Society for Advancement of Wheat and Barley Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Journal of Cereal Research

11(3): 231-241

Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Research Article

Combining ability and gene action studies for physiological, phenological and yield traits in rice (*Oryza sativa*)

Ramanjeet Singh, Deo Prakash Pandey* and Anjali Kumari

Rice and Wheat Research Centre, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Malan, Himachal Pradesh-176 047

Article history

Received: 23., Oct., 2019
Revised: 21 Dec., 2019
Accepted: 29 Dec., 2019

Citation

Singh R, DP Pandey and A Kumari. 2019. Combining ability and gene action studies for physiological, phenological and yield traits in rice (*Oryza sativa*). *Journal of Cereal Research* **11**(3): 231-241. http://doi.org/10.25174/2249-4065/2019/94698

***Corresponding author**

Email: pandeydp04@yahoo.co.in

© *Society for Advancement of Wheat and Barley Research*

Abstract

Thirty F_1 hybrids involving 10 lines and three testers alongwith their parents were evaluated for combining ability and gene action. Analysis of variance for line tester mating design with respect to parents, crosses and parents vs. crosses for yield and physiological traits revealed significant differences for almost all the traits studied except total tillers per plant, effective tillers per plant and spikelet fertility in case of parents. Magnitude of dominance variance was found to be higher than that of additive for all the parameters. The average degree of dominance was observed more than one for all the traits. Narrow-sense heritability was obtained low (<50%) in all the traits studied. Genetic advance was highest for spikelets panicle^{-1} (2.36) followed by grains panicle^{-1} (1.99), plant height (1.78), gel consistency (0.86) and 1000 grain weight (0.49). Among lines, HPR 2750, HPR 2754 and HPR 2878 were good general combiners for grain yield and contributing traits. The best combinations for SCA effects were HPR 2880 × HPR 2143, HPR 2756 × HPR 2720, HPR 2872 × HPR 2720, HPR 2880 × HPR 2612 and HPR 2880 × HPR 2720. The cross HPR 2872 x HPR 2720 showed highest heterosis over standard check for grain yield plant^{-1} and its contributing traits. Crosses *viz.,* HPR 2756 × HPR 2612 and HPR 2769 × HPR 2612 were found have strong aroma.

Keywords: Combining ability, gene action, grain quality, heterosis, line x tester analysis

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops, feeding more than half of the world's population (Khush, 1997). In the Asia and Pacific region, where 90 per cent of it is produced and consumed, it will remain the lifeline of the people. Globally, rice is grown over an area of 163.21 million hectares with total production of 481.0 million tonnes (Anonymous, 2018). In India rice covers 44 million hectares with production of 110.15 million tonnes (Anonymous, 2018). Further, area under rice in Himachal Pradesh is 74 thousand hectares with production of 132 thousand metric tonnes (Anonymous, 2018). The demand of local as well as improved cultivars is continuously increasing because there is a great diversity in agro-climatic conditions under which rice is cultivated. Therefore, combining desirable attributes with high yield is always a matter of concern for breeders to meet the increasing demand of the population. For this purpose, combining ability analysis can be used for the evaluation of inbreds based on their genetic value, in the selection of suitable parents to be used in hybridization and also helps in the identification of superior cross combinations for exploiting heterosis (Sarker *et al.,* 2002; Muhammad *et al.,* 2007).

The present investigation was undertaken to assess the genetic architecture of rice genotypes for yield and its component traits and to identify potential parents and crosses for desirable traits.

2. Materials and methods

The investigation was carried out at RWRC, Malan, during *Kharif* 2015. The experimental material consisted of F_1 population of 30 crosses developed

Table 1: List of rice genotypes used in making crosses in line × tester mating design.

Sr. No.	Genotypes	Parentage
Lines		
1.	HPR 2880	HPU 2216 × Tetep
2.	HPR 2750	Hasan Serai/T23//IR 66295
3.	HPR 2779	VL 221/HPU2216//HPR 1149
4.	HPR 2872	HPR 2143/AC 19166//VL 30424
5.	HPR 2873	HR-2143/AC 19166/11/36042
6.	HPR 2754	Hassan Serai/T23//IR 66295-36-2
7.	HPR 2878	HPR 2143/C 19180//VL 30424
8.	HPR 2769	Hasan Serai/T23//IR 66295
9.	HPR 2751	Hasan Serai/T23//IR 66295
10.	HPR 2756	Hasan Serai/T23//IR 66295
Testers		
1.	HPR 2612	HS/T23//IR66295-36-2
2.	HPR 2720	Pure line selection from IC 4553331
3.	HPR 2143	HPU 741/PP72

(Table 1) by crossing 10 lines/genotypes *viz.,* HPR 2880, HPR 2750, HPR 2779, HPR 2872, HPR 2873, HPR 2754, HPR 2878, HPR 2769, HPR 2751 and HPR 2756 with three testers *viz.,* HPR 2143, HPR 2612 and HPR 2720 in a line × tester mating design. During *Kharif* 2015, the F_1's along with their parents [lines (10) + testers (3)] were evaluated with three replications in single row of 2 m length with spacing of 20 cm × 15 cm. The observations were recorded on five random plants of each genotype/cross combinations for various traits except days to 50% flowering and days to maturity being recorded on plot basis. Observations were recorded for 19 characters *viz.,* plant height, days to 50% flowering, days to maturity, total tillers plant^{-1}, effective tillers plant^{-1}, panicle length, spikelets panicle^{-1}, grains panicle^{-1}, spikelet fertility, grain yield plant^{-1}, 1000 grain weight, grain length, grain breadth, protein content (%), amylose content (%), gelatinization temperature, gel consistency and aroma. Analysis of variance was done by the method suggested by Panse and Sukhatme (1985). Line × tester analysis was conducted following model given by Kempthorne (1957).

Table 2: Analysis of variance for combining ability analysis in line × tester design for grain yield, physiological, phenological and grain quality traits.

