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COMBININGABILITYANALYSIS FOR GRAIN YIELD AND QUALITY TRAITS IN BASMATI RICE (*ORYZASATIVA* L.)

Aarti Sharma and H. K. Jaiswal

Department of Genetics and Plant Breeding, IAS, Banaras Hindu University, Varanasi-221 005 (U.P.) INDIA.

Abstract

Combining ability analysis on 36 F_1s and nine parents revealed that, parent HUBR10-9 had the best general combining ability for yield/plant followed by Pusa Basmati-1. Pusa Basmati-1121 and Pusa Basmati-1509 possessed good general combining ability for most of the quality traits studied in the experiment. GCA effect of Type-3 was the best for aroma. Other varieties having good GCA effect for aroma were Basmati-370, Taraori Basmati and Ranbir Basmati. High specific combining ability for yield per plant was observed in 14 crosses. Specific combining ability variance (σ^2s) was observed more than the general combining ability variance (σ^2g) for most of the traits. For 100-grain weight, grains per panicle and kernel length σ^2g/ σ^2s ratio were near to one, indicating the role of both additive and non-additive gene action in the inheritance of the traits.

Key words: GCA effect, sca effect, GCA variance, sca variance, basmati rice.

Introduction

The organoleptic properties of basmati rice make it exclusive and class apart from non-aromatic rice. Basmati rice has a profound demand in domestic as well as international markets. There are only 29 notified varieties of basmati in India. There is a need to develop new varieties with yield and quality parameters at par with traditional basmati varieties. Incorporating both quality and yield traits in basmati rice makes the breeding program more complex. Identification of the best genotypes/parents or crosses obtained through a hybridization can be used for the future breeding programs. General combining ability and specific combining ability studies can assist in the selection of suitable parents for a hybridization program and selection of superior hybrids combinations. In view of the aforementioned information, an experiment was designed to study the combining ability through half-diallel mating design.

Materials and Methods

In the present study, experimental material consisted of nine basmati rice genotypes *viz.*, Type-3, Basmati-370, Taraori Basmati, Ranbir Basmati, Pusa Basmati-1, CSR-30, Pusa Basmati-1121, HUBR10-9 and Pusa Basmati-1509. Parents were crossed in half-diallel mating design in *kharif* 2016. Parents and 36 F_1s obtained from the crossing program were sown in three replications, in Randomized Block Design in *kharif* 2017. The spacing of (15×20) cm was maintained and the required package of practices was followed to ensure healthy crop. Data on 18 yield and quality traits namely, days to 50% flowering (DF), days to maturity (DM), plant height (PH), main panicle length (PL), number of panicles per plant (P/P), total number of grains per panicle (G/P), 100-grain weight (100-GW), yield per plant (Y/P), kernel length (KL), kernel breadth (KB), kernel length/breadth ratio (L/B ratio), kernel length after cooking (KLAC), elongation ratio (ER), kernel breadth after cooking (KBAC), elongation index (EI), aroma, alkali spread value (ASV) and amylose content (AC) were recorded in field and laboratory. General combining ability (GCA) of parents and Specific combining ability (SCA) of crosses were analyzed following Method II (Griffing, 1956) and Model I (Eisenhart, 1947).

***Author for correspondence :** E-mail: aartisharma4564@gmail.com

Results and Discussion

Analysis of variance

ANOVA of 9 parents and 36 F_1s showed highly significant differences for parents, hybrids and parent *vs*

Table 1: Analysis of variance for yield traits in basmati rice.

SV	Degree of freedom	DF	DM	PH	PL	P/ P	G/P	100-GW	Y/P
Replicates	2	0.39	0.92	0.43	1.35	3.52*	92.18	0.00	0.42
Treatments	44	61.91***	69.61***	1163.76***	15.03***	21.73***	2149.84***	0.25***	329.68***
Parents	8	63.67***	49.62***	1833.35***	5.55***	9.00***	2795.91***	0.29***	80.15***
Hybrids	35	43.14***	60.91***	1028.41***	13.17***	22.43***	1901.07***	0.24***	354.57***
Parent Vs.Hybrids	1	704.98***	534.02***	544.43***	155.9***	98.90***	5688.42***	0.33***	1454.88***
Error	88	1.06	1.88	2.50	0.76	1.12	79.58	0.00	3.53

Significance Levels * = <.05, ** = <.01 & *** = <.001, SV= source of variation, DF= days to 50% flowering, DM= days to maturity, PH= plant height (cm), PL= main panicle length (cm), P/P= number of panicles/plant, G/P= total number of grains per panicle, 100-GW= grain weight (g), Y/P= yield/plant(g).

