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Combining Ability Analysis for Yield and Quality Related Traits in Non- Basmati Aromatic Rice (*Oryza sativa* L.)

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In view to invigorate hybrid rice breeding and exploration of heterosis in untapped, low productive genetic pool of non-basmati aromatic rice, altogether thirtyF_1's were generated in L x T design fashion with thirteen parents (3 testers and 10 lines), and were evaluated along with the parents to unravel the combining ability for 28 yield and yield contributing traits. The study revealed importance of both additive and non-additive gene effects in governing yield and yield components with preponderance of non-additive gene action for most of the yield components. The parental lines IET 21842 along with Tenduphool, Tulsimongra, Kumbhdev and Bhatamahsuri were found to be a good general combiner for most of the characters studied. Thirteen out of 30 hybrids evaluated were exhibited significant positive SCA effect (predominance of non-additive, inter-allelic interaction), indicated predominance of non-additive gene action. The crosses CRMS 31AxIET 21842, CRMS 32A x Tulsimongra and CRMS 31A x Chhinguchhi shown high *sca* effects for GY which found in high x high general combiner category (additive and/or additive x additive type gene effect, more fixable in nature). Therefore, there is high probability of obtaining good transgressive segregants in the progeny of these crosses for improvement of this trait.

Introduction

Aromatic rice is very popular in South Asia and recently have gained wider acceptance in USA, Europe, China and South Africa.

Aromatic rice occupies a prime position in Indian culture not only because of their high quality but also of its auspicious nature. India had an immense wealth of aromatic rice; many have been lost during the last four decades as an aftermath of the green revolution where main emphasis was given on yield rather than quality (Yoshihashi *et al.,* 2004 and Singh *et al.,* 2011). Among aromatic rice, basmati rice is known as 'Crown Jewel' of South Asian gift of India and Pakistan to the world, prized for its exquisite aroma and taste. Basmati is highly valued in the international market due to its unique combination of aroma, grain, cooking and eating qualities (Singh *et al.,* 1988, 2000).

Besides the much sought after basmati types which get high price in international markets, the country also abounds with hundreds of indigenous short grain aromatic cultivars and landraces grown in pockets of different states. Almost every state has its own collection of aromatic rice that performs well in native areas. These aromatic rice lines also possess exemplary quality traits like aroma, fluffiness and taste. However, the improvement of these rice varieties very much neglected as they lack export value per se. The short and medium grained aromatic rice varieties are generally low yielders, susceptible to lodging, pest and diseases. Due to quest for high yielding varieties, a large number of these aromatic rice varieties slowly vanished from the farmer's field.

In order to formulate efficient breeding strategies for utilization of this untapped gene pool in further rice improvement, hybrid rice *per se*, it is essential to characterise the nature and mode of gene action that determines the yield and its components. A sound breeding methodology rests on a proper understanding of the gene effects involved (Kumar *et al.*, 2012).

The combining ability studies of the parents and their crosses facilitate breeder to formulate breeding strategies and selection of desirable parents and thus precise improvement. Success of any plant breeding programme depends on the choice of right type of genotypes as parents in the hybridization programme. Combining ability analysis provides information on two components of variance viz., additive and dominance variance. Its role is important to decide parents, crosses and adoption of appropriate breeding procedures to be followed to select desirable segregants (Salgotra *et al.*, 2009). Therefore, the present investigation was undertaken to select right type of aromatic rice land races as parents in the hybridization programme (Kumar *et al.*, 2012).

Materials and Methods

The material comprised of 13 rice genotypes (three CMS, used as tester; and 10 breeding line/landraces as line) namely IR 58025A, CRMS31A, CRMS 32A, IET 21842, Tulsimongra, Bisni, Gopalbhog, Badshabhog, Govindphool, Tenduphool, Bhatamahsuri, Kumbhdev and Chhinguchhi were crossed in Line x Tester fashion during Rabi 2015.DuringKharif2015season, Altogether 43 entries (30 crosses and 13 parents) along with one standard hybrid check of the same duration, US 314 were grown in a randomised block design with three replications at the Research and Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh and Research Farm of National Rice Research Institute (NRRI), Cuttack, Odisha (India). Single seedling hill^{-1} was transplanted at a spacing of 20 cm x 15 cm. The F_1's and parents were planted in a two row plot of 2 meter length. Data were collected from 5 randomly selected competitive plants, leaving border row of each genotype (Dhaliwal and Sharma, 1990). Observations were recorded on 28 characters *viz*., days to 50% flowering (DF), plant height (PH), panicle length (PL), number of panicles plant^{-1} (PN), grain number panicle^{-1} (GP), pollen fertility (PF), spikelets fertility (SF), 1000-grain weight (TW), grain yield plant^{-1} (GY), biological yield plant^{-1} (BY), harvest index (HI), hulling % (HUL), milling% (ML), head rice recovery (HRR), paddy length (PDL), paddy breadth (PDB), paddy L/B ratio (PDLB), brown rice length (BRL), brown rice breadth (BRB), brown rice L/B ratio (BRLB), kernel length (KL), kernel breadth (KB), kernel L/B ratio (LBR), kernel length after cooking (KLAC), kernel breadth after cooking (KBAC), cooked rice L/B ratio (KLBAC), elongation ratio (ER) and alkali spreading value (ASV). Combining ability analysis was carried out by the method suggested by Kempthorne (1957).

Results and Discussion

Results of the ANOVA for combining ability (Table 1) revealed that mean square due to general combining ability (*gca*) was highly significant for all characters except ML. Mean squares due to specific combining ability (*sca*) were also significant for all the characters.

This suggests the predominance of both additive (non inter-allelic) and non-additive (inter-allelic) gene effects/interaction in the materials under study.

The study also showed that the magnitude of *gca*variances were greater than *sca* variances for DF, PH, GP, PF, TW, GY, BY, HI, HUL, HRR, PDL, PDB, PDLB, BRB, BRLB, KL and ER, while for rest of the characters the magnitude of *sca* variance was greater.

Hence approach like transgressive breeding, doubled haploid breeding, genetic diversification that facilitates simultaneous exploitation of additive and non-additive gene effects would be most facilitated and which provides most precise way for the improvement of these traits.