Sources of variation		Mean Sum of Square					
		Replications	Crosses	Lines	Testers	Lines × Testers	Error
Traits	Df	2	29	9	2	18	58
Yield traits and physiological traits							
Plant height		44.47	594.71*	1166.08*	1219.88*	239.56*	13.35
Total tillers plant^{-1}		0.19	1.53	2.20	1.12	1.24	1.11
Effective tillers plant^{-1}		0.24	1.06	0.97	0.76	1.14	1.05
Panicle length		1.39	16.78*	34.34*	16.82	7.99*	1.95
Spikelets panicle^{-1}		55.70	1841.25*	3147.89*	3447.55*	1009.45*	131.72
Grains panicle^{-1}		7.89	1035.93*	1845.13*	2150.46*	505.87*	70.02
Spikelet fertility		13.15	104.45*	131.35*	8.64	101.65*	10.69
Grain yield plant^{-1}		0.52	34.72*	70.67*	4.28	20.12*	1.24
1000 grain weight		0.16	47.98*	110.85*	2.18	21.64*	0.21
Phenological traits							
Days to 50% flowering		72.41	13.63	24.05	25.28	7.12	15.65
Days to maturity		80.40	13.83	24.20	36.40	6.13	11.79
Grain quality traits							
Grain length [L]		0.24	0.77*	1.19*	1.02	0.54*	0.14
Grain breadth [B]		0.01	0.09*	0.161*	0.01	0.0603	0.02
L:B ratio		0.06	0.41*	0.63*	0.22	0.32	0.10
Protein content		0.28	3.74*	3.61*	7.66*	3.36*	0.07
Amylose content		0.11	30.69*	57.85*	4.49*	20.03*	0.01
GT		0.01	1.82*	3.70*	1.19*	0.95*	0.04
Gel consistency		4.01	492.65*	286.48*	99.81*	639.39*	1.44

*Significant at 5% level of significance, GT = gelatinization temperature

Table 3: Analysis of variance with respect to parents vs. crosses for grain yield, physiological, phenological and grain quality traits.

Sources of variation		Mean Sum of Square					
		Replication	Treatments	Parents	Crosses	Parents vs. Crosses	Error
Traits	Df	2	42	12	29	1	84
			Yield and physiological traits				
Plant height		32.71	656.12*	667.57*	594.71*	2299.420	13.41
Total tillers plant^{-1}		0.32	1.86	2.30	1.53	6.43	1.21
Effective tillers plant^{-1}		0.54	1.35	1.75	1.06	4.86	1.08
Panicle length		0.92	15.10*	12.14*	16.77*	2.09	3.476
Spikelets panicle^{-1}		62.31	1756.99*	1574.22*	1841.25*	1506.79	112.47
Grains panicle^{-1}		26.30	989.08*	941.59*	1034.93*	229.57	66.27
Spikelet fertility		5.61	94.24*	*59.89	104.45*	210.37	9.20
Grain yield plant^{-1}		42.29	31.64*	20.66*	34.72*	74.37	1.19
1000 grain weight		0.11	49.93*	52.11*	47.98*	80.30*	0.21
			Phenological traits				
Days to 50% flowering		45.24	16.39	18.73	13.631	68.62	14.188
Days to maturity		50.84	18.19	24.44	13.82	69.65	11.98
			Grain quality traits				
Grain length [L]		0.38	0.97*	1.52*	0.77*	0.01	0.12
Grain breadth [B]		0.01	0.08*	0.08*	0.09*	0.04	0.02
L:B ratio		0.08	0.45*	0.59*	0.41*	0.11	0.0811
Protein content		0.17	3.51*	3.23*	3.740*	0.42	0.07
Amylose content		0.12	35.77*	46.00*	30.69*	60.031*	0.01
GT		0.04	2.17*	3.18*	1.82*	0.11	0.05
Gel consistency		3.26	515.94*	607.661*	492.65*	90.77	1.65

*Significant at 5% level of significance, GT = gelatinization temperature

3. Results and discussion

Analysis of variance for line × tester mating design with respect to crosses revealed significant for majority of the yield, physiological, phenological and quality traits studied (Table 2). Further partitioning of variance of the crosses into lines, testers and lines × testers indicated significant differences for all the traits, except total tillers per plant and effective tillers per plant among lines; except total tillers plant^{-1}, spikelet fertility, grain yield per plant, 1000 grain weight, effective tillers plant^{-1}, grain breadth, grain length and L:B ratio among testers whereas, line × tester differed significantly for all traits except effective tillers per plant, total tillers per plant and L:B. Among phenological traits, lines, testers and crosses showed non-significant difference for both days to 50% flowering and days to maturity.

Analysis of variance for line × tester mating design with respect to parents, crosses and parents vs. crosses (Table 3) revealed significant differences for all the traits studied except total tillers per plant, effective tillers per plant and spikelet fertility in case of parents, except total tillers and effective tillers per plant in crosses and in parents vs. crosses, all were non- significant except 1000 grain weight and amylose content. Results were in confirmation with the findings of Sarker *et al.* (2002), Jayasudha and Sharma (2009), Rahimi *et al.* 2010, Sanghera and Hussain (2012) and Singh and Babu (2012). Phenological traits exhibited non-significant differences.

The average degree of dominance was more than one for all the traits. The highest average degree of dominance value was observed for spikelet fertility (144.66) followed by protein content (39.15) and gel consistency (19.38). Genetic advance (Table 4) was highest for spikelets panicle^{-1} (2.36) followed by grains panicle^{-1} (1.99) and plant height (1.78). Sathya (2014) and Shrivastava *et al.* (2014) also reported the same.

Table 4: Estimates of additive (σ^2A) and dominance (σ^2D) variance, average degree of dominance $(\sigma^2D/\sigma^2A)^{1/2}$, narrow sense heritability (%) and genetic advance (5%) for yield, physiological, phenological and grain quality traits.

