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Estimation of heterosis for yield and associated traits in rainfed upland rice genotypes of Uttarakhand hills

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ABSTRACT

In the present study a set of 45 F_1s developed through crossing in a half diallel fashion involving ten parents were evaluated for yield and its component traits. Significantly higher heterosis was observed in most of the hybrids for days to 50% flowering, days to maturity, kernel length, grain yield and grain number. In general, the estimated values of heterosis were low for plant height and days to maturity as compared to grain yield and other traits. The magnitude of heterosis for all yield traits was not expressed in a single hybrid combination and varied from cross to cross due to diverse genetic background of the parents. Crosses VL 8116 x Sukradhan 1, VL 30560 x Sukradhan1, VL 30560 x VL 8116, VL 30560 x Sukradhan1, VL 7620 x Sukradhan1 manifested significant heterosis for grain yield as well as kernel length in the desirable range. Whereas, parents VL 30560, VL 30240, VL 8116, VL 7620 and Sukradhan1 were the best parent for both grain quality and yield.

Key words: *Rainfed upland rice, heterosis, yield, quality*

Globally, rice (*Oryza sativa* L.) is grown in an area of 162.7 million hectares with 741.47 million tons production (FAOSTAT, 2014). The rainfed rice ecosystem which occupy nearly 38% of the total rice cropped area, contributes only 21% of the total rice production (Khush, 1997) due to frequent occurrence of drought. In Indian agriculture, rice occupies a pivotal place covering 44.0 million hectares (22 per cent) of the cropped area with production of 108.0 million tons. In Uttarakhand, rice is cultivated in an area of about 261.7 thousand ha with 603.6 thousand ton production and average productivity of 2307 kg/ha (DES, 2014). The area of rice under hills and plains are almost equal but the production of rice in plains is more than double to the hill rice mainly due to irrigation facility (almost100%), high soil fertility and adoption of improved rice varieties. Whereas, about 90% area under hills are rainfed, soils are fragile, less fertile and low adoption of improved varieties are the main constraints of low rice production. In Uttarakhand, rice is grown over a wide range of altitude between 250 to 2500m amsl. The crop is frequently challenged by biotic and abiotic stresses resulting in low and fluctuating yields. The major challenges to rice production in the plains and valley comprise shrinking land resources due to urbanization, development of infrastructure and conversion of rice land to more profitable endeavors like horticulture and growing water scarcity resulting from competing water uses and climate change.

Despite the advances of molecular breeding, classical quantitative genetics remains useful in practical rice improvement. Thus, estimation of genetic parameters such as heterosis gives inferences about the predominant action of the genes and indicates the appropriate selection strategy to be applied in the breeding program and allows the identification of the best parents. The grain yield and component traits of F1 hybrids are used to explore for the estimation and prediction heterosis in rice (Xangsayasane et al., 2010; Melchinger et al., 2008; Gartner et al., 2009; Cho et al., 2004); and a full or partial diallel cross often conducted to define the heterosis and heterobeltiosis (Zhang et al., 1994; Torres and Geraldi, 2007). The heterosis level is clearly a function of the combination

Table 1. Heterosis over mid parent (MP) and better parent (BP) for grain yield and other traits

Cross combination	Plant height		Days to 50% flowering		Days to maturity		Flag leaf length		Flag leaf width		Tillers per plant		Panicles per plant		Panicle length	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
VLD 221 x Vivek Dhan 154	2.27	-0.94	-11.86**	-16.13**	-8.87**	-11.57**	-5.87	-8.65	-9.09	-11.11	22.58*	18.75	20.93	13.04	5.79	0.98
VLD 221 x VL 30240	-4.03	-7.74	-5.15**	-10.89**	-3.40**	-7.12**	-2.96	-10.07	3.53	-2.22	1.69	0	24.32	15	-4.26	-9.88
VLD 221 x VL 7620	-1.29	-5.25	8.94**	3.23**	5.97**	2.67**	5.96	1.69	-6.67	-6.67	35.71**	26.67*	37.78**	24	-8.87	- 12.29
VLD 221 x VL 30560	-7.02	-13.12**	1.2	0.4	2.22**	1.76	-2.31	-2.88	8.05	4.44	33.33*	13.33	17.95	15	4.38	3.73
VLD 221 x VL 8116	-8.17*	-15.10**	-10.78**	-16.53**	-7.60**	-11.57**	-2.97	-8.19	-2.27	-4.44	18.52	6.67	36.84**	30	-3.53	-9.35
VLD 221 x VL 8549	-4.87	-7.86	-15.21**	-15.73**	-10.98**	-10.98**	-1.48	-4.06	-1.2	-8.89	22.03*	20	38.46**	35.00*	5.7	2.52
VLD 221 x VL 8724	-5.26	-9.73 *	-22.68**	-24.32**	-15.37**	-16.47**	-8.98	-12.09	-5.49	-6.52	-5.08	-6.67	11.63	4.35	0.22	-4.2
VLD 221 x VL 8732	6.1	-2.79	8.79**	7.26**	5.34**	5.34**	7.99	3.1	-21.74**	-23.40**	-3.45	-6.67	-12.2	-14.29	2.65	2.22
VLD 221 x Sukradhan1	1.27	-4.19	-10.81**	-13.03**	-6.86**	-8.33**	4.12	2.41	4.88	-4.44	1.75	-3.33	15.79	10	1.52	-2.1
Vivek Dhan 154 x VL 30240	-2.34	-3.1	7.24**	5.80**	4.46**	3.47**	0.5	-9.4	6.02	2.33	-21.31*	-25.00*	-10	-21.74	3.56	-6.67
Vivek Dhan 154 x VL 7620	-4.36	-5.25	5.38**	4.91**	2.05*	1.89	16.80*	8.92	-4.55	-6.67	17.24	6.25	-4.17	-8	8.36	-0.26
Vivek Dhan 154 x VL 30560	-2.87	-6.41	-9.24**	-14.29**	-6.85**	-10.00**	-11.82	-13.93	-1.18	-2.33	35.85**	12.5	19.05	8.7	-3.06	-8.01
Vivek Dhan 154 x VL 8116	-4.04	-8.55*	2.73**	0.89	1.76*	0.32	14.81	5.61	4.65	4.65	14.29	0	12.2	0	0.89	-9.23

