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Research Article

Magnitude of heterosis and gene effects for yield and quality traits in rice (*Oryza sativa* L.)

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Abstract
Heterosis, heterobeltiosis, standard heterosis, GCA and SCA effects for yield and quality traits were estimated in 18 cross combinations generated through Line × Tester mating design. The estimates of heterosis were low for quality traits when compared to yield and yield components. Eighteen hybrids showed significant average heterosis, heterobeltiosis and standard heterosis for grain yield / plant. The crosses Kavya × JGL19618, Kavya × CN1448-5-2-5-5-MLD-6 , MTU1075 × JGL19618, CN1774-303-313-19-8-8 × CN1448-5-2-5-5-MLD6 and HKR08-62 × CN1448-5-2-5-5-MLD6 recorded significant heterobeltiosis for grain yield/plant. Considering both yield and quality traits together HKR08-62 × CN1448-5-2-5-5-MLD6, CN1774-303-313-19-8-8 × JGL19618, HKR 08-62 × JGL19618 and MTU1075 × CR3005-230-5-50 could be isolated for possessing desirable average heterosis, heterobeltiosis and standard heterosis. Higher estimates of heterosis was observed for grain yield / plant, filled grains per panicle, test weight, plant height, head rice recovery, effective tillers and alkali spreading value, where as estimates were low for panicle length, hulling recovery, milling recovery, length/breadth ratio, kernel length and kernel width. Majority of the crosses with high SCA effects for grain yield were involved with high / low combinations *i.e.* MTU1075 × CR3005-230-5-50, Kavya × JGL19618 for grain yield / plant, filled grains per panicle and flag leaf length indicating additive × dominance, dominance × dominance type of gene interactions for expression of traits.

Key words
Heterosis, Rice, Grain quality and Yield

Introduction

Rice is a staple food crop for more than 40% of the world population.(Khush 1997). Millions of people depend on it as a source of food and income. Thus it requires a continuous improvement in productivity besides profitability in rice farming systems on sustainable basis. Apart from the yield, food consumption pattern in the recent years encouraged the attention of the grain quality.

Heterosis is the hybridization between unrelated strains in self and cross pollinated crops that generally leads to an increased vigor and fertility. This aspect is of great significance in breeding. Commercial exploitation of heterosis for enhancing rice yields is now in an acceptable proposition. Even though several of the research publications reported heterosis in rice for yield and component traits, the information on heterosis for grain quality traits like shape and size which are ultimately important for commercial success of a variety is very limited.

The combining ability analysis provides the information about the parents for hybridization. Efficient identification of superior cross combinations is another issue in hybrid breeding. Phenotypic selection of promising parental lines can be performed either based on GCA and SCA is most important for predicting hybrid performance based on GCA effects (Fischer *et al*., 2008).

The objectives of this study were to examine the magnitude of heterosis over mid parent, better parent and standard variety to identify best combiner for grain yield and its component characters and quality traits to isolate the high heterotic crosses.

Materials and Methods

The Six elite lines with good plant type with agronomic features and quality traits *i.e*. Kavya, MTU1075, BPT5204, CN1774-303-313-19-8-8, HKR08-62 and Swarna were crossed with three testers namely CR3005-250-5-50, JGL19618 and CN1448-5-2-5-5-MLD6 in Line × Tester mating design during *Rabi* 2013 at Regional Agricultural Research Station, Warangal. The resultant F_1s along with a parents were evaluated during Kharif 2014 in Randomized block design with 3 replications. Each entry consists of 2 rows of 3 meters length with a spacing of 20cm between the rows and 15 cm between the plants. Twenty five days old seedlings were transplanted and all the recommended crop management practices were taken up to raise a good crop.

Observations were recorded in 10 plants selected randomly from each cross for all metric traits studied except days to 50% flowering. Days to 50% was computed on plot basis. Observations were recorded on 21 agronomical and quality traits *viz*., days to 50% flowering, plant height (cm), effective tillers per plant, panicle length (cm) flag leaf length (cm), flag leaf width (cm) filled seeds per panicle, test weight (g),grain yield / plant (g), hulling recovery (%), milling recovery (%), head rice recovery (%), kernel length (mm), kernel width (mm), length/breadth ratio, kernel length after cooking (mm), kernel width after cooking (mm), kernel elongation ratio, alkali spreading value, volume expansion ratio and water uptake. Observations were taken on hulling and milling with the help of SATAKE company make laboratory huller and polisher. Data on head rice recovery was recorded. Kernel length and kernel width of 20 whole milled rice were measured by means of dial caliper and length/breadth ratio was computed as per Murthy and GovidaSwamy (1967). Kernel elongation ratio was determined by soaking 5g of whole milled rice in 12 ml distilled water for 10 minutes and later cooked for 15 minutes in water bath. Observations on length and breadth of cooked kernel and kernel elongation ratio were recorded with the help of graph sheet to quantity cooking traits. Volume expansion ratio, water uptake and alkali spreading value were estimated by following standard procedures. The analysis of variance was done as formula suggested by Panse and Sukhatme (1967). The combining ability analysis for L × T design was performed as per method suggested by Kempthorne (1957). Heterosis was estimated as the percentage increase or decrease in F_1 over the mid parent (MP), better parent (BP) and Cheek (SH) by following standard procedures.

