RESEARCH ARTICLE

Heterosis and gene action studies involving aromatic lines for grain quality traits in rice

Gonya Nayak P, Sreedhar M, Surender Raju Ch, and Vanisree S

Department of Genetics and Plant Breeding, College of Agriculture, Acharya N.G. Ranga Agriculture University, Rajendranagar, Hyderabad.

Manuscript details:

Received: 23.11.2016
Accepted: 29.12.2016
Published : 01.02.2017

Editor: Dr. Arvind Chavhan

Cite this article as:
Gonya Nayak P, Sreedhar M, Surender Raju Ch, and Vanisree S (2016) Heterosis and gene action studies involving aromatic lines for grain quality traits in rice, *International J. of Life Sciences*, 4 (4): 517-528.

Acknowledgement:
Authors are thankful to prof. K.K. Sharma former dean of science and Head department of zoology for his guidance and encouragement during this research

ABSTRACT

Sixteen crosses developed from four aromatic lines and four non scented testers were evaluated for various grain quality traits to assess the heterosis of the crosses and to identify best combinations. The estimates of heterosis, heterobeltiosis and standard heterosis were variable among the crosses. Heterosis in desirable direction was recorded for important quality attributes viz., head rice recovery (22.16%), kernel length (10.28%), L/B ratio (12.84%), kernel elongation ratio (14.17%), volume expansion ratio (22.10%), aroma (35.21%), alkali spreading value (45.32) and Protein (19.95). Some of these heterotic crosses have turned out to be best specific crosses and exhibited desirable *per se.* Among the heterotic crosses Yamini/MTU1010(Milling Recovery), Pusa1121/BM-71(Kernel Length), Ranbir Basmati/BM71(Kernel Breadth, L/B ratio), Pusa 1121/MTU1081(Kernel Length after Cooking), RNR2354/BM71(Kernel Elongation Ratio), Yamini/Sye632003(Aroma, Alkali spreading value) and Pusa1121/BM71(Protein) were found to be superior, expressing heterosis, heterobeltiosis and standard heterosis in desirable direction. Quality attributes viz., milling recovery, head rice recovery, kernel length after cooking, kernel breadth after cooking, kernel elongation ratio and aroma exhibit non-additive gene action. The results of the present study indicated the potential of these parental lines in the improvement of grain quality of rice hybrids.

Key words: *Heterosis , Kernel Length, L/B ratio, Aroma, Protein*

INTRODUCTION

Aromatic rices constitute a small but special group which is considered as the best in quality. Popularity of such rices has been documented in the Orient and now becoming more popular in Middle East, Europe and United States. Although aromatic rices which are popular in world market are long grain types, majority of the Indian indigenous aromatic rices are small and medium grain types. With the advent of "Geographical Indications" under WTO regulations, basmati kind of aromatic rice is accepted internationally when it is produced from North-western part of India due to its location specific eating quality, thus necessitating research efforts to evolve scented rice genotypes suitable to local requirements.

Successful application of biometrical procedures to understand genetics of quantitative characters helped the breeders to systematically plan for result oriented breeding programmes.

The challenge of quality improvement also needs to be addressed by evolving cultivar genotypes that combined high yield potential with quality attributes meeting stringent national and international standards.

MATERIAL AND METHODS

The material for the present investigation comprised of eight parents and their corresponding 16 F_1crosses obtained following Line X Tester design (Kempthorne,1957). The experiment was conducted in randomised block design with three replications at Rice Section, Agricultural Research Institute, ANGRAU, Rajendranagar, Hyderabad during *rabi* 2010-11. All the parents and F_1 S' were planted in rows of 3 m length with 20 x 15 cm spacing. Recommended agronomic, cultural and plant protection practices were followed. Five competitive plants for each parent and F_1 per replication were randomly selected for data generation.

Ten grams of representative sample was used for estimating milling and head rice recovery with Satake huller and Kett type T2 polisher respectively. Kernel dimensions were obtained using dial micrometer and L/B ratio was computed as per Murty and Govindaswamy (1967). Graph sheet was used to quantify cooking traits. Kernel elongation ratio was determined using standard method of Verghese (1950) as modified by Murthy (1965). Aroma was scored as per the scale given by Khush *et al.* (1988).

RESULTS AND DISCUSSION

HETEROSIS:

Further, partitioning of the genotypes into parents and crosses and comparison of parents Vs crosses showed significant differences among themselves indicating that the crosses performed well compared to parents. The differences among lines and testers and the interaction component was also significant.

Hybrid vigour was first reported in rice by Jones (1926). There after many workers documented varying levels of heterosis in relation to mid parent, superior parent and standard check. In the present study marked heterosis was observed for all the characters. Heterosis was calculated for all the nine characters in respect of 16 F_1's and was expressed as heterosis over the mid parent (H_1), heterobeltiosis over the better parent (H_2) and standard heterosis (H_3) i.e., increase over standard check. Character wise performance of the hybrids is presented in the Tables 1,2 and 3.

Significantly positive heterosis was observed for milling Recovery (%) in 11 hybrids ranging from 3.35 (RNR-2354 x MTU-1081) to 10.22 per cent in respect of RNR-2354 x Sye-632003. Heterobeltiosis values were significantly negative in two hybrids Pusa-1121 x MTU-1081 and Ranbir Basmati x MTU-1010, similarly two hybrids viz., Pusa-1121 x Sye-632003 and RNR-2354 x Sye-632003 recorded significantly positive heterobeltiosis (Table1). Standard heterosis were significantly positive in two hybrids viz., Ranbir Basmati x BM-71 and RNR-2354 x Sye-632003 which registered 3.87 and 3.86 per cent respectively.