Table 2: Analysis of variance for quality traits in basmati rice.

SV	DF	KL	KB	L/B ration	KLAC	ER	KBAC	EI	ASV	Aroma	AC
Replicates	2	0.029	0.001	0.017	0.244	0.005	0.018*	0.005	0.005	0.004	0.196
Treatments	44	0.74***	0.02***	0.32***	14.29***	0.15***	0.20***	0.18***	7.40***	0.81***	9.61***
Parents	8	1.21***	0.02***	0.30***	21.45***	0.11***	0.05***	0.13***	3.93***	1.84***	6.02 ***
Hybrids	35	0.59***	0.01***	0.23***	12.71***	0.15***	0.22***	0.14***	7.18***	0.47***	7.97***
Parent Vs. Hybrids	1	2.04***	0.22***	3.76***	12.17***	0.58***	0.96***	2.08***	42.78***	4.45***	95.74***
Error	88	0.016	0.001	0.009	0.180	0.002	0.006	0.003	0.037	0.027	0.219

Significance Levels * = <.05, ** = <.01 & *** = <.001, SV= source of variation, df= degree of freedom, KL=kernel length (mm), KB=kernel breadth (mm), L/B ratio= Kernel length/kernel breadth ratio, KLAC= kernel length after cooking (mm), ER= elongation ratio, KBAC=kernel breadth after cooking (mm), EI= elongation index, ASV=alkali spreading value, AC= amylose content.

Table 3: Analsyis of variance of combining ability for yield traits in basmati rice.

SV	df	DF	DM	PH	PL	P/ P	G/P	100-GW	Y/P
GCA	8.00	25.72***	24.83***	453.15***	10.30***	11.01***	2689.71***	0.32***	340.95***
SCA	36.00	19.51***	22.84***	373.43***	3.84***	6.40***	278.15***	0.03***	58.55***
Error	88.00	0.35	0.63	0.83	0.25	0.37	26.53	0.00	1.18

Significance Levels * = <.05, ** = <.01 & *** = <.001, SV= source of variation, df= degree of freedom.

Table 4: Analsyis of variance of combining ability for quality traits in basmati rice.

SV	Df	KL	KB	L/B RATIO	KLAC	ER	KBAC	EI	ASV	AROMA	AC
GCA	8	0.97***	0.003***	0.25***	15.38***	0.11***	0.12***	0.10***	6.67***	0.69 ***	3.05 ***
SCA	36	0.08***	0.007***	0.08***	2.40***	0.04***	0.06***	0.05***	1.53***	0.18 ***	3.24 ***
Error	88	0.005	0.000	0.003	0.060	0.001	0.002	0.001	0.012	0.009	0.073

Significance Levels * = <.05, ** = <.01 & *** = <.001, SV= source of variation, df= degree of freedom.

hybrids in 18 traits studied. Significant results indicated that sufficient genetic diversity existed in the experimental material. ANOVA table is listed in tables 1 and 2.

ANOVA results for combining ability revealed that the mean sum of square due to GCA and sca were highly significant for all traits. This indicates the role of both additive and non-additive gene action in expression of these traits. SCA and GCA effect are calculated when the mean sum of square of SCA and GCA are significant. Non-significance mean square for GCA suggests that there are non-significant differences among the GCA effects of parents. In other words, GCA effects of all the parents are comparable. Similarly, non-significance of mean square for sca implies that there are non-significant differences among the sca effect of cross combinations (Dabholkar, A.R., 1999). ANOVA table for combining ability is given in tables 3 and 4.

Table 5: Estimation of components of variance for yield traits in basmati rice.

Components	DF	DM	PH	PL	P/ P	G/P	100-GW	Y/P
σ^2g	2.31	2.20	41.12	0.91	0.97	242.11	0.03	30.89
σ^2s	19.16	22.22	372.59	3.58	6.03	251.62	0.03	57.37
σ^2g/σ^2s	0.12	0.10	0.11	0.25	0.16	0.96	1.02	0.54

Table 6: Estimation of components of variance for quality traits in basmati rice.

Components	KL	KB	L/B RATIO	KLAC	ER	KBAC	EI	ASV	AROMA	AC
σ^2g	0.09	0.00	0.02	1.39	0.01	0.01	0.01	0.60	0.06	0.27
σ^2s	0.08	0.01	0.07	2.34	0.04	0.06	0.05	1.52	0.17	3.17
σ^2g/σ^2s	1.10	0.04	0.30	0.59	0.28	0.19	0.19	0.40	0.37	0.08

Table 7: Estimates of General combining ability (GCA) effects of parents for yield traits in basmati rice.