Traits	Additive variance	Dominance variance	Average degree of dominance	Narrow sense heritability (%)	Genetic advance (%)
		Yield traits & physiological traits			
Plant height	13.28	75.40	2.84	0.06	1.78
Total tillers plant^{-1}	0.01	0.04	2.01	0.01	0.01
Effective tillers plant^{-1}	0.01	0.03	4.96	0.001	0.01
Panicle length	0.33	1.29	1.98	0.034	0.22
Spikelets panicle^{-1}	31.10	292.57	4.70	0.04	2.36
Grains panicle^{-1}	19.78	145.28	3.67	0.05	1.99
Spikelet fertility	0.10	30.32	144.65	0.002	0.03
Grain yield plant^{-1}	0.54	6.29	5.76	0.04	0.32
1000 grain weight	0.98	7.14	3.62	0.06	0.49
		Phenological traits			
Days to 50% flowering	0.24	2.84	5.84	0.012	0.10
Days to maturity	0.29	1.88	3.28	0.01	0.13
		Grain quality traits			
Grain length [L]	0.01	0.13	7.52	0.02	0.03
Grain breadth [B]	0.10	0.01	6.3	0.02	0.01
L:B ratio	0.00	0.07	11.75	0.012298	0.01
Protein content	0.01	1.09	39.15	0.011017	0.025
Amylose content	0.39	6.67	8.37	0.033414	0.23
GT	0.03	0.30	4.63	0.041488	0.07
GC	5.49	212.65	19.37	0.03	0.85

Table 5: Estimates for general combining ability (GCA) effects of parents for grain yield and physiological traits.

Traits	Plant height	Total tillers plant^{-1}	Effective tillers plant^{-1}	Panicle length	Spikelets panicle^{-1}	Grains panicle^{-1}	Spikelet fertility	Grain yield plant^{-1}	1000 grain weight
Lines									
HPR 2880	2.88*	0.91*	0.49	-2.31*	-4.53	-2.72	0.52	-1.80*	0.05
HPR 2750	-4.41*	0.09	-0.27	1.54*	21.96*	16.39*	-2.07	3.92*	-1.76*
HPR 2779	-11.90*	0.65	0.49	-1.31	-3.55	4.90	6.66*	2.16*	3.23*
HPR 2872	4.25*	-0.06	0.22	0.67	11.53*	8.56*	0.21	3.64*	2.92*
HPR 2873	2.03	-0.49	-0.34	1.78*	6.69	6.24*	0.32	0.97*	3.53*
HPR 2754	-5.77*	-0.64	-0.42	0.21	15.13*	14.79*	1.87	-2.74*	-1.08*
HPR 2878	-11.88*	-0.40	-0.07	-1.97*	-25.60*	-23.93*	-2.74*	-4.04*	1.06*
HPR 2769	11.73*	-0.18	-0.14	-0.31	-26.04*	-19.20*	2.12	0.42	3.29*
HPR 2751	23.52*	-0.15	-0.16	3.66*	23.21*	8.88*	-8.08*	0.47	-5.45*
HPR 2756	-10.46*	0.27	0.20	-1.97*	-18.80*	-13.92*	1.19	-2.99*	-5.79*
SE (gi) ±	1.21	0.35	0.34	0.67	3.826	2.78	1.09	0.37	0.15
SE (gi-gj) ±	1.72	0.49	0.48	0.95	5.41	3.94	1.54	0.52	0.22
Testers									
HPR 2143	-3.09*	-0.21	-0.18	-0.63	-2.70	-2.72	-0.51	0.25	-0.09
HPR 2612	-4.25*	0.17	0.11	-0.20	-9.11*	-6.77*	0.56	-0.43*	0.30*
HPR 2720	7.33*	0.04	0.07	0.83*	11.81*	9.49*	-0.05	0.18	-0.22*
SE (gi) ±	0.67	0.19	0.18794	0.39	2.09	1.53	0.60	0.20	0.08
SE (gi-gj) ±	0.94	0.27	0.26	0.52	2.96	2.16	0.84	0.29	0.12

* Significant at 5% level of significance

Table 6: Estimates for general combining ability (GCA) effects of parents for phenological and grain quality traits.

Traits	Days to 50% flowering	Days to maturity	Grain length [L]	Grain breadth [B]	L:B ratio	Protein content	Amylose content	GT	GC
Lines									
HPR 2880	-0.71	0.27	-0.77*	-0.07	-0.28*	0.13	2.64*	1.62*	-4.77*
HPR 2750	0.84	0.93	0.03	-0.17*	0.31*	-0.43*	2.06*	-0.40*	-4.32*
HPR 2779	1.62	0.16	-0.02	0.01	-0.05	0.60*	-3.42*	-0.18*	-1.88*
HPR 2872	0.18	0.60	0.03	0.24*	-0.31*	-0.47*	-2.34*	0.28*	-8.10*
HPR 2873	-0.82	-1.84	0.63*	0.06	0.20	0.43*	-0.76*	0.02	-4.54*
HPR 2754	-3.49*	-3.18*	0.23	0.05	-0.00	-1.19*	-3.86*	-0.60*	7.68*
HPR 2878	-0.04	-0.73	-0.31*	-0.07	-0.07	0.82*	0.67*	-0.61*	7.68*
HPR 2769	1.40	2.49*	-0.09	0.14*	-0.27*	-0.45*	-0.05*	-0.25*	-0.32
HPR 2751	2.07	1.60	0.21	-0.20*	0.48*	0.60*	3.10*	0.06	4.79*
HPR 2756	-1.04	0.29	0.05	0.01	-0.00	-0.04	1.96*	0.06	3.79*
SE (gi) ±	1.32	1.14	0.12	0.05	0.10	0.09	0.03	0.07	0.40
SE (gi-gj) ±	1.86	1.62	0.18	0.07	0.15	0.13	0.05	0.09	0.5650
Testers									
HPR 2143	-0.89	-1.07	-0.07	0.02	-0.05	-0.51*	-0.29*	-0.21*	0.19
HPR 2612	-0.06	-0.07	0.21*	0.00	0.10	0.50*	-0.15*	0.02	-1.91*
HPR 2720	0.94	1.13	-0.14	-0.02	-0.05	0.01	0.44*	0.19*	1.72*
SE (gi) ±	0.72	0.63	0.07	0.03	0.06	0.05	0.02	0.04	0.22
SE (gi-gj) ±	1.02	0.87	0.10	0.04	0.08	0.07	0.03	0.05	0.31

* Significant at 5% level of significance, GT = Gelatinization temperature, GC = Gel consistency

The magnitude of GCA variance was higher than the SCA variance for all the traits studied. The comparative variances due to gca and sca revealed the predominance of non-additive gene action in the expression of the traits. The presence of non-additive genetic variance offers scope for exploitation of heterosis.

