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Heterosis and Combining Ability in Aromatic Hybrid Rice (*Oryza sativa* L.)

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Abstract
Out of seventy two hybrids developed by 4 x 18 Line x Tester crossing programme in aromatic rice, carried out at Navsari Agriculture University, Navsari, 14.74 per cent standard heterosis was observed for grain yield plant^{-1} over aromatic hybrid check Pusa RH 10 in KJTCMS 6A x Pusa sugandh 4, followed by IR 58025A x Pusa sugandh 5 (13.79%) and IR 58025A x SKL 41-30 (10.79%). The range of standard heterosis over GR 104 was -34.37 per cent (RTN 17A/GR-104) to 35.02 per cent (IR 58025A/Pusa sugandh 5) and -44.23 per cent (RTN 17A/GR-104) to 14.74 per cent (IR 58025A/Pusa sugandh 5) over aromatic hybrid check Pusa RH 10. Among the hybrids with positive and significant SCA effects for grain yield, the frequency of good x good combiner was more. Regarding combination of parents among top three hybrids, it was found that, topmost hybrid KJTCMS 6A/Pusa sugandh 4 had combination of average x good parents and hybrids IR 58025A x Pusa sugandh 5 and IR 58025A x SKL 41-30 were having both the parents of good performance. Among top eight performing hybrids, three hybrids *viz.* KJTCMS 6A x Pusa sugandh 4 followed by IR 58025A x Pusa sugandh 5 and IR 58025A x SKL 41-30 exhibited significant favorable heterobeltotis, standard heterosis, GCA and SCA effects for yield and most of the related traits. Hence, these could be utilized for commercial cultivation after proper evaluation by means of multi-location trials.

Keywords: heterosis, combining ability, GCA, SCA, aromatic hybrid rice.

1. Introduction
Among the many genetic approaches being explored to break the yield barrier in rice production and productivity, hybrid rice technology is one of the potential option for increasing rice production and productivity. Hybrid rice technology has been widely acclaimed and accepted to enhance genetic potential. China produced an extra 22.5 m tons raw paddy by saving 4.0 m ha of land and 2.4 billion cubic meters of water through adoption of hybrid rice technology (Cheng *et al*, 2007)[3]. The cooking quality preferences vary within the country, within ethnic group and from country to country to another within different geographical regions (Juliano *et al*, 1964) [5]. The aroma of rice plays a role in its consumer acceptability and it draws a premium price in certain specialty markets. Considering the importance of better quality aromatic rice, scope exists for the export of japonica rice and short to medium slender aromaticrice. It is possible to develop hybrids of desirable grain quality with short to medium slender grains having better quality.
The present investigation was carried out to study the magnitude of heterosis, combining ability effects of aromatic/non aromatic hybrids along with standard checks.

2. Material and Methods
The experimental material comprised of four CMS lines, eighteen identified restorers both of aromatic and non-aromatic origin, seventy two F_1s obtained by L x T mating design along with two aromatic checks viz. GR-104 (variety check) and Pusa RH-10 (hybrid check). The experiment was conducted in Randomized block design, replicated thrice over three locations viz. Navsari, Bardoli and Vyara in Gujarat state during Kharif 2010 in a single row plot of thirty plants, planted at 20 x 15 cm. spacing. All the management practices including plant protection were followed as per recommendation. The observations were recorded on five randomly selected plants in each replication for ninety six treatments consisting of seventy two F_1 hybrids, four female parents, eighteen male parents and two checks on sixteen characters including yield. General combining ability and specific combining ability variances were estimated with method suggested by Kempthorne (1957) [6] for Line x Tester analysis.

3. Results and Discussion

Heterosis study

Commercial exploitation of heterosis in crop plant is regarded as one of the major breakthrough in the field of plant breeding. Heterosis study is considered to be an outstanding application of principles of genetics to agriculture. The scope of exploitation of hybrid vigour depends on directions and magnitude of heterosis and type of gene action involved. Therefore, in present investigation, heterosis was reported over better parent and standard checks GR 104 (aromatic variety check= SC-I), Pusa RH 10 (aromatic hybrid check = SC-II).