Results and Discussion

Analysis of variance for yield, yield components and quality traits revealed significant differences between genotypes except hulling recovery, volume expansion ratio and water uptake (Table 1) indicating wide range of variability for the genotypes. Significant differences among parents were observed for most of the characters except hulling recovery. milling recovery and volume expansion ratio.

Estimates of heterosis over their respective mid and better parents along with range are presented in Table-2. Out of 18 crosses, 13 crosses exhibited significant heterosis over the better parent for days to 50% flowering and range for this character was from -18.10 to 3.54. Highest negative values were observed in crosses BPT5204 × JGL19618, Kavya × CR3005-230-5-50 and BPT5204 × CN1448-5-2-5-5-MLD6. Among the yield components number of grains per panicle is considered as very important and to realize it, plants with more number of grains per panicle with increased panicle length will be selected. Excess sterility is often associated with short and compact panicle in which more spike lets are accommodated very closely. In the present study 14 crosses for number of grain per panicle and one crosses for panicle length showed significant superiority over their respective better parents which indicated the prevalence of partial dominance relationship in expression of heterosis for these characters. The cross HKR08-62 × CR3005-230-5-50, MTU1075 × CN1448-5-2-5-5-MLD6, BPT5204 × CN1448-5-2-5-5-MLD6 and MTU1075 × JGL19618 were identified as better crosses for panicle characters. The spectrum of variation for heterobeltiosis ranged from -8.45 to 11.24 and 1.23 to 118.85 percent for panicle length and number of grain per panicle respectively. Significant positive heterosis for these traits were also reported by Vanisree *et.al* (2011).

For yield per plant, the heterobeltiosis ranged from -14.60 to 184.5 percent. Seventeen crosses ex hibited significant positive hetrobeltiosis and the highest being by the crosses Kavya × JGL19618 (184.5^{**}) Kavyan × CN1448-5-2-5-5-MLD6 (176.8^{**}) MTU1075 × JGL-19618 (114.49^{**}) CN1774-303-313-19-8-8 × CN1448-5-2-5-5, MLD6 (109.3^{**}) and HKR08-62 × Cn1448-5-2-5-5-MLD6 (106.1**) respectively. All the eighteen crosses ex hibited significant standard heterosis and it was ranged from 65.44 to 333.7 percent. The crosses MTU1075 × CR3005-230-5-50 (332.7%) followed by Kavya × JGL19618 (305.38%) CN1774-303-313-19-8-8 × JGL 19618 (263.2%) HKR08-62 × CR3005-230-5-50 (258.5%) and Swarna × CR3005-230-5-50 (250.0%) exhibited significant standard heterosis.

For plant height, the heterobeltiosis and standard heterosis ranged from -1.04 to 11.76 percent and -10.14 to 48.86 percent respectively. Negative heterosis is more desirable to avoid lodging. None of the crosses showed significant negative heterobeltiosis for plant height, where as two crosses BPT5204 × CN1448-5-2-5-5-MLD6 and Swarna × CN1448-5-2-5-5 exhibited significant negative standard heterosis. Dwarf plant type is more important for hybrids to with stand lodging (Chandramohan singh and Suresh babu, 2012) In case of effective tillers heterosis over better parent and standard heterosis ranged from -21.57 to 24.01 and -21.06 to 37.96 per cent respectively. Out of 18 crosses only four and eight crosses exhibited significant positive heterobeltiosis and standard heterosis respectively. Grain yield per plant was found to be emerged as the first heterotic trait, because out of 18 crosses all 18 crosses and 17 crosses showed significant positive standard heterosis. High amount of heterosis for grain yield was mainly exhibited to corresponding superiority in filled grains per panicle, effective tillers, test weight and panicle length and only limited number of crosses exhibited heterosis for these component traits. Among the hybrids for heterobeltiosis. Kavya × JGL19618 (184.54^{**}) Kavya × CN1448-5-2-5-5MLD6 (176.81^{**}) MTU1075 × JGL19618 (114.69^{**}), CN1774-303-313-19-8-8 × CN1448-5-2-5-5-MLD6 (109.32^{**}) HKR0862 × CN1448-