PARENTS	DF	DM	PH	PL	P/ P	G/P	100-GW	Y/P
Type-3	-0.61***	1.13***	8.31***	0.35*	-1.66***	-7.89***	-0.15***	-5.54***
Basmati-370	-0.16	1.25***	7.86***	-0.19	0.27	-0.33	-0.15***	-2.35***
Taraori Basmati	1.18***	1.04***	1.73***	-0.67***	-0.18	-4.22**	-0.01	-2.94***
Ranbir Basmati	-0.43*	-1.21***	2.99***	0.64***	-0.72***	4.82**	-0.18***	-3.09***
Pusa Basmati1	-2.64***	-2.39***	-11.08***	1.38***	-0.49**	12.36***	-0.14***	2.79***
CSR-30	1.60***	1.52***	2.98***	-1.13***	0.97***	-4.80**	0.06***	-1.34***
Pusa Basmati-1121	-1.22***	-0.57*	-3.96***	-1.08***	-0.33	-22.62***	0.27***	-1.42***
HUBR10-9	2.39***	1.04***	-4.87***	1.32***	1.80***	32.64***	0.06***	13.48***
Pusa Basmati-1509	-0.10	-1.81***	-3.96***	-0.62***	0.35	-9.98***	0.24***	0.41
Gi S.E.	**0.17**	**0.23**	**0.26**	**0.14**	**0.17**	**1.46**	**0.01**	**0.31**

Significance Levels * = <.05, ** = <.01 & *** = <.001.

Components of genetic variance

The GCA variance (σ^2g) and sca variance (σ^2s) for a trait are the consequence of additive genetic variance and non-additive genetic variance. Results are presented in tables 5 and 6. The ratio of σ^2g/σ^2s provides information on which type of genetic variance (additive or non- additive) is predominant in the expression of a trait. In the present study, σ^2g/σ^2s ratio obtained for KL, 100- GW and G/P were close to unity which suggests the role of both additive and non-additive genetic variance in the inheritance of these traits. For other traits *viz.*, DF, DM, PH, PL, P/P, Y/P, KB, KLAC, KBAC, ER, EI, L/B ratio, ASV, aroma and AC σ^2s was more than σ^2g which suggests the role of non- additive gene action in expression of these traits. Similar findings have been observed in work of Tyagi *et al.*, (2008); Pradhan *et al.*, (2008); Patil *et al.*, (2012); Aditya *et al.*, (2015); Kumar *et al.*, (2015); Chuwang *et al.*, (2018); Akanksha and Jaiswal, (2019), where non-additive gene action played major role in expression of yield and quality traits.

GCA effect

A study on GCA facilitates in selection of proper parents for a breeding program on the basis of performance of their progeny. GCA effect of parents has been listed in tables 7 and 8. A low GCA value indicates that parental mean of a particular cross does not differ much from the general mean of the crosses and vice versa. A high GCA value suggests preponderance of additive gene action of parents. In the present study, only two parents, *viz.*, HUBR10-9 and Pusa Basmati-1 showed significant positive GCA effect for yield per plant. However, Kour *et al.*, (2019) and Kumar *et al.*, (2015) have recorded positive GCA effect for yield per plant in five and seven parents, respectively

Table 8: Estimates of General combining ability (GCA) effects of parents for quality traits in basmati rice.

PARENTS	KL	KB	L/B RATIO	KLAC	ER	KBAC	EI	ASV	AROMA	AC
Type-3	-0.26***	0.01	-0.15***	-0.52***	-0.01	0.16***	-0.09***	-1.01***	0.51***	-1.12***
Basmati-370	-0.26***	-0.03***	-0.10***	-0.18*	0.04***	0.01	0.00	-0.32***	0.19***	0.10
Taraori Basmati	0.09***	-0.01	0.06***	-0.57***	-0.09***	0.01	-0.07***	-0.18***	0.09***	0.40***
Ranbir Basmati	-0.24***	-0.01	-0.13***	-0.69***	-0.03***	-0.10***	0.04***	-1.11***	0.09**	-0.51***
Pusa Basmati1	-0.10***	-0.01*	-0.02	-0.57***	-0.05***	0.10***	-0.10***	0.78***	-0.11***	0.18*
CSR-30	-0.03	-0.01**	0.03	-1.32***	-0.16***	-0.14***	-0.06***	-0.26***	-0.14***	0.12
Pusa Basmati-1121	0.54***	0.01**	0.25***	2.08***	0.14***	-0.09***	0.16***	1.09***	-0.30***	0.39***
HUBR10-9	-0.15***	0.03***	-0.15***	-0.15*	0.02*	0.10***	-0.03***	0.30***	-0.24***	0.57***
Pusa Basmati-1509	0.41***	0.01*	0.20***	1.91***	0.15***	-0.06***	0.14***	0.71***	-0.09***	-0.13
Gi S.E.	**0.02**	**0.00**	**0.02**	**0.07**	**0.01**	**0.01**	**0.00**	**0.03**	**0.03**	**0.08**