The estimates of *sca* effect and *gca: sca* ratio (Table 2) indicate non additive gene effect controlling most of the characters except PH, PL and KB.

Although the mean square for *gca* (additive genetic variance) was significant, the dominant component was preponderant for all the characters except for PH, PL and KB.

Occurrence of both additive and non-additive gene effects with preponderance of non-additive gene action for yield and important yield components in rice were reported by several scientists like Peng and Virmani (1990), Manuel and Prasad (1992), Sharma *et al.*, (1996), Ganesan *et al.*, (1997) and Vanaja *et al.*, (2003).

General combining ability effects

The genotype IET 21842 was found to be a good general combiner for, PL, GP, PF, SF, TW, GY, HUL, MIL, HRR, PDL, PDB, PDLB, BRL, BRB, KL, KB, KLB, KLAC and KBAC (Table 2). Apart from IET 21842, other good general combiners for different characters were Tenduphool for PL, TW, BY, HI, PDL, PDB, PDLB, BRL, BRB, BRLB, KL, KB, KLB, KLAC, KBAC, KLBAC, ER and ASV; Tulsimongra for PH, PF, SF, TW, GY, HI, HUL, PDL, BRB, KL, KLAC, KBAC, and ASV; Kumbhdev for DF, NP, PF, SF, TW, BY, HUL, MIL, HRR, PDB, BRB and KBAC; Bhatamahsuri for NP, GP, HUL, MIL, PDL, PDLB, BRL, BRLB, KL, KLB, KLAC, KLBAC and ASV;C for PH and Chhinguchhi for DF, GP, PF, GY, HI, PDLB, BRL, BRLB, KLB, KLBAC, ER and ASV; W and UPR 3003-11-1-1 for DF, PH, FL, GP, GY, HI, KL, LBR and AS.

Specific combining ability

Altogether 13 crosses out of thirty generated were exhibited significant positive SCA effect (predominance of non-additive, inter-allelic interaction) (Table 3) indicated the preponderance of non-additive gene and their involvement in expression of yield and in attributing traits (Mirarab, 2011; Ghara *et al.*, 2014; Pratap *et al.*, 2013; Malik and Singh 2013). Among these hybrids all 11 have at least one parent with positive *gca* effect, while 3 hybrids have both parents with positive *gca* effect (Table 3). The hybrid IR58025A x Tulsimongra and CRMS32A x Gopalbhog showed significant favourable *sca* effects for 15 yield components (Table 4).

Table.1 Analysis of variance for general combining ability (*gca*) and specific combining ability (*sca*) for different characters

Sl. No.	Source of Variation	d.f.	Mean sum of squares														
			Days to 50% flowering (Days)	Plant height (cm)	Number of effective tillers per plant (no.)	Panicle length (cm)	Number of grains per panicle (no.)	Spikelet fertility (%)	Pollen Fertility %	Test or 1000-seed weight (g)	Grain yield per plant (g)	Biological Yield/P (g)	HI%	Hulling %	Milling%	Head rice recovery (%)	Paddy length (mm)
1.	GCA	11	113.36**	1048.91**	23.04**	0.025**	2.62**	12.05**	1357.78**	13.32**	279.68**	892.09**	72.31**	0.35**	0.009	0.19**	1.47**
2.	SCA	29	31.30**	282.23**	24.11**	0.02**	3.15**	46.88**	583.45**	3.47*	199.36**	1196.71**	32.08**	0.24**	0.012**	0.13**	0.60**
3.	Error	105	5.84	19.97	8.11	0.007	0.80	1.56	30.46	2.24	0.78	6.98	0.98	0.07	0.005	0.064	0.14
4.	GCA/SCA		3.62	3.72	0.96	1.25	0.83	0.26	2.33	3.83	1.40	0.75	2.25	1.47	0.75	1.44	2.45

* and ** Significant at 5 and 1 per cent probability levels, respectively

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Sl. No.	Source of Variation	d.f.	Mean sum of squares												
			Paddy breadth (mm)	Paddy L/B ratio	Brown rice length (mm)	brown rice breadth (mm)	Brown rice L/B ration	Kernel length (mm)	Kernel breadth (mm)	Kernel length/ breadth ratio	Kernel length after cooking (mm)	Kernel breadth after cooking (mm)	Kernel L/B ratio	Elongation ratio	Alkali spreading value
1.	GCA	11	0.25**	230.25**	10.26**	103.32**	1008.02**	123.04**	0.15**	22.62**	312.05**	157.78**	213.32**	1279.68**	89.09**
2.	SCA	29	0.18**	16.45**	33.45**	41.30**	232.13**	20.11**	0.42**	33.15**	416.88**	283.45**	303.47*	1099.36**	119.71**
3.	Error	105	0.08	1.28	0.86	5.14	12.6	6.25	0.002	1.80	11.56	20.46	12.24	12.78	6.9
4.	GCA/SCA		2.52	3.04	4.20	3.62	4.06	0.96	1.02	0.23	4.26	2.14	4.83	8.40	1.75

*, ** significant at 5% and 1% probability level

Table.2 Estimate of general combining ability (*gca*) effect of parents for various characters