Table 1. Continued

Cross combination	Plant height		Days to 50% flowering		Days to maturity		Flag leaf length		Flag leaf width		Tillers per plant		Panicles per plant		Panicle length	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Vivek Dhan 154 x VL 8549	-2.2	-2.2	12.58**	7.76**	8.87**	5.64**	14.5	14.11	13.58	6.98	21.31*	15.63	28.57*	17.39	3.63	1.93
Vivek Dhan 154 x VL 8724	-1.39	-3.04	5.18**	-1.93*	3.47**	-0.87	7.61	0.98	-7.87	-10.87	-11.48	-15.63	-8.7	-8.7	20.89**	20.71*
Vivek Dhan 154 x VL 8732	-5.92	-11.17**	-4.95**	-8.30**	-3.98**	-6.82**	12.91	4.77	4.44	0	-33.33**		-37.50**	-27.27*	-30.43*	8.533.19
Vivek Dhan 154 x Sukradhan1	0.92	-1.5	-7.63**	-14.18**	-5.26**	-9.48**	16.92*	11.66	17.50*	9.3	1.69	-6.25	21.95	8.7	18.11*	16.87
VL 30240 x VL 7620	0.77	0.62	6.36**	5.41**	3.35**	2.53*	-8.7	-11.97	-3.53	-8.89	5.45	0	-4.76	-20	-7.52	-9.63
VL 30240 x VL 30560	-6.91	-9.62*	0.85	-5.95**	0.15	-4.12**	-5.58	-12.98	7.32	4.76	4	-10.34	0	-5.26	-7.95	-12.84
VL 30240 x VL 8116	-3.86	-7.69	-4.15**	-4.59**	-4.68**	-5.14**	-5.2	-7.27	3.61	0	16.98	6.9	20	16.67	-7.46	-7.63
VL 30240 x VL 8549	11.39**	10.53*	-1.94*	-7.35**	-1.85*	-5.64**	4.51	-5.48	10.26	7.5	13.79	13.79	50.00**	42.11*	5.13	-3.83
VL 30240 x VL 8724	-10.43**	-11.25**	18.66**	9.27**	13.85**	8.09**	-4.61	-8.61	-4.65	-10.87	-13.79	-13.79	-15	-26.09	4.1	-6.05
VL 30240 x VL 8732	-3.38	-8.10*	-0.22	-4.98**	-1.85*	-5.64**	-9.06	-11.86	-1.15	-8.51	-1.75	-3.45	-5.26	-14.29	-5.68	-10.86
VL 30240 x Sukradhan1	2.28	0.6	4.38**	-4.21**	1.97*	-3.45**	0.65	-5.26	24.68**	20.00*	-3.57	-6.9	2.86	0	2.04	-7.16
VL 7620 x VL 30560	-2.85	-5.54	7.17**	0.79	6.10**	2.35*	3.41	-1.33	3.45	0	31.91*	19.23	4.55	-8	2.74	-0.52
VL 7620 x VL 8116	-11.70**	-15.10**	14.16**	12.61**	9.62**	8.23**	-6.23	-7.6	-4.55	-6.67	8	3.85	-16.28	-28.00*	-11.98	-14.15
VL 7620 x VL 8549	3.12	2.16	9.21**	4.08**	5.97**	2.67**	-3.28	-9.52	3.61	-4.44	5.45	0	-9.09	-20	-7.96	-13.97
VL 7620 x VL 8724	4.75	3.95	3.95**	-3.47**	4.53**	0	-2.61	-3.25	-3.3	-4.35	-16.36	-20.69	-4.17	-8	6.95	-1.42