Results have been presented in Table 5 and Table 6. Estimation of GCA effects of lines revealed that HPR 2880 exhibited significant and positive GCA for plant height, total tillers per plant, amylose content and gelatinization temperature (GT). Therefore, HPR 2880 was considered as good combiner for the respective traits. HPR 2750 exhibited significant and positive GCA for panicle length, spikelets panicle^{-1}, grains panicle^{-1}, grain yield plant^{-1}, grain length: grain breadth (L:B) ratio and amylose content. HPR 2779 exhibited significant and positive GCA for spikelet fertility, grain yield plant^{-1}, 1000 grain weight and protein content. HPR 2872 exhibited significant and positive GCA for plant height, spikelets panicle^{-1}, grains panicle^{-1}, grain yield plant^{-1}, 1000 grain weight, grain breadth and GT. HPR 2873 exhibited significant and positive GCA for panicle length, grains panicle^{-1}, grain yield plant^{-1}, 1000 grain weight, grain length and protein content. HPR 2754 exhibited significant and positive GCA for spikelets panicle^{-1}, grains panicle^{-1} and gel consistency (GC). HPR 2878 exhibited significant and positive GCA for 1000 grain weight, protein content, amylose content and GC. Similarly, HPR 2769 exhibited significant and positive GCA for plant height, 1000 grain weight, days to maturity and grain breadth. HPR 2751 exhibited significant and positive GCA for plant height, panicle length, spikelets panicle^{-1}, grains panicle^{-1}, L:B ratio, protein content, amylose content and GC. HPR 2756 exhibited significant and positive GCA only for amylose content and GC. Among testers, HPR 2612 exhibited significant and positive GCA for 1000 grain weight, grain length and protein content whereas HPR 2720 exhibited significant and positive GCA for plant height, panicle length, spikelets panicle^{-1}, grains panicle^{-1}, amylose content, GT and GC. Tester HPR 2143 was non- significant for all the traits, Therefore, all the lines and testers were good combiners for some particular traits. List of good general combiners have been presented in Table 9.

The usefulness of a particular cross in the exploitation of heterosis is judged by specific combining ability effects. SCA is the estimation of the effects of non-additive gene action for a trait. Non-additive gene action is necessary for the selection of a hybrid combination. Therefore, a highly significant SCA is desired for a successful breeding programme. Results have been presented in Table 7 and Table 8. The crosses HPR 2880 × HPR 2612, HPR 2750 × HPR 2720, HPR 2779 × HPR 2143, HPR 2872 × HPR

Table 7: Estimates for specific combining ability (SCA) effects of parents for grain yield and physiological traits.

Traits	Plant height	Total tillers plant-1	Effective tillers plant-1	Panicle length	Spikelets panicle-1	Grains panicle-1	Spikelet fertility	Grain yield plant-1	1000 grain weight
Crosses									
HPR 2880 × HPR 2143	3.18	1.17	0.96	1.03	-9.65	-5.83	2.12	-0.77	1.10*
HPR 2880 × HPR 2612	6.33*	-0.08	0.13	0.85	9.56	10.95*	2.68	1.03	0.20
HPR 2880 × HPR 2720	-9.51*	-1.09	-1.09	-1.88	0.10	-5.12	-4.81*	-0.26	-1.30*
HPR 2750 × HPR 2143	-1.27	-0.34	-0.22	-1.44	7.12	3.99	-0.89	-3.66*	-0.72*
HPR 2750 × HPR 2612	-3.64	0.14	0.09	1.24	-3.93	-9.36	-4.93*	0.20	0.24
HPR 2750 × HPR 2720	4.91*	0.20	0.13	0.20	-3.19	5.37	5.82*	3.46*	0.48
HPR 2779 × HPR 2143	5.15*	-0.37	-0.24	0.97	8.63	5.08	-2.15	2.58*	0.17
HPR 2779 × HPR 2612	1.85	0.05	-0.24	0.72	2.31	-2.07	-3.29	-1.76*	0.11
HPR 2779 × HPR 2720	-7.00*	0.31	-0.07	-1.69	-10.95	-3.00	5.44*	-0.81	-0.27
HPR 2872 × HPR 2143	-2.00	-0.32	-0.31	-0.08	9.48	14.56*	3.58	0.66	2.08*
HPR 2872 × HPR 2612	-6.64*	-0.24	-0.33	-2.96*	-35.58*	-23.96*	5.28*	-5.04*	-0.51
HPR 2872 × HPR 2720	8.64*	0.56	0.64	3.04*	26.10*	9.41	-8.86*	4.38*	-1.56*
HPR 2873 × HPR 2143	-1.85	0.63	0.38	-1.01	7.66	1.41	-3.38	1.60*	-0.55*
HPR 2873 × HPR 2612	-8.62*	0.05	0.16	0.59	0.73	0.26	-0.43	0.43	-0.03
HPR 2873 × HPR 2720	10.47*	-0.69	-0.54	0.43	-8.39	-1.67	3.82*	-2.03*	0.58*
HPR 2754 × HPR 2143	-2.78	-0.21	-0.20	0.52	-17.12*	-8.48	4.80*	0.75	2.38*
HPR 2754 × HPR 2612	-7.22*	0.01	-0.02	-1.58	-0.44	-5.36	-3.49	0.85	-1.07*
HPR 2754 × HPR 2720	10.00*	0.20	0.22	1.06	17.57*	13.84*	-1.31	-1.60*	-1.31*
HPR 2878 × HPR 2143	-3.74	-0.46	-0.42	1.52	18.28*	5.00	-10.53*	-0.02	-1.51*
HPR 2878 × HPR 2612	-2.51	0.90	1.02	0.51	9.76	9.63*	0.82	-0.20	1.41*
HPR 2878 × HPR 2720	6.25*	-0.44	-0.60	-2.02	-28.03*	-14.63*	9.70*	0.22	0.10
HPR 2769 × HPR 2143	4.19*	0.59	0.58	0.35	-8.38	-3.32	4.90*	-0.93	1.63*
HPR 2769 × HPR 2612	5.30*	-0.52	-0.44	-0.89	16.03*	15.23*	1.86	0.64	0.41
HPR 2769 × HPR 2720	-9.49*	-0.06	-0.14	0.54	-7.66	-11.90*	-6.76*	0.30	-2.04*
HPR 2751 × HPR 2143	2.47	-0.03	0.00	-1.18	8.83	7.77	0.82	1.77*	2.08*
HPR 2751 × HPR 2612	-2.11	-0.48	-0.56	0.67	-13.59*	-9.45	-0.12	1.56*	-0.52
HPR 2751 × HPR 2720	-0.36	0.51	0.55	0.51	4.75	1.69	-0.70	-3.33*	-1.56*
HPR 2756 × HPR 2143	-3.36	-0.66	-0.55	-0.67	-24.85*	-20.17*	0.73	-1.97*	-6.65*
HPR 2756 × HPR 2612	17.27*	0.16	0.02	0.86	15.16*	14.15*	1.61	2.31*	-0.23
HPR 2756 × HPR 2720	-13.91*	049	0.53	-0.20	9.70	6.02	-2.34	-0.33	6.88*
SE (S_{ij}) ±	2.11	0.61	0.591	1.17	6.63	4.83	1.89	0.64	0.27
SE (S_{ij}-S_{kl}) ±	2.98	0.86	0.83	1.65	9.37	6.83	2.67	0.91	0.38