Sl. No.	Components of genetic variance	DFF	PH (cm)	Number of eff. Tillers/plant	Panicle length (cm)	Number of grains /panicle	Spikelet fertility (%)	Pollen Fertility %	TW(g)	Grain yield /plant	Biological Yield/P	HI%
1	IR58025A	-16.53**	-2.64	2.97**	-2.64	6.06**	-23.12**	-26.05**	-10.63**	-0.53**	-10.80	0.036
2	CRMS31A	-23.73**	-3.34	4.34**	-3.34	3.63*	7.20*	4.45	-5.28**	6.04**	-4.46	0.031
3	CRMS32A	15.37**	0.05	-.69**	0.05	-0.61	24.10**	24.16**	-3.79**	4.62**	-34.30**	0.019
4	IET-21842	16.63**	0.02	-0.59**	0.02	0.88	5.19	15.01*	5.46**	3.49**	-35.46**	-0.11
5	Tulsimongra	6.13**	-1.54	-1.52**	-1.54	-0.93	15.86**	15.33*	5.12**	1.78**	-41.63**	0.026
6	Bisni	-11.69**	-0.94	-1.76**	-0.94	1.04	20.31**	5.69	1.90**	-0.15	11.36	0.12**
7	Gopalbhog	7.17**	2.98	-0.92**	2.98	-0.11	-22.91**	1.20	2.36**	-4.94**	55.20**	-0.11**
8	Badshabhog	2.63**	3.22	-0.89**	3.22	-3.63	-7.53*	-9.12	0.71**	-2.39**	16.03**	0.10**
9	Govindphool	4.83**	1.32	-0.19	1.32	-4.29*	-12.88**	-21.05**	3.14**	-3.63**	6.86	-0.03
10	Tenduphool	-0.83	0.88	-0.72**	0.88	-0.34	-6.21	-9.64	0.99**	-4.29**	37.20**	0.081**
11	Kumbhdev	-0.65	-0.93	0.63**	0.93	-0.47	1.90	0.55	3.00**	-0.34**	4.91	-0.01
12	Bhatamasuri	2.93**	1.04	0.18	-1.04	5.46*	-0.74	-5.76	-1.14**	-0.47**	-3.88	-0.02
13	Chhindguchi	-2.28**	-0.11	-0.81**	-0.11	5.12*	-1.16	5.20	-1.85**	0.81**	-1.03	0.19**
	SE (gi)	0.51	5.19	0.09	3.8	1.90	2.42	5.53	0.13	0.10	5.39	0.017
	S E (gi-gj)	0.73	7.34	0.13	5.23	2.36	3.42	7.82	0.19	0.14	7.63	0.025

* and ** Significant at 5 and 1 per cent probability levels, respectively

Contd.....

Sl. No.	Components of genetic variance	Hulling %	Milling%	HRR (%)	Paddy length (mm)	Paddy bredth (mm)	Paddy L/B ratio	Brown rice length (mm)	Brown rice breadth (mm)
1	IR58025A	6.62**	15.90**	8.01**	0.51**	-0.18	0.56**	0.58**	-0.18*
2	CRMS31A	3.64**	11.60**	9.28**	0.69**	-0.17	0.64**	0.68**	-0.17*
3	CRMS32A	-0.69	-6.31**	-4.68**	-1.85**	-0.009	-0.93**	-1.02**	-0.009
4	IET-21842	7.32**	8.23**	8.58**	0.58**	0.16	0.03	0.06**	0.16*
5	Tulsimongra	0.90	-1.89**	-0.016	0.63**	0.20	-0.01	0.008	0.20**
6	Bisni	3.64**	10.93***	7.65**	-0.99**	0.13	-0.67**	-0.71**	0.13
7	Gopalbhog	-3.44**	-16.57**	-13.01**	-0.14**	-0.04	0.007	0.0029	-0.04
8	Badshabhog	-7.11**	-8.54**	-6.40**	-0.39**	0.01	-0.18**	-0.20**	0.01
9	Govindphool	-5.51**	-0.67**	0.48**	-0.62**	-0.11	-0.13**	-0.17**	-0.11
10	Tenduphool	-5.37**	-12.67**	-9.89**	1.59**	0.02	0.69**	0.76**	0.023
11	Kumbhdev	0.005	0.32**	0.99**	-0.17**	0.07	-0.18**	-0.18**	0.076**
12	Bhatamasuri	1.02**	0.51**	-0.36**	0.18**	-0.005	0.08**	0.08**	-0.005
13	Chhindguchi	-1.02**	-0.84**	-0.63**	-0.012	-0.07	0.09**	0.09**	-0.07**
	SE (gi)	0.37	0.054	0.032	0.025	1.08	0.013	0.016	0.004
	S E (gi-gj)	0.53	0.077	0.054	0.048	1.16	0.019	0.023	0.075

* and ** Significant at 5 and 1 per cent probability levels, respectively

Contd.....

Sl. No.	Components of genetic variance	Brown rice L/B ratio	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio	KLAC	KBAC	K L/B AC	ER	ASV
1	IR58025A	0.51**	0.51**	-0.18	0.70**	0.57**	-0.32**	0.48**	-0.007	-2.06**
2	CRMS31A	0.57**	0.69**	-0.17	0.81**	1.55**	-0.31**	0.87**	0.12**	-0.23**
3	CRMS32A	-0.72**	-1.85**	-0.009	-1.19**	-2.33**	-0.01*	-0.88**	0.003	0.37**
4	IET-21842	-0.03	0.58**	0.16	0.06**	0.51**	0.28**	-0.03**	-0.04**	-1.39**
5	Tulsimongra	-0.09	0.63**	0.20	-0.009	0.84**	0.36**	-0.005	0.003	1.27**
6	Bisni	-0.55**	-0.99**	0.13	-0.82**	-1.48**	0.23**	-0.69**	-0.05**	-0.89**
7	Gopalbhog	0.02	-0.14**	-0.04	0.008	-0.21**	-0.08**	-0.007	-0.01*	0.10**
8	Badshabhog	-0.12	-0.39**	0.01	-0.22**	-0.63**	0.01*	-0.20**	-0.02**	-0.06**
9	Govindphool	-0.06	-0.62**	-0.11	-0.19**	-0.79**	-0.20**	-0.14**	-0.003	0.93**
10	Tenduphool	0.48**	1.59**	0.02	0.87**	1.96**	0.04**	0.61**	0.001	1.97**
11	Kumbhdev	-0.15	-0.17**	0.076	-0.21**	-0.19**	0.13**	-0.14**	0.001	-0.27**
12	Bhatamasuri	0.05	0.18**	-0.005	0.09**	0.20**	-0.009**	0.05**	-0.01**	0.23**
13	Chhindguchi	0.09	-0.012**	-0.07	0.11**	-0.008	-0.12**	0.08**	0.009**	0.03**
	SE (gi)	0.075	0.002	0.13	0.012	0.0051	0.002	0.007	0.0028	0.0012
	S E (gi-gj)	0.10	0.012	0.41	0.017	0.006	0.0038	0.010	0.004	0.002

*, ** significant at 5% and 1% probability level

Table.3 Estimate of specific combining ability (*sca*) effect for different characters