Table 1. Continued

Cross combination	Kernel length		Kernel width		1000grain weight		Grain yield per plot		Fertile grains per panicle		Grains per panicle	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
VLD 221 x Vivek Dhan 154	-0.05	-1.67	-4.81*	-7.14**	-2.57	-10.34*	-6.18	-24.77**	21.20*	8.48	29.32*	20.15
VLD 221 x VL 30240	-1.08	-2.66	-3.65	-4.51	-3.01	-4.55	6.57	-9.6	0.24	-12.29	0.21	-5.06
VLD 221 x VL 7620	-9.85**	-11.37**	5.88*	1.39	-9.52*	-13.23**	-17.89**	-22.01**	7.38	-11.11	5.34	-12.82
VLD 221 x VL 30560	1.35	-6.06**	0.43	-2.5	2.69	-1.89	-26.07**	-33.33**	-28.32**	-41.09**	-38.40**	-54.06**
VLD 221 x VL 8116	-4.04*	-5.10*	3.45	2.09	2.95	2.08	-0.18	-13.62	-34.46**	-47.64**	-29.95**	-43.83**
VLD 221 x VL 8549	1.9	0.49	2.89	-0.83	9.92*	7.57	13.48	-6.19	25.86*	14.12	16.7	10.87
VLD 221 x VL 8724	-0.13	-5.61*	-5.95*	-8.54**	3.5	3.21	-19.77**	-26.23**	-37.35**	-54.38**	-20.30*	-39.55**
VLD 221 x VL 8732	-2.98	-7.39**	-14.16**	-15.30**	-18.10**	-20.31**	-21.56**	-24.06**	17.48*	2.98	19.49	2.82
VLD 221 x Sukradhan1	9.34**	8.32**	10.43**	3.06	28.09**	20.84**	3.77	1.18	35.75**	34.25**	34.04*	30.45
Vivek Dhan 154 x VL 30240	0.96	-2.24	-7.66**	-9.13**	2.43	-7.11	0	-6.67	-6.09	-8.47	1.33	-0.75
Vivek Dhan 154 x VL 7620	-1.83	-1.9	8.91**	1.85	0.02	-4.2	-27.80**	-44.29**	-10.53	-18.15*	-5.65	-16.81
Vivek Dhan 154 x VL 30560	10.93**	1.29	3.42	-1.98	7.22	-5.35	-27.64**	-46.27**	-43.89**	-49.09**	-48.37**	-59.40**
Vivek Dhan 154 x VL 8116	4.07*	3.53	-7.01**	-10.45**	-4.76	-13.03**	-0.23	-8.9	-31.15**	-39.53**	-26.66*	-37.53**
Vivek Dhan 154 x VL 8549	8.74**	5.53*	1.9	-4.1	-10.70**	-19.43**	74.88**	68.25**	8.7	-10.71	16.63	3.36
Vivek Dhan 154 x VL 8724	7.55**	0.1	-7.05**	-7.36**	0.75	-7.52	-23.45**	-42.34**	-12.42*	-30.93**	-2.66	-22.02*
Vivek Dhan 154 x VL 8732	-2.05	-5.01*	0.41	-3.31	-13.04**	-17.89**	-23.33**	-40.00**	-8.06	-10.21	-8.35	-15.67

Table 1. Continued

Cross combination	Kernel length		Kernel width		1000grain weight		Grain yield per plot		Fertile grains per panicle		Grains per panicle	
	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Vivek Dhan 154 x Sukradhan1	-7.04**	-9.39**	2.39	-6.61*	-9.83*	-21.31**	-28.60**	-43.82**	19.01*	7.59	22.11	16.42
VL 30240 x VL 7620	3.44	0.1	2.88	-2.32	3.62	-2.15	-32.88**	-45.40**	-6.32	-12.22	-1.64	-14.81
VL 30240 x VL 30560	12.43**	5.80*	-6.32*	-9.84**	9.69*	6.44	-44.18**	-56.47**	-15.85*	-21.82**	-23.59*	-40.81**
VL 30240 x VL 8116	-3.44	-6.02**	-8.66**	-10.66**	-6.47	-7.17	9.33	6.78	-19.92**	-28.04**	-12.54	-26.77*
VL 30240 x VL 8549	7.99**	7.75**	-5.36*	-9.56**	9.24*	8.61	-10.55	-13.33	45.79**	17.37	45.26**	31.13*
VL 30240 x VL 8724	15.42**	10.78**	-12.66**	-14.32**	6.25	4.85	-33.44**	-47.27**	0.64	-19.07**	7.12	-15.51
VL 30240 x VL 8732	0.95	-5.10*	-2.65	-4.78	3.23	-1.1	-30.53**	-42.61**	-37.58**	-37.71**	-7.99	-16.93
VL 30240 x Sukradhan1	-0.63	-1.3	12.47**	4.1	8.98	4.39	-10.44	-25.59**	5.52	-6.78	16.4	13.23
VL 7620 x VL 30560	-5.94**	-14.18**	7.57**	6.06*	-8.54*	-16.04**	-1.45	-6.72	27.34**	26.18**	-0.85	-13.25
VL 7620 x VL 8116	-11.08**	-11.61**	3.68	0.57	-9.38*	-13.81**	-3.19	-19.78**	21.91**	16.55*	16.67	12.07
VL 7620 x VL 8549	-15.48**	-18.03**	15.02**	14.24**	-11.54**	-16.91**	-19.30*	-35.93**	75.85**	34.81**	67.38**	33.05**
VL 7620 x VL 8724	-6.19**	-12.75**	-2.33	-8.94**	-14.07**	-17.82**	-26.34**	-28.83**	-20.06**	-32.22**	-11.06	-20.45*
VL 7620 x VL 8732	-10.19**	-12.85**	3.53	0.43	-9.79*	-11.14*	-15.91*	-17.55*	0.2	-6.3	2.09	-2.56

*, ** Significant at 5% and 1% levels of probability, respectively.