5-2-5-5-MLD6(106.1**) were highly promising for grain yield per plant. Interestingly heterosis for yield was associated with heterosis for other component traits. Most promising crosses for grain yield were accompanied by heterosis for two or three component traits *viz*., MTU1075 × CR3005-230-5-50 and Kavya × JGL19618 for number of filled grains per panicle, flag leaf length, panicle length and days to 50% flowering in desired direction, CN1774-303-313-19-8-8 × JGL19618 for test weight and panicle length, while Kavya × CN1448-5-2-5-5-MLD6 for number of grains per panicle and flag leaf length and HKR08-62 × CR3005-230-5-50 for effective tillers and panicle length. This indicated that heterosis manifestation for grain yield is due to cumulative effect of highly significant and desirable heterosis for yield attributing traits (Krishnaveni *et.al* 2005, Vanisree *et.al* 2011).

For test weight 11 crosses and 12 crosses exhibited significant relative and standard heterosis with a range of -16.14 to 23.51% and -7.40 to 68.49 percent respectively. The cross MTU1075 × CR3005-230-5-50 showed significant relative and standard heterosis. Heterosis with respect to 1000 grain weight was expressed in positive as well as in negative directions which is in confirmity with the findings of Singh *et.al* 2007.

The genetic basis for higher manifestation of heterosis over better parent is mainly attributed to dominance (h) and epistatic gene interactions of dominance × dominance (l) of complementary in nature (both h and l on plus sides). Li *et.al* (1997) suggested epistasis might be an important genetic basis of heterosis in rice. For test weight, mid parental heterosis was predominant,which indicated that it was mostly under genetic effects of partial dominance. (Raju *et. al* 2005).

In general magnitude of heterosis was low for grain quality characters, when compared to heterosis for yield and yield attributes. Among the traits plant height, hulling recovery, milling recovery, kernel length, length/breadth ratio, kernel breadth after cooking, kernel elongation ratio, alkali spreading value, volume expansion ratio and water uptake recorded low heterosis values. Similar reports were stated by Reddy *et.al* (1991) and Venkatesan *et.al(* 2008).

Among the quality traits hulling per cent, milling percent and kernel length recorded less heterosis and none of the crosses showed significant heterosis for hulling and milling percent. Head rice recovery is a very important character. For this character, 11 crosses showed significant average heterosis with a range of – 30.24 to 55.62 percent, 3 crosses showed significant heterobeltiosis with a range of -36.26 to 42.41 percent and two crosses showed significant standard heterosis with a range of -23.24 to 10.77 percent respectively. The crosses MTU1075 × CN1448-5-2-5-5-MLD6 and HKR08-62 × CN1448-5-2-5-5-MLD6 showed significant average heterosis (55.82**, 35.63**) and heterobeltiosis (42.41**, 10.15**), while BPT5204 × CR3005-230-5-50 recorded significant heterobeltiosis (8.01**) and standard heterosis (10.77**) respectively. The crosses HKR08-62 × JGL19618 showed significant positive heterosis for volume expansion ratio, kernel length and kernel length after cooking, while another cross HKR08-62 ×CN1448-5-2-5-5-MLD6 manifested significant average heterosis for length/breadth ratio (-14.77**) kernel length (11.21**), kernel width (-7.89×) in desired direction, alkali spreading value (-27.27×) and kernel length after cooking (5.96×). Poor manifestation of heterosis for grain length and grain width was observed by Singh and Singh (1985), Vivekanandan and Giridharan (1995) also revealed poor heterosis for grain length/breadth ratio.