Sl. No.	Crosses	DFF	PH (cm)	Number of eff. tillers /plant	Panicle length (cm)	Number of grains /panicle (no.)	SF (%)	Pollen Fertility %	TW	Grain yield /plant	Biological Yield/P (g)
1	IR58025A X IET-21842	2.22*	0.06	-1.23**	0.06	0.035	-31.90**	-32.47**	-8.12**	-5.35**	-13.25
2	CRMS31A X IET-21842	-0.27	-1.31	0.81**	-1.31	0.006	60.74**	69.59**	11.69**	11.81**	8.05
3	CRMS32A X IET-21842	-1.95*	1.24	0.41**	1.24	-0.04	-28.84**	-37.12**	-3.57**	-6.45**	5.20
4	IR58025A X Tulsimongra	2.42**	0.26	-1.20**	0.26	0.02	28.26**	30.20**	2.38**	6.01**	-7.08
5	CRMS31A X Tulsimongra	-3.37**	-1.11	-0.05	-1.11	-0.001	-59.59**	-56.66**	-9.28**	-11.80**	2.21
6	CRMS32A X Tulsimongra	0.95	0.84	1.25**	0.84	-0.019	31.32**	26.45**	6.89**	5.79**	4.86
7	IR58025A X BISNI	-42.18**	-3.03	1.03**	-3.03	0.15	-4.85	3.17	-2.50**	2.85**	-16.75
8	CRMS31A X BISNI	16.93**	1.08	0.18	1.08	0.011	11.57**	9.63	0.57*	-1.75*	17.05
9	CRMS32A X BISNI	25.25**	1.94	-1.21**	1.98	-0.16	-6.72	-12.80	1.92**	-1.10**	-0.30
10	IR58025A X Gopalbhog	3.85**	-1.50	0.13	-1.50	0.04	-20.15**	-10.41	11.12**	-1.93**	-18.08
11	CRMS31A X Gopalbhog	-17.73**	-1.38	1.38**	-1.38	-0.003	6.98	7.83	-5.05**	0.43	41.21**
12	CRMS32A X Gopalbhog	13.88**	2.88	-1.51**	2.88	-0.04	13.17**	2.58	-6.07**	1.49*	-23.13*
13	IR58025A X Badshabhog	5.65**	-0.43	-0.03	-0.43	0.006	10.58**	9.47	1.44**	-1.08*	8.08
14	CRMS31A X Badshabhog	12.26**	0.78	-0.08	0.78	-2.11	-14.69**	-12.84	0.83**	-2.11**	6.88
15	CRMS32A X Badshabhog	-17.91**	-0.35	0.11	-0.35	3.20	4.10	3.36	-2.27**	3.20**	-14.96
16	IR58025A X Govindphool	9.98**	-2.73	-0.4*	-2.73	-0.12	9.75*	26.96**	-1.10**	-0.12	25.08**
17	CRMS31A X Govindphool	-8.60**	0.66	-0.35*	0.68	3.19**	7.55	0.34	0.89**	3.19**	-21.11*
18	CRMS32A X Govindphool	-1.38	2.04	0.75**	2.04	-3.06**	-17.31**	-27.31**	0.20	-3.06**	-3.96
19	IR58025A X Tenduphool	-16.68**	0.93	-0.53**	0.93	0.56**	10.44*	-20.57*	1.66**	0.56**	-11.25
20	CRMS 31A X Tenduphool	7.73**	-0.34	0.21	-0.34	0.69**	-5.54	-27.58**	-1.52**	0.69**	-27.45**
21	CRMS 32A X Tenduphool	8.95**	-0.58	0.31*	-0.58	-1.26**	-4.90	48.16**	-0.14	-1.26*	38.70**
22	IR58025A X Kumbhdev	20.25**	3.10	1.03**	3.10	-2.23**	-16.39**	-15.47	3.36**	-2.23**	27.91**
23	CRMS31A X Kumbhdev	4.56**	1.72	-1.01**	1.72	-1.55**	-3.96	0.33	-1.55**	-1.55*	-3.28
24	CRMS32A X Kumbhdev	-24.81**	-4.82	-0.01	-4.82	3.8**	20.36**	15.13	-1.80**	3.79**	-24.63**
25	IR58025A X Bhatamasuri	11.75**	4.90	0.83**	4.90	0.015	-3.19	6.60	-3.85**	0.05	13.58
26	CRMS31A X Bhatamasuri	-7.63**	-1.98	-1.11**	-1.98	0.75**	3.41	3.41	1.37**	0.72**	-19.11*
27	CRMS32A X Bhatamasuri	-4.11**	-2.92	0.28	-2.92	-0.76**	-0.22	-10.01	2.48**	-0.78**	5.53
28	IR58025A X Chhindguchi	2.72**	-1.56	0.36*	-1.56	1.25**	17.44**	2.51	-4.39**	1.24*	-8.25
29	CRMS31A X Chindguchi	3.87**	1.85	0.01	1.85	0.371*	-6.47	5.92	2.03**	0.37*	-4.45
30	CRMS32A X Chindguchi	1.15	-0.28	-0.38*	-0.28	-1.63**	-10.97**	-8.44	2.35**	-1.61*	12.70
	SE (sij)	0.89	8.99	0.16	7.90	0.182	4.20	9.58	0.23	0.18	9.35