Table 1. Continued

Cross combination	Kernel length		Kernel width		1000grain weight		Grain yield per plot		Fertile grains per panicle		
Grains per panicle		MP	BP	MP	BP	MP	BP	MP	BP	MP	BP MP BP
VL 7620 x Sukradhan1	-17.22**	-19.36**	12.57**	9.57**	-3.63	-12.59**	-9.59	-11.98	15.3	-3.7	12.46 -4.84
VL 30560 x VL 8116	20.07**	10.16**	-4.14	-5.71*	13.77**	9.59	5.33	-16.42*	-10.68	-13.85	-25.56** -32.48**
VL 30560 x VL 8549	-2.18	-8.15**	-3.57	-4.28	-1.47	-3.86	-18.43*	-37.81**	-0.24	-24.00**	-17.33 -40.38**
VL 30560 x VL 8724	26.09**	23.51**	4.59	-1.18	22.54**	17.39**	-52.73**	-53.73**	-20.66**	-32.22**	-30.12** -31.84**
VL 30560 x VL 8732	13.86**	1.12	-1.09	-2.71	15.24**	7.27	-30.92**	-35.82**	26.27**	17.09*	7.5 -9.62
VL 30560 x Sukradhan1	18.76**	11.04**	3.08	-1.03	17.31**	15.76**	-32.08**	-37.31**	24.56**	3.27	12.8 -14.32
VL 8116 x VL 8549	-5.87**	-8.18**	13.97**	11.29**	7.1	5.69	-7.38	-12.29	28.18**	-4.73	23.81* -4.46
VL 8116 x VL 8724	-6.31**	-12.37**	5.82*	1.58	7.59	6.99	-6.6	-24.68**	-33.33**	-41.24**	-36.32** -40.90**
VL 8116 x VL 8732	-5.96**	-9.27**	0.57	0.57	4.09	0.45	-20.83*	-33.33**	-8.85	-18.24*	-8.57 -16.01
VL 8116 x Sukradhan1	-4.03*	-5.97**	11.41**	5.29	11.27*	5.82	19.44*	1.18	-16.14*	-32.43**	-18.59 -33.33**
VL 8549 x VL 8724	16.31**	11.39**	1.82	-4.47	7.52	5.51	-22.15**	-39.74**	-47.37**	-63.92**	-43.87** -58.88**
VL 8549 x VL 8732	-1.54	-7.25**	6.36*	3.86	18.59**	12.99**	19.78*	-3.48	1.85	-17.87*	-3.04 -20.06
VL 8549 x Sukradhan1	8.77**	8.28**	-2.17	-5.4	18.11**	13.77**	16.88*	-5.29	26.77*	13.81	19.11 10.29
VL 8724 x VL 8732	-6.83**	-15.71**	6.91**	2.63	4.53	1.43	-41.92**	-44.94**	-32.26**	-45.62**	-18.59* -30.11**
VL 8724 x Sukradhan1	-1.29	-5.87*	3.9	-5.52*	6.46	0.71	-14.48*	-19.48**	14.94*	-15.72**	17.73 -8.99
VL 8732 x Sukradhan1	-12.09**	-16.83**	16.40**	10.00**	6.63	-1.96	-5.99	-6.67	-19.23*	-28.51**	-28.83* -37.30**
SEm(±)	1.301	1.503	0.571	0.659	1.116	1.289	0.772	0.892	6.016	6.947	11.326 13.079
CD (P=0.05)	2.579	2.978	1.131	1.306	2.212	2.554	1.531	1.768	11.925	13.77	22.451 25.924

*, ** Significant at 5% and 1% levels of probability, respectively.

of two parents used for crossing and production of offspring, which may result in a major challenge for plant breeders, as usually several thousand combinations of parents have to be tested for identifying the best combinations (Gartner et al., 2009; Umakanta, 2002). Both positive and negative heterosis is useful in crop improvement depending on the breeding objectives. In general, positive heterosis is desired for yield and negative heterosis for early maturity ((Nuruzzaman et al., 2002). Heterosis is expressed in three ways, depending on the criteria used to compare the performance of a hybrid (Gupta, 2000; Rahimi et al., 2010). These three ways are mid-parents heterosis (the performance of a hybrid compared with the average performance of its parents), better parent heterosis or heterobeltiosis (the performance of a hybrid compared with that of the best parent in the cross) and standard heterosis (the performance of a hybrid compared with high yielding variety in the region). However, the success of hybrid rice program depends upon the magnitude of heterosis, which also helps in the identification of potential cross combinations to be used in the conventional breeding program to create wide array of variability in the segregating generations. Prediction of heterosis in rice breeding is of great meaning for breeders. How to make it come true with a high efficiency and veracity is of their concerns. Many methodologies were attempted, but no one was ideal. Many studies have been reported on the hybrid vigour for yield and yield components but information on the heterosis for rainfed rice in Uttarakhand hills is still very limited. Hence, an attempt was made in the present investigation to estimate the magnitude of heterosis of yield and associated traits over mid parent and better parent.

