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Deepayan Roy
PhD Research Scholar, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Indra Deo
Dr. Indra Deo Pandey, Professor and Principal Rice-Breeding Scientist, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Babita Kohli
M.sc. Research Scholars, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Kuldeep Nagar
M.sc. Research Scholars, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Corresponding Author:
Deepayan Roy
Ph.D Research Scholar, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Deciphering the estimates of combining ability and heterosis for yield and quality traits through line × tester analysis in basmati rice (*Oryza sativa* L.)

Deepayan Roy, Indra Deo, Babita Kohli and Kuldeep Nagar

Abstract
Nine lines and three testers were crossed in Line × Tester mating design during kharif season 2017 in Norman E. Borlaug Crop Research Center, GBPUAT, Pantnagar. In kharif season 2018, field experiment with 39 genotypes comprising 12 parents and 27 F_1s was laid down in randomized block design with three replications. Sixteen characters including yield and quality parameters were taken under study. Among lines UPR-3716-27-1-1 emerged as a good general combiner for the maximum number of traits. Among the testers, Taraouri Basmati and Lal Basmati was found good general combiners. UPR-3709-11-1-1 ×Lal Basmati, Pusa Sugandh Dhan 4 ×Sugandhmati and Hariyana Basmati ×Sugandhmati was identified as the best specific combination for most of the traits and Pusa Sugandh Dhan 4 ×Sugandhmati was identified as the best specific combination for grain yield plant^{-1}. Relative heterosis, heterobeltiosis and standard heterosis was estimated for all the characters among which for grain yield Hariyana Basmati ×Sugandhmati and Basmati 370 ×Taraouri Basmati excelled over maximum levels. Basmati 370 ×Sugandhmati and UPR-3506-7-1-1 ×Taraouri Basmati was identified as best heterotic combination at different levels for maximum traits like, days to 50% flowering, hulling recovery, grain yield plant^{-1} etc.

Keywords: Combining ability, heterosis, hybrid, line × tester, basmati rice

Introduction
Rice (*Oryza sativa* L.) is one of the most premiere cereal crop grown in Indian Sub-Continent and is consumed as staple diet by 2/3rd of the country's total population. Rice is also the staple food for almost 90% of the people inhabiting South-East Asia. The acreage for Rice is maximum in India and it occupies near-about 43.97 million hectares but in the terms of production, India is second next to China and produces around 110.15 million tonnes, hence it plays a pivotal role in India's livelihood and nutritional security **(**Directorate of Economics & Statistics, Govt. of India, 2017-18) [15]. But, India is lagging behind many countries like Japan, China, Vietnam, USA and Indonesia in terms of Productivity. Globally it provides food to over 2.5 billion people; and about 20% calories and protein in developing countries. In 2017 -18, world production of paddy rice is forecasted to be 503.8 million tons (FAO, 2017) [16]. led by China and India with a combined 49% of this total. As the global population is increasing at an alarming rate, the demand for rice as food will rise in order to meet the nutritional requirement of this ever increasing human population. Simultaneously, the arable lands have been decreasing due to rapid urbanization and industrialization and thus in order to increase the production of rice from this limited land resources, in the near future, we have to shift our focus on increasing the productivity of rice (Subbaiah *et al*. 2011) [11].

Basmati, the unique scented rice of the sub-continent, derives its name from *Bas* meaning aroma and *mati* meaning already ingrained and among the handful varieties of rice that are traded internationally. Basmati is also acknowledged as "Crown Jewel", "Prince of Rice" and "Queen of Fragrance" among the South-Asian rice and often romanticized as the gift of nature to the sub-continent and for hundreds of years being favored by emperors and praised by poets (Thakrar and Ahuja, 1990) [12]. This kind of rice is defined by its geographical location (origin) and by the genotype and hence is cultivated in 1million hectares of the. Indo-.Gangetic. Plains of India and 0.75 million hectares of Pakistan. It is mainly cultivated on the foothills of the Himalayas and the agro-climatic and agro-ecological conditions of this region bestows unique properties to this quality rice.

The fragrance of basmati quality rice is attributed by a volatile chemical compound called 2-acetyl-1-pyroline.

Basmati rice is actually referred to a distinctive group of rice having a pleasant aroma, cooking qualities and exclusive grains which includes high length/breadth ratio with long slender kernels and a slight twist in the tip. Aromatic rice means all those rice having aroma but Basmati rice has some additional qualities and features. Its grain dimensions are- length- 6.5 mm (min.), breadth- 2 mm (max.) and length-breadth ratio being 3.5 or above. Upon cooking, the kernel shows nearly double linear elongation in comparison to the actual length, possessing a fluffy texture with exquisite aroma and wonderful taste. Its price in domestic and global business is almost three times higher than the non-basmati types. India has now become self-sufficient in terms of food grain generation but now it is the second most consigner of quality rice in the world (Sreedhar *et al.* 2005) [10]. Basmati rice varieties in India are classified into 2 categories *viz.*, Traditional Basmati (derived from pureline selection or selection from natural mutation) e.g., Basmati 370, Basmati 386, Type 3, Taraori Basmati, Basmati 217, Ranbir Basmati etc. and Evolved Basmati (varieties derived from cross-breeding) e.g., Haryana Basmati-1, Super Basmati. Pusa Basmati 1121 etc. The traditional basmati cultivars are tall with weak culms, possess light green leaves and are less responsive to fertilizers, hence yielding very low. It is difficult to fit them in cropping systems due to its- photo-sensitivity, thermo-sensitivity, delay maturation and lodging susceptibility. Addressing these drawbacks basmati breeders from the Indian Sub-Continent are trying for a long time to make NPT (new plant types) having lodging resistance in addition to a shorter duration. They employed cross and backcross methods of breeding to develop semi-dwarf varieties as these methods can break undesirable linkages in undesirable agronomic traits and desirable preferential quality traits e.g., Sona and Basmati 370, pureline selection of Dehradooni Basmati (Ahuja *et al.* 1995) [1] are crossed to make Haryana Basmati-1 which is a semi-dwarf aromatic rice from Haryana (Panwar *et al.* 1991) [6].

Attempts that have been shaped to improve the yield of Basmati rice through hybridization to make it dwarf and non-lodging type has been partly successful. Basmati rice has a narrow genetic base lacking donor parents for grain quality. Poor combining ability attributed to the mutation on the *BADH* gene having impact an on pollen tube growth leading to chaffiness. The local landraces of these areas thus need to be incorporated into breeding programmes for their enhancement and hence developing NPT i.e., new plant types out of them. Hence the need of the hour is to explore parents which would be great combiners and which can be effectively used in hybridization to produce excellent genotypes without having lost any of the traditional Basmati quality is the need of the hour.

One of the effective approaches available for estimating the combining ability effects is combining. Ability analysis through 'L×T' mating which aids in the selection of desirable parents and crosses for the effective utilization and exploitation of heterosis (Singh and Kumar, 2004) [9].