For head rice recovery 11 hybrids recorded significantly positive heterosis which ranged from 5.97 (RNR-2354 x BM-71) to 22.16 percent (RNR-2354 x Sye-632003) and only one hybrid Ranbir Basmati x MTU-1010 exhibited negatively significant heterosis (Table1). Heterobeltiosis values were significantly positive in seven hybrids. Cross RNR-2354 x Sye-632003 recorded highest of and 16.83 per cent and Pusa-1121 x MTU-1010 had a lowest of 4.16 per cent. Standard heterosis was significantly positive in 12 hybrids which ranged from 6.23 per cent in (Yamini x BM-71) to 20.97 per cent in (RNR-2354 x Sye-632003). Six hybrids viz., RNR-2354 x Sye-632003, Pusa-1121 x Sye-632003, Pusa-1121 x MTU-1010, RNR-2354 x MTU-1010 Ranbir Basmati x Sye-632003 and Yamini x Sye-632003 recorded significant superiority over mid, better parent and standard check and recorded heterosis of varying degrees. Considering the performance of all the hybrids for milling traits cross RNR-2354 x Sye-632003 were found to be consistent in terms of manifestation of heterosis in desirable direction. Heterosis for these traits was earlier was reported by Singh (2005), Singh and Lal (2005), and Shivani *et al*. (2009).

Attributes like kernel length, breadth and Length/Breadth ratio form the core of the physical quality. Majority of rice importing nations as well as domestic consumers prefer slender and super fine types. Ten crosses out of 16 recorded a significantly positive heterosis for kernel length (mm). It ranged from 1.35 per cent (Pusa-1121 x Sye-632003) to 10.28 per cent (Pusa-1121 x BM-71) and significantly negative heterosis was recorded in 2 hybrids (Ranbir Basmati x MTU-1081 and Pusa-1121 x MTU-1010). While 13 hybrids recorded significantly negative heterobeltiosis which ranged from -2.01 per cent in (RNR-2354 x MTU-1010) to -20.56 per cent in (Pusa-1121 x Sye-632003). Exhibition of heterosis in negative direction for this trait indicated reduction in kernel length of crosses. This phenomenon could be successfully exploited in selecting short grain aromatic genotypes suiting the local demand. However, Standard heterosis was significantly positive in all the 16 hybrids which ranged from 25.27 per cent (RNR-2354 x Sye-632003) to 79.69 per cent in (Pusa-1121 x BM-71) and 10 hybrids recorded more than 40 per cent standard heterosis (Table1). The magnitude of heterosis realized for this trait indicated the quantum of variability existed for this trait and potential to obtain segregants with desirable kernel length. Similar instances of manifestation heterosis for this trait was also documented by researchers like Sumanaratne *et al.* (2007), Shivani *et al*. (2009) and Kumar Babu *et al.* (2010).

Lesser dimensions of kernel breadth (mm) are desirable, since it enhances the length/breadth ratio and kernel elongation ability after cooking. Bold kernels with higher breadth are often discriminated against because, they break in milling (Jennings *et al.* 1979). Lesser kernel breadth gives slender appearance and will have superior cooking behaviour. Heterosis in negative direction is desirable for this trait and accordingly significant negative heterosis was recorded in two hybrids viz., RNR-2354 x MTU-1081 (-3.49%) and Ranbir Basmati x BM-71 (-5.15%, Table2). Similarly, three hybrids recorded significantly negative heterobeltiosis which ranged from -6.86 percent in (Ranbir Basmati x BM-71) to -7.89 percent in (RNR-2354 x MTU-1081). Three hybrids recorded significantly negative standard heterosis from -3.55 (Ranbir Basmati x BM-71) to -6.75% (RNR-2354 x MTU-1081). Negative heterosis for kernel breadth was also reported by Krishna Veni *et al*. (2005) and Kumar Babu *et al.* (2010).

The estimates of heterosis indicated that, four hybrids recorded significantly positive heterosis ranging from 5.69 per cent in (Ranbir Basmati x MTU-1010) to 12.84 per cent in (Ranbir Basmati x BM-71) and significant negative heterosis was recorded in five hybrids (Table2) in case of L/B ratio. Heterobeltiosis values were significantly positive in only one cross Ranbir Basmati x BM-71 (7.68), while 13 hybrids recorded significantly negative heterobeltiosis ranged from -7.97 per cent in (RNR-2354 x BM-71) to -19.94 per cent in (Pusa-1121 x Sye-632003). Appearance of crosses with lesser L/B ratios improved the possibility of obtaining segregants with short and slender grains which if combined with reasonable level aroma would yield desirable short grain scented cultures. However, Standard heterosis was significantly positive in all 16 hybrids which ranged from 30.77 per cent (RNR-2354 x BM-71) to 69.23 per cent in (Pusa-1121 x BM-71), and all the crosses recorded more than 30 per cent standard heterosis. Only one cross Ranbir Basmati x BM-71 exhibited significant heterosis, heterobeltiosis and standard heterosis of varying degrees. Two crosses viz., Ranbir Basmati x BM-71 and RNR-2354 x MTU-1081 exhibited significant heterosis, heterobeltiosis and standard heterosis in positive direction for both kernel length, breadth and Length/Breadth ratio. Earlier researchers like Krishna Veni *et al*. (2005), Sumanaratne *et al.* (2007) and Kumar Babu *et al.* (2010) documented positive heterosis for Length/Breadth ratio.