Ten rice genotypes *viz.,* VL Dhan 221, Vivek Dhan 154, VL 30240, VL 7620, VL 30560, VL 8116, VL 8549, VL 8724, VL 8732 and Sukradhan1 were grown at Experimental Farm of ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora in *Kharif* 2013 and crossed in a half diallel mating design. In next growing season (*Kharif* 2014), 45F_1 hybrids and their ten parents were planted in randomized block design with three replications and observations on 14 important agronomic traits were recorded. The measured traits were plant height (cm), days to 50 per cent flowering, days to maturity, flag leaf length (cm),

Table 2. Mean performance of grain yield and components traits of cross combinations and parents

Cross combination	Plant height	Days to 50% flowering	Days to maturity	Flag leaf length	Flag leaf width	Tillers per plant	Panicles per plant	Panicle length	Kernel length	Kernel width	1000 grain weight	Grain yield per plot	Fertile grains per panicle	Grains per panicle
VLD 221 x Vivek Dhan 154	99	83	112	25.43	1.5	10	7	23.83	6.77	2.40	26.10	0.108	59	77
VLD 221 x VL 30240	105	69	99	23.23	1.3	13	9	24.07	6.88	2.34	27.84	0.081	81	107
VLD 221 x VL 7620	99	74	104	26.80	1.5	10	8	24.33	6.59	2.33	24.91	0.097	69	81
VLD 221 x VL 30560	102	85	115	28.13	1.4	13	10	22.60	6.21	2.43	24.67	0.093	80	102
VLD 221 x VL 8116	99	84	115	24.70	1.6	11	8	25.03	6.36	2.34	25.61	0.089	54	72
VLD 221 x VL 8549	99	69	99	26.17	1.4	11	9	24.57	6.57	2.45	26.64	0.093	52	71
VLD 221 x VL 8724	98	70	100	24.40	1.4	12	9	24.43	6.80	2.38	28.08	0.101	67	85
VLD 221 x VL 8732	99	65	96	24.00	1.4	9	8	22.83	6.39	2.32	26.94	0.095	59	90
VLD 221 x Sukradhan1	116	89	118	28.83	1.2	9	6	24.57	6.90	2.03	21.99	0.087	81	109
Vivek Dhan 154 x VL 30240	107	76	106	26.93	1.4	10	7	23.33	7.33	2.47	31.54	0.115	81	106
Vivek Dhan 154 x VL 7620	106	75	106	23.93	1.4	11	8	21.67	7.00	2.52	31.05	0.065	75	89
Vivek Dhan 154 x VL 30560	104	79	109	27.00	1.5	8	6	25.20	6.84	2.29	28.85	0.070	72	89
Vivek Dhan 154 x VL 8116	102	78	108	30.13	1.4	11	8	25.70	6.87	2.57	29.75	0.067	74	97
Vivek Dhan 154 x VL 8549	107	72	102	21.63	1.4	12	8	22.20	7.09	2.47	29.39	0.072	47	63
Vivek Dhan 154 x VL 8724	107	75	106	30.10	1.5	11	8	24.60	7.24	2.26	27.01	0.072	60	79
Vivek Dhan 154 x VL 8732	104	88	119	27.50	1.5	12	9	22.83	7.38	2.42	25.02	0.118	67	92
Vivek Dhan 154 x Sukradhan1	106	85	114	27.57	1.4	9	7	26.23	7.00	2.35	28.72	0.074	89	116
VL 30240 x VL 7620	106	74	105	29.30	1.6	7	5	24.80	7.07	2.44	25.50	0.069	70	90
VL 30240 x VL 30560	110	75	105	29.37	1.6	10	8	25.87	6.34	2.35	24.44	0.064	80	104