Materials and Methods

The research study carried out during at Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture & Technology, Pantnagar. The research center lies about 30 km south of the Himalayan foothills of the *Shivalik* range having coordinates 29°N latitude and 79.29°E longitude which is actually the *Tarai* region. The research material for the present study comprises 27 F_1 crosses involving 12 parents. Out of 12 parents, 9 are being used as lines (Female) and 3 as testers (Male). Line × tester mating system was used to cross 9 lines with 3 testers to generate 27 F_1 hybrids for quantitative and qualitative traits for evaluation in rice. The detailed information about planting materials is as follows:

Table 1: Description of the lines and testers used in the study

S. No.	Designation	Genotype
1	L_1	Pant Basmati 1
2	L_2	UPR-3716-27-1-1
3	L_3	UPR-3709-11-1-1
4	L_4	Pant Sugandh Dhan 17
5	L_5	Basmati 370
6	L_6	Pusa Sugandh 4
7	L_7	Hariyana Basmati
8	L_8	2110-Kharif-2017
9	L_9	UPR-3506-7-1-1
10	T_1	Taraouri Basmati
11	T_2	Sugandhmati
12	T_3	Lal Basmati

In the first Season 27 F_1s of rice were produced with the help of 9 lines and 3 testers which were crossed in a line×tester fashion. The F_1 seeds that were produced were harvested in the month of November and then the F_1 seeds were counted and kept in packets. Some insecticides and fungicides were also put in the packets to avoid any damage. Out of all the crosses made some actually failed to produce seeds, those parents were planted again in green house in off-season nursery. Crosses were made and simultaneously seeds were harvested. Nursery was sown using total seeds harvested in the first season and from off-season crosses. All F_1s are planted along with parents in the second year in Randomized Block Design having 3 replications with plot size of two meter length. Observations on different morphological, yield contributing and quality traits were recorded.

The experimental material which consisted of 40 genotypes i.e., 9 lines, 3 testers, 27 F_1's and 1 check was laid out in a Randomized Block Design (RBD) with 3 replications during *kharif* 2018. The seeds of all 40 genotypes were sown in rice nursery at Norman E. Borlaug Crop Research Centre. Twenty one days old seedling were transplanted in the main field in a single row of 2 m length maintaining a spacing of 30 cm between two entries. The plant to plant spacing of 15 cm was kept for better evaluation and recording of data.

Table 2: Description of the Crosses used in the study

S. No.	Designation	Genotypes
1.	L1 × T1	Pant basmati 1 × Taraouri Basmati
2.	L1 × T2	Pant Basmati 1 × Sugandhmati
3.	L1 × T3	Pant Basmati 1 × Lal Basmati
4.	L2 × T1	Upr-3716-27-1-1 × Taraouri Basmati
5.	L2 × T2	Upr-3716-27-1-1 × Sugandhmati
6.	L2 × T3	Upr-3716-27-1-1 × Lal Basmati

7.	L3 × T1	Upr-3709-11-1-1 × Taraouri Basmati
8.	L3 × T2	Upr-3709-11-1-1 × Sugandhmati
9.	L3 × T3	Upr-3709-11-1-1 × Lal Basmati
10.	L4 × T1	Basmati 370 × Taraouri Basmati
11.	L4 × T2	Basmati 370 × Sugandhmati
12.	L4 × T3	Basmati 370 × Lal Basmati
13.	L5 × T1	Pant Sugandh Dhan 17 × Taraouri Basmati
14.	L5 × T2	Pant Sugandh Dhan 17 × Sugandhmati
15.	L5 × T3	Pant Sugandh Dhan 17 × Lal Basmati
16.	L6 × T1	Pusa Sugandh Dhan 4 × Taraouri Basmati
17.	L6 × T2	Pusa Sugandh Dhan 4 × Sugandhmati
18.	L6 × T3	Pusa Sugandh Dhan 4 × Lal Basmati
19.	L7 × T1	Hariyana Basmati × Taraouri Basmati
20.	L7 × T2	Hariyana Basmati × Sugandhmati
21.	L7 × T3	Hariyana Basmati × Lal Basmati
22.	L8 × T1	2110-Kharif-2017 × Taraouri Basmati
23.	L8 × T2	2110-Kharif-2017 × Sugandhmati
24.	L8 × T3	2110-Kharif-2017 × Lal Basmati
25.	L9 × T1	Upr-3506-7-1-1 ×Taraouri Basmati
26.	L9 × T2	Upr-3506-7-1-1 × Sugandhmati
27.	L9 × T3	Upr-3506-7-1-1 × Lal Basmati

Observations in respect to days to 50 percent flowering were recorded on the whole plot basis whereas five randomly selected competitive plants from the F_1 crosses, lines and the testers were used to record the observations for some of the characters like plant height, number of tillers plant^{-1}, panicle length, grain length, grain breadth, l/b ratio, 1000 grain weight, grain yield plant^{-1}, hulling recovery, milling recovery, amylose content (by a method described by Sowbhagya and Bhatacharya), gel consistency and alkali digestion value as described by Little *et al.* (1958) [5]. The calculation of average values for these plants were used for statistical and genetic analysis.

Emasculation in Rice Genotypes

Clipped Rice Panicles

Removal of anthers by Suction Method

Results and Discussion

Analysis of variance for sixteen characters namely - days to 50% flowering, plant height (cm), number of tillers plant^{-1}, number of grains panicle^{-1}, panicle length (cm), kernel length (mm), kernel breadth (mm), L/B ratio, 1000 grain weight (g), hulling recovery (%), milling recovery (%), head rice recovery (%), amylose content (%), gel consistency, alkali digestion value and seed yield plant^{-1} (g) was done and consequently significant differences among the genotypes were observed for all the characters under study. The analysis of variance for all the characters was carried out following completely RBD (randomized block design) analysis.

Estimates of combining ability effects

The results of combining ability analysis i.e. the GCA effect of line and testers and the SCA effect for twenty-seven cross combinations are given in table 1 and 2 for all sixteen characters under study, respectively. All the yield contributing traits have shown significant positive GCA and SCA effects, hence the grain yield plant^{-1} has also shown significant GCA and SCA effects and similar results were revealed by Faiz *et al.* (2009) [2] and Gahtyari *et al.* (2017) [3]. On the Basis of GCA effect values of parents (lines and testers), the result revealed that none of the lines and testers were found best for all the character under study. Lines UPR-3716-27-1-1 and UPR-3506-7-1-1 were found as good general combiner for 5 characters each followed by Basmati 370, Pusa Sugandh Dhan 4, Hariyana Basmati and 2110-kharif-2017 for four

characters each**.** UPR-3716-27-1-1 was found good general combiner for no. of tillers plant^{-1}, no. of grains panicle^{-1}, head rice recovery, grain yield plant^{-1} and amylose content. UPR-3506-7-1-1 was good general combiner for panicle length, 1000 grain weight, milling recovery, amylose content and alkali digestion value. Basmati 370 was good general combiner for 50% flowering, plant height, head rice recovery and grain yield plant^{-1}. Pusa Sugandh Dhan 4 was good general combiner for number of tillers plant^{-1}, grain yield plant^{-1}, amylose content and alkali digestion value. Hariyana Basmati was good general combiner for plant height, number of tillers plant^{-1}, amylose content and alkali digestion value. 2110-kharif-2017 was good general combiner for 1000 grain weight, kernel breadth, head rice recovery and alkali digestion value.