A good number of hybrids had significant desired heterosis over better parent and standard checks for various traits. An examination of performance of hybrids over environments in respect of heterosis revealed that 60, 15 and 7 hybrids manifested significant positive heterosis over better parent, GR 104(SC-I) and Pusa RH 10(SC-II) respectively for grain yield plant^{-1}(Table-1,2). The highest extent of heterosis for grain yield plant^{-1} on pooled basis was recorded by the hybrid KJTCMS 6A/Pusa Sugandh 4 (BP = 74.07 %, SC-I = 35.02% %, SC-II = 14.74%) with first rank in respect of significant positive sca effects and *per se* performance. On pooled basis, many hybrids exhibited significant heterosis over BP, SC-I and SC-II respectively in desirable direction for different component traits such as days to 50 per cent flowering (4, 58, 28), productive tillers plant^{-1} (16, 20, 16), plant height (5, 72, 49), panicle length (10, 5, 5), pollen fertility% (65, 0, 22), spikelet fertility% (8, 61, 15), straw yield plant^{-1} (16, 18, 7), kernel length (1, 25, 15) , L:B ratio (5, 16, 4), elongation ratio (5, 71, 0), test weight (5, 24, 14), milling % (17, 56, 58), head rice recovery(21, 21, 43), and amylose content(34, 11, 29). It was also observed that none of the hybrids showed significant positive heterosis over Pusa RH 10 for elongation ratio as Pusa RH 10 is a long slender basmati hybrid rice having more elongation ratio. For all the traits, a sufficient number of crosses manifested positive significant heterosis over better parent and three standard checks. Significant positive heterosis for grain yield plant^{-1} and straw yield plant^{-1} have been reported by many researchers, some of them were Pandey *et al*. (1995)[8], Rogbell and Subbaraman (1997)[15], Ramlingam *et al.* (2000)[14], Yolanda and Vijendradas (1995)[21], and Singh *et al.* (2007)[17]. However, Vishwakarma *et al.* (1999) [19] reported significant positive heterosis for productive tillers plant^{-1} , test weight, pollen and spikelet fertility and plant height and in negative direction for days to 50% flowering.

As regards to quality traits, milling % was found to be most heterotic attribute. Among the 72 hybrids, 56 crosses registered significant positive heterosis over GR 104 and 58 crosses over Pusa RH 10. For kernel length, 25 crosses over GR 104, 15 crosses over Pusa RH 10 depicted significant positive heterosis. For head rice recovery, 21 crosses over GR 104, and 43 crosses over Pusa RH 10 depicted significant positive heterosis. Sixteen crosses over GR 104, and 4 crosses over Pusa RH 10 registered significant positive heterosis for kernel L: B ratio. Eleven crosses over GR 104 and 29 crosses over Pusa RH 10 recorded significant positive heterosis for amylose content. Significant positive heterosis for kernel length, L: B ratio, milling %, head rice recovery, amylase content have been reported by Singh (2005) [19]. Many of the crosses in present study showed low expression of heterosis for yield and its component characters which are attributed to disharmony between the gene combinations of the parents involved (Paramasivan and Rangaswamy, 1988) [9].

Out of 72 hybrids tested, the 8 promising hybrids were identified which were found superior than their respective better parents as well as standard checks in respect of grain yield plant^{-1} and most of the traits (Table 3). All the promising hybrids showed significant positive heterosis over their respective better parent and standard checks, GR 104 and Pusa RH 10. The best three hybrids on the basis of heterosis over high yielding hybrid check Pusa RH 10 were KJTCMS 6A/Pusa Sugandh 4 (14.74 %), IR 58025A/Pusa Sugandh 5 (13.79 %), and IR 58025A/SKL 41-30(10.79 %). All the top eight crosses depicted significant positive sca effects for grain yield plant^{-1} on pooled basis, hence indicated involvement of non-additive gene action in the heterotic response of these hybrids. This was also confirmed by the ratio of variance components for grain yield plant^{-1} in the pooled analysis of variance for combining ability. The predominance of non-additive gene action in the expression of grain yield plant^{-1} was also reported by Ram *et al*. (1991) **[11]**, Rogbell and Subbaraman (1997) **[15]**, Shunmugavalli *et al*. (1999) **[16]**.