*** and ** Significant at 5 and 1 per cent probability levels, respectively**

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Sl. No.	Crosses	HI%	Hulling %	Milling%	HRR(%)	Paddy length (mm)	Paddy L/B ratio	Brown rice length (mm)	Brown rice breadth (mm)	Brown rice L/B ratio	Kernel length (mm)	Kernel breadth (mm)
1	IR58025A X IET-21842	0.035	1.24	0.84**	-0.73	0.13	0.24**	0.24	-0.11*	0.23	0.15**	-0.11
2	CRMS31A X IET-21842	0.006	3.12**	4.95**	2.34**	-0.12	-0.18**	-0.18	0.072	-0.18	-0.12**	0.07
3	CRMS32A X IET-21842	-0.04	-4.37**	-5.79**	-1.59**	-0.014	-0.06**	-0.06	0.047	-0.05	-0.01	0.04
4	IR58025A X Tulsimongra	0.02	2.07**	1.34**	1.00**	0.27	0.21**	0.21	-0.06	0.17	0.27**	-0.06
5	CRMS31A X Tulsimongra	-0.001	-2.94**	-2.84**	-3.13**	-0.30	-0.04**	-0.04	-0.04	0.010	-0.30**	-0.04
6	CRMS32A X Tulsimongra	-0.01	0.86	1.50**	2.13**	0.032	-0.17**	-0.16	0.11*	-0.18	0.32**	0.11
7	IR58025A X BISNI	0.15**	-6.61**	3.36**	4.66**	0.54*	0.09**	0.14	0.15**	0.04	0.54**	0.15
8	CRMS31A X BISNI	0.011	-4.14**	3.34**	3.02**	-0.70**	0.09**	0.01	-0.35**	0.15	-0.70**	-0.35
9	CRMS32A X BISNI	-0.16**	10.76**	-6.70**	-7.69**	0.16	-0.18**	-0.15	0.20**	-0.19	0.16**	0.20
10	IR58025A X Gopalbhog	0.04	-14.84**	-14.68**	-9.83**	0.44*	0.19**	0.20	-0.03	0.12	0.44**	-0.03
11	CRMS31A X Gopalbhog	-0.03	2.32**	-11.47**	22.43**	-1.86**	-1.04**	-1.11**	0.14**	-0.80**	-1.86**	0.14
12	CRMS32A X Gopalbhog	-0.04	12.51**	26.16**	6.60**	1.42**	0.85**	0.91**	-0.10	0.67**	1.42**	-0.10
13	IR58025A X Badshabhog	0.006*	5.65**	5.84**	5.96**	-0.97**	-0.77**	-0.79**	0.31**	-0.61**	-0.97**	0.31
14	CRMS31A X Badshabhog	-0.16**	16.33**	8.80**	-12.59**	2.64**	1.11**	1.22**	0.01	0.76**	2.94**	0.01
15	CRMS32A X Badshabhog	0.15**	-21.99**	-14.64**	-0.065	-1.66**	-0.34**	-0.43**	-0.33**	-0.15	-1.68**	-0.33
16	IR58025A X Govindphool	-0.13**	2.07**	1.91**	-0.30	0.39	0.39**	0.40**	-0.19**	0.33*	0.39**	0.01
17	CRMS31A X Govindphool	0.26**	-3.42**	-1.14**	0.36	-0.47*	-0.53**	-0.53**	0.29**	-0.44**	-0.47**	-0.33
18	CRMS32A X Govindphool	-0.13**	1.34*	-0.76**	-1.39**	0.08	0.13**	0.12	-0.10	0.10	0.08*	-0.19
19	IR58025A X Tenduphool	0.015	4.35**	-2.17**	5.36**	1.31**	0.95**	1.01**	-0.19**	0.81**	1.33**	0.29
20	CRMS 31A X Tenduphool	0.023	2.77**	5.72**	-3.96**	-0.43	-0.08**	-0.11	-0.09*	-0.03	-0.43**	-0.10
21	CRMS 32A X Tenduphool	-0.038	-7.13**	-3.55**	-4.10**	-0.87**	-0.87**	-0.90**	0.29**	-0.77**	-0.87**	-0.19
22	IR58025A X Kumbhdev	-0.20**	8.41**	-4.63**	-5.32**	-0.06	-0.29**	-0.30*	0.15**	-0.30*	-0.06	-0.09
23	CRMS31A X Kumbhdev	-0.16**	-7.23**	-9.39**	9.42**	-0.25	-0.34**	-0.35**	0.12**	-0.33**	-0.25**	0.29
24	CRMS32A X Kumbhdev	0.36**	-1.17	14.03**	-1.29**	0.32	0.64**	0.65**	-0.27**	0.64**	0.32**	0.15
25	IR58025A X Bhatamasuri	-0.001	-0.55	-2.79**	0.86*	-0.52*	-0.48**	-0.50**	0.13**	-0.43**	-0.52**	0.12
26	CRMS31A X Bhatamasuri	0.03	-2.14**	3.71**	0.43	-0.47*	0.11**	-0.018	-0.15**	0.07	-0.47**	-0.27
27	CRMS32A X Bhatamasuri	-0.02	2.70**	-0.92**	7.92**	0.99**	0.47**	0.52**	0.02	0.35**	0.99**	0.13
28	IR58025A X Chhindguchi	0.056	-1.80**	10.99**	1.05**	-1.53**	-0.55**	-0.63**	-0.13**	-0.37**	-1.53**	-0.15
29	CRMS31A X Chindguchi	0.006*	-4.67**	-1.68**	-8.98**	2.00**	1.02**	1.12**	-0.007	0.78**	2.10**	0.02
30	CRMS32A X Chindguchi	-0.056	6.48**	9.30**	0.086	-0.47*	-0.46**	-0.49**	0.14**	-0.41**	-0.47**	-0.13
	SE (sij)	0.031	0.65	0.094	0.38	0.24	0.023	0.028	0.006	0.13	0.042	0.46