* Significant at 5% level of significance, GT = Gelatinization temperature, GC = Gel consistency

2720, HPR 2873 × HPR 2720, HPR 2754 × HPR 2720, HPR 2878 × HPR 2720, HPR 2769 × HPR 2143, HPR 2769 × HPR 2612 and HPR 2756 × HPR 2612 were having significant and positive SCA effect for plant height and hence these can be considered as good specific combinations for plant height. The crosses HPR 2872 × HPR 2720, HPR 2754 × HPR 2720, HPR 2878 × HPR 2143, HPR 2769 × HPR 2612 and HPR 2756 × HPR 2612 exhibited significant and positive SCA effects for spikelets panicle^{-1}. The crosses HPR 2880 × HPR 2612, HPR 2872 × HPR 2143, HPR 2754 × HPR 2720, HPR 2878 × HPR 2612, HPR 2769 × HPR 2612 and HPR 2756 × HPR 2612 were having significant and positive SCA effect for grains panicle^{-1}. The crosses HPR 2750 × HPR 2720, HPR 2779 × HPR 2720, HPR 2872 × HPR 2612, HPR 2873 × HPR 2720, HPR 2754 × HPR 2143, HPR 2878 × HPR 2720 and HPR 2769 × HPR 2143 exhibited significant and positive SCA effects for spikelet fertility. The crosses HPR 2750 × HPR 2720, HPR 2779 × HPR 2143, HPR 2872 × HPR 2720, HPR 2873 × HPR 2143, HPR 2751 ×

Table 8: Estimates for specific combining ability (SCA) effects of parents for phenological and grain quality traits.

Traits	Days to 50% flowering	Days to maturity	Grain length [L]	Grain breadth [B]	L:B ratio	Protein Content	Amylose content	GT	GC
Crosses									
HPR 2880 × HPR 2143	-2.22	-2.60	0.10	0.08	-0.11	-0.24	1.41*	-0.49*	25.70*
HPR 2880 × HPR 2612	0.94	1.73	-0.04	-0.07	0.12	-2.15*	0.28*	0.74*	-20.53*
HPR 2880 × HPR 2720	1.28	0.87	-0.05	-0.02	-0.01	2.39*	-1.68*	-0.25*	-5.17*
HPR 2750 × HPR 2143	-1.44	-0.60	0.25	-0.07	0.26	-0.39*	0.42*	0.50*	2.92*
HPR 2750 × HPR 2612	-0.61	-0.93	-0.31	-0.01	-0.13	0.50*	-2.05*	-0.67*	1.69*
HPR 2750 × HPR 2720	2.06	1.53	0.06	0.08	-0.12	-0.11	1.63*	0.17	-4.61*
HPR 2779 × HPR 2143	0.44	0.18	0.32	-0.09	0.28	1.39*	1.27*	0.11	-12.19*
HPR 2779 × HPR 2612	-0.39	-0.82	0.09	0.02	0.01	-0.45*	0.08	-0.06	3.24*
HPR 2779 × HPR 2720	-0.06	0.64	-0.41	0.06	-0.30	-0.94*	-1.35*	-0.05	8.94*
HPR 2872 × HPR 2143	-0.78	-0.93	-0.44*	0.22*	-0.45*	0.42*	-0.33*	-0.18	-18.30*
HPR 2872 × HPR 2612	-0.61	0.07	0.36	0.03	0.08	0.38*	-0.35*	-0.58*	18.80*
HPR 2872 × HPR 2720	0.39	0.87	0.08	-0.25*	0.37*	-0.80*	0.67*	0.76*	-0.50
HPR 2873 × HPR 2143	0.22	-0.16	-0.25	0.16	-0.42*	-0.74*	0.76*	-0.02	-1.86*
HPR 2873 × HPR 2612	0.39	0.18	-0.38	-0.08	-0.06	0.55*	-1.59*	0.68*	5.24*
HPR 2873 × HPR 2720	-0.61	-0.02	0.63*	-0.09	0.48*	0.20	0.83*	-0.65*	-3.39*
HPR 2754 × HPR 2143	-1.44	0.18	0.22	0.07	-0.03	-0.19	-0.07	0.53*	10.92*
HPR 2754 × HPR 2612	0.06	0.18	0.47*	-0.04	0.30	-0.47*	0.41*	-0.67*	-10.31*
HPR 2754 × HPR 2720	1.39	-0.36	-0.69*	-0.03	-0.27	0.65*	-0.34*	0.14	-0.61
HPR 2878 × HPR 2143	1.78	1.40	0.25	0.03	0.05	0.83*	-1.17*	-0.46*	-12.41*
HPR 2878 × HPR 2612	-1.06	-0.93	-0.23	-0.06	-0.01	0.16	1.19*	0.31*	3.02*
HPR 2878 × HPR 2720	-0.72	-0.47	-0.02	0.02	-0.03	-0.99*	-0.02	0.15	9.39*
HPR 2769 × HPR 2143	2.00	0.84	-0.07	-0.29*	0.40*	-0.27	-2.77*	0.25*	-16.41*
HPR 2769 × HPR 2612	0.17	-0.49	0.38	0.11	-0.03	0.89*	-2.26*	-0.05	11.02*
HPR 2769 × HPR 2720	-2.17	-0.36	-0.31	0.18*	-0.38*	-0.62*	5.03*	-0.21	5.39*
HPR 2751 × HPR 2143	0.00	-0.93	0.11	-0.09	0.21	-0.34*	3.59*	-0.12	6.81*
HPR 2751 × HPR 2612	0.50	1.07	-0.13	-0.02	-0.01	-0.02	-0.64*	-0.36*	6.24*
HPR 2751 × HPR 2720	-0.50	-0.13	0.03	0.11	0.21	0.36*	-2.95*	0.48*	-13.06*
HPR 2756 × HPR 2143	1.44	2.62	-0.46*	-0.05	-0.19	-0.48*	-3.11*	-0.12	14.81*
HPR 2756 × HPR 2612	0.61	-0.04	-0.21	0.11	-0.27	0.61*	4.92*	0.64*	-18.42*
HPR 2756 × HPR 2720	-2.06	-2.58	0.67*	-0.07	0.46*	-0.14	-1.81*	-0.52*	3.61*
SE (S_{ij}) ±	2.28	1.98	0.21	0.09	0.18	0.16	0.06	0.12	0.69
SE (S_{ij}-S_{kl}) ±	3.23	2.80	0.31	0.12	0.25	0.22	0.08	0.16	0.98