Consumer preference for quality rice has the inclination towards varieties that remain slender after cooking, remain crisp and undisturbed. Hence, cooking quality attributes such as kernel length, breadth after cooking and kernel elongation ratio in particular are determining factors to satisfy the ethnic preference for fine rice with aroma. Lengthwise expansion of kernel after cooking is a highly desirable feature and manifestation of heterosis for this trait is useful. Among the hybrids studied, three hybrids recorded a significantly positive heterosis ranging from 4.86 per cent (Ranbir Basmati x MTU-1010) to 13.70 per cent in (RNR-2354 x BM-71). Heterobeltiosis values were significantly positive only in one cross RNR-2354 x BM-71 (6.08%), while 11 combinations recorded significantly negative heterobeltiosis. Standard heterosis was significantly positive in 12 hybrids ranging from 10.52 per cent (Pusa-1121 x Sye-632003) to 46.80 per cent in (Pusa-1121 x MTU-1081). Only one hybrid RNR-2354 x BM-71 recorded a significant heterosis, heterobeltiosis and standard heterosis of varying degrees in desirable direction (Table2).

Breadth wise expansion after cooking renders coarseness to cooked rice. For kernel breadth (mm) after cooking desirable heterosis in negative direction was recorded in respect of three hybrids though statistically non significant. Crosses viz., Yamini x MTU-1081, Yamini x MTU 1010 and Ranbir Basmati x Sye-632003 had lower breadth wise expansion after cooking. Two hybrids recorded significantly negative heterobeltiosis viz., Yamini x MTU-1081(-7.68) and Yamini x MTU-1010(-9.80%). Only one hybrid recorded significantly negative standard heterosis of -10.88 per cent (Ranbir Basmati x Sye-632003).

Similarly, kernel elongation ratio is an important cooking quality characteristic in quality rice breeding. A genotype must be superior for physical and cooking quality to pass this test. Only two hybrids recorded significantly positive heterosis of 5.56 per cent (Ranbir Basmati x Sye-632003) and 14.17 per cent (RNR-2354 x BM-71). For kernel elongation ratio significantly negative heterosis were recorded in seven hybrids (Table 3). Heterobeltiosis values were significantly positive in only one hybrid RNR-2354 x BM-71 (9.44%) which had also exhibited desirable superiority of crosses in comparison with parents and standard check. Singh (2005), Krishna Veni *et al*. (2005) and Roy *et al*, (2009) documented manifestation of heterosis for kernel length after cooking and kernel elongation ratio.

A volatile chemical compound 2 acetyl-1 pyroline imparts the typical fragrance to scented rice which is popular universally. The existence of considerable variability in the experimental material studied provides scope to isolate lines with higher content of this compound. Tyagi *et al.* (2010) studied 27 hybrids for aroma and reported that Basmati-370 x Heibao was found to be heterotic and good specific combiner for aroma and cross P-1463 x P-44 expressed high sca effects and heterosis for aroma. In the present investigation also, five hybrids recorded significantly positive heterosis ranging from 7.41 per cent (Pusa-1121 x BM-71) to 35.21 per cent in (Yamini x MTU-1081). Significantly positive heterobeltiosis were recorded in two hybrids viz., Yamini x Sye-632003 (27.86%) and Yamini x MTU-1081(34.67). Only two hybrids Yamini x MTU-1081(10.08%) and Pusa-1121x MTU-1081(8.90%) recorded significantly positive standard heterosis. Standard heterosis was significantly negative in11 hybrids (Table 3).

Combined perusal of manifestation of heterosis indicated that parents Pusa-1121 and Yamini were outstanding in producing heterotic crosses that were superior in simultaneously recording desirable location and magnitude of heterosis for aroma and other physical, cooking attributes.

GENE ACTION:

Combining ability variances:

Visual appeal of rice after milling with uniform colour, texture without white belly is of paramount importance to the consumer thus in turn to the producer and miller. High yield of head rice without brokens and desirable milling out put is one of the features of quality breeding. In case of hulling recovery gca variance for lines was higher when compared to that of testers. The sca variance was higher than gca variance, the gca to sca variance ratio was 0.070. Among the lines and testers the gca variance for testers was higher magnitude when compared to that of lines in respect of milling recovery (Table 4). The sca variance was higher than gca variance, the gca to sca variance ratio was 0.138 for milling recovery. For head rice recovery The gca variance for lines was higher magnitude than that of testers, the sca variance was higher than gca variance and gca to sca variance ratio was 0.383. For all the milling traits studied i.e., hulling, milling and head rice recovery, importance of non-additive gene action was noticed. Since non-additive gene action can not be fixed, recurrent selection is advocated to break the gene constellations and release the free variability. Earlier researchers viz., Munhot *et al.* (2000) and Shivani *et al.* (2009) reported similar gene action.