Table 2. Continued

Cross combination	Plant height	Days to 50% flowering	Days to maturity	Flag leaf length	Flag leaf width	Tillers per plant	Panicles per plant	Panicle length	Kernel length	Kernel width	1000grain weight	Grain yield per plot panicle	Fertile grains per	Grains per panicle
VL 30240 x VL 8116	108	73	104	29.80	1.3	10	6	27.00	6.55	2.44	25.27	0.075	79	86
VL 30240 x VL 8549	109	78	108	26.23	1.4	10	7	24.40	7.01	2.38	27.83	0.065	79	100
VL 30240 x VL 8724	103	79	109	25.93	1.5	9	6	23.53	6.93	2.20	26.90	0.058	72	92
VL 30240 x VL 8732	108	69	98	27.63	1.4	10	7	25.03	6.51	2.18	23.82	0.084	71	93
VL 30240 x Sukradhan1	119	76	106	28.17	1.4	11	9	25.97	7.09	2.21	27.45	0.065	92	112
VL 7620 x VL 30560	97	94	125	27.23	1.4	8	6	25.37	7.26	2.17	27.21	0.068	105	125
VL 7620 x VL 8116	110	76	106	26.27	1.4	9	6	24.07	7.07	2.32	27.29	0.066	49	88
VL 7620 x VL 8549	112	83	112	28.23	1.6	9	6	25.07	6.56	2.54	26.38	0.084	73	97
VL 7620 x VL 8724	108	74	105	27.67	1.5	9	8	25.77	7.01	2.19	28.44	0.120	90	117
VL 7620 x VL 8732	108	85	116	27.30	1.5	10	8	25.63	6.01	2.39	23.88	0.125	116	135
VL 7620 x Sukradhan1	99	83	114	26.33	1.4	9	6	23.27	6.19	2.35	24.51	0.096	115	142
VL 30560 x VL 8116	110	85	115	25.03	1.4	10	7	22.17	5.74	2.54	23.63	0.077	121	156
VL 30560 x VL 8549	114	83	115	26.77	1.5	8	8	25.40	6.11	2.31	23.37	0.091	88	118
VL 30560 x VL 8724	114	85	115	25.30	1.4	9	7	26.70	6.49	2.34	25.27	0.099	84	114
VL 30560 x VL 8732	112	79	110	25.73	1.5	8	6	22.47	5.65	2.40	24.86	0.105	87	111
VL 30560 x Sukradhan1	114	84	113	25.13	1.4	7	6	24.13	5.78	2.26	23.77	0.134	92	156
VL 8116 x VL 8549	112	94	123	28.33	1.5	8	6	23.13	7.63	2.20	28.12	0.112	85	105
VL 8116 x VL 8724	115	86	116	27.60	1.4	8	7	24.70	6.05	2.16	24.02	0.083	70	93
VL 8116 x VL 8732	111	86	116	27.50	1.3	9	7	22.27	7.44	2.51	30.47	0.062	88	106
VL 8116 x Sukradhan1	113	86	116	30.20	1.5	8	7	25.03	7.53	2.27	29.60	0.086	107	141
VL 8549 x VL 8724	109	73	103	25.30	1.4	9	7	23.67	7.38	2.23	27.52	0.084	95	134

Table 2. Continued

Cross combination	Plant height	Days to 50% flowering	Days to maturity	Flag leaf length	Flag leaf width	Tillers per plant	Panicles perplant	Panicle length	Kernel length	Kernel width	1000grain weight	Grain yield per plot	Fertile grains per panicle	Grains per panicle
VL 8549 x VL 8732	117	72	103	28.50	1.4	8	6	27.10	6.92	2.33	25.66	0.079	99	127
VL 8549 x Sukradhan1	109	82	112	25.73	1.5	7	6	24.33	6.36	2.60	27.12	0.069	94	121
VL 8724 x VL 8732	115	82	112	27.43	1.5	9	7	25.20	6.07	2.58	27.77	0.097	76	88
VL 8724 x Sukradhan1	115	92	120	22.83	1.4	8	6	21.30	6.76	2.35	27.71	0.077	81	107
VL 8732 x Sukradhan1	109	87	116	28.90	1.5	9	7	26.23	6.51	2.46	27.15	0.115	67	85
Parents														
VLD 221	106	82	112	24.10	1.3	10	6	22.40	6.58	2.22	24.98	0.070	48	69
Vivek Dhan 154	105	82	112	25.93	1.4	9	7	23.07	7.33	2.42	27.38	0.077	47	61
VL 30240	115	87	116	27.43	1.2	9	6	22.23	6.91	2.42	31.17	0.111	64	85
VL 7620	111	88	116	28.00	1.4	8	6	25.17	7.19	2.10	28.42	0.107	69	89
VL 30560	110	86	115	27.30	1.5	10	8	21.73	6.03	2.54	25.95	0.128	129	148
VL 8116	97	94	121	27.30	1.5	8	6	24.13	6.28	2.60	27.98	0.071	70	104
VL 8549	108	87	117	25.70	1.4	9	6	27.30	6.25	2.40	26.14	0.103	109	135
VL 8724	119	80	112	27.97	1.6	9	7	24.03	7.45	2.33	27.59	0.115	78	106
VL 8732	114	95	124	25.77	1.4	9	7	24.07	6.19	2.57	27.05	0.107	56	67
Sukradhan1	111	87	116	26.30	1.2	9	6	22.13	6.64	2.08	23.15	0.113	60	81

flag leaf width (cm), number of tillers per plant, number of panicles per plant, panicle length (cm), brown grain length(mm), brown grain width(mm), thousand grain weight(g), grain yield per plot(g), number of fertile grains per panicle and number of grains per panicle. Five random plants per plot were used for measuring traits except days to 50 per cent flowering, days to maturity and grain yield, for which the data was recorded on plot basis. Data analysis was carried out based on the mean value of replicated data and subjected to statistical analysis using INDOSTAT software package (Version 8.1) and mean values were utilized for calculating the heterosis as percent increase or percent decrease of F1s over mid parent (average heterosis) and over better parent (heterobeltiosis).