Significance Levels * = <.05, ** = <.01 & *** = <.001 G_i= GCA of i_{th} line; S.E. = standard error

Table 9: Estimates of Specific combining ability (sca) effects of 36 F_1 s for yield traits in basmati rice

Crosses	DF	DM	PH	PL	P/ P	G/P	100-GW	Y/P
Type3 × Basmati 370	-2.44***	1.23	-16.33***	0.23	-0.08	-15.44**	-0.08*	-2.90**
Type3 × Taraori Basmati	-2.77***	2.44**	-0.77	0.83	-2.56 ***	3.32	-0.07	-0.32
Type3 × Ranbir Basmati	-1.16*	-2.65***	-14.34***	-0.84	-1.28 *	-14.32**	-0.06	-2.62*
Type3 × Pusa Basmati1	2.05***	-2.13**	35.17 ***	1.69 ***	1.29*	8.51	0.08*	-1.73
Type3 × CSR30	-3.19***	-3.04***	-12.35***	-1.87 ***	-0.77	-1.36	-0.17***	-3.04**
Type3 × Pusa Basmati1121	0.62	-2.28**	2.82 **	1.07*	2.42 ***	14.76**	0.16***	7.94***
Type3 × HUBR10-9	0.02	-1.56*	11.54 ***	0.58	1.93 **	-7.27	0.12***	0.07
Type3 × Pusa Basmati1509	-2.50***	-0.71	-13.20 ***	0.35	-0.92	0.28	0.08*	-0.65
Basmati 370 × Taraori Basmati	-4.22***	-8.68***	5.13 ***	-0.65	2.04 ***	11.46*	0.00	-2.34*
Basmati 370 × Ranbir Basmati	-2.62***	-3.44**	14.44 ***	2.96 ***	2.55 ***	40.16***	0.07*	13.72***
Basmati 370 × Pusa Basmati1	0.59	1.75*	-25.04 ***	1.85 ***	0.32	28.41***	0.13***	3.08**
Basmati 370 × CSR30	-2.65***	-4.16***	-31.11 ***	1.54 **	3.03 ***	-3.05	-0.14***	1.90
Basmati 370 × Pusa Basmati1121	3.17***	1.59*	3.36 ***	-3.38 ***	1.53 **	13.66**	-0.05	4.13***
Basmati 370 × HUBR10-9	3.56***	5.32***	4.70 ***	1.66 ***	0.43	-17.33***	-0.01	-1.85
Basmati 370 × Pusa Basmati1509	3.05***	2.17**	22.80 ***	-2.07 ***	-2.21 ***	-7.75	0.17***	-2.40*
Taraori Basmati × Ranbir Basmati	-1.95***	-2.22**	-19.82 ***	1.68 ***	0.70	-5.19	-0.07*	1.32
Taraori Basmati × Pusa Basmati1	1.26*	1.96*	11.98 ***	0.22	-0.43	14.37**	0.09*	2.75**
Taraori Basmati × CSR30	-4.98***	-2.95***	-35.39 ***	-0.10	3.35 ***	-9.96*	-0.25***	-0.70
Taraori Basmati × Pusa Basmati1121	-1.16*	-3.86***	-0.67	2.30 ***	0.54	7.09	0.32***	2.86**
Taraori Basmati × HUBR10-9	5.23***	2.53**	-35.80 ***	0.58	1.38 *	16.12**	-0.09**	4.92***
Taraori Basmati × Pusa Basmati1509	-6.28***	-7.62***	32.03 ***	1.04 *	0.00	24.10***	0.25***	-2.50*
Ranbir Basmati × Pusa Basmati1	-1.13*	-3.80***	-22.56 ***	1.67 ***	-0.18	1.23	0.20***	-2.64*
Ranbir Basmati × CSR30	-3.04***	-3.71***	11.59 ***	-0.14	-4.44 ***	7.78	-0.03	-4.72***
Ranbir Basmati × Pusa Basmati1121	-0.56	0.38	0.88	0.75	2.06 ***	1.45	0.20***	1.33
Ranbir Basmati × HUBR10-9	5.84***	7.78***	9.35 ***	2.04 ***	0.96	11.72*	0.18***	5.37***
Ranbir Basmati × Pusa Basmati1509	-0.68	-2.38**	-12.46 ***	-0.48	-0.19	-0.10	-0.46***	-0.79
Pusa Basmati1 × CSR30	-5.16***	-3.86***	31.50 ***	-1.48 **	3.06 ***	-22.51***	-0.08*	7.96***
Pusa Basmati1 × Pusa Basmati1121	-5.35***	0.56	-1.68	-0.07	-2.44 ***	-8.89	-0.15***	-2.20*
Pusa Basmati1 × HUBR10-9	-1.95***	-2.04**	-7.99 ***	-0.27	-1.77 **	11.20*	0.05	5.95***
Pusa Basmati1 × Pusa Basmati1509	-0.47	-1.19	-4.93 ***	2.03	3.75 ***	6.10	0.05	15.99***
CSR 30 × Pusa Basmati1121	-3.59***	-1.01	-19.59 ***	0.11	-0.70	-10.26*	0.03	-8.66***
CSR 30 × HUBR10-9	3.81***	9.058**	17.83 ***	0.76	5.57 ***	-0.09	0.16***	12.70***
CSR 30X Pusa Basmati1509	-1.71**	3.90***	-2.42 **	1.65	-3.58 ***	2.93	0.25***	-4.42***
Pusa Basmati1121 × HUBR10-9	-5.38***	-5.86***	4.18 ***	2.16	-0.03	10.43*	0.02	10.16***
Pusa Basmati1121 × Pusa Basmati1509	-0.89	-1.68*	15.21 ***	-0.89	-1.64 **	-8.15	-0.06	-6.68***
HUBR10-9 × Pusa Basmati1509	-4.50***	-5.62 ***	5.78 ***	1.84***	1.69 **	13.45**	0.05	8.12***
S_{ij} S.E	0.54	0.72	0.83	0.46	0.56	4.71	0.03	0.99