Among the testers, Taraouri Basmati was found good general combiner for milling recovery, head rice recovery, amylose content and grain yield plant^{-1}. Lal Basmati was found good general combiner for plant height, kernel breadth, alkali digestion value and gel consistency. Sugandhmati was found good general combiner for number of tillers plant^{-1}, alkali digestion value and grain yield plant^{-1}. Crosses like- UPR-3709-11-1-1 × Lal Basmati, Pusa Sugandh Dhan 4 × Sugandhmati, Hariyana Basmati × Sugandhmati were found to be good specific combiners for eight characters each followed by Basmati 370 × Taraouri Basmati which showed up to be good specific combiner for 7 characters under study namely- days to 50% flowering, no. of tillers plant^{-1}, 1000 grain weight, hulling recovery, milling recovery, amylose content and grain yield plant^{-1}. The good specific combiners for grain yield in addition to the associated component traits are found in crosses like- Pant Basmati 1 × Lal Basmati, UPR-3716-27-1-1 × Sugandhmati, UPR-3709-11-1-1 × Sugandhmati, UPR-3709-11-1-1 × Lal Basmati, Basmati 370 × Taraouri Basmati, Basmati 370 × Sugandhmati, Pant Sugandh Dhan 17 × Taraouri Basmati, Pant Sugandh Dhan 17 × Lal Basmati, Pusa Sugandh Dhan 4 × Sugandhmati, Hariyana Basmati × Sugandhmati, 2110-kharif-2017 × Taraouri Basmati, 2110-kharif-2017 × Lal Basmati, UPR-3506-7-1-1 × Taraouri Basmati, UPR-3506-7-1-1 × Lal Basmati. Similar trends of results also obtained by Salgotra *et al.* (2009) [7] and Saravanan *et al.* (2018) [8].

Table 3: Analysis of variance for combing ability of all the traits under study

Sourced of variation	d.f.	Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Panicle length (cm)	1000 grain weight (gm)	Number of grains per panicle	Kernel length (mm)	Kernel breadth (mm)
GCA (Line)	8	111.88**	343.25**	57.46**	39.69**	26.71**	873.09**	1.61**	0.05
GCA (Tester)	2	214.83**	188.28**	65.83**	45.69**	120.99**	118.92**	0.72	0.15**
SCA (Line x Tester)	16	40.60	181.50**	47.61**	55.55**	12.05	58.44	0.49	0.04
Error	52	25.62	26.06	0.20	10.09	5.41	81.42	0.61	0.02

Table 4: Analysis of variance for combing ability of all the traits under study

Sourced of variation	d.f.	Length-breadth ratio	Hulling recovery (%)	Milling recovery (%)	Head rice recovery	Alkali digestion value	Gel consistency (mm)	Amylose content	Yield per plant
GCA (Line)	8	0.31	233.18**	60.70**	63.35**	5.10**	431.28**	24.21**	414.26**
GCA (Tester)	2	0.67**	70.30**	19.47**	40.26**	5.53**	529.15**	4.89**	992.55**
SCA (Line x Tester)	16	0.27	114.57**	134.66**	146.29**	3.00**	441.90**	19.45**	217.21**
Error	52	0.27	4.68	2.96	1.99	0.02	48.93	0.30	0.74

Table 5: Estimates of GCA efffects for parents

S. No.	Parents	Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Panicle length (cm)	1000 grain weight (gm)	Number of grains per panicle	Kernel length (mm)	Kernel breadth (mm)	Length-breadth ratio	Hulling recovery (%)	Milling recovery (%)	Head rice recovery	Alkali digestion value	Gel consistency (mm)	Amylose content	Yield per plant
1	Pant Basmati 1	3.35*	0.05	-3.27**	0.81	-2.34**	0.48	-0.32	-0.02	-0.14	-3.28	1.86*	0.88	0.91**	-0.63	-1.34**	-0.68*
2	UPR-3716-27-1-1	-2.43	-0.56	0.62**	1.04	0.10	24.93**	-0.17	0.01	-0.09	0.39	-0.44	1.88**	-0.20*	-0.41	0.72**	0.87**
3	UPR-3709-11-1-1	5.57**	2.89	0.95**	0.30	-0.45	-1.63	0.31	0.01	0.14	6.32	0.91	1.44**	-1.64**	-1.96	-1.14**	6.74**
4	Basmati 370	-4.21**	-5.58**	0.06	-3.70**	-1.17	-6.63*	0.53	-0.01	0.33	7.51	0.42	1.09**	-0.09*	-8.63**	-2.09**	10.40**
5	Pant Sugandh Dhan 17	-3.32*	-2.06	3.40**	-2.31*	-1.49	2.48	-0.32	0.01	-0.22	-8.80	-3.68**	-5.43**	-0.42**	15.59**	-1.08**	-2.54**
6	Pusa Sugandh Dhan 4	-0.77	0.24	1.40**	-0.47	0.27	-4.07	-0.22	-0.06	0.01	1.58	1.02	-0.07	0.25**	1.26	2.93**	4.71**
7	Hariyana Basmati	3.68*	-10.82**	2.39**	-0.12	-0.07	-5.07	0.22	-0.02	0.20	-0.53	-4.72**	-2.71**	0.14**	-6.41**	0.36*	-0.34
8	2110-Kharif-2017	-2.77	4.89**	-4.27**	0.78	1.86*	-3.74	0.59	0.18*	-0.10	-4.32	1.38	3.41**	0.25**	-2.41	-0.24	-10.36**
9	UPR-3506-7-1-1	0.90	10.95**	-1.27**	3.68**	3.31**	-6.74*	-0.61	-0.10	-0.13	1.14	3.24**	-0.50	0.80**	3.59	1.89**	-8.80**
1	Taraouri Basmati	3.20**	2.42*	-0.90**	1.09	1.83	-0.37	0.00	-0.08*	0.18	1.00	0.85**	1.40**	-0.49**	-2.63	0.48*	2.41**
2	Sugandhmati	-2.14	0.39	1.80**	0.35	0.49	2.26	-0.16	0.01	-0.12	0.86	-0.01	-0.82**	0.10**	-2.48	-0.31**	4.49**
3	Lal Basmati	-1.06	-2.81*	-0.90**	-1.44*	-2.32**	-1.89	0.17	0.07*	-0.06	-1.86	-0.84**	-0.59*	0.39**	5.11**	-0.17	-6.90**