*Significant at 5% level of significance, GT = Gelatinization temperature, GC = Gel consistency

HPR 2143, HPR 2751 × HPR 2612 and HPR 2756 × HPR 2612 were having significant and positive SCA effect for grain yield plant^{-1}. The results were in accordance with the findings of Singh and Kumar (2004), Rosamma and Vijayakumar (2005), Pradhan *et al.* (2006), Muhammad *et al.* (2007) and Hossain *et al.* (2009), who emphasized that grain yield plant^{-1} have high specific combining ability (SCA) variance suggesting the predominance of non-additive genetic variance. The crosses HPR 2880 × HPR 2143, HPR 2872 × HPR 2143, HPR 2873 × HPR 2720, HPR 2754 × HPR 2143, HPR 2878 × HPR 2612, HPR 2769 × HPR 2143, HPR 2751 × HPR 2143 and HPR 2756 × HPR 2720 exhibited significant and positive sca effects for 1000-grai weight. The crosses HPR 2873 × HPR 2720, HPR 2754 × HPR 2612 and HPR 2756 × HPR 2720 were having significant and positive sca effect for grain length.

The crosses HPR 2872 × HPR 2143 and HPR 2769 × HPR 2720 were having significant and positive SCA effect for grain breadth. The crosses HPR 2872

Table 9: List of heterotic crosses over standard check (%), good specific combinations and good general combiners for yield, physiological, phenological and grain quality traits.

Traits	Heterotic crosses	Good specific combinations	Good general combiners
Yield and physiological traits			
Plant height			
	HPR 2754 ×HPR 2612(-6.71)	HPR 2756 × HPR 2612	HPR 2751
	HPR 2756 × HPR 2720(-6.53)	HPR 2756 × HPR 2720	HPR 2779
	HPR 2756 × HPR 2143(-6.40)	HPR 2873 × HPR 2720	HPR 2878
	HPR 2779 × HPR 2612(-3.98)	HPR 2754 × HPR 2720	HPR 2769
Total tillers plant^{-1}			
	HPR 2880 × HPR 2143	HPR 2880 × HPR 2143	HPR 2880
		HPR 2880 × HPR 2720	HPR 2779
		HPR 2878 × HPR 2612	HPR 2754
		HPR 2873 × HPR 2720	HPR 2873
Effective tillers plant^{-1}			
	HPR 2880 × HPR 2143(5.15)	HPR 2878 × HPR 2612	HPR2779
	HPR 2878 × HPR 2612(2.06)	HPR 2880 × HPR 2720	HPR 2880
	HPR 2872 × HPR 2720(0.00)	HPR 2880 × HPR 2143	HPR 2754
		HPR 2872 × HPR 2720	HPR 2873
Panicle length			
	HPR 2751 × HPR 2720(22.96)	HPR 2880 × HPR 2720	HPR 2880
	HPR 2872 × HPR 2720(20.89)	HPR 2750 × HPR 2612	HPR 2756
	HPR2751 × HPR 2612(19.08)	HPR 2880 × HPR 2143	HPR 2878
	HPR2750 × HPR 2720(12.15)	HPR 2880 × HPR 2612	HPR2873
Spikelets panicle^{-1}			
	HPR 2878 × HPR 2720(53.00)	HPR 2872 × HPR 2612	HPR 2769
	HPR 2754 × HPR 2720(48.330	HPR 2750 × HPR 2143	HPR 2878
	HPR 2751 × HPR 2720(43.84)	HPR 2878 × HPR 2720	HPR 2751
	HPR 2750 × HPR 2720(35.120	HPR 2872 × HPR 2720	HPR2750
Grains panicle^{-1}			
	HPR 2754 × HPR 2720(37.54)	HPR 2872 × HPR 2612	HPR 2878
	HPR 2750 × HPR 2720(30.28)	HPR 2756 × HPR 2143	HPR 2769
	HPR 2872 × HPR 2720(26.27)	HPR 2750 × HPR 2143	HPR 2750
	HPR 2872 × HPR 2143(18.80)	HPR 2769 × HPR 2612	HPR 2754
Grain yield plant^{-1}			
	HPR 2872 × HPR 2720(75.63)	HPR 2872 × HPR 2612	HPR 2878
	HPR 2750 × HPR 2720(63.97)	HPR 2872 × HPR 2720	HPR 2750
	HPR 2779 × HPR 2143(41.95)	HPR 2750 × HPR 2143	HPR 2872
	HPR 2872 × HPR 2143(37.38)	HPR 2750 × HPR 2720	HPR2754
1000 grain weight			
	HPR 2872 × HPR 2143 (16.67)	HPR 2756 × HPR 2720	HPR 2756
	HPR 2769 × HPR 2143(16.39)	HPR 2756 × HPR 2143	HPR 2751
	HPR 2769 × HPR 2612(13.05)	HPR 2754 × HPR 2143	HPR 2873
	HPR 2873 × HPR 2720(12.61)	HPR 2751 × HPR 2143	HPR2779