Significance Levels * = <.05, ** = <.01 & *** = <.001

in their study. HUBR10-9 was the best general combiner for yield per plant followed by Pusa Basmati-1. Besides, yield per plant trait HUBR10-9 was the best general combiner for panicle length, number of panicles per plant, total numbers of grain per panicle and plant height. Akanksha and Jaiswal, (2019) also observed HUBR10-9 as the best general combining parent for yield/plant trait in their study. Pusa Basmati-1 appeared as the best general combiner for earliness in DF, DM, short plant height and increased number of panicles per plant. Positive high GCA for yield per plant has been reported in Pusa Basmati-1 by Kumar *et al.*, (2015); Aditya *et al.*, (2015) and Bano and Singh, (2019). However, Salgotra *et al.*, (2009) and Pradhan *et al.*, (2008) have reported average and low GCA effect of Pusa Basmati-1, for yield per plant trait.

In the present study traditional basmati varieties, Type-3, Basmati-370, Taraori Basmati and Ranbir Basmati were poor general combiner for yield per plant. Similar findings for poor yield per plant were recorded by Pradhan *et al.*, (2008) in Type-3, Kumar *et al.*, (2015) in Type-3 and Basmati-370. However, Salgotra *et al.*, (2009), has found high GCA for Basmati-370 and Ranbir Basmati.

Estimates of GCA effect for KL, L/B ratio, KLAC,

Table 10. Estimates of Specific combining ability (sca)effects of 36 F_1 s for quality traits in basmati rice