The perusal of Table 3 also revealed that all the promising hybrids manifested significant and desired heterosis for five to twelve component traits. The best three hybrids on the basis of performance also had significant positive heterosis for productive tillers plant^{-1}, panicle length, spikelet fertility, straw yield plant^{-1}, test weight, kernel L: B ratio, milling % and head rice recovery. This emphasized that high degree of heterosis for grain yield might be attributed due to the heterosis for these component traits. Whitehouse *et al*. (1958)**[20]** and Grafius (1959)**[4]** have suggested that there cannot be any gene system for grain yield *per se* as yield is an end product of the multiplicative interaction of several yield components. All the 8 promising hybrids registered significant desired heterosis over Pusa RH 10 for straw yield plant^{-1} and productive tillers hill^{-1}. Similarly, significant heterosis in desired direction was exhibited by eight hybrids, five each for L: B ratio, pollen fertility and spikelet fertility and eight each for milling %, head rice recovery and amylose content over Pusa RH 10.

Line x Tester analysis for combining ability

Combining ability analysis is a powerful tool to discriminate good as well as poor combiners. It also gives information of nature of gene effect involved in inheritance. With the advancement in biometrical genetics, several techniques are now available which permit quantitative genetic analysis and selection of promising parents and crosses for further exploitation.

Table 3 shows the top eight cross combinations with significant sca effect. These crosses were derived from parents having high, average and low gca effects. For example, crosses at Sr. No. 2, 3, 4, 6 and 8 involved parents with high x high gca suggesting presence of additive x additive type of gene action. Crosses at Sr. No. 1, 5 and 7 involving at least one parent having good gca effect. These results also clearly indicate that high performance of hybrids need not be ones with high sca effect and vice-versa. Similar results were also obtained by Peng and Virmani (1990) [10] who reported that the best heterotic hybrids always did not registered significant sca effects for yield.

A perusal of Table 2 showed a good agreement between best general combining parents and best performing parents for most of the traits. This suggested that while selecting the parents for hybridization programme, *per se* performance of parents should be given due weightage. It is also evident from Table 2 that, the three best performing hybrids for various characters also had high heterotic response over better parent and standard checks and desired sca effects. Therefore, it can be concluded that *per se* performance of parents and hybrids agrees well with general combining ability effects of parents and heterotic response of hybrids, respectively. Thus, the potentiality of a genotype to be used as a parent in hybridization, or a cross to be used as a commercial hybrid may be judged by comparing *per se* performance of parents and hybrids, along with combining ability effects of parents and heterotic response of hybrids. The crosses exhibiting higher *per se* performance, high heterosis and significant desirable sca effects for various traits involved either good x good, good x poor, average x good, and poor x good combining parents. Thus, crosses exhibiting high sca effects did not always involve parents with high gca effects. It may be suggested that interallelic interactions were also important for these characters.

The best three hybrids for grain yield plant^{-1} *viz*., KJTCMS 6A/Pusa Sugandh 4 (average x good), IR 58025A/Pusa Sugandh 5 (good x good) and IR 58025A/SKL 41-30 (good x good) had significant desired sca effects and significant desired heterotic response over better parent as well as both standard checks. High yielding hybrids had high sca effects, high heterosis as well as high *per se* performance for most of the yield contributing characters. This appeared appropriate as yield being a complex character depends on a number of its component traits.

Considering the *per se* performance, heterotic response and sca effects in desirable direction, hybrid KJTCMS 6A/Pusa Sugandh 4 showed its superiority for productive tillers plant^{-1}, panicle length, grain yield plant^{-1}, straw yield plant^{-1}, whereas IR 58025A / Pusa Sugandh 5 indicated superiority for productive tillers plant^{-1}, panicle length, grain yield plant^{-1}, straw yield plant^{-1}, kernel L : B ratio and IR 58025A/SKL 41-30 indicated superiority for productive tillers plant^{-1}, grain yield plant^{-1}, kernel L : B ratio (Table 3). Similar results have been reported by Pandey *et al*. (1995) [8], Ramlingam *et al*.(2000) [14], Annadurai and Nandarajan (2001a) [1].