* and ** Significant at 5 and 1 per cent probability levels, respectively

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Sl. No.	Crosses		Kernel L/B ratio	KLAC	KBAC	K L/B AC	ER	ASV
1	IR58025A X IET-21842	7	0.33**	-0.21**	-0.20**	0.06**	-0.06*	0.27**
2	CRMS31A X IET-21842	11	-0.22**	0.26**	0.12**	-0.0015	0.08**	-0.23**
3	CRMS32A X IET-21842	2	-0.07**	-0.04**	0.08**	-0.058**	-0.01	-0.03
4	IR58025A X Tulsimongra	15	0.25**	1.30**	-0.11**	0.57**	0.16**	0.44**
5	CRMS31A X Tulsimongra	1	-0.04*	-0.72**	-0.07**	-0.16**	-0.05*	1.43**
6	CRMS32A X Tulsimongra	10	-0.21**	-0.57**	0.19**	-0.40**	-0.11**	-1.83**
7	IR58025A X BISNI	14	0.16**	0.52**	0.26**	0.06**	-0.04	1.14**
8	CRMS31A X BISNI	6	0.02	-1.02**	-0.62**	-0.03*	-0.05*	-1.17**
9	CRMS32A X BISNI	8	-0.18**	0.50**	0.35**	-0.02	0.09**	0.03
10	IR58025A X Gopalbhog	8	0.22**	0.72**	-0.06**	0.21**	0.03	-0.39**
11	CRMS31A X Gopalbhog	7	-1.27**	-2.34**	0.25**	-0.92**	-0.01	0.09*
12	CRMS32A X Gopalbhog	15	1.05**	1.61**	-0.19**	0.71**	-0.02	0.29**
13	IR58025A X Badshabhog	9	-0.90**	-1.28**	0.55**	-0.68**	0.003	-1.56**
14	CRMS31A X Badshabhog	13	1.38**	3.57**	0.03**	1.09**	0.04	-0.07
15	CRMS32A X Badshabhog	3	-0.48**	-2.29**	-0.58**	-0.41**	-0.04	1.63**
16	IR58025A X Govindphool	15	0.46**	0.49**	-0.33**	0.32**	0.004	3.60**
17	CRMS31A X Govindphool	6	-0.60**	-0.68**	0.52**	-0.45**	0.008	-1.40**
18	CRMS32A X Govindphool	7	0.14**	0.19**	-0.18**	0.12**	-0.02	-2.20**
19	IR58025A X Tenduphool	14	1.19**	1.58**	-0.34**	0.85**	0.01	-2.89**
20	CRMS 31A X Tenduphool	6	-0.12**	-0.47**	-0.17**	-0.05**	-0.009	2.09**
21	CRMS 32A X Tenduphool	7	-1.06**	-1.10**	0.52**	-0.79**	0.01	0.79**
22	IR58025A X Kumbhdev	8	-0.36**	-0.26**	0.26**	-0.34**	-0.01	0.27**
23	CRMS31A X Kumbhdev	4	-0.42**	-0.36**	0.21**	-0.33**	-0.04	-0.23**
24	CRMS32A X Kumbhdev	12	0.79**	0.61**	-0.48**	0.67**	0.009	-0.03
25	IR58025A X Bhatamasuri	5	-0.59**	-0.80**	0.22**	-0.49**	0.04	-0.72**
26	CRMS31A X Bhatamasuri	5	-0.006	-0.61**	-0.27**	-0.01	-0.03	-0.23**
27	CRMS32A X Bhatamasuri	13	0.60**	1.41**	0.04**	0.51**	0.002	0.96**
28	IR58025A X Chhindguchi	8	-0.71**	-2.05**	0.24**	-0.57**	0.02	-0.16**
29	CRMS31A X Chindguchi	13	1.29**	2.37**	-0.01*	0.89**	-0.011	-0.27**
30	CRMS32A X Chindguchi	6	-0.57**	-0.31**	0.25**	-0.32**	0.03	0.43**
	SE (sij)		0.021	0.0056	0.0042	0.013	0.024	0.042

* and ** Significant at 5 and 1 per cent probability levels, respectively

DF- Days to 50 % flowering, PH- Plant height, PL- Panicle length, PN- Number of panicles plant^{-1}, GP- Grain number panicle^{-1}, TW- 1000 grain weight, GY- Grain yield plant^{-1}, BY- Biological yield plant^{-1}, HI- Harvest index, KL- Kernel length, KB- Kernel breadth, LBR- Kernel L/B ratio, PF-pollen fertility%, SF-spikelets fertility%, HUL-hulling%, MIL-milling%, HRR-head rice recovery%, PDL-paddy length, PDB-paddy breadth, PDLB-paddy l/b ratio, BRL-brown rice length, BRB-brown rice breadth, BRLB-brown rice L/B ratio, ASV-alkali spreading value, ER-elongation ration etc.

Table.4 Three of the top parents, F_1's, general combiners and specific combiners for yield, yield contributing and quality characters

S. No.	Characters	Parent*	F_1's*	General Combiner	Specific Combiner
1	**Days to 50% flowering**	IR 58025A, CRMS 31A, Kumbhdev	IR58025A X Chhindguchi, IR58025A X Gopalbhog, IR58025A X IET-21842	IET-21842, Tulsimongra CRMS32A	**IR58025A X Bisni, CRMS32A X Badshabhog, CRMS32A X Kumbhdev**
2	**Plant height (cm)**	CRMS 31A, CRMS 32A, IR 58025A	CRMS32A X Tulsimongra, IR58025A X Tulsimongra, IR58025A X Kumbhdev	Badshabhog, Gopalbhog, Govindphool	**IR58025A X Bisni, CRMS32A X Kumbhdev, IR58025A X Govindphool**
3	**Panicle length (cm)**	Govindphool, Tulsimongra, Bisni	IR58025A X BISNI, CRMS32A X Tulsimongra, CRMS32A X BISNI	Badshabhog, Gopalbhog, Govindphool	**CRMS32A X Kumbhdev, CRMS32A X Tulsimongra, IR58025A X Bisni**
4	**Number of panicles plant^{-1}**	CRMS 32A, CRMS 31A, IR 58025A	CRMS32A X BISNI, CRMS32A X Tulsimongra, IR58025A X Kumbhdev	CRMS 31A, IR 58025A, Kumbhdev	**IR58025A X Bhatamahsuri, IR58025A X Kumbhdev, CRMS32A X Gopalbhog**
5	**Grain number panicle^{-1}**	Govindphool, CRMS31A, Tenduphool	IR58025A X Tulsimongra, CRMS 32A X Tenduphool, IR58025A X Kumbhdev	IR 58025A, Bhatamahsuri, Chhinguchhi	**CRMS32A X Kumbhdev, CRMS32A X Badshabhog, CRMS31A X Govindphool**
6	**Spikelets fertility %**	Tulsimongra, Chhindguchi, Tenduphool	IR58025A X IET-21842, CRMS32A X Kumbhdev, CRMS32A X Gopalbhog	CRMS 32A, Bisni, Tulsimongra	**CRMS31A X IET-21842, CRMS32A X Tulsimongra, CRMS32A X IET-21842**
7	**Pollen fertility%**	IET-21842 (R 1536-136-1-77-1), Tulsimongra, Tenduphool	IR58025A X Bhatamasuri, IR58025A X Tenduphool, CRMS 31A X Tenduphool	CRMS 32A, IET 21842, Tulsimongra	**CRMS31A X IET-21842, CRMS 32A X Tenduphool, IR58025A X Tulsimongra**
8	**1000-grain weight (g)**	**Gopalbhog, Tenduphool, Kumbhdev**	**CRMS31A X Govindphool, CRMS31A X Govindphool, CRMS 31A X Tenduphool**	**IET 21842, Tulsimongra Govindphool**	**CRMS31A X IET-21842, IR58025A X Gopalbhog, CRMS32A X Tulsimongra**