CROSSES	KL	KB	L/B RATIO	KLAC	ER	KBAC	EI	ASV	AROMA	AC
Type3 X Basmati 370	-0.20**	-0.13***	0.16**	0.09	0.07**	0.19***	-0.12***	-1.20***	0.13	-0.44
Type3 X Taraori Basmati	-0.11	-0.08***	0.13*	-0.77**	-0.09***	0.13**	-0.16***	-0.93***	-0.88***	1.45***
Type3 X Ranbir Basmati	-0.02	-0.12***	0.24***	-1.76***	-0.24***	0.28***	-0.36***	-0.47***	0.30**	-0.03
Type3 X Pusa Basmati1	0.05	0.05**	0.06	-1.45***	-0.21***	0.01	-0.15***	-1.74***	0.39***	0.61*
Type3 X CSR30	-0.00	-0.11***	0.22***	-0.26	-0.03	0.11**	-0.14***	-0.80***	0.45***	-1.50***
Type3 X Pusa Basmati1121	0.35***	0.06***	-0.048	2.53***	0.23***	0.20***	0.11***	-0.19	-0.07	0.28
Type3 X HUBR10-9	-0.06	0.09***	-0.24***	-0.03	0.02	-0.12**	0.13***	-0.82***	-0.28**	-0.81**
Type3 X Pusa Basmati1509	0.45***	-0.04*	0.32***	2.66***	0.23***	0.08*	0.07*	1.85***	-0.42***	-1.36***
Basmati 370 X Taraori Basmati	0.49***	-0.04*	0.35***	2.55***	0.21***	-0.31***	0.30***	2.65***	-0.60***	1.87***
Basmati 370 X Ranbir Basmati	0.19**	0.02	0.04	1.25***	0.12***	-0.24***	0.24***	-0.64***	-0.30**	1.71***
Basmati 370 X Pusa Basmati1	0.05	-0.01	0.04	0.50*	0.06*	0.14***	-0.04	1.76***	0.05	-2.13***
Basmati 370 X CSR30	0.30***	-0.04*	0.29***	-0.61**	-0.17***	0.08*	-0.19***	-0.64***	-0.19*	1.12***
Basmati 370 X Pusa Basmati1121	-0.50***	-0.06***	-0.12*	-1.53***	-0.07**	0.10*	-0.18***	-0.55***	-0.54***	2.47***
Basmati 370 X HUBR10-9	-0.11	0.07***	-0.20***	-1.05***	-0.11***	0.13**	-0.10***	-0.77***	-0.14	1.83***
Basmati 370 X Pusa Basmati1509	0.41***	0.04*	0.12*	0.29	-0.057*	0.14**	-0.10**	-1.58***	-0.07	2.05***
Taraori Basmati X Ranbir Basmati	0.06	-0.06**	0.17**	-1.42***	-0.212***	0.38***	-0.37***	-1.38***	-0.37***	-0.87**
Taraori Basmati X Pusa Basmati1	0.24**	0.028	0.059	-0.47*	-0.12***	0.15***	-0.12***	0.65***	0.05	-0.94***
Taraori Basmati X CSR30	0.10	-0.06***	0.21***	-0.53*	-0.09***	0.27***	-0.23***	-0.70***	0.04	0.79**
Taraori Basmati X Pusa Basmati 1121	0.26***	0.027	0.088	-3.79***	-0.45***	-0.17***	-0.30***	0.38***	-0.01	1.38***
Taraori Basmati X HUBR10-9	-0.08	0.07***	-0.21***	0.50*	0.08**	0.03	0.09**	-0.16	-0.24**	1.28***
Taraori Basmati X Pusa Basmati	0.19**	-0.01	0.15**	2.77***	0.29***	-0.00	0.18***	-1.25***	-0.01	0.90***
Ranbir Basmati X Pusa Basmati 1509	0.21	0.01	0.09	-0.39	-0.11***	0.25***	-0.21***	0.23*	-0.64***	-1.59***
Ranbir Basmati X CSR30	0.02	-0.12***	0.30***	-0.00	-0.01	-0.19***	-0.02	-1.00***	-0.13	-0.92***
Ranbir Basmati X Pusa Basmati 1121	0.11	0.02	0.03	-0.64**	-0.10***	-0.16***	0.00	0.02	-0.07	0.176
Ranbir Basmati X HUBR10-9	-0.07	0.07***	-0.20***	1.10***	0.17***	0.25***	0.02	-1.00***	-0.51***	2.907***
Ranbir Basmati X Pusa Basmati 1509	-0.64***	0.05**	-0.47***	-1.25***	0.00	-0.17***	0.12***	0.24*	-0.16	-0.870**
Pusa Basmati1 X CSR30	0.31**	0.011	0.12*	-0.74**	-0.16***	-0.22***	-0.02	0.44***	0.08	0.45
Pusa Basmati1 X Pusa Basmati 1121	0.03	-0.05**	0.15**	1.01***	0.11***	0.24***	-0.10**	-1.044***	-0.24**	0.60*
Pusa Basmati1 X HUBR10-9	0.07	-0.03*	0.10	1.94***	0.24***	0.06	0.11***	-0.10	0.17	1.06***
Pusa Basmati1 X Pusa Basmati 1509	0.09	-0.02	0.08	-1.45***	-0.20***	0.31***	-0.29***	-0.35**	0.10	0.10
CSR 30 X Pusa Basmati1121	-0.09	-0.08***	0.15**	0.81***	0.13***	-0.20***	0.16***	0.13	-0.21*	1.66***
CSR 30 X HUBR10-9	0.10	-0.04*	0.13*	-0.91***	-0.15***	-0.33***	0.04	-1.20***	0.16	1.00***
CSR 30X Pusa Basmati1509	0.18*	-0.01	0.09	-1.49***	-0.21***	0.00	-0.17***	-1.20***	0.05	1.00***
Pusa Basmati1121 X HUBR10-9	0.10	-0.08***	0.28***	-1.09***	-0.16***	0.30***	-0.32***	0.88***	0.33***	-1.00***
Pusa Basmati1121 X Pusa Basmati1509	-0.09	-0.08***	0.17**	-1.60***	-0.19***	-0.23***	-0.06*	0.35**	0.22*	1.48***
HUBR10-9 X Pusa Basmati1509	-0.14	-0.08***	0.13*	-0.14	0.02	0.02	-0.07*	0.01	0.28**	-0.56*
Sij S.E	**0.07**	**0.02**	**0.05**	**0.22**	**0.02**	**0.04**	**0.03**	**0.10**	**0.09**	**0.25**