Kernel size attributes exercise profound bearing on head rice yields. Though slender kernels have comparatively lower head rice recovery, they are commercially accepted and fetch premium price. Among the lines and testers studied for kernel length and breadth the gca variance for lines was higher when compared to that of testers. The gca variance was higher than sca variance, the gca to sca variance

Table 1. Estimates of Heterosis (H_1), Heterobeltiosis (H_2) and Standard heterosis (H_3) for milling recovery, head rice recovery and kernel length in rice

Cross	Milling Recovery (%)			Head Rice Recovery (%)			Kernel Length (mm)		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
Yamini x BM-71	3.81*	0.58	0.94	2.37	-6.71**	6.23**	5.19**	-4.42**	62.48**
Yamini x MTU-1010	5.74**	2.40	2.86	6.71**	-0.69	8.02**	2.69**	-6.79**	58.45**
Yamini x Sye-632003	2.30	1.86	-3.30	10.09**	4.85*	8.56**	6.68**	-13.36**	47.29**
Yamini x MTU-1081	3.59*	-1.02	2.24	7.89**	-1.28	11.42**	5.15**	-7.80**	56.74**
Pusa-1121 x BM-71	5.04**	0.00	0.36	2.36	-11.28**	1.04	10.28**	-3.90**	79.69**
Pusa 1121 x MTU-1010	4.45*	-0.59	-0.15	17.82**	4.16*	13.30**	-2.29**	-14.93**	59.07**
Pusa-1121 x Sye-632003	9.38**	6.97**	1.54	19.27**	7.76**	11.57**	1.35*	-20.56**	48.53**
Pusa 1121 x MTU-1081	0.89	-5.24**	-2.12	-3.46	-16.00**	-5.19*	0.62	-15.22**	58.53**
Ranbir Basmati x BM-71	4.61**	3.50	3.87*	6.68**	-0.71	`13.07**	5.45**	0.76	53.64**
Ranbir Basmati x MTU-1010	-6.34**	-7.37**	-6.96**	-5.88**	-10.50**	-2.65	4.45**	-0.31	52.02**
Ranbir Basmati x Sye-632003	3.43*	1.69	-0.11	11.19**	8.27**	12.10**	0.66	-14.64**	30.16**
Ranbir Basmati x MTU-1081	2.47	-0.04	3.25	-3.50	-9.81**	1.79	-1.60*	-9.46**	38.06**
RNR-2354 x BM-71	6.96**	3.33	3.69	5.97**	-3.04	10.41**	-0.32	-3.07**	34.65**
RNR-2354 x MTU-1010	3.27	-0.29	0.16	11.82**	4.49*	13.65**	0.66	-2.01*	35.81**
RNR-2354 x Sye-632003	10.22**	9.41**	3.86*	22.16**	16.83**	20.97**	5.55**	-4.55**	25.27**
RNR-2354 x MTU-1081	3.35*	-1.53	1.71	15.97**	6.54**	20.24**	2.45**	1.24	32.87**
SE ±	1.10	1.27	1.27	1.79	2.06	2.06	0.04	0.04	0.04

* significant at p= 0.05, ** significant at p= 0.01.

Table 2. Estimates of Heterosis (H_1), Heterobeltiosis (H_2) and Standard heterosis (H_3) for kernel breadth, L/B ratio and kernel length after cooking in rice

Cross	Kernel Breadth (mm)			Length/Breadth Ratio			Kernel Length After Cooking (mm)		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
Yamini x BM-71	3.87**	1.37	4.97**	0.85	-10.30**	54.28**	2.02	-4.05	25.49**
Yamini x MTU-1010	3.21**	-0.34	5.51**	-1.06	-13.00**	49.64**	2.62	-8.30**	19.93**
Yamini x Sye-632003	10.62**	4.14**	2.66	-2.57*	-16.88**	42.96**	11.32**	-5.84*	23.16**
Yamini x MTU-1081	3.29**	1.93	3.20*	1.66	-11.90**	51.52**	-7.75**	-14.85**	11.37**
Pusa-1121 x BM-71	3.66**	2.06	5.68**	5.90**	-8.84**	69.23**	-19.06**	-37.18**	31.05*
Pusa 1121 x MTU-1010	2.50*	-0.17	5.68**	-5.05**	-19.16* *	50.07**	-11.12**	-33.62**	38.46**
Pusa-1121 x Sye-632003	6.35**	-0.71	-0.36	-3.21**	-19.94**	48.62**	-26.09**	-47.02**	10.52**
Pusa 1121 x MTU-1081	3.26**	2.81*	4.09**	-2.51*	-18.14**	51.96**	-8.04**	-29.63**	46.80**
Ranbir Basmati x BM-71	-5.15**	-6.86**	-3.55*	12.84**	7.68**	58.78**	0.17	-1.64	17.60**
Ranbir Basmati x MTU-1010	0.35	-2.52	3.20*	5.69**	-0.39	46.88**	4.86*	-2.42	16.67**
Ranbir Basmati x Sye-632003	4.94**	-1.78	-1.95	-1.35	-10.04**	32.66**	-2.42	-14.29**	2.48
Ranbir Basmati x MTU-1081	-0.35	-1.05	0.18	0.48	-6.79**	37.45**	-3.89	-7.47**	10.63**
RNR-2354 x BM-71	5.00**	-0.86	2.66	-5.26**	-7.97**	30.77**	13.70**	6.08*	22.23**
RNR-2354 x MTU-1010	-0.36	-6.88**	-1.42	0.75	-3.37*	37.30**	-0.84	-2.37	0.52
RNR-2354 x Sye-632003	4.96**	2.12	-6.04**	0.88	-6.44**	32.95**	-1.13	-6.50*	-6.71*
RNR-2354 x MTU-1081	-3.49**	-7.89**	-6.75**	6.06**	0.10	42.24**	-11.65**	-16.00**	-7.04*
SE ±	0.02	0.02	0.02	0.09	0.10	0.10	0.22	0.26	0.26

*significant at p= 0.05, ** significant at p= 0.01.