* Based on *per se* performance

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S. No.	Characters	Parent*	F_1's*	General Combiner	Specific Combiner
9	Grain yield plant^{-1} (g)	Bisni, IET-21842 (R 1536-136-1-77-1), Govindphool	IR58025A X IET-21842, CRMS31A X Chindguchi, IR58025A X Bhatamasuri	CRMS 31A, CRMS 32A, IET 21842	**CRMS31A X IET-21842, CRMS32A X Tulsimongra, IR58025A X Tulsimongra**
10	Biological yield plant^{-1} (g)	Chhinguchhi, Badshabhog, CRMS32A	CRMS31A X Govindphool, CRMS32A X IET-21842, CRMS31A X Badshabhog	Gopalbhog, Badshabhog, Tenduphool	**CRMS31A X Gopalbhog, CRMS 32A X Tenduphool, IR58025A X Kumbhdev**
11	Harvest index (%)	Bhatamahsuri, IET-21842 (R 1536-136-1-77-1), IR58025A	IR58025A X IET-21842, IR58025A X Bhatamasuri, CRMS32A X Kumbhdev	Chhinguchhi, Bisni, Badshabhog	**CRMS32A X Kumbhdev, CRMS31A X Govindphool, CRMS32A X Badshabhog**
12	Hulling%	Bisni, Govindphool, Kumbhdev	CRMS31A X IET-21842, CRMS32A X Chindguchi, CRMS 32A X Tenduphool	IET 21842, Bisni, Bhatamahsuri	**CRMS31A X Badshabhog, CRMS32A X Gopalbhog, CRMS32A X BISNI**
13	Milling%	Govindphool, IR58025A, Chhinguchhi	CRMS 32A X Tenduphool, CRMS 31A X Tenduphool, CRMS32A X Chindguchi	IR 58025A, CRMS 31A, Bisni	**CRMS32A X Gopalbhog, CRMS32A X Kumbhdev, IR58025A X Chhindguchi**
14	HRR%	Govindphool, IR58025A, Tenduphool	CRMS 31A X Tenduphool, IR58025A X IET-21842, CRMS31A X IET-21842	IR 58025A, CRMS 31A, IET 21842	**CRMS31A X Gopalbhog, CRMS31A X Kumbhdev, CRMS32A X Bhatamasuri**
15	Paddy length (mm)	Kumbhdev, Govindphool, Gopalbhog	IR58025A X Badshabhog, CRMS 32A X Tenduphool, CRMS31A X Badshabhog	Tenduphool, CRMS 31A, Tulasimongra	**CRMS31A X Badshabhog, CRMS31A X Chindguchi, CRMS32A X Gopalbhog**
16	Paddy L/B ratio (mm)	Kumbhdev, Govindphool, CRMS32A	IR58025A X Badshabhog, CRMS 32A X Tenduphool, CRMS32A X IET-21842	Tenduphool, CRMS 31A, IR 58025A	**CRMS31A X Badshabhog, CRMS31A X Chindguchi, IR58025A X Tenduphool**
17	Brown rice length (mm)	Kumbhdev, Govindphool, Gopalbhog	IR58025A X Badshabhog, CRMS 32A X Tenduphool, CRMS31A X Badshabhog	Tenduphool, CRMS 31A, IR 58025A	**CRMS31A X Badshabhog, CRMS31A X Chindguchi, IR58025A X Tenduphool**
18	Brown rice breadth (mm)	Tenduphool, Badshabhog, Kumbhdev	IR58025A X IET-21842, CRMS32A X Tulsimongra, CRMS32A X Badshabhog	Tulsimongra, IET 21842, Kumbhdev	**IR58025A X Badshabhog, CRMS31A X Govindphool, CRMS 32A X Tenduphool**

19	**Brown rice L/B ratio**	Kumbhdev, Govindphool, CRMS32A	CRMS 32A X Tenduphool, IR58025A X Govindphool, IR58025A X Badshabhog	Tenduphool, CRMS 31A, IR 58025A	**IR58025A X Tenduphool, CRMS31A X Chhinguchhi, CRMS31A X Badshabhog**
20	**Kernel length (mm)**	Kumbhdev, Govindphool, CRMS32A	CRMS31A X Badshabhog, IR58025A X Kumbhdev, IR58025A X Tulsimongra	Tenduphool, CRMS 31A, Tulsimongra	**CRMS31A X Badshabhog, CRMS31A X Chhinguchhi, CRMS32A X Gopalbhog**
21	**Kernel breadth (mm)**	Tenduphool, Badshabhog, Kumbhdev	IR58025A X IET-21842, CRMS32A X Tulsimongra, CRMS31A X Tulsimongra	Tulsimongra, IET 21842, Bisni	**IR58025A X Badshabhog, CRMS32A X Bisni, CRMS31A X Kumbhdev**
22	**Kernel L/B ratio**	Kumbhdev, Govindphool, CRMS32A	IR58025A X Badshabhog, CRMS 32A X Tenduphool, CRMS32A X IET-21842	Tenduphool, CRMS 31A, IR 58025A	**CRMS31A X Badshabhog, CRMS31A X Chhinguchhi, IR58025A X Tenduphool**
23	**KLAC (mm)**	Kumbhdev, Govindphool, CRMS32A	IR58025A X Badshabhog, CRMS 32A X Tenduphool, IR58025A X Govindphool	CRMS 31A, Tenduphool, Bisni	**CRMS31A X Badshabhog, CRMS31A X Chhinguchhi, IR58025A X Tenduphool**
24	**KBAC (mm)**	Tenduphool, IET-21842 (R 1536-136-1-77-1), Gopalbhog	IR58025A X IET-21842, CRMS32A X Tulsimongra, CRMS31A X Tulsimongra	Tulsimongra, IET 21842, Bisni	**IR58025A X Badshabhog, CRMS 32A X Tenduphool, CRMS31A X Govindphool**
25	**KL/B AC**	CRMS32A, Kumbhdev, Govindphool	IR58025A X Badshabhog, CRMS 32A X Tenduphool, IR58025A X Govindphool	CRMS 31A, IR 58025A, Tenduphool,	**CRMS31A X Badshabhog, CRMS31A X Chhinguchhi, IR58025A X Tenduphool**
26	**ER**	Bisni, CRMS32A, Kumbhdev	IR58025A X Govindphool, CRMS32A X Badshabhog, CRMS31A X Kumbhdev	CRMS 31A, Chhinguchhi Tulsimongra	**IR58025A X Tulsimongra, CRMS32A X Bisni, CRMS31A X IET-21842**
27	**ASV**	**Chhindguchi, Bhatamasuri, CRMS32A**	**IR58025A X Tulsimongra, IR58025A X Bhatamasuri, IR58025A X Badshabhog**	**Tenduphool, Tulsimongra, CRMS 32A**	**IR58025A X Govindphool, CRMS 31A X Tenduphool, CRMS32A X Badshabhog**