Specific combining ability refers chiefly to dominance and epistatic interaction (dominance × dominance, additive × dominance, additive ×additive) and it has relationship with heterosis. Therefore good specific combiners identified in present study for yield and its components are proposed for heterosis breeding (Table-3). It was observed that majority of the crosses with high SCA effects for grain yield were involved with high / low combinations. *i.e*. MTU1075 × CR3005-230-5-50. Kavya × JGL-19618 for yield per plant, number of grains per panicle and flag leaf length, Swarna × JGL19618 for filled grains per panicle and HKR08-62 × CN1448-5-2-5-5-MLD6 for head rice recovery indicating additive × dominance, dominance × dominance type of gene interactions for expression of traits, for which single pedigree breeding would not be sufficient instead population improvement through mass selection with random mating in early segregating generations could be prospective breeding for yield improvement in rice. Very few crosses showing low × low general combiners showed high SCA effects *i.e*. Swarna × CN1448-5-2-5-5-MLD6 for kernel breadth after cooking, MTU1075 × CR3005-230-5-50 for days to 50% flowering suggesting the epistatic gene action may be due to genetic diversity in the form of heterozygous loci and these also crosses may be ex ploited for heterosis breeding programmes. Very few crosses having high × high general combiners showed high SCA effects *i.e.* MTU1075 × CR3005-230-5-50 for filled grains per panicle, which could be ascribed due to predominance of additive × additive type of gene action. Thus in majority of the crosses, high SCA effects for yield per plant and other component characters were attributed to dominance and epistatic gene action and only few cases attributed to additive interactions. Crosses with high *per se* and SCA effects, pedigree or population improvement is suggested depending on the mode of gene action. Similar interactions have also been reported by Pradhan *et.al* (2008).

For practical value a variety / hybrid with good yield potential, combining quality features in the desirable range are useful. If we consider both yield and quality together, the crosses HKR-08-62 × CN1448-5-2-5-5-MLD6 and HKR-08-62 × JGL-19618 for days to 50% flowering, panicle length, filled grains per panicle, yield per plant, test weight, kernel length, alkali spreading value, volume expansion ratio and kernel length after cooking in desirable range. Hence there combinations could be exploited for their yield potential and quality traits to get desirable segregates in further breeding programme.

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Table 1. Analysis of variance for yield, yield components and quality traits of nine parents and 18 F_1s in rice

Source of Variation	DF	Days to 50% flowering	Effective tillers	Plant height (cm)	Panicle length (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Filled seeds /Panicle)	Test weight (g)	Yield/ plant (g)
Replicates	1	21.41	275.6	5.35	8.08	4.68	0.40**	93.35	0.58	64.4**
Genotypes	26	116.53**	5411.0**	844.6**	12.62**	79.8**	0.09**	11068.0**	27.84**	385.1**
Error (A)	26	5.33	315.4	15.27	1.71	7.0	0.03	217.77	0.58	3.42
Total	**53**	**60.18**	**2814.40**	**421.94**	**7.19**	**42.69**	**0.067**	**5538.18**	**13.96**	**191.82**

Source of Variation	DF	Hulling recovery (%)	Milling recovery (%)	Head Rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	Length/ breadth ratio	Kernel length after cooking (mm)	Kernel breadth after cooking (mm)	Kernel elongation ratio	Alkali spreading value	Volume expansio n ratio	Water uptake
Replicates	1	3.28	14.9	30.98	0.004	0.018**	0.034**	0.520	0.66	0.003	0.074	0.03	4125.6
Genotypes	26	3.07	65.4**	148.6**	0.444**	0.059**	0.178**	0.817**	5.36**	0.009**	1.514**	0.11	1649.3
Error (A)	26	2.54	9.25	4.4	0.033	0.004	0.006	0.049	0.022	0.003	0.420	0.08	1056.7
Total	**53**	**2.81**	**36.88**	**75.69**	**0.234**	**0.03**	**0.091**	**0.434**	**0.071**	**0.0060**	**0.950**	**0.094**	**1405.3**

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

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Table 2. Ex tent of Heterosis (H_1), Heterobeltiosis (H_2) and Standard heterosis (H_3) in eighteen crosses for yield, yield components and quality traits in rice