Table 10: Description of aroma as per panel test.

Aroma	Testers	Lines	Crosses
Absent	HPR 2143 HPR 2720	HPR 2769, HPR 2750, HPR 2779, HPR 2756, HPR 2751	HPR 2769 × HPR 2143, HPR 2769 × HPR 2720, HPR 2750 × HPR 2143, HPR 2750 × Palam Lal Dhan, HPR 2779 × HPR 2143, HPR 2779 × HPR 2720, HPR 2756 × HPR 2143, HPR 2751 × HPR 2143 , HPR 2751 × HPR 2720
Slight aroma	-	HPR 2754 HPR 2880	HPR 2754 × HPR 2612, HPR 2754 × HPR 2143, HPR 2754 × HPR 2720, HPR 2880 × HPR 2612
Moderate aroma	-	HPR 2872, HPR 2873, HPR 2878	HPR 2872 × HPR 2143, HPR 2873 × HPR 2143, HPR 2872 × HPR 2720, HPR 2873 × HPR 2612, HPR 2878 × HPR 2143, HPR 2878 × HPR 2612, HPR 2872 × HPR 2612
Strong aroma	HPR 2612	-	HPR 2756 × HPR 2612, HPR 2769 × HPR 2612

× HPR 2720, HPR 2873 × HPR 2720, HPR 2769 × HPR 2143 and HPR 2756 × HPR 2720 were having significant and positive SCA effect for L:B ration. The crosses HPR 2880 × HPR 2720, HPR 2750 × HPR 2612, HPR 2779 × HPR 2143, HPR 2872 × HPR 2143, HPR 2872 × HPR 2612, HPR 2873 × HPR 2612, HPR 2754 × HPR 2720, HPR 2878 × HPR 2143, HPR 2769 × HPR 2612, HPR 2751 × HPR 2720 and HPR 2756 × HPR 2612 exhibited significant and positive SCA effects for protein content. The crosses HPR 2880 × HPR 2143, HPR 2880 × HPR 2612, HPR 2750 × HPR 2143, HPR 2750 × HPR 2720, HPR 2779 × HPR 2143, HPR 2872 × HPR 2720, HPR 2873 × HPR 2143, HPR 2873 × HPR 2720, HPR 2754 × HPR 2612, HPR 2878 × HPR 2612, HPR 2769 × HPR 2720, HPR 2751 × HPR 2143 and HPR 2756 × HPR 2612 exhibited significant and positive SCA effects for amylose content. The crosses HPR 2880 × HPR 2612, HPR 2750 × HPR 2143, HPR 2872 × HPR 2720, HPR 2873 × HPR 2612, HPR 2754 × HPR 2143, HPR 2878 × HPR 2612, HPR 2769 × HPR 2143, HPR 2751 × HPR 2720 and HPR 2756 × HPR 2612 were having significant and positive SCA effect for GT.

The crosses HPR 2880 × HPR 2143, HPR 2750 × HPR 2143, HPR 2750 × HPR 2612, HPR 2779 × HPR 2612, HPR 2779 × HPR 2720, HPR 2872 × HPR 2612, HPR 2873 × HPR 2612, HPR 2754 × HPR 2143, HPR 2878 × HPR 2612, HPR 2878 × HPR 2720, HPR 2769 × HPR 2612, HPR 2769 × HPR 2720, HPR 2751 × HPR 2143, HPR 2751 × HPR 2612, HPR 2756 × HPR 2143 and HPR 2756 × HPR 2720 exhibited significant and positive SCA effects for GC. Further, for grain quality parameters higher estimates of SCA variances than GCA variances has also been revealed by Vanaja *et al.* (2003) and Thakare *et al.* (2010). List of good specific combiners have been presented in Table 9.

Heterotic response for the characters ranged from -23.03 to 187.94 per cent over better parent and -19.28 to 75.63 per cent over standard check. Nine crosses exhibited significant positive heterosis over the better parent whereas, five crosses exhibited significant positive heterosis over the standard check. The maximum significant positive heterosis over better parent was observed for HPR 2750 × HPR 2720 (187.94%) followed by HPR 2750 × HPR 2612 (94.35%) and HPR 2751 × HPR 2612 (61.25%) and positive heterosis over standard check was observed for HPR 2872 × HPR 2720 (75.63%) followed by HPR 2750 × HPR 2720 (68.9%) and HPR 2779 × HPR 2143 (41.9%). These crosses expressed significant positive heterosis over better parent and standard check for grain yield plant^{-1}. The results are in confirmation with the findings of Roy and Mondal (2001), Singh and Kumar (2004), Muhammad *et al.* (2007), Viswanathan *et al.* (2008), Saleem *et al.* (2010), Soroush and Rabiei (2009) and Sanghera and Hussain (2012).

Two genotypes/cross combinations had strong aroma whereas 10 genotypes/cross combinations had moderate aroma. Six genotypes/cross combinations had slight aroma and 14 genotypes/cross combinations were found to have no aroma (Table 10). The results are in confirmation with the findings of Sarial (2014).