Table 3. Estimates of Heterosis (H_1), Heterobeltiosis (H_2) and Standard heterosis (H_3) for kernel breadth after cooking, kernel elongation ratio and aroma in rice

Cross	Kernel Breadth After Cooking (mm)			Kernel Elongation Ratio			Aroma		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
Yamini x BM-71	8.93**	5.83	17.50**	-3.40	-6.94**	-22.97**	4.80	3.20	-15.64**
Yamini x MTU-1010	-4.29	-9.80**	0.15	0.21	-1.46	-24.40**	-17.81**	-16.33**	-31.61**
Yamini x Sye-632003	13.83**	4.11	15.59**	3.45	-1.69	-16.27**	28.43**	27.86**	4.52
Yamini x MTU-1081	-3.33	-7.68*	2.50	-12.92**	-17.74**	-29.03**	35.21**	34.67**	10.08**
Pusa-1121 x BM-71	9.61**	2.53	7.35	-21.85**	-29.63**	-27.27**	7.41*	-7.51*	1.51
Pusa 1121 x MTU-1010	0.62	-2.99	-4.71	-2.25	-16.05**	-13.24**	-13.23**	-23.14**	-15.64**
Pusa-1121 x Sye-632003	6.74	6.23	-2.21	-20.30**	-27.31**	-24.88**	-24.80**	-34.65**	-28.27**
Pusa 1121 x MTU-1081	13.54**	8.01*	9.12*	-2.44	-10.49**	-7.50**	14.13**	-0.78	8.90*
Ranbir Basmati x BM-71	5.98	0.84	5.59	-5.15*	-7.71**	-23.60**	-10.89**	-22.98**	-16.23**
Ranbir Basmati x MTU-1010	16.09**	13.92**	11.91**	0.00	-2.65	-23.76**	-12.45**	-22.14**	-15.31**
Ranbir Basmati x Sye-632003	-4.49	-5.75	-10.88**	5.56*	1.13	-13.72**	0.76	-12.09**	-4.38
Ranbir Basmati x MTU-1081	-1.50	-4.66	-3.68	-2.71	-7.21**	-19.94**	-11.27**	-22.56**	-15.77**
RNR-2354 x BM-71	6.85*	0.84	5.59	14.17**	9.44**	-9.41**	8.55*	3.77	-9.82*
RNR-2354 x MTU-1010	10.15**	7.19	5.29	-1.81	-2.94	-26.32**	-24.94**	-25.90**	-35.60**
RNR-2354 x Sye-632003	4.29	3.80	-3.53	-7.72**	-12.73**	-25.68**	-22.68**	-25.30**	-35.08**
RNR-2354 x MTU-1081	-1.59	-5.53	-4.56	-13.08**	-18.30**	-29.51**	-2.30	-5.57	-17.93**
SE ±	0.07	0.08	0.08	0.07	0.08	0.08	0.15	0.18	0.18

* significant at p= 0.05, ** significant at p= 0.01.

Table 4. GCA and SCA variance for physical quality characters in rice

Component	Milling Recovery (%)	Head Rice Recovery (%)	Kernel Length (mm)	Kernel Breadth (mm)	Length/Breadth Ratio
σ^2GCA (Lines)	0.431	7.500	0.320**	0.004**	0.035*
σ^2GCA (Testers)	0.728	2.303	0.128**	0.001	0.016
σ^2GCA	0.580	4.901	0.224**	0.002**	0.026**
σ^2SCA	4.198**	12.775**	0.050**	0.002**	0.024**
σ^2GCA/ σ^2 SCA	0.138	0.383	4.480	1.000	1.083

* significant at p= 0.05, ** significant at p= 0.01.

Table 5. GCA and SCA variance for cooking quality characters in rice

Component	Kernel Length After Cooking (mm)	Kernel Breadth After Cooking (mm)	Kernel Elongation Ratio	Aroma
σ^2GCA (Lines)	1.254*	0.0070	0.002	0.149
σ^2GCA (Testers)	0.390	0.0079	0.000	0.199
σ^2GCA	0.822**	0.007	0.001	0.174
σ^2SCA	0.828**	0.028**	0.030**	0.441**
σ^2GCA/ σ^2 SCA	0.995	0.250	0.033	0.394

* significant at p= 0.05, ** significant at p= 0.01.

Table 6. Top ranking desirable crosses for sca and their *per se* performance along with magnitude of heterosis (H_1), heterobeltiosis (H_2) and Standard heterosis (H_3)