The data from table 3 revealed that, parents with good *per se* performance were in general, good combiners for most of the traits. Further, good general combiners may not necessarily produce good specific combinations for different traits. Similar results were reported by Ramlingam *et al*. (1997) [12]. In many cases, it was observed that at least one good general combining parent was involved in heterotic hybrid having desirable sca effects. This was true for most of the traits studied. Parents with highest gca effects will not necessarily generate top specific cross combinations as also reported by Peng and Virmani (1990) [10], Ramalingam *et al*. (1993)[13], Annadurai and Nadarajan (2001b) [2].

The hybrids viz., KJTCMS 6A/Pusa Sugandh 4 (productive tillers plant^{-1}), RTN 17A/VDN 96204 (plant height) and KJTCMS 6A/PR 116 (head rice recovery %), RTN 17A/PR 118 (spikelet fertility) resulted from one good and one poor general combiner. This might be due to additive x dominant type of interaction with non-additive, non-fixable genetic component for grain yield. Random mating and selection among the segregants could lead to transgressive desirable early segregants in later generations as suggested by Langham (1961) [7].

Table 1: Estimates of range of standard heterosis and number of hybrids exhibiting significant heterosis for yield and other characters.

S.N.	Characters	Range (%)	S.E. +/-	No. of hybrids showing desirable significant heterosis over		
				BP	GR 104	PRH 10
1.	Days to 50 % flowering					
2.	Productive tillers plant^{-1}	-67.33 to 48.40	0.15	15	20	16
3.	Plant height	-15.50 to 59.35	0.40	65	0	21
4.	Panicle length	-17.33 to 12.70	0.40	10	5	5
5.	Pollen fertility	-15.50 to 59.59	0.74	65	0	22
6.	Spikelet fertility	-13.54 to 8.21	0.43	8	61	15
7.	Grain yield plant^{-1}	-6.04 to 85.82	0.73	60	15	7
8.	Straw yield plant^{-1}	-54.20 to 55.32	0.73	16	18	7
9.	Kernel length	-34.34 to 4.26	0.06	1	25	15
10.	Kernel L: B ratio	-39.41 to 28.64	0.13	5	16	4
11.	Elongation ratio	-19.09 to 12.55	0.06	5	71	0
12.	Test weight	-44.98 to 4.95	0.06	5	24	14
13.	Milling (%)	-22.17 to 3.29	0.06	17	56	58
14.	Head rice recovery	-25.43 to 7.76	0.06	21	21	43
15.	Amylose content	-26.39 to 10.60	0.06	34	11	29

Table 2: Top most performing hybrids in respective traits.

Character	Best performing hybrid	GCA effect	SCA effect	Hetero-beltiosis	Std. heterosis over	
					GR 104	Pusa RH 10
Days to 50 % flowering	IR 58025A/PKV Makarand	G x G	-4.592**	-4.53**	-16.40**	-9.01**
	IR 62829A/PR 115	G x G	-0.672**	-3.46**	-16.14**	-8.73**
	IR 62829A/PR 116	G x G	-3.44**	-4.61**	-15.50**	-8.03**
Productive tillers plant^{-1}	KJTCMS 6A/PS-4	P x G	4.997**	48.40**	58.04**	40.27**
	IR 58025A/SKL-41-30	G x G	3.455**	19.14**	49.68**	32.85**
	IR 58025A/PS-5	G x G	3.713**	41.17**	45.09**	28.77**
Plant height	IR 62829A/PR 115	G x G	-6.525**	2.04**	-32.11**	-22.10**
	IR 62829A/VDN 90140	G x G	-4.767**	-19.05**	-31.06**	-20.18**
	RTN 17A/VDN 96204	P x G	-7.625**	-8.58**	-29.86**	-18.79**
Panicle length	KJTCMS 6A/Pusa Sugandh 4	G x G	2.173**	10.51**	9.20**	8.34**
	IR 58025A/Pusa Sugandh 5	A x G	3.584**	3.37*	7.98**	7.13**
	IR 58025A/Pusa Sugandh 4	A x G	1.683**	6.89**	5.63**	4.79**
Pollen fertility	TN 17A/PR 118	P x G	5.376**	9.54**	11.57**	8.25**