Significance Levels * = <.05, ** = <.01 & *** = <.001; Sij = SCA of ijth cross; S.E=standard error

ER, KBAC, EI revealed that Pusa Basmati-1121 and Pusa Basmati-1509 were good general combiners for these traits. Tyagi *et al.*, (2008) reported positive significant GCA effect for 100-GW and average GCA effect for yield per plant in Pusa Basmati-1121. In present findings, Pusa Basmati-1121 recorded high GCA effect for 100-GW and low GCA effect for yield per plant. Type- 3 showed good general combining ability for aroma followed by Basmati-370, Taraori Basmati and Ranbir Basmati. Among the parents, CSR-30 and Type-3 were

Table 11: GCA effects of 18 yield and quality traits.

Parents	High GCA	LowGCA	Average GCA
Type-3	DF, PL, Aroma,	P/P, G/P, DM, 100-GW, Y/P, PH, ASV, AC, KL, L/B ratio, KLAC, KBAC, EI	KB,ER
Basmati-370	ER, Aroma, KB	DM, 100-GW, PH, KL, L/B ratio, KLAC, Y/P, ASV	DF, KBAC, EI, AC, PL, P/P, G/P,
Taraori Basmati	L/B ratio, Aroma, ASV, KL	DF, DM, PH, PL, G/P, Y/P, KLAC, ER, EI	100-GW, P/P, KB, KBAC, AC
Ranbir Basmati	DF, DM, PL, P/P. G/P, 100-GW, KBAC, EI , Aroma	PH, G/P, KL, KB, L/B ratio, KLAC, ER, ASV, AC	
Pusa Basmati1	DF, DM, PH, PL, G/P, Y/P, KBAC, ASV, AC	P/P, 100-GW, KL, KLAC, ER, KB, EI, Aroma	L/B ratio
CSR-30	KB, KBAC, P/P, 100-GW	DF, DM, PH, PL, G/P, Y/P, KLAC, ER, EI, Aroma, ASV	KL, L/B ratio, AC
Pusa Basmati-1121	DF, DM, PH, 100-GW, KL, KLAC, L/B ratio, ER,KBAC, EI, ASV, AC	KB, Aroma, Y/P, G/P, PL	P/P
HUBR10-9	PH, PL, P/P, G/P, 100-GW, Y/P, KLAC, ASV, AC	DF, DM, KL, KB, L/B ratio, ER,	KBAC, EI, Aroma
Pusa Basmati-1509	DM, PH, 100-GW,KL, L/B ratio, KLAC, ER, KBAC, EI	PL, G/P, KB, Aroma	DF, P/P, Y/P,

DF= days to 50% flowering, DM= days to maturity, PH= plant height (cm), PL= main panicle length (cm), P/P= number of panicles/plant, G/P= total number of grains per panicle, 100-GW= grain weight (g), Y/P= yield/plant(g), KL=kernel length (mm), KB=kernel breadth (mm), L/B ratio= Kernel length/kernel breadth ratio, KLAC= kernel length after cooking (mm), ER= elongation ratio, KBAC=kernel breadth after cooking (mm), EI= elongation index, ASV=alkali spreading value, AC= amylose content.

poor general combiner for most of the traits except aroma and ASV. One particular parent having a desirable GCA effect for all traits were not observed in the present study. A brief summary of GCA effects showed by parents for 18 traits is presented in table 11.