Table 6: Estimates of SCA for hybrids

S. No.	Parents	Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Panicle length (cm)	1000 grain weight (gm)	Number of grains per panicle	Kernel length (mm)	Kernel breadth (mm)	Length-breadth ratio	Hulling recovery (%)	Milling recovery (%)	Head rice recovery	Alkali digestion value	Gel consistency (mm)	Amylose content	Yield per plant
1	Pant Basmati 1 × Taraouri Basmati	2.14	-4.03**	3.68**	-2.38*	0.21	5.37	0.24	0.06	0.02	-2.78**	0.64	-0.20	0.27**	18.41**	0.05	-4.55**
2	Pant Basmati 1 × Sugandhmati	-1.53	-4.67**	-5.02**	-2.17	0.80	-4.26	-0.31	-0.06	-0.02	-3.38**	-9.75**	-4.87**	0.01	-11.74**	0.35	-4.75**
3	Pant Basmati 1 × Lal Basmati	-0.60	8.70**	1.34**	4.55**	-1.01	-1.11	0.07	0.01	0.00	6.16**	9.11**	5.07**	-0.29	-6.67**	-0.39	9.30**
4	UPR-3716-27-1-1 × Taraouri Basmati	-2.75	9.58**	0.79**	4.12**	-0.02	-6.07	0.62*	0.09	0.12	2.41**	6.24**	-6.09**	-1.28**	0.19	-2.41**	-0.48
5	UPR-3716-27-1-1 × Sugandhmati	3.58*	-0.72	0.42**	2.46*	0.52	2.96	-0.26	-0.16*	0.22	-0.67	-2.56**	2.19**	0.12	-7.96**	4.22**	5.64**
6	UPR-3716-27-1-1 × Lal Basmati	-0.83	-8.85**	-1.21**	-6.58**	-0.50	3.11	-0.35	0.08	-0.34	-1.74*	-3.68**	3.90**	1.16**	7.78**	-1.82**	-5.16**
7	UPR-3709-11-1-1 × Taraouri Basmati	2.25	-3.53*	-0.88**	-6.77**	-2.94**	-1.85	0.17	0.02	0.03	-4.03**	-7.16**	-7.58**	1.16**	1.74	-1.14**	-7.05**
8	UPR-3709-11-1-1 × Sugandhmati	1.91	3.83*	-3.58**	1.88	2.07**	2.85	0.13	0.14*	-0.22	-0.52	5.13**	1.13**	-0.43**	0.26	0.38	2.83**
9	UPR-3709-11-1-1 × Lal Basmati	-4.16**	-0.30	4.46**	4.89**	0.86	-1.00	-0.30	-0.16*	0.19	4.54**	2.03**	6.45**	-0.73**	-2.00	0.75**	4.22**
10	Basmati 370 × Taraouri Basmati	-4.64**	-2.27	0.35**	1.53	1.44*	4.15	-0.35	0.03	-0.22	2.36**	4.66**	-0.01	-1.40**	-1.93	0.50*	10.65**
11	Basmati 370 × Sugandhmati	-2.98	8.50**	-0.36	-4.26**	-1.24*	-2.48	0.54	0.14	-0.05	4.44**	2.99**	-2.12**	1.01**	-5.07	-1.97**	1.36**
12	Basmati 370 × Lal Basmati	7.62**	-6.23**	0.01	2.73*	-0.20	-1.67	-0.19	-0.17*	0.28	-6.80**	-7.66**	2.12**	0.38**	7.00**	1.47**	-12.01**
13	Pant Sugandh Dhan 17 × Taraouri Basmati	1.47	1.61	0.68**	-1.79	0.67	-3.63	-0.56	0.03	-0.40*	9.82**	4.02**	12.29**	-0.06	-2.15	0.40	6.03**
14	Pant Sugandh Dhan 17 × Sugandhmati	-1.86	-6.89**	-5.36**	-3.11**	-0.01	-2.93	0.03	0.00	0.01	-12.21**	-5.41**	-2.10**	0.01	-2.30	0.19	-11.39**
15	Pant Sugandh Dhan 17 × Lal Basmati	0.40	5.28**	4.68**	4.91**	-0.66	6.56	0.53	-0.03	0.39*	2.40**	1.38**	-10.19**	0.05	4.44	-0.59**	5.36**
16	Pusa Sugandh Dhan 4 × Taraouri Basmati	-0.09	-10.89**	-3.32**	2.63**	0.86	0.26	-0.20	-0.11	0.16	2.93**	4.10**	0.86	-0.73**	1.19	4.68**	-7.88**
17	Pusa Sugandh Dhan 4 × Sugandhmati	1.91	5.91**	6.97**	1.71	1.29*	2.96	-0.21	0.07	-0.28	2.04**	2.01**	4.28**	0.68**	23.04**	-2.68**	11.27**
18	Pusa Sugandh dhan 4 × Lal Basmati	-1.83	4.98**	-3.65**	-4.34**	-2.15**	-3.22	0.40	0.04	0.13	-4.97**	-6.11**	-5.15**	0.05	-24.22**	-2.00**	-3.38**
19	Hariyana Basmati × Taraouri Basmati	3.47*	2.81	-2.65**	0.05	0.42	-0.07	0.16	0.02	0.03	-7.78**	-5.45**	-2.54**	1.39**	-4.15	-2.05**	-5.07**
20	Hariyana Basmati × Sugandhmati	-2.53	-6.22**	3.98**	1.30	1.58*	1.63	0.08	-0.16*	0.48*	5.70**	2.82**	3.11**	-1.54**	-9.30**	-0.55	8.24**
21	Hariyana Basmati × Lal Basmati	-0.94	3.41	-1.32**	-1.35	-2.00**	-1.56	-0.24	0.14*	-0.51**	2.09**	2.63**	-0.57	0.16*	13.44**	2.60**	-3.17**
22	2110-Kharif-2017 × Taraouri Basmati	-3.75*	-0.87	-0.32	-0.61	0.33	-0.74	-0.01	-0.10	0.21	-2.48**	-9.46**	-4.96**	-0.06	-7.48**	2.75**	4.56**
23	2110-Kharif-2017 × Sugandhmati	0.25	7.83**	0.31	2.13	-2.77**	4.63	0.28	0.06	0.00	5.57**	7.30**	7.59**	-0.32**	9.04**	-1.65**	-6.14**
24	2110-Kharif-2017 × Lal Basmati	3.51*	-6.96**	0.01	-1.52	2.44**	-3.89	-0.28	0.04	-0.21	-3.09**	2.16**	-2.63**	0.38**	-1.56	-1.10**	1.58**
25	UPR-3506-7-1-1 × Taraouri Basmati	1.91	7.60**	1.68**	3.23**	-0.97	2.59	-0.07	-0.04	0.06	-0.44	2.40**	8.22**	0.72**	-5.81*	-2.79**	3.79**
26	UPR-3506-7-1-1 × Sugandhmati	1.25	-7.57**	2.64**	0.06	-2.25**	-5.37	-0.28	-0.01	-0.14	-0.97	-2.54**	-9.23**	0.46**	4.04	1.72**	-7.05**
27	UPR-3506-7-1-1 × Lal Basmati	-3.16	-0.03	-4.32**	-3.29**	3.22**	2.78	0.36	0.05	0.07	1.42*	0.13	1.00	-1.17**	1.78	1.07**	3.26**

Manifestation of heterosis

Manifestation of heterosis was estimated by comparing the mean value for all the sixteen characters of F_1 hybrids with better-parent (heterobeltiosis), mid-parent (relative heterosis) and standard-parent, Pant Basmati 1 (standard heterosis) expressed as percentage increase or decrease is represented in the Table 7, 8, 9, 10 and 11.

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Table 7: Estimates of Heterosis –Better Parent (BP) and Mid-Parent (MP) for hybrids for Days to 50% flowering, Plant height (cm), Number of tillers per plant and Panicle length (cm)