S.No Character	Cross combinations	*Per se* performance	gca of parents	Hetertosis (%)		
				H_1	H_2	H_3
I Physical quality						
Milling recovery (%)	Yamini x MTU-1010	72.48	Low x Low	5.74	-	-
	Ranbir Basmati x MTU-1081	72.76	Low x Low		-	-
Head rice recovery (%)	Pusa-1121 x MTU-1010	61.97	Low x Low	17.82	4.16	13.30
	Ranbir Basmati x BM-71	61.84	Low x Low	6.68	-	13.07
	RNR-2354 x MTU-1081	65.77	High x Low	15.97	6.54	20.24
	Yamini x MTU-1081	60.94	Low x Low	7.89	-	11.42
Kernel length (mm)	Pusa-1121 x BM-71	7.72	High x High	10.28	-	79.69
	Ranbir Basmati x MTU-1010	6.53	Low x High	4.45	-	52.02
	RNR-2354 x Sye-632003	5.38	Low x Low	5.55	-	25.27
	RNR-2354 x MTU-1081	5.71	Low x Low	2.45	-	32.87
Kernel breadth (mm)	Ranbir Basmati x BM-71	1.81	High x Low	-5.15	-6.86	-3.55
	RNR-2354 x MTU-1081	1.75	High x High	-3.49	-7.89	-6.75
Length/Breadth ratio	Ranbir Basmati x BM-71	3.64	Low x High	12.84	7.68	58.78
	Pusa-1121 x BM-71	3.88	High x High	5.90	-	69.23
	RNR-2354 x MTU-1081	3.26	Low x Low	6.06	-	42.24
	RNR-2354 x Sye-632003	3.05	Low x Low	-	-	39.95

Table 7. Top ranking desirable crosses for sca and their *per se* performance along with magnitude of heterosis (H_1), heterobeltiosis (H_2) and Standard heterosis (H_3)

S.No Character	Cross combinations	*Per se* performance	gca of parents	Hetertosis (%)		
				H_1	H_2	H_3
II Cooking quality						
Kernel length after cooking (mm)	Pusa-1121 x MTU-1081	13.20	High x Low	-	-	46.80
	RNR-2354 x BM-71	10.99	Low x High	13.70	6.08	22.23
	Yamini x Sye-632003	11.08	High x Low	11.32	-	23.16
	Pusa-1121 x MTU-1010	12.45	High x High	-	-	38.46
Kernel breadth after cooking (mm)	Pusa-1121 x MTU-1010	2.16	Low x Low	-	-	-
	Ranbir Basmati x Sye-632003	2.02	Low x High	-	-	-10.88
	Yamini x MTU-1010	2.27	Low x Low	-	-9.80	-
Kernel elongation ratio	RNR-2354 x BM-71	1.89	Low x Low	14.17	9.44	-
	Pusa-1121 x MTU-1081	1.93	Low x Low	-	-	-
	Yamini x Sye-632003	1.75	Low x Low	-	-	-
	Pusa-1121 x MTU-1010	1.81	Low x Low	-	-	-
Aroma	Yamini x Sye-632003	5.25	High x Low	28.43	27.86	-
	RNR-2354 x BM-71	4.66	Low x High	8.55	-	-
	Ranbir Basmati x Sye-632003	4.44	Low x Low	-	-	-
	Yamini x MTU-1081	5.37	High x High	35.21	34.67	10.08

ratio was 4.480 and 1.00 for kernel length and breadth respectively (Table 4). Similarly for Length/Breadth ratio also the gca variance for lines was higher magnitude when compared to that of testers. Further, the gca variance was higher than sca variance and gca to sca variance ratio was 1.083. Importance of additive variance for these kernel traits indicated that the variability available is fixable in nature by pursuing simple selection procedures aimed at capturing segregants with slender grain types. These results are in conformity with the findings of Sharma *et al.* (2007) and Sanjeev Kumar *et al.* (2007).

The analysis worked out to determine the gene action for cooking quality attributes revealed preponderance of non-additive gene action. Among the lines and testers the gca variance for lines was of higher magnitude than that of testers for kernel length after cooking and the sca variance was higher than gca variance and the gca to sca variance ratio was 0.995. However, for kernel breadth after cooking gca variance for testers was higher than lines. The sca variance was higher than gca variance, the gca to sca variance ratio was 0.250. With regard to kernel elongation ratio the sca variance was higher than gca variance, the gca to sca variance ratio was 0.033. (Table 5).

Pradhan and Singh (2008), Shivani *et al.* (2009) and Tyagi *et al.* (2010) earlier reported similar gene action for cooking traits. Under these circumstances it would be difficult to obtain homozygous desirable segregants. Breeding methods that would minimize the effects of restrictive recombination and release hidden variability would be of immense help in bringing about desirable improvement in these traits.

Similarly, in case of aroma also the gca variance for testers was higher when compared to that of lines. The sca variance was higher than gca variance, the gca to sca variance ratio was 0.394 indicating the importance of non additive gene control in the inheritance of this trait.

Combining ability effects:

The desirable effects of prepotency of parents is generally manifested as general and specific combining ability, heterotic behaviour and *per se* performance etc., The concept of combining ability has been the focus point in crop breeding to facilitate the selection of parents with built in genetic potential and isolating superior crosses. General combining ability is mainly due to additive and additive x additive gene action and is fixable in nature. The results for milling recovery per cent indicated that significantly positive gca effects were recorded in RNR-2354 and BM-71 which were identified as good general combiners besides recording high *per se* of more than 65 per cent.