* Based on *per se* performance

The hybrids IR58025A X Bisni and IR58025A X Tenduphool showed significant favourable *sca* effects for 14 yield components; CRMS31A X Badshabhog, CRMS32A X Bhatamahsuri and CRMS31A X Chhinguchhi for thirteen yield components; CRMS32A X Kumbhdev for 12 yield components (Table 3).

The crosses CRMS 31AxIET 21842, CRMS 32A x Tulsimongra and CRMS 31A x Chhinguchhifor GY showing high *sca* effects were in the category of high x high general combiner cross combinations. This is attributable to additive and/or additive x additive type of gene effects which are fixable in nature (Singh *et al.*, 1971). Therefore, there is high probability of obtaining good transgressive segregants in the progeny of these crosses for improvement of this trait. On the other hand, CRMS 32A x Gopalbhog, CRMS 32A x Badshabhog and CRMS 32A x Kumbhdev displayed high *sca* effects for GY had common female parent with significant *gca* while male parent with non-significant *gca* respectively.

The case of high*sca* between high x poor combiners could produce good segregants only if the additive genetic effects are present in the good general combiners and complimentary epistatic effects in the poor combiners and they act in the same direction to maximise desirable plant attributes (Singh and Chaudhary, 1992).

The crosses with non-significant *sca* effect as exhibited by IR58025A X Bhatamahsuri, CRMS31A X Gopalbhog for GY are expected to produce desirable recombinants in advance generation of inbreeding (Devraj and Nadarajan, 1996, Borah, 2010). The crosses showed high *sca* effect while parents were poor x poor general combiners. This is believed to be due to epistatic gene action. In other hybrids also, all kinds of parental combinations like high x high, high x low, medium x medium and medium x low were found. These type of interactions, according to Dhaliwal and Sharma (1990), Katre and Jambhale (1996), Ramalingam *et al.*, (1997) and Vanaja *et al.*, (2003) attributed to either additive x additive and/or additive x dominance genetic interactions. Also they suggested that the superiority of these crosses may be due to complimentary and duplicate type of gene interactions. Therefore, these crosses are expected to produce desirable segregants and could be exploited successfully in varietal improvement programme.

The present study reveals importance of both additive and non-additive gene effects (Utharasu and Anandakumar, 2013; Tiwari 2014) in governing yield and yield attributes with preponderance of non-additive gene action. In this situation, where both non-additive and additive components were important for the expression of characters, especially when the former component is preponderant, simple pedigree method of selection would be ineffective for its improvement.

Population improvement programme like reciprocal recurrent selection which may allow to accumulate the fixable gene effects as well as to maintain considerable variability and heterozygocity for exploiting non-fixable gene effects will prove to be the most effective method (Joshi, 1979). However rice is the highly self-pollinated crop, forming single seed per pollination, this selection procedure not practicable. Three of the top parents, F_1's, general combiners and specific combiners for various characters based on *per se* performance of parents and F_1's are given in Table 4.

So possible choice is the use of biparental mating among selected crosses or use of selection procedure such as diallel selective mating (Jensen, 1970) to exploit both the additive and non-additive genetic components. The parent IET 21842, Tenduphool, Tulsimongraand Kumbhdev could be utilised in hybridization programme because of its good general combining ability for yield and its components. Hybrids namely IR58025A x Tulsimongra, CRMS32A x Gopalbhog, IR58025A X Bisni, IR58025A X Tenduphool, CRMS31A X Badshabhog, CRMS32A X Bhatamahsuri, CRMS31A X Chindguchi, CRMS32A X Kumbhdev, IR 58025A x Chhinguchhi, CRMS 31A x Tenduphool, CRMS 31A x Govindphool, CRMS 32A x Badshabhog, CRMS 32A x Tulsimongra and CRMS 31A x IET 21842could be utilised for development of high yielding basmati hybrids.

Hybrids namely IR58025A x Tulsimongra, CRMS32A x Gopalbhog, IR58025A X Bisni, IR58025A X Tenduphool, CRMS31A X Badshabhog, CRMS32A X Bhatamahsuri, CRMS31A X Chindguchi, CRMS32A X Kumbhdev, IR 58025A x Chhinguchhi, CRMS 31A x Tenduphool, CRMS 31A x Govindphool, CRMS 32A x Badshabhog, CRMS 32A x Tulsimongra and CRMS 31A x IET 21842 could be utilised for development of high yielding basmati hybrids.

Authors' Contribution

Conceptualization of research (MB, DS);Designing of the experiments (MB, DS, ONS, RLV); Contribution of experimental materials (DS);Execution of field/lab experiments and data collection (MB, RKL, DJ, NS); Analysis of data and interpretation (MB, RLV, DJ); Preparation of manuscript (MB, RLV).

Declaration

The authors declare no conflict of interest.

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