	KJTCMS 6A/PR 118	G x G	2.110**	1.64	9.38**	6.13**
	KJTCMS 6A/Pusa Sugandh 3	G x G	2.824**	0.96	8.65**	5.42**
Spikelet fertility	RTN-17A/PR 118	P x G	5.941**	8.21**	14.44**	7.82**
	KJTCMS 6A/PR 118	G x G	3.908**	3.88**	13.93**	7.04**
	IR 62829A/SYE 14-9	P x G	2.933**	4.53**	11.62**	4.87**
Grain yield plant^{-1}	KJTCMS 6A/Pusa Sugandh 4	A x G	12.148**	74.07**	35.02**	14.74**
	IR 58025A/Pusa Sugandh 5	G x G	13.604**	76.57**	33.91**	13.79**
	IR 58025A/SKL-41-30	G x G	10.040**	69.97**	30.37**	10.79**
Straw yield plant^{-1}	KJTCMS 6A/Pusa Sugandh 4	G x G	15.145**	18.63**	35.37**	18.07**
	IR 58025A/Pusa Sugandh 5	G x G	13.493**	11.71**	25.47**	9.19**
	KJTCMS 6A/PR 114	G x G	11.964**	8.98**	21.47**	5.71**
Kernel length	RTN 17A/Pusa Sugandh 5	G x G	0.000	-20.16**	17.58**	9.33**
	RTN 17A/PR 114	G x G	0.267**	-3.20**	17.13**	8.91**
	RTN 17A/GR 7	G x G	0.145**	4.26**	16.72**	8.53**
Kernel L: B ratio	IR 58025A/Pusa Sugandh 4	G x G	0.527**	8.62*	27.29**	15.30**
	IR 58025A/SKL 41-30	G x G	0.471**	8.37*	26.90**	4.94**
	IR 58025A/Pusa Sugandh 5	G x G	0.266**	-7.95**	24.71**	12.96**
Elongation ratio	IR 62829A/Pusa Sugandh 4	A x G	0.042	-15.45**	50.00**	5.68
	IR 62829A/SKL 41 30	A x G	0.034	10.18**	48.39**	4.55**
	IR 62829A/Pusa Sugandh 5	A x G	0.029	-4.35	47.82**	4.17
Test weight	RTN 17A/Pusa Sugandh 5	G x G	0.387**	-14.28**	30.90**	10.39**
	RTN 17A/Pusa Sugandh 4	G x G	0.363**	-7.01**	30.25**	9.83**
	RTN 17A/SKL 41 30	G x G	0.676**	4.95**	29.87**	9.52**
Milling (%)	IR 62829A/GR 7	G x G	2.514**	3.29**	15.58**	18.85**
	IR 62829A/PR 116	G x G	1.223**	-2.22**	15.17**	18.43**
	IR 62829A/Pusa Sugandh 2	G x P	-0.303**	-3.29**	8.22**	11.28**
Head rice recovery (%)	IR 62829A/SYE 131-16	G x G	8.663**	4.76**	22.60**	30.55**
	KJTCMS 6A/PR 116	P x G	3.943**	2.97**	14.60**	22.04**
	IR 62829A/PR 116	G x G	0.502**	0.37**	12.21**	19.49**
Amylose content	RTN 17A/VDN 96204	G x G	0.549**	24.72**	10.60**	15.74**
	IR 62829A/Pusa Sugandh 3	G x G	0.544**	2.97**	8.80**	13.85**
	IR 62829A/SYE 14-9	G x G	0.682**	11.92**	7.52**	12.52**

*, ** Significant at 5 and 1 per cent probability levels, respectively;
G = Good parent having significant GCA effect in desired direction;
A = Average parent having either positive or negative but non-significant GCA effects;
P = Poor parent having significant GCA effects in undesired direction;

Table 3: Promising hybrids for grain yield with heterosis, combining ability and component traits showing significant desired heterosis pooled over environment in rice.