Yield is the ultimate aim of the breeder. From the study, four cross combinations *viz.,* HPR 2872 × HPR 2612, HPR 2872 × HPR 2720, HPR 2750 × HPR 2143 and HPR 2750 × HPR 2720 were selected as good specific combiners for grain yield per plant. Hence, these could be further used for the exploitation of heterosis in hybrid breeding programme.

4. Conclusions

Combining ability analysis revealed the presence of both additive and dominance component of variance. The highest average degree of dominance observed for spikelet fertility, protein content, gel consistency, L:B ratio and amylose content. High narrow sense heritability were observed for 1000 grain weight, plant height, grains panicle^{-1}, grain yield per plant and panicle length The lines HPR 2750, HPR 2754 and HPR2878 were good general combiners for various traits. The crosses HPR 2880 x HPR2143, HPR 2756 x HPR 2720, HPR 2872 x HPR 2720, HPR 2880 x HPR2612 & HPR 2880 x HPR 2720 are good specific combinations for various traits.

5. References

1. AOAC. 1965. Official Methods of Analysis of Official Analytical Chemists. Washington, DC, USA.
2. Anonymous. 2018. Food and Agriculture Organization of the United Nations. http://www. FAO stat.fao.org.com.
3. Anonymous. 2018. Statistical year book of Himachal Pradesh 2013-14. Department of Economics and Statistics, Himachal Pradesh.
4. Ghara AG, G Nematzadeh, N Bagheri, M Oladi and A Bagheri. 2014. Heritability and heterosis of agronomic traits in rice lines. *International Journal of Farming and Allied Sciences* **3**: 66-70.
5. Hossain KA, HB Akter, A Ansari and MM Rahman. 2009. Line × Tester analysis for yield and its related traits in rice (*Oryza sativa* L.). *Bangladesh Journal of Plant Breeding and Genetics* **22**: 1-6.
6. Karthikeyan P, Y Anbuselvam, K Palaniraja and R Elangaimannan. 2009. Combining ability of rice genotypes under coastal saline soils. *Electronic Journal of Plant Breeding* **1**: 18-23.
7. Kempthorne O. 1957. An introduction of genetic statistics. John Willey & Sons, New York. pp 468-473.
8. Khush GS. 1997. Origin, dispersal, cultivation and variation of rice. *Plant Molecular Biology* **35**: 25–34.
9. Mirarab M, A Ahmadikhah and MH Pahlavani. 2011. Study on combining ability, heterosis and genetic parameters of yield traits in rice. *African Journal of Biotechnology* **10**: 12512-12519.
10. Muhammad R, AA Cheema and A Muhammad. 2007. Line × tester analysis in basmati rice. *Pakistan Journal of Botany* **39**: 2035-2042.
11. Panse VG and PV Sukhatme. 1985. Statistical methods for agricultural workers. ICAR Publication, New Delhi. pp145-152.
12. Panwar LL. 2005. Line × tester analysis of combining ability in rice (*Oryza sativa* L.). *Indian Journal of Genetics and Plant Breeding* **65**: 51-52.
13. Pradhan SK, LK Bose and J Meher. 2006. Studies on gene action and combining ability analysis in basmati rice. *Journal of Central European Agriculture* **7**: 267-272.
14. Rosamma CA and NK Vijayakumar. 2005. Heterosis and combining ability in rice (*Oryza sativa* L.) hybrids developed for Kerala state. *Indian Journal of Genetics and Plant Breeding* **65**: 119-120.
15. Roy B and AB Mandal. 2001. Combining ability of some quantitative traits in rice. *Indian Journal of Genetics* **61**: 162-164
16. Saleem MY, JI Mirza and MA Haq. 2010. Combining ability analysis for yield and related traits in basmati rice (*Oryza sativa* L.). *Pakistan Journal of Botany* **42**: 627-637.
17. Sanghera GS and W Hussain. 2012. Heterosis and combining ability estimates using line × tester analysis to develop rice hybrids for temperate conditions. *Notulae Scientia Biologicae* **4**: 131-142.
18. Sarial AK. 2014. Heterosis and combining ability analysis for grain quality and physico-chemical traits involving fertility restorers with basmati background in rice (*Oryza sativa* L.) *Electronic Journal of Plant Breeding* **5**: 615-625.
19. Sarker U, PS Biswas, B Prasad and MMA Khaleque. 2002. Heterosis and genetic analysis in rice hybrid. *Pakistan Journal of Biological Sciences* **5**: 1-5.
20. Sathya R. 2014. Genetic studies (heritability and genetic advance) from three line rice hybrids under aerobic condition. *Trends in Biosciences* **7**: 2642-2645.
21. Shikari AB, AG Rather, MA Ganai, Gul-Zafar and Rouf-Ahmed. 2009. Line × tester analysis for yield and its components in temperate hill rice. *Asian Journal of Experimental Sciences* **23**: 473-478.
22. Shrivastava A, DK Mishra, GK Koutu and SK Singh. 2014. Heritability and genetic advance, estimation from parental lines of hybrid rice. *International Journal of Scientific Research* **3**: 11-13.
23. Singh NK and A Kumar. 2004. Combining ability analysis to identify suitable parents for heterotic rice breeding. *International Rice Research* **29**: 21-12.
24. Soroush HR and B Rabiei. 2009. An evaluation of combining ability and gene effect in rice genotypes. *Iranian Journal of field Crop Science* **40(4)**: 25-33.

25. Thakare IS, AM Mehta, JS Patel and SR Takle. 2010. Combining ability analysis for yield and grain quality traits in rice hybrids. *Journal of Rice Research* **3**: 1-5.

26. Vanaja T, LC Babu, VV Radhakrishnan and K Pushkaran. 2003. Combining ability analysis for yield and yield components in rice varieties of diverse origin. *Journal of Tropical Agriculture* **41**: 7-15.

27. Verma PK. 1992. Studies on heterosis, combining ability and gene action in rice (*Oryza sativa* L.). Ph D Thesis. Department of Plant Breeding and Genetics, CSKHPKV, Palampur, India.

28. Viswanathan S and K Thiyagarajan. 2008. Combining ability studies for yield and yield components in rice. *International Journal of Plant Science* **3**: 61-68.