Among the forty-five hybrids studied, most of them exhibited significantly positive heterosis over mid parent (MP) and better parent (BP) for most of the yield related traits with few exceptions (Table 1). The maximum expression of heterobeltiosis (68.25%) and relative heterosis (74.88%) for grain yield per plant were observed for the hybrid Vivek Dhan 154 x VL 8549 followed by VL 8549 x VL 8732 (19.78%), VL 8116 x Sukradhan 1 (19.44%) and VL 8549 x Sukradhan1 (16.88%) over mid parent heterosis, which may be due to the cumulative favourable heterotic effects of some other yield attributing traits. Bhati et al. (2015) and Aditya et al. (2012) reported, heterosis for many yield and yield contributing characters. In general, short plant stature is an important character of hybrid to withstand lodging particularly under irrigated ecosystem. However, intermediate to long plant stature is desirable under rainfed ecosystem, which is also related to high seedling vigour, an important parameter of rice in rainfed situation. Only one cross VL 30240 x VL 8549 has shown significant heterosis over mid parent (11.39%) and better parent (10.53%) for plant height. Negative heterosis is desirable for days to 50% flowering and days to maturity to get early maturing genotypes, which may escape few drought days in rainfed ecology. Cross VLD 221 x VL 8724 has recorded the highest significant heterobeltiosis and relative heterosis followed by VLD 221 x VL 8549, VL 30560 x Sukradhan1 and VLD 221 x VL 8116 for days to 50% flowering and days to maturity. Similar findings were reported by earlier workers *viz.,* Bhati et al. (2015), Latha et al. (2013) for days to 50% flowering and maturity. The

Table 3. Range of yield and its component characteristics in parents and hybrids.

Character	Heterosis range (%)		Range	Based on mean		Best Hybrids
	Average heterosis	Heterobeltiosis	Parents	Hybrids	performanceBest Parents	
Plant height	-14.99 to 11.39	-18.44 to10.53	92- 127	89-123	VL 8724	VL 8724 x Sukradhan1, VL 30240 x Sukradhan1
Days to 50% flowering	-22.68 to 21.23	-24.32 to 14.94	80-95	65-95	VL 8724	VLD 221 x VL 8732
Days to maturity	-15.37 to 13.89	-16.47 to 8.53	112-126	96-126	VL 8724, Vivek Dhan 154, VLD 221	VL 30240 x VL 8732, VLD 221 x VL 8732
Flag leaf length	-19.13 to 16.92	-19.88 to 14.11	21.7- 30.9	18.8- 34.2	VL 30240	VL 8116 x Sukradhan1
Flag leaf width	-21.74 to 24.68	-23.40 to 20.00	1.1-1.8	1.1-1.8	VL 8116	Vivek Dhan 154 x VL 8732, Vivek Dhan 154 x VL 8724
Tillers per plant	-33.33 to 35.85	-37.50 to 26.67	6-13	5-16	VLD 221	Vivek Dhan 154 x VL 8116, VLD 221 x VL 30560
Panicles per plant	-27.27 to 50.00	-30.43 to 42.11	5-8	4-15	Sukradhan1, VL 8732, VL 8724, VL 30560, Vivek Dhan 154	VLD 221 x VL 30560
Panicle length	-16.69 to 24.47	-21.40 to 23.34	20.3-27.7	17.8-29.6	VL 8549, VL 8116	VLD 221 x VL 8724, VL 30240 x VL 8116,VL 30240 x VL 8549
Kernel length	-17.22 to 26.09	-19.36 to 23.51	5.78-7.70	5.51-7.81	VL 8724, Vivek Dhan 154	VL 8116 x VL 8549, VL 8116 x VL 8732, VL 8116 x Sukradhan1
Kernel width	-14.16 to 16.40	-15.30 to 14.24	2.0-2.68	1.98-2.70	VLD 221, Sukradhan1	VLD 221 x Sukradhan1
1000 grain weight	-18.10 to 28.07	-21.31 to 20.84	22.50-32.92	20.24-33.69	VL 30240	VL 8116 x Sukradhan1, Vivek Dhan 154 x VL 30240
Grain yield per plot	-44.18 to74.88	-56.47 to 68.25	64-135	49-158	VL 30560	VL 30560 x Sukradhan1, VL 7620 x VL 8732
Fertile grains per panicle	-47.37 to 75.85	-63.92 to 34.81	42-143	40-129	VL 30560	VL 30560 x VL 8116, VL 7620 x Sukradhan1, VL 7620 x VL 8732
Grains per panicle	-48.37 to 67.38	-59.40 to 33.05	56-171	56-182	VL 30560, VL 8549	VL 30560 x Sukradhan1, VL 30560 x VL 8116, VL 7620 x Sukradhan1