S. No.	Hybrid	Grain yield plant^{-1} (g)	Heterobe-ltosis (%)	Standard heterosis(%)		GCA effects	SCA effects	Useful and significant for component traits Heterobeltosis
				SC-I	SC-II			
1.	KJTCMS 6A/ Pusa Sugandh 4	62.64	74.07 **	35.02 **	14.74 **	A x G	12.148**	PT,PL,SF,SY,KL,ER, TW,M%,HR
2.	IR 58025A/ Pusa Sugandh 5	62.13	76.57 **	33.91 **	13.79 **	G x G	13.604**	PT,PL,SF,SY,KL,LB, ER,TW,M%,HR,AC
3.	IR 58025A/ SKL 41-30	60.49	69.97 **	30.37 **	10.79 **	G x G	10.040**	PT,PL,PF,SF,SY,LB, ER,TW,M%,HR,AC
4.	IR 58025A/ Pusa Sugandh 4	60.32	67.63 **	30.02 **	10.49 **	G x G	8.360**	PT,PL,PF,SF,SY,KL,LB, ER,TW,M%,HR,AC
5.	KJTCMS 6A/ PR 116	58.52	68.24 **	26.14 **	7.19 **	A x G	12.308**	PT,PL,PF,SF,SY,KL, TW, M%,HR
6.	RTN 17A/ GR 7	58.32	85.82 **	25.71 **	6.83 **	G x G	15.862**	PT,PL,PF,SF,SY,KL,ER,TW,M%,HR,AC
7.	IR 62829A/ Pusa Sugandh 2	56.49	77.70 **	21.75 **	3.46 *	G x A	15.124**	PT,PL,PF,SF,SY,KL,LB,TW, M%,HR
8.	RTN 17A/ SYE 131-16	54.34	59.88 **	17.12 **	-0.47	G x G	11.806**	PT,KL,TW,M%,HR

*, ** Significant at 5 and 1 per cent probability levels, respectively; G = Good parent having significant GCA effect in desired direction; A = Average parent having either positive or negative but non-significant GCA effects; P = Poor parent having significant GCA effects in undesired direction.

DF= Days to 50 % flowering
PT= Productive tillers hill^{-1}
PH= Plant height (cm)
PL= Panicle length (cm)
PF= Pollen fertility (%)
SF= Spikelet fertility (%)
GY= Grain yield plant^{-1} (g)
SY= Straw yield plant^{-1} (g)
KL= Kernel length (mm)
LB= Length to breadth ratio
ER= Kernel elongation ratio
TW=1000-grain weight (g)
M%= Milling recovery (%)
HR= Head rice recovery (%)
AC= Amylose content (%)

4. Conclusion

From the above discussion, it is clear that, a substantial degree of heterosis over better parent, standard checks GR 104 (variety check) and Pusa RH 10 (Hybrid check) were available in several crosses. Hybrids viz., KJTCMS 6A / Pusa Sugandh 4, IR 58025A / Pusa Sugandh 5, IR 58025A / SKL 41-30, IR 58025A / Pusa Sugandh 4 and KJTCMS 6A / PR 116 having high mean, high heterosis over better parents and standard checks, desirable sca effects for grain yield plant^{-1} and its related traits. It is also clear that the high degree of non-additive gene action for grain yield and its component traits observed in the present study favors hybrid breeding programme. Besides, having high mean, high heterosis over better parent, standard checks with desirable sca effect for grain yield plant^{-1} the topmost three ranked hybrids viz., KJTCMS 6A / Pusa Sugandh 4, IR 58025A / Pusa Sugandh 5 and IR 58025A / SKL 41-30 showed significance for useful quality traits such as kernel length, elongation ratio, test weight, milling % and head rice recovery . Hence, these can be exploited commercially by proper evaluation through multi-location evaluation trials. Thus, hybrids with high magnitude of heterosis combined with good marketing and cooking quality will make this technology commercially feasible in India.

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6. Abbreviations used

Gca	=	Genotypic coefficient of variance
Sca	=	Specific coefficient of variance.
SC-I	=	Standard check-I
SC-II	=	Standard check-II
%	=	Per cent
BP	=	Better parent

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