S. No.	Crossess	Days to 50% flowering		Plant height (cm)		Number of tillers per plant		Panicle length (cm)	
		BP	MP	BP	MP	BP	MP	BP	MP
1	Pant Basmati 1 × Taraouri Basmati	7.55	5.28	-0.89	1.14	13.95**	15.29**	4.65	5.31**
2	Pant Basmati 1 × Sugandhmati	-2.16	-2.86	-3.26	2.47	-29.53**	-28.73**	2.64	6.10**
3	Pant Basmati 1 × Lal Basmati	0.00	-2.63	-11.43*	-3.58	-2.35**	-2.35**	0.21	9.72**
4	UPR-3716-27-1-1 × Taraouri Basmati	-6.32	-7.13*	-1.97	5.97	23.81**	36.84**	31.68**	32.35**
5	UPR-3716-27-1-1 × Sugandhmati	-4.26	-4.76	-11.70*	-1.15	34.12**	51.30**	23.78**	26.54**
6	UPR-3716-27-1-1 × Lal Basmati	-8.77**	-10.03**	-24.97**	-22.86**	7.00**	19.51**	-33.75**	-26.71**
7	UPR-3709-11-1-1 × Taraouri Basmati	5.52	2.86	-5.49	0.07	14.29**	23.06**	-23.18**	-18.28**
8	UPR-3709-11-1-1 × Sugandhmati	2.48	-1.53	-1.10	8.55	9.12**	20.00**	3.36	12.77**
9	UPR-3709-11-1-1 × Lal Basmati	-6.48	-8.36**	-16.02**	-11.81**	48.84**	62.00**	-0.31	3.45
10	Basmati 370 × Taraouri Basmati	-1.16	-6.74	-9.94	-5.39	-19.67**	-4.85**	-5.56*	-1.15
11	Basmati 370 × Sugandhmati	-5.41	-9.43**	-2.63	6.07	-9.84**	4.77**	-28.27**	-22.96**
12	Basmati 370 × Lal Basmati	8.11*	1.45	-26.76**	-22.47**	-21.31**	-7.69**	-19.52**	-15.12**
13	Pant Sugandh Dhan 17 × Taraouri Basmati	4.92	0.00	-1.35	2.44	1.69**	18.81**	-3.93	-3.81
14	Pant Sugandh Dhan 17 × Sugandhmati	-4.92	-8.06**	-10.39	-3.48	-15.25**	-2.90**	-11.80**	-9.27**
15	Pant Sugandh Dhan 17 × Lal Basmati	-1.14	-6.28	-15.55**	-9.58*	22.03**	41.18**	-8.41**	0.74
16	Pusa Sugandh Dhan 4 × Taraouri Basmati	-3.45	-5.56	-2.94	-1.80	-2.33**	-1.18**	20.23**	21.78**
17	Pusa Sugandh Dhan 4 × Sugandhmati	-4.26	-7.69*	13.39**	16.46**	84.13**	86.23**	16.84**	18.54**
18	Pusa Sugandh dhan 4 × Lal Basmati	-10.58**	-12.08**	-14.06**	-3.72	-4.65**	-4.65**	-31.46**	-23.66**
19	Hariyana Basmati × Taraouri Basmati	20.16**	11.97**	-0.49	1.67	-2.08**	4.44**	5.02*	8.26**
20	Hariyana Basmati × Sugandhmati	6.72	0.93	-6.78	-5.19	56.25**	63.06**	6.82**	13.04**
21	Hariyana Basmati × Lal Basmati	9.88**	1.83	-23.48**	-13.51**	6.23**	12.07**	-21.08**	-15.51**
22	2110-Kharif-2017 × Taraouri Basmati	0.77	-4.54	-0.83	4.60	-22.75**	-20.95**	-0.34	5.73**
23	2110-Kharif-2017 × Sugandhmati	-0.77	-4.60	4.71	14.49**	0.00	0.01	6.42**	15.81**
24	2110-Kharif-2017 × Lal Basmati	4.21	-1.81	-19.50**	-15.13**	-20.45**	-19.5**	-18.80**	-15.51**
25	UPR-3506-7-1-1 × Taraouri Basmati	26.52**	11.92**	7.38	15.15**	2.06**	8.88**	38.36**	40.05**
26	UPR-3506-7-1-1 × Sugandhmati	18.70**	6.64	-6.42	3.97	24.99**	30.46**	26.47**	28.39**
27	UPR-3506-7-1-1 × Lal Basmati	14.35**	0.57	-9.81	-6.50	-35.43**	-31.88**	-15.26**	-5.66**

Table 8: Estimates of Heterosis –Better Parent (BP) and Mid-Parent (MP) for hybrids for 1000 grain weight (gm), Number of grains per panicle, Kernel length (mm) and Kernel breadth (mm)

S. No.	Crossess	1000 grain weight (gm)		Number of grains per panicle		Kernel length (mm)		Kernel breadth (mm)	
		BP	MP	BP	MP	BP	MP	BP	MP
1	Pant Basmati 1 × Taraouri Basmati	83.59**	95.90**	7.25	13.54*	10.00**	14.31**	-33.08**	-16.67**
2	Pant Basmati 1 × Sugandhmati	63.95**	70.60**	11.59	12.07	-3.65**	-1.84**	-34.34**	-18.24**
3	Pant Basmati 1 × Lal Basmati	42.31**	42.86**	-1.91	3.84	10.00**	14.29**	-29.29**	-14.04**
4	UPR-3716-27-1-1 × Taraouri Basmati	9.75**	48.48**	22.14**	28.00**	27.18**	33.01**	14.58**	27.61**
5	UPR-3716-27-1-1 × Sugandhmati	6.38**	33.54**	49.16**	51.39**	-0.91	9.35**	4.17**	16.01**
6	UPR-3716-27-1-1 × Lal Basmati	-9.75**	17.00**	30.92**	37.20**	14.81**	20.11**	15.46**	32.14**
7	UPR-3709-11-1-1 × Taraouri Basmati	38.47**	63.30**	-8.33	-5.95	27.69**	33.01**	-4.68**	2.32**
8	UPR-3709-11-1-1 × Sugandhmati	60.92**	72.73**	-0.36	8.48	10.96**	21.99**	6.12**	13.90**
9	UPR-3709-11-1-1 × Lal Basmati	36.33**	52.34**	-9.06	-6.69	23.01**	28.17**	-6.47**	-2.53**
10	Basmati 370 × Taraouri Basmati	50.61**	82.37**	-9.86	-6.23	15.94**	19.40**	9.37**	20.55**
11	Basmati 370 × Sugandhmati	27.58**	41.09**	-14.08	-5.24	19.63**	23.00**	21.88**	34.33**
12	Basmati 370 × Lal Basmati	17.45**	35.03**	-17.61*	-14.29*	20.77**	24.35**	-0.20	13.08**
13	Pant Sugandh Dhan 17 × Taraouri Basmati	40.17**	71.70**	-0.76	6.12	6.67**	10.93**	11.46**	11.46**
14	Pant Sugandh Dhan 17 × Sugandhmati	28.94**	44.49**	16.88**	17.65**	0.91	10.78**	14.58**	14.58**
15	Pant Sugandh Dhan 17 × Lal Basmati	9.65**	27.65**	9.16	16.73**	26.09**	31.17**	9.59**	13.02**
16	Pusa Sugandh Dhan 4 × Taraouri Basmati	15.13**	55.34**	-3.82	-0.59	4.72**	9.09**	-11.32**	-6.93**
17	Pusa Sugandh Dhan 4 × Sugandhmati	11.24**	39.20**	9.39	12.61*	-0.91	0.70	3.77**	8.91**
18	Pusa Sugandh dhan 4 × Lal Basmati	-15.28**	9.51**	-9.54	-6.51	15.57**	20.36**	5.66**	7.59**
19	Hariyana Basmati × Taraouri Basmati	21.45**	59.39**	-5.34	-2.55	17.09**	21.45**	0.78	4.42**
20	Hariyana Basmati × Sugandhmati	20.60**	46.20**	5.67	9.21	9.13**	11.40**	-5.04**	-1.61**
21	Hariyana Basmati × Lal Basmati	-8.82**	14.37**	-8.78	-6.09	13.76**	17.97**	16.28**	16.85**
22	2110-Kharif-2017 × Taraouri Basmati	56.86**	92.16**	-8.09	-6.37	15.86**	22.18**	8.35**	10.89**
23	2110-Kharif-2017 × Sugandhmati	32.19**	48.13**	0.74	8.95	16.89**	17.30**	23.26**	26.14**