Specific combining ability is the result of non-additivity and is not fixable in the segregating generations. In the present investigation Yamini x MTU 1010 (LxL), Ranbir Basmati x MTU-1081 (LxL) were the best specific crosses for milling recovery (Table 6). These specific crosses had milling recovery of 72 per cent and also exhibited heterosis to the tune of 5.7 per cent. Availability of parents with acceptable head rice yields and ability to combine well with other lines to result in out standing specific combinations would pave the way for good quality rice. In the present study, Line RNR-2354 recorded significantly positive gca effects for head rice recovery, and among the testers Sye-632003 recorded a significant and positive gca effect and were found to be potential donors owing to their highly positive gca. These parents also had maximum *per se* values of 56 per cent. This is indicative of bright chances of spotting good segregants from the progenies of these parents. For the most important milling trait i.e., Head rice recovery four crosses were found to have registered positively significant sca effects. Highest positive sca effect was recorded in the cross Pusa-1121 x MTU-1010 (LxL) followed by, Ranbir Basmati x BM-71 (LxL), RNR-2354 x MTU-1081 (HxL) and Yamini x MTU-1081 (LxL). These crosses also had high *per se* values ranging from 55 to 61 per cent (Table 6). In all these crosses except RNR-2354 x MTU-1081 (HxL), complimentary gene effect of poor x poor gca parents was involved resulting in best specific combiners.

For important grain dimension parameter Kernel Length (mm), among the four lines significantly positive gca effects were recorded in two lines viz., Pusa-1121 and Yamini and testers BM-71 and MTU-1010 were the best donors. These best general combiners had recorded mean kernel length of up to 8.04 mm and desirable gca effects. Close association between *per se* performance and gca for kernel length was earlier reported by Singh and Singh (1985). As there are more than one good general combiners, these parents may be intercrossed to produce a composite of these lines or an intermating population involving all possible crosses among them subjected to biparental progeny selection is expected to offer maximum improvement for this trait. Six crosses have registered positively significant sca effects. Highest positive sca effect was recorded in the cross Pusa-1121 x BM-71 (HxH) followed by Ranbir Basmati x MTU-1010 (LxH), RNR-2354 x Sye-632003 (LxL) and RNR-2354 x MTU-1081 (LxL). These crosses had high *per se* values up to 7.72 mm and exhibited maximum heterosis of 10.28 and standard heterosis of 79 per cent (Table 6). These results are in conformity with the statement of Singh and Singh (1985) that selection of crosses be made based on *per se* and sca effects.

Characters viz., kernel breadth and Length/Breadth ratio are negatively correlated as lower kernel breadth naturally enhances the Length/Breadth ratio. For kernel breadth RNR-2354, Sye-632003 and Ranbir Basmati contributed maximum favourable genes and recorded comparatively low kernel breadth values. Best general combiners for kernel breadth viz., Ranbir Basmati and RNR-2354 also produced best specific crosses viz., Ranbir Basmati x BM-71 (HxL) and RNR-2354 x MTU-1081 (HxH) which recorded significantly negative sca effects (Table 6). Singh and Singh (1985) suggested that, crosses for kernel breadth should be selected based on *per se* and sca effects. These two best specific crosses also recorded significant negative heterosis, heterobeltiosis and standard heterosis values of up to -5.15, -7.89 and -6.75 per cent respectively. Similarly, the results for length/ breadth ratio indicated that, lines Pusa-1121 and Yamini and tester BM-71 recorded significant and positive gca effects and possessed length/breadth ratio of more than 3.0. These parental lines also contributed maximum favourable genes for the improvement of length/breadth ratio and could be considered as potential donors for this trait. The results also indicated positively significant sca effects in five crosses. Highest positive sca effect was recorded in the cross Ranbir Basmati x BM-71 (LxH) followed by Pusa-1121 x BM-71 (HxH) and RNR-2354 x MTU-1081 (LxL). Among these crosses, the best specific cross Ranbir Basmati x BM-71 recorded high *per se* (3.64), and heterosis (12.84%), heteobeltiosis (7.68%) and standard heterosis (58.78%) (Table 6).

The perusal of results indicated that parents Yamini, Pusa-1121 and BM-71 appeared to have contributed maximum favourable genes for kernel length and L/B ratio. These parents can be widely used in crossing programmes to improve physical quality. Among the crosses RNR-2354 x MTU-1081 was found to be highly promising by expressing heterosis in all forms and sca effects in desirable direction for physical quality attributes.

As discussed earlier, kernel length after cooking plays pivotal role among various attributes that influence the consumption quality. Parents which were found to be outstanding for kernel length were also found to be potential donors for kernel length after cooking. During the evaluation of cooking quality attributes parents Pusa-1121, BM-71, Yamini and MTU-1010 exhibited significantly positive gca effects for kernel length after cooking and possesed up to 18.76 mm length and contributed maximum favourable genes. Thus parental performance was good indicator of their gca effects. Positively significant sca effects were recorded in four crosses for this trait. Cross Pusa-1121 x MTU-1081 (HxL) documented highest positive sca effect and was followed by RNR-2354 x BM-71 (LxH) and Yamini x Sye-632003 (HxL) which were identified as the best specific crosses (Table 7). In all these crosses at least one parent was a good general combiner. These crosses registered more than 11 per cent heterosis, 6 per cent heterobeltiosis and 22 per cent standard heterosis respectively. These crosses can be used to spot good segregants from the subsequent generations. All these crosses were result of High x Low gca parents. The superior performance of these crosses was due to additive x dominance effect which is not fixable in nature and careful selection in segregating generations for accumulation of desirable genes may lead to isolation of true breeding cultures with higher kernel elongation.