SCA effects

SCA effect is a function of non-additive gene action. A high value of SCA effect implicates role of epistatic and dominance genetic variance in expression of characters. In the present study, 14 crosses showed significant positive SCA effect for yield per plant, Pusa Basmati-1 × Pusa Basmati-1509 showed highest value for SCA effect for the trait. Kumar *et al.*, (2015) recorded 16 crosses out of 28 and Chuwang *et al.*, (2018) recorded 13 out of 28 crosses showing positive SCA effect for yield per plant trait in their study. However, Aditya *et al.*, (2015) recorded 6 out of 36 and Kour *et al.*, (2019) recorded 6 out of 33 crosses, which showed positive SCA effect for yield per plant trait. The difference in number of crosses with desirable SCA effects varied in different studies. This could be result of different parental material used in different experiments. Seven cross combinations with HUBR10-9 as one of the parents showed high sca effect. These crosses had HUB10-9 which was the best general combiner with high *per se* performance.

Considering both quality and yield traits studied Basmati-370 × Taraori Basmati and Basmati-370 × Ranbir

Table 12: Promising hybrids on the basis of *per se performance* GCA and sca effect.

CROSSES	sca effect	GCA effect	*per se performance*
CSR-30 × HUBR10-9	12.7***	L × H	54.96
Pusa Basmati-1121 × HUBR10-9	10.16***	L × H	52.35
Pusa Basmati-1 × HUBR10-9	5.95***	H × H	52.34
HUBR10-9 × Pusa Basmati-1509	8.12***	H × L	52.13
Pusa Basmati-1 × Pusa Basmati-1509	15.99***	H × A	49.32
Ranbir Basmati × HUBR10-9	5.37***	L × H	45.89
Taraori Basmati × HUBR10-9	4.92***	L × H	45.59
Pusa Basmati-1 × CSR-30	7.96***	H × L	39.53
Basmati-370 × R Basmati	13.72***	L × L	38.40
Basmati-370 × Pusa Basmati-1	3.08**	L × H	33.65
Taraori Basmati × Pusa Basmati-1	2.75**	L × H	32.73
Type-3 × Pusa Basmati-1121	7.94***	L × L	31.10
Basmati-370 × Pusa Basmati-1121	4.13***	L × L	30.49
Taraori Basmati × Pusa Basmati-1121	2.86**	L × L	28.62

Significance Levels ** = <.01 & *** = <.001

Basmati showed desired SCA effects for 13 out of 18 traits. Cross combination Basmati-370 × Ranbir Basmati performed best for yield traits as it showed desirable SCA effect in 7 out of eight yield traits. Basmati-370 × Taraori Basmati showed desirable SCA effect for all the quality traits studied in this experiment except aroma. Pusa Basmati-1 × Pusa Basmati- 1509 cross combination did not show desirable SCA effect for any quality traits.

For ASV 10 and for AC 19 crosses showed significant positive SCA effects. Bano and Singh, (2019) have also recorded more number of crosses with positive SCA effect for AC (12 crosses out of 28) and ASV (13 crosses out of 28). However, Kumar *et al.,* (2015) have obtained 5 crosses with positive SCA effect each for AC and ASV in their study. 21 cross combinations showed desired SCA effects for days to 50% flowering; 20 for days to maturity; 19 each for L/B ratio; 18 for KB, 15 each for PH, PL and 100-GW; 14 for P/P; 12 each for G/P, KL and ER; 11 each for KLAC and KBAC; 10 for EI and 6 for aroma.

In the present study SCA effect showed by crosses could be result of (high GCA × high GCA), (high GCA × low GCA), and (low GCA × low GCA) which are attributed to additive × additive gene action, additive × non-additive gene action and non-additive × non-additive gene action, respectively. Pradhan *et al.,* (2008); Patil *et al.,* (2012); Aditya *et al*, (2015); Chuwang *et al.,* (2018); and Akanksha and Jaiswal, (2019) obtained similar SCA effect for different traits studied by them. Table 10 and 11 present the details of SCA effect of 36 crosses.

However, the superiority of crosses cannot be judged only on the basis SCA effect. In general, an effective way of selection is to consider a cross having favorable SCA effect with at least one parent showing high GCA effect. The crosses which showed positive SCA effect for yield/plant are listed below in table 12 with their respective GCA effect and per se performance.

Conclusion

Parental material showed low, high and average values of GCA effect for the 18 traits studied. Most of the crosses showing high SCA effect had cross combination with (low × high) GCA effects. None of the crosses showed good sca for all traits studied. However, a few cross combinations showed desirable sca effect for most of the traits. Results obtained from this experiment clearly indicate a significant role of both additive and non-additive gene action in expression of traits. Non-additive gene action was more prevalent than additive gene action. In view of the gene action reported in this experiment, reciprocal recurrent selection can be used as an effective tool in exploiting non-fixable gene effects and in the accumulation of fixable gene effects (Joshi, 1979).

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