24	2110-Kharif-2017 × Lal Basmati	45.55**	69.44**	-13.24	-11.61	14.48**	20.70**	23.29**	24.26**
25	UPR-3506-7-1-1 × Taraouri Basmati	34.92**	75.08**	-5.64	-4.92	3.33**	6.44**	0.00	11.24**
26	UPR-3506-7-1-1 × Sugandhmati	22.46**	46.53**	-11.65	-5.43	-7.31**	-4.72**	7.29**	19.35**
27	UPR-3506-7-1-1 × Lal Basmati	35.16**	67.45**	-7.14	-6.44	12.02**	15.37**	7.63**	23.04**

Table 9: Estimates of heterosis –better parent (BP) and Mid-Parent (MP) for hybrids Length-breadth ratio, Hulling recovery (%), Milling recovery (%) and Head rice recovery

S.No.	Crossess	Length-breadth ratio		Hulling recovery (%)		Milling recovery (%)		Head rice recovery	
		BP	MP	BP	MP	BP	MP	BP	MP
1	Pant Basmati 1 × Taraouri Basmati	8.29**	30.82**	-11.05**	-9.12**	-2.26	-2.01	16.58**	23.19**
2	Pant Basmati 1 × Sugandhmati	-10.95**	12.49**	-8.10**	-7.42**	-20.28**	-19.99**	-3.86**	4.27**
3	Pant Basmati 1 × Lal Basmati	8.54**	27.95**	-3.38	-1.19	3.45*	5.79**	13.22**	24.60**
4	UPR-3716-27-1-1 × Taraouri Basmati	-2.71**	4.16**	0.38	4.13*	3.38*	5.36**	6.00**	11.51**
5	UPR-3716-27-1-1 × Sugandhmati	-6.91**	-5.77**	2.00	2.84	-12.77**	-10.55**	12.63**	21.62**
6	UPR-3716-27-1-1 × Lal Basmati	-17.59**	-9.29**	-8.84**	-5.35**	-18.91**	-15.31**	12.89**	23.70**
7	UPR-3709-11-1-1 × Taraouri Basmati	15.67**	28.77**	-5.73**	-3.08	-24.95**	-20.46**	1.82	13.10**
8	UPR-3709-11-1-1 × Sugandhmati	-9.12**	6.36**	-1.61	4.01**	-9.17**	-4.29**	9.56**	24.72**
9	UPR-3709-11-1-1 × Lal Basmati	20.75**	30.78**	1.24	3.99**	-14.60**	-11.64**	17.07**	35.11**
10	Basmati 370 × Taraouri Basmati	-12.69**	-1.10**	8.78**	9.14**	-4.86**	-1.43	17.45**	32.11**
11	Basmati 370 × Sugandhmati	-15.08**	-8.71**	11.27**	14.88**	-8.53**	-5.80**	2.21*	17.77**
12	Basmati 370 × Lal Basmati	-7.79**	7.19**	-6.64**	-6.42**	-25.17**	-24.36**	7.81**	25.91**
13	Pant Sugandh Dhan 17 × Taraouri Basmati	-3.94**	-0.04	-1.91	-1.84	-6.79**	-5.97**	29.92**	48.31**
14	Pant Sugandh Dhan 17 × Sugandhmati	-12.04**	-3.37**	-30.43**	-28.45**	-22.55**	-22.34**	-11.09**	3.92**
15	Pant Sugandh Dhan 17 × Lal Basmati	16.39**	17.57**	-15.35**	-15.21**	-16.21**	-14.85**	-29.48**	-16.47**
16	Pusa Sugandh Dhan 4 × Taraouri Basmati	15.42**	16.38**	2.59	10.57**	2.32	3.29*	16.80**	24.13**
17	Pusa Sugandh Dhan 4 × Sugandhmati	-13.50**	-7.75**	7.33**	12.57**	-3.48*	-1.97	12.91**	23.13**
18	Pusa Sugandh dhan 4 × Lal Basmati	10.59**	13.04**	-11.48**	-4.51**	-20.34**	-17.58**	-8.89**	0.81
19	Hariyana Basmati × Taraouri Basmati	16.79**	16.89**	-17.04**	-15.53**	-30.48**	-26.26**	3.76**	6.36**
20	Hariyana Basmati × Sugandhmati	7.30**	13.47**	-0.44	4.27**	-20.26**	-15.92**	5.13**	10.70**
21	Hariyana Basmati × Lal Basmati	-2.29**	0.76	-8.32**	-6.74**	-21.67**	-18.88**	-5.05**	1.50
22	2110-Kharif-2017 × Taraouri Basmati	7.26**	10.50**	-12.00**	-8.96**	-21.66**	-19.99**	7.72**	9.70**
23	2110-Kharif-2017 × Sugandhmati	-9.56**	-7.02**	4.08*	4.66**	2.07	3.62*	26.81**	28.02**
24	2110-Kharif-2017 × Lal Basmati	-7.95**	-2.38**	-16.65**	-13.69**	-7.56**	-7.21**	2.99**	5.63**
25	UPR-3506-7-1-1 × Taraouri Basmati	-17.37**	-5.75**	-5.02**	-3.70**	-7.17**	-2.29	31.79**	68.90**
26	UPR-3506-7-1-1 × Sugandhmati	-26.58**	-20.48**	-5.86**	-1.81	-15.30**	-11.37**	-15.58**	10.34**
27	UPR-3506-7-1-1 × Lal Basmati	-21.63**	-8.28**	-6.28**	-5.06**	-12.73**	-10.34**	2.43**	35.38**

Table 10: Estimates of heterosis –better parent (BP) and Mid-Parent (MP) for hybrids Alkali digestion value, Gel consistency (mm), Amylose content and Yield per plant