significant mid parent heterosis for flag leaf length was observed in the cross Vivek Dhan 154 x VL 7620 and Vivek Dhan 154 x Sukradhan 1 whereas, cross VL 30240 x Sukradhan 1 has recorded the highest mid parent and better parent heterosis for flag leaf width followed by Vivek Dhan 154 x Sukradhan 1. The significant maximum heterobeltiosis and relative heterosis was recorded by the cross VLD 221 x VL 7620 for tiller per plant followed by Vivek Dhan 154 x VL 30560, VLD 221 x VL 30560, VL 7620 x VL 30560, VL D 221 x Vivek Dhan 154, VLD 221 x VL 8549, Vivek Dhan 154 x VL 9549 over mid parent. Cross VL 30240 x VL 8549 (50.00% and 42.11%) showed significant maximum heterobeltiosis and relative heterosis for panicles per plant followed by VL 221 x VL 8549 (38.46% and 35.00%). Only two cross VL 8724 x Sukradhan1 (24.47% and 23.34%) and Vivek Dhan 154 x VL 8724 (20.89% and 20.71%) exhibited significant heterobeltiosis and relative heterosis for panicle length. Kernel length and kernel width are one of the important parameters for quality attributes in rice. The heterobeltiosis and relative heterosis for kernel length were found to be significantly higher in the cross VL 30560 x VL 8724 followed by VL 8549 x VL 8724, VL 30560 x Sukradhan1, VL 30560 x VL 8116, VL 30240 x VL 8724, VL 8549 x Sukradhan1, VL 30240 x VL 8549, VL 30240 x VL 30560, VLD 221 x Sukradhan1, Vivek Dhan 154 x VL 8549. Thousand grain weight, fertile grains per panicle and total grains per panicle are important parameters contributing for grain yield. Significantly higher heterobeltiosis and relative heterosis were recorded by the cross VL 221 x Sukradha 1, VL 30560 x VL 8724, VL 30560 x Sukradhan1, VL 8549 x VL 8732 and VL 8549 x Sukradhan1 for thousand grain weight. The heterobeltiosis and relative heterosis were found to be significantly higher in the cross VL 7620 x VL 8549 followed by VLD 221 x Sukradhan1, VL 7620 x VL 30560, VL 30560 x VL 8732 and VL 7620 x VL8116 for fertile grains per panicle whereas, cross VL 7620 x VL 8549 and VL 30240 x VL 8549 exhibited significant and higher heterobeltiosis and relative heterosis for grains per panicle. Similarly, Gnanamalar and Vivekanandan (2013), Rahimi et al. (2010), Bhati et al. (2015), Krishna et al. (2016) reported heterosis in rice for tillers per plant, panicle length and fertile grain per panicle, grains per panicle, thousand grain weight, kernel length and kernel width.

The mean performance of cross combinations and parents for various traits are given in Table 2. Among cross, VL 30240 x Sukradhan1 showed tall plant height; VLD 221 x VL 8732, VLD 221 x VL 30240 and VLD 221 x VL 8549 recorded minimum days to 50 % flowering and early maturity; VL 8116 x Sukradhan1, Vivek Dhan 154 x VL 8116 and Vivek Dhan 154 x VL 8724 showed long flag leaf length; VLD 221 x VL 30560 recorded maximum number of tiller and panicles; VL 8549 x VL 8732 and VL 30240 x VL 8116 observed highest panicle length; VL 8116 x VL 8549, VL 8116 x VL Sukradhan1 and VL 8116 x VL 8732 had highest kernel length. Thousand grain weight (mean) was maximum in cross Vivek Dhan 154 x VL 30240 and Vivek Dhan 154 x VL 7620. The highest mean plot yield was observed in cross VL 30560 x Sukradhan1,VL 7620 x VL 8732 and VL 7620 x VL 8724. The maximum number of fertile grains per panicle and total grains per panicle was recorded in cross VL 30560 x VL 8116, VL 7620 x Sukradhan 1 and VL 7620 x VL 8732.

Among parents, VL 30560 had recorded the highest mean for tillers per plant, panicles per plant, grain yield per plant, fertile grains per panicle and total number of grains per panicle. VL 8724 was the tall statured plant, whereas VL 221, Vivek Dhan 154 and VL 8724 were the first to mature. The highest panicle length was observed in VL 8549, whereas VL 8724 and Vivek Dhan 154 recorded the highest kernel length. Thousand grain weight was maximum in VL 30240. It can be inferred that none of the cross and parent recorded highest mean for all the characters but, some parents and crosses showed highest mean for a number of characters. Parents with highest mean may not necessarily produce highest cross combinations for different traits.

The range of parents, hybrids and range of heterosis for all the fourteen characters are presented in Table 3. In general, the magnitude of heterosis was low for grain quality characters as compared to the heterosis for grain yield and its component traits. Among component traits, plant height and days to maturity manifested low heterosis. The hybrids recorded -44.18 to 74.88% average heterosis and -56.47 to 68.25% heterobeltiosis for grain yield per plant. For practical utility, a variety/hybrid with good yield potential combining with all quality characters in the desirable range is useful. If consider both yield and quality together, crosses VL 8116 x Sukradhan 1, VL 30560 x Sukradhan1, VL 30560 x VL 8116, VL 30560 x Sukradhan1, VL 7620 x Sukradhan1 manifested significant heterosis for grain yield as well as kernel length characteristics in the desirable range. Whereas, parent VL 30560, VL 30240, VL 8116, VL 7620, Sukradhan1 were the best parent for both quality characters and grain yield. Hence, these crosses and parents could be exploited for their yield potential and quality traits in the further breeding programmes. Thus, the findings from the present study indicated that the higher and desirable magnitude of all yield related traits were not expressed in a single hybrid combination and varied from cross to cross due to diverse genetic background of their parents.

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