yield and yield components in rice (*Oryza sativa* L.). *Indian J. Genet*., 59(2): 237-238.

Singh S K, Vikash Sahu, Amita Sharma, Pradeep Kumar Bhati 2013 Heterosis for yield and yield components in rice (*Oryza sativa* L.). *Bioinfolet*, 10(2B): 752-761.

Thirumeni S, Subramanian M 2000 Heterosis in coastal saline rice (*Oryza sativa* L.). *Crop Research (Hisar)*, 19(2): 245-250.

Tiwari D K, Pandey P, Giri S P, Dwivedi J L 2011 Heterosis studies for yield and its components in rice hybrids using CMS system. Asian J. Plant Science, 10: 29-42. https://doi.org/10.3923/ajps.2011.29.42

Tseng T H, Huang C S 1987 Yield and combining ability of hybrid rice. *J. Agric. Research China*, 36: 151-164.

USDA (United States Department of Agriculture) Post, February 2015.

Vaithiyalingan M, Nadarajan N 2006 Studies on the fertility restoring abilities of different wide compatible varieties to the WA source of rice male sterile lines, *Crop Research (Hisar)*, 31(3): 380-382.

Viraktamath B C 1987 Heterosis and combining ability studies in rice (*Oryza sativa* L.) with respect to yield, yield components and some quality characteristics. Ph. D. Thesis, IARI, New Delhi, India.

Virmani S S, Chaudhary R C, Khush G S 1981 Current outlook on hybrid rice. *Oryza*, 18: 67-84.

Virmani S S, Virakamath B C, Laral C L, Toledo R S, Lopez M T, Manalo J O 1997 *Hybrid rice breeding manual*, 151. Manila, IRRI.

Young J, Virmani S S 1990 Heterosis in rice over environments. *Euphytica*, 51(1): 87-93.