S. No.	Crossess	Alkali digestion value		Gel consistency (mm)		Amylose content		Yield per plant	
		BP	MP	BP	MP	BP	MP	BP	MP
1	Pant Basmati 1 × Taraouri Basmati	0.00	2.83**	-14.39**	-12.82**	-20.64**	-12.93**	-26.73**	-21.89**
2	Pant Basmati 1 × Sugandhmati	11.70**	26.62**	-44.78**	-39.09**	-22.52**	-10.98**	-10.01**	18.53**
3	Pant Basmati 1 × Lal Basmati	11.64**	26.60**	-35.42**	-33.09**	-24.80**	-12.17**	-1.01	10.73**
4	UPR-3716-27-1-1 × Taraouri Basmati	-44.44**	-44.44**	-33.81**	-25.05**	-5.39**	-2.37**	-10.13**	6.55**
5	UPR-3716-27-1-1 × Sugandhmati	-11.11**	3.23**	-26.61**	-25.75**	29.53**	32.23**	66.14**	100.02**
6	UPR-3716-27-1-1 × Lal Basmati	11.11**	29.07**	-20.14**	-8.18	0.52	4.57**	-29.68**	-29.51**
7	UPR-3709-11-1-1 × Taraouri Basmati	-27.78*	-21.21**	-33.81**	-20.69**	-12.51**	-10.36**	-12.20**	-2.54**
8	UPR-3709-11-1-1 × Sugandhmati	-33.33**	-28.57**	-17.43**	-10.89*	-9.33**	-2.34**	53.64**	96.16**
9	UPR-3709-11-1-1 × Lal Basmati	-33.27**	-28.47**	-31.94*	-17.30**	-7.09**	1.86**	16.76**	25.50**
10	Basmati 370 × Taraouri Basmati	-44.44***	-44.43**	-44.96***	-33.77**	-4.94**	-3.45**	50.97**	77.08**
11	Basmati 370 × Sugandhmati	5.67**	22.68**	-33.94**	-28.36**	-17.47**	-14.42**	83.93**	123.73**
12	Basmati 370 × Lal Basmati	0.06	16.20**	-29.51**	-13.98**	-0.43	5.18**	-19.92**	-19.06**
13	Pant Sugandh Dhan 17 × Taraouri Basmati	-31.58**	-29.73**	-19.06**	-6.05	-1.13**	-0.92**	-0.97	3.03**
14	Pant Sugandh Dhan 17 × Sugandhmati	-21.00**	-6.19**	3.21	7.40	-5.79**	-0.63	-41.78**	-21.98**
15	Pant Sugandh Dhan 17 × Lal Basmati	-15.79**	0.03	-6.94	9.61	-8.72**	-1.95**	-24.57**	-13.71**
16	Pusa Sugandh Dhan 4 × Taraouri Basmati	-27.78**	-25.74**	-30.94**	-23.96**	37.54**	37.61**	-29.57**	-25.38**
17	Pusa Sugandh Dhan 4 × Sugandhmati	11.64**	26.56**	13.66*	15.96**	-0.05	5.17**	26.18**	79.84**
18	Pusa Sugandh dhan 4 × Lal Basmati	5.88**	20.07**	-51.74**	-46.02**	3.79**	11.21**	-42.16**	-28.28**
19	Hariyana Basmati × Taraouri Basmati	5.61**	26.73**	-44.96**	-39.76**	-19.61**	-13.08**	-27.27**	-1.24
20	Hariyana Basmati × Sugandhmati	-7.69**	-4.00**	-40.00**	-38.39**	-16.86**	-5.78**	150.00**	155.07**
21	Hariyana Basmati × Lal Basmati	38.49**	43.98**	-20.49**	-11.58*	-3.94**	10.70**	-26.33**	-12.57**
22	2110-Kharif-2017 × Taraouri Basmati	-16.67**	3.45**	-44.24**	-31.87**	10.50**	12.22**	-28.40**	-9.56**
23	2110-Kharif-2017 × Sugandhmati	23.15**	33.42**	-5.96	3.80	-12.77**	-6.83**	-20.95**	-11.10**
24	2110-Kharif-2017 × Lal Basmati	46.27**	58.40**	-31.94**	-15.70**	-9.64**	-1.74**	-48.89**	-44.60**
25	UPR-3506-7-1-1 × Taraouri Basmati	5.56**	5.56**	-35.97**	-27.64**	-1.71**	-1.71**	-26.09**	-4.87**
26	UPR-3506-7-1-1 × Sugandhmati	11.11**	29.03**	-4.59	-3.70	15.39**	21.46**	-13.26**	-4.68**
27	UPR-3506-7-1-1 × Lal Basmati	-11.11**	3.26**	-22.22**	-10.76*	13.06**	21.20**	-35.01**	-27.88**

Table 11: Estimates of standard heterosis over check- Pant Basmati-1 for all the traits under study

S. No.	Parents	Days to 50% flowering	Plant height (cm)	Number of tillers per plant	Panicle length (cm)	1000 grain weight (gm)	Number of grains per panicle	Kernel length (mm)	Kernel breadth (mm)	Length-breadth ratio	Hulling recovery (%)	Milling recovery (%)	Head rice recovery	Alkali digestion value	Gel consistency (mm)	Amylose content	Yield per plant
1	Pant Basmati 1 × Taraouri Basmati	7.55*	-0.89	13.95**	4.65	83.59**	20.60	10.00**	-33.07**	65.23**	-7.10**	-2.26	30.60**	5.82**	-11.19	-20.64**	-16.37**
2	Pant Basmati 1 × Sugandhmati	-2.16	-3.26	-27.91**	2.64	77.82**	11.59	0.04	-34.36**	52.72**	-8.10**	-19.69**	13.89**	11.69**	-44.78**	-22.52**	-10.01**
3	Pant Basmati 1 × Lal Basmati	0.00	5.79	-2.34**	21.23**	42.31**	10.30	10.00**	-29.28**	55.84**	1.10	8.24**	38.52**	11.64**	-30.60**	-24.80**	-1.01
4	UPR-3716-27-1-1 × Taraouri Basmati	-3.96	10.68	20.93**	30.03**	100.64**	37.34**	17.60**	-30.57**	70.97**	4.83**	2.85	18.74**	-41.22**	-31.34**	-22.14**	2.59**
5	UPR-3716-27-1-1 × Sugandhmati	-2.88	-0.30	37.21**	20.98**	94.48**	52.36**	2.89*	-36.86**	63.61**	0.50	-12.13**	33.42**	-5.94**	-40.30**	0.01	30.26**
6	UPR-3716-27-1-1 × Lal Basmati	-6.47	-10.39	7.00**	-19.85**	65.00**	47.21**	6.22**	-25.49**	44.84**	-4.61**	-15.15**	38.10**	17.58**	-14.18*	-22.39**	-44.60**
7	UPR-3709-11-1-1 × Taraouri Basmati	10.07**	2.08	11.63**	-13.82**	73.98**	8.58	18.07**	-33.07**	76.49**	4.15**	-15.82**	14.06**	-23.58**	-31.34**	-24.39**	0.23
8	UPR-3709-11-1-1 × Sugandhmati	3.96	6.83	11.63**	15.96**	102.18*	18.03**	15.22**	-25.49**	55.84**	8.70**	1.89	29.79**	-41.22**	-32.84**	-21.64**	40.61**
9	UPR-3709-11-1-1 × Lal Basmati	-1.44	0.30	48.84**	20.60**	71.28**	7.73	13.80**	-34.36**	73.38**	11.85**	-4.22**	43.22**	-41.15**	-26.87**	-19.70**	6.86**
10	Basmati 370 × Taraouri Basmati	-7.91*	-4.33	13.95**	2.39	102.05**	9.87	13.80**	-33.71**	73.98*	14.36**	1.74	31.57**	-41.22**	-42.91**	-21.78**	72.33**
11	Basmati 370 × Sugandhmati	-11.87**	3.44	27.91*	-22.24**	71.15**	4.72	24.22**	-26.14**	69.25**	16.98**	-2.19	21.09**	11.76**	-46.27**	-34.19**	48.03**
12	Basmati 370 × Lal Basmati	0.72	-12.52**	11.63**	-2.64	57.56**	0.43	18.53**	-35.61**	83.74**	-1.85	-19.98**	31.89**	5.82**	-24.25**	-20.60**	-35.54**
13	Pant Sugandh Dhan 17 × Taraouri Basmati	-0.36	2.26	39.54**	-4.90*	93.72**	11.59	-1.38*	-32.46*	46.56**	2.44	-5.60**	45.54**	-23.58**	-16.04**	-18.30**	13.05**
14	Pant Sugandh Dhan 17 × Sugandhmati	-9.71**	-7.12	16.28**	-12.69**	78.21**	15.88**	4.79**	-30.57**	50.84**	-27.44**	-21.56**	5.33**	-11.76**	-16.04**	-22.14**	-38.71**
15	Pant Sugandh Dhan 17 × Lal Basmati	-6.12	0.86	67.45**	10.81**	51.54**	22.75**	16.64**	-29.28*	67.10**	-1.42**	-2.33**	-3.72**	-5.94**	0.00	-24.56**	-0.59**
16	Pusa Sugandh Dhan 4 × Taraouri Basmati	0.72	-6.82	-2.32**	18.72**	108.72**	8.15	5.26**	-40.64**	76.12**	7.14**	1.80	30.85**	-23.58**	-28.36**	13.18**	-9.45**
17	Pusa Sugandh Dhan 4 × Sugandhmati	-2.88	6.32	88.38**	12.44*	101.67**	15.02	2.89**	-30.57**	48.33**	5.76**	-2.77	33.75**	11.64**	-3.73	-17.83**	62.22**
18	Pusa Sugandh dhan 4 × Lal Basmati	-5.76	2.64	-4.65**	-17.08**	53.59**	1.72	16.17**	-29.28**	65.98**	-7.37**	-16.65**	11.46**	5.87**	-48.13**	-14.68**	-25.65**
19	Hariyana Basmati × Taraouri Basmati	9.35**	-4.48	9.31**	10.30**	102.69**	6.44	16.64**	-34.36**	78.48*	-10.14**	-21.89**	16.24**	11.76**	-42.91**	-22.14**	-16.97**
20	Hariyana Basmati × Sugandhmati	-2.88	-14.33**	74.42**	12.19**	101.28**	12.02	13.33**	-38.14**	84.00**	7.84**	-10.41**	24.54**	-29.45**	-48.51**	-19.49**	34.98**
21	Hariyana Basmati × Lal Basmati	0.00	-8.60	18.59**	-4.52	52.18**	2.58	13.33**	-24.24**	49.34**	-0.70	-12.00**	16.16**	5.77**	-14.55**	-6.97**	-41.96**
22	2110-Kharif-2017 × Taraouri Basmati	-5.40	6.23	-20.95**	11.18**	116.79**	7.30	19.49**	-31.17**	73.86**	-8.10**	-18.65**	25.20**	-11.82**	-42.16**	-6.21**	-18.27**
23	2110-Kharif-2017 × Sugandhmati	-6.84	12.17**	2.33**	18.72**	82.69**	17.60**	21.38**	-21.70**	55.09**	2.55	5.99**	50.22**	-5.87**	-23.51**	-25.96**	-47.36**
24	2110-Kharif-2017 × Lal Basmati	-2.16	-3.86	-18.60**	-1.76	101.15**	1.29	18.07**	-20.45**	49.19**	-12.79**	-3.28**	25.99**	11.69**	-26.87**	-23.30**	-59.73**
25	UPR-3506-7-1-1 × Taraouri Basmati	4.68	19.17**	13.95**	36.62**	117.95**	7.73	1.47*	-39.39**	67.37**	2.00	2.61	47.64**	11.69**	-33.58**	-19.12**	-15.63**
26	UPR-3506-7-1-1 × Sugandhmati	-1.80	3.86	39.56**	21.86**	97.82**	0.86	-3.74**	-34.96**	48.70**	1.10	-6.37**	0.00	17.58**	-22.39**	-5.05**	-45.16**
27	UPR-3506-7-1-1 × Lal Basmati	-5.76	7.72	-27.91**	2.51	118.33**	6.01	10.00**	-30.57**	58.73**	0.65	-3.53**	25.32**	-5.94**	-16.42**	-6.97**	-48.80**