In respect of for kernel breadth after cooking significantly negative value was recorded in case of Sye-632003 with low *per se* of 2.08 mm. Three crosses viz.,Yamini x MTU-1010 (LxL), Ranbir Basmati x Sye-632003 (LxH) and Pusa-1121 x MTU-1010 (LxL) were the best specific combiners for kernel breadth after cooking (Table 7). All these crosses involved one parent with low kernel breadth after cooking. The results of combining ability analysis for kernel elongation ratio indicated that, among the parents Pusa-1121 and Sye-632003 were important. RNR-2354 x BM-71 (LxL), Pusa-1121 x MTU-1081 (LxL) and Yamini x Sye-632003 (LxL) were the best specific crosses (Table 7). This indicated specific interaction effects, most likely complimentary, Poor x Poor parental combinations performed best. These specific combinations also exhibited maximum heterosis of 14.17, heterobeltiosis of 9.44 per cent (Table 7), besides scoring highest mean value of 1.93 (Table 7).

In the present investigation also, lines MTU-1081, Yamini, Pusa-1121 and BM-71 exhibited significantly positive gca effect for aroma and were the best donors for this trait. Out of sixteen crosses studied, six crosses recorded positively significant sca effects for aroma. Highest positive sca effect were recorded in the cross Yamini x Sye-632003(HxL), RNR-2354 x BM-71(LxH) and Ranbir Basmati x Sye-632003(LxL) (Table 7). Contribution of aromatic parental lines viz., Yamini, Pusa-1121 and non aromatic lines viz., BM-71, MTU-1081 was considered important in transferring the aroma component to the best specific crosses. Tyagi *et al.* (2010) reported similar results in case of aroma. Considering the cooking quality attributes parent Yamini and Pusa-1121 contributed maximum favourable genes in desirable manner. Among the crosses RNR-2354 x BM-71 can be exploited to isolate desirable segregants with good cooking quality attributes like kernel length after cooking, volume expansion ratio, kernel elongation ratio along with aroma.

CONCLUSION

It can be concluded that the good quality of flavoured cow milk can be prepared by using cow milk, sugar (9%), guar gum (0.2%) and cocoa powder (1%). Guar gum could be better utilized to improve the rheological and mouthfeel properties of flavoured milk. Moreover the process is techno economically feasible and can be explored on commercial level.

Conflicts of interest: The authors stated that no conflicts of interest.

REFERENCES

Jones JW (1926) Hybrid vigour in rice. *Journal of American Society of Agronomy*. 18: 423-428 (Originals not seen).

Kempthorne O (1957) An introduction to genetics statistics. *John wiley and Sons Inc New York.*

Khush GS, Kumar I and Virmani SS (1988) International rice research institute Manilla, Philippines. *Hand book of hybrid rice*. 210-211.

Krishana Veni B, Shobha Rani N and Prasad ASR (2005) Heterosis for yield components and key quality traits in basmati rice. *Oryza.* 42(2): 97-102.

Kumar Babu G, Satyanarayana PV, Panduranga Rao C and Srinivasa Rao V (2010) Heterosis for yield, components and quality traits in hybrid rice (Oryza sativa L.). The Andhra Agriculture Journal 57 (3): 226-229.

Munhot MK, Sarawgi AK and Rastogi NK (2000) Gene action and combining ability for yield, grain quality and other related characters in rice. *Oryza.* 37 (1): 1-6.

Murthy PSN and Govindaswamy S (1967) Inheritance of grain size and its correlation with the hulling and cooking qualities. *Oryza.* 4(1): 12-21.

Murthy PSN (1965) Genetic studies in rice with special reference to certain quality features. M.sc. (Botany). *Thesis submitted to Orissa University of Agriculture and Technology, Bhubaneshwar*.

Pradhan SK and Singh S (2008) Combining ability and gene action for morphological and quality traits in basmati rice. *Oryza.* 45 (3): 193-197.

Roy SK, Senapati BK, Sinhamahapatra SP and Sarkar KK (2009) Heterosis for yield and quality traits in rice. *Oryza*. 46: 87-93.

Sanjeev Kumar, Singh HB and Sharma JK (2007) Combining ability analysis for grain yield and other associated traits in rice. *Oryza.* 44 (2): 108-114.

Sharma MK, Sharma AK, Agarwal RK and Richharia AK (2007) Combining ability and gene action for yield and quality characters in Ahu rices of Assam. *Indian Journal of Genetics*. 67(3): 278-280.

Shivani D, Viraktamath BC and Shobha Rani (2009) Combining ability for grain quality characters in indica/indica hybrids of rice. *Oryza.* 46(3): 152-155.

Shivani D, Viraktamath BC and Shobha Rani (2009) Heterosis for quality traits in indica/indica hybrids of rice. *Oryza.* 46 (3): 250-253.

Singh NB and Singh HG (1985) Heterosis and combining ability for kernel size in rice. *Indian Journal of Genetics.* 45(2):181-185.

Singh RK and Lal JP (2005) Expliotation of heterosis in aromatic rices for different physico-chemical traits. *Indian Journal of Genetics and plant Breeding*. 65(1):47-48.

Singh RK (2005) Heterosis breeding in aromatic rice for yield and quality characters. *Indian Journal of Genetics and Plant breeding*. 65 (3): 176-179.

Sumanaratne JP, Sudheer kumar., Ilyas Ahmed, M and Narendranath, V.V. 2007. Evaluation and development of maintainer genepool in rice for development of improved hybrids. *Pg. Thesis page No*. 84.

Verghese EJ (1950) A standard process for cooking of rice for experimental purpose. *Madras Agricultural Journal.* 37: 217- 221.

Tyagi JP Tejbir Singh and Singh VP (2010) Genetic analysis of combining ability forquality characters in Basmati rice. *Oryza.* 47 (2): 96-99.