For days to 50% flowering, Pusa Sugandh Dhan 4 × Lal Basmati (-10.58), Pusa Sugandh Dhan 4 × Lal Basmati (-12.08) and Basmati 370 × Sugandhmati (-11.87) were found superior crosses in respect to heterobeltiosis, average heterosis and standard heterosis, respectively. For number of tillers plant^{-1} the cross Pusa Sugandh Dhan 4 × Sugandhmati was found superior in respect to heterobeltiosis, average heterosis and standard heterosis. For panicle length the cross UPR-3506-7-1-1 × Taraouri Basmati was found superior in respect to heterobeltiosis, average heterosis and standard heterosis and also superior for head rice recovery over better-parent and mid-parent. For number of grains panicle^{-1} the cross UPR-3716-27-1-1 × Sugandhmati was found superior in respect to heterobeltiosis, average heterosis and standard heterosis. For hulling recovery the cross Basmati 370 × Sugandhmati was found superior in respect to heterobeltiosis, average heterosis and standard heterosis. For milling recovery the cross Pant Basmati 1 × Lal Basmati was found superior in respect to heterobeltiosis, average heterosis and standard heterosis. For amylose content the cross Pusa Sugandh Dhan 4 × Taraouri Basmati was found superior in respect to heterobeltiosis, average heterosis and standard heterosis. Cross Hariyana Basmati × Sugandhmati was found best heterotic cross for grain yield plant-1 in respect to better parent and mid parent and also for L/B ratio over check parent. Cross 2110-kharif-2017 × Lal Basmati was found best heterotic cross for alkali digestion value in respect to better parent and mid parent and also for kernel breadth over better parent.

Negative heterosis for days to 50% flowering was observed in crosses Basmati 370 × Sugandhmati (-11.87) Pant Sugandh Dhan 17 × Sugandhmati (-9.71) over standard parent Pant Basmati 1. For plant height Basmati 370 × Lal Basmati (-12.52) and Hariyana Basmati × Sugandhmati (-14.33) showed negative heterosis over standard parent Pant Basmati 1. Similar results were obtained by Latha *et al.* (2013) [4]. Utharasu *et al.* (2013) [13] and Santosh kumar *et al.* (2017) [14].

Conclusions

The presence of significant variation among the genotypes for all the characters under study indicated that there is suitability to carry out selection for further improvement. For grain yield plant^{-1}, Basmati 370 × Taraouri Basmati and Hariyana Basmati × Sugandhmati were exhibited significant positive SCA effects and emerged as best specific combiner with highly significant positive standard heterosis over the standard parent Pant Basmati 1 and could be expected to be utilized in future breeding programme for high grain yield. Based on of GCA effects, the lines viz., UPR-3716-27-1-1 (no. of tillers plant^{-1}, no. of grains panicle^{-1}, head rice recovery, grain yield plant^{-1} and amylose content), UPR-3506-7-1-1 (panicle length, 1000 grain weight, milling recovery, amylose content and alkali digestion value) and the testers Taraouri Basmati (milling recovery, head rice recovery, amylose content and grain yield plant^{-1}), Lal Basmati (plant height, kernel breadth, alkali digestion value and gel consistency) were found good general combiners for these traits therefore, these lines and testers would be generate best cross combinations in later generations. Crosses viz., Pant Basmati 1 × Lal Basmati, UPR-3716-27-1-1 × Sugandhmati, UPR-3709-11-1-1 × Sugandhmati, UPR-3709-11-1-1 × Lal Basmati, Basmati 370 × Taraouri Basmati, Basmati 370 × Sugandhmati, Pant Sugandh Dhan 17 × Taraouri Basmati, Pant Sugandh Dhan 17 × Lal Basmati, Pusa Sugandh Dhan 4 × Sugandhmati, Hariyana Basmati × Sugandhmati, 2110-kharif-2017 × Taraouri Basmati, 2110-kharif-2017 × Lal Basmati, UPR-3506-7-1-1 × Taraouri Basmati, UPR-3506-7-1-1 × Lal Basmati found as best specific combiners for grain yield, hence, these crosses should be produce better progenies in later generations.

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