Crosses	Days to 50% flowering			Effective tillers			Plant Height (cm)			Panicle length (cm)		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
Kavya × CR3005-230	-11.49 **	-14.22 **	-14.22 **	9.95 *	5.74	14.51 *	21.70 **	4.90	44.93 **	10.42 *	4.54	17.00 **
Kavya × JGL19618	-3.57	-10.43 **	-10.43 **	-8.82	-17.72 **	2.23	-0.47	-3.62	2.90	2.58	0.00	5.30
Kavya × CN1448-5	-7.28 **	-9.48 **	-9.48 **	-20.67 **	-21.05 **	-21.05 **	7.77 *	3.86	3.86	7.12	6.30	7.95
MTU1075 × CR3005-230	-10.24 **	-13.21 **	-12.80 **	5.24	-2.36	5.74	19.18 **	2.10	41.06 **	7.66	5.33	17.88 **
MTU1075 × JGL19618	4.33 *	-3.30	-2.84	-10.15 *	-21.57 **	-2.55	6.35	2.26	9.18 *	-6.86	-7.63	-1.10
MTU1075 × CN1448-5	-1.69	-4.25	-3.79	-2.16	-5.31	-6.22	9.09 *	5.88	4.35	-6.03	-8.45	-1.99
BPT5204 × CR3005-230	-3.72	-10.78 **	-1.90	18.20 **	6.19	14.99 *	22.48 **	0.00	38.16 **	3.50	-6.71	4.42
BPT5204 × JGL19618	-7.99 **	-18.10 **	-9.95 **	31.06 **	11.04 *	37.96 **	2.49	-6.79	-0.48	3.62	-3.98	1.10
BPT5204 × CN1448-5	-7.62 **	-13.79 **	-5.21 *	11.36 *	4.19	3.19	-0.27	-3.13	-10.14 *	0.35	-5.43	-3.97
CN1774-303-313× CR3005-230	-12.16 **	-13.66 **	-16.11 **	0.37	-1.03	7.18	16.04 **	2.45	41.55 **	12.56 *	9.51	29.58 **
CN1774-303-313 ×JGL19618	-1.55	-7.32 **	-9.95 **	-7.85	-14.89 **	5.74	12.27 **	11.76 **	19.32 **	16.68 **	10.26	30.46 **
CN1774-303-313 × CN1448-5	0.00	-0.98	-3.79	7.26	4.09	9.57	17.76 **	10.50 **	16.91 **	15.86 **	7.65	27.37 **
HKR08-62 × CR3005-230	5.67 *	3.54	-2.84	45.84 **	22.53 **	32.70 **	20.87 **	6.29 *	46.86 **	11.24 *	11.24 *	24.50 **
HKR08-62 × JGL19618	-1.35	-3.68	-13.27 **	-7.33	-26.19 **	-8.29	3.20	2.26	9.18 *	4.27	1.18	13.25 *
HKR08-62 × CN1448-5	-5.37 *	-7.96 **	-12.32 **	-2.49	-14.98 *	-15.79 *	17.36 **	10.60 **	15.94 **	6.93	1.97	14.13 *
Swarna × CR3005-230	-1.83	-10.08 **	1.42	42.71 **	24.01 **	34.29 **	32.74 **	4.90	44.93 **	13.08 *	3.16	15.45 *
Swarna × JGL19618	0.24	-11.76 **	-0.47	10.94 *	-8.86	13.24 *	19.90 **	4.98	12.08 **	12.40 *	5.45	11.04
Swarna × CN1448-5	-0.23	-7.98 **	3.79	30.66 **	18.04 **	16.91 **	6.15	-1.04	-8.21 *			

*Significant at p= 0.05, **Significant at p= 0.01

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Table 2. Contd.,

Crosses	Flag leaf length(cm)			Flag leaf width(cm)			Number of grains per panicle			Test weight (g)		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
Kavya × CR3005-230	5.33	-6.39	20.41 *	22.39 *	13.89	13.89	62.43 **	23.79 **	136.15 **	12.79 **	8.28	17.68 **
Kavya × JGL19618	18.26 *	17.47 *	17.47 *	31.83 **	30.00 **	30.00 **	140.08 **	118.85 **	118.85 **	14.53 **	7.72	7.72
Kavya × CN1448-5	49.81 **	43.76 **	43.76 **	7.69	0.00	16.67	96.59 **	93.66 **	99.62 **	17.32 **	0.69	40.51 **
MTU1075 × CR3005-230	25.37 **	6.62	37.15 **	22.58 *	22.58	5.56	73.83 **	41.94 **	170.77 **	-1.00	-4.16	11.25 *
MTU1075 × JGL19618	3.89	-0.60	-1.91	13.64	7.14	4.17	85.98 **	56.37 **	88.85 **	2.36	-9.97 *	4.50
MTU1075 × CN1448-5	-9.68	-10.54	-17.77 *	4.11	-9.52	5.56	39.18 **	28.98 **	55.77 **	-14.72 **	-21.89 **	9.00
BPT5204 × CR3005-230	-0.68	-16.89 *	6.90	14.75	12.90	-2.78	37.53 **	18.95 **	126.92 **	-3.97	-10.65 *	-2.89
BPT5204 × JGL19618	4.12	-2.23	-3.52	10.77	2.86	0.00	94.79 **	54.97 **	115.77 **	1.95	-1.03	-7.40
BPT5204 × CN1448-5	5.76	2.72	-5.58	2.78	-11.90	2.78	12.70	-1.93	36.54 **	-16.14 **	-29.95 **	-2.25
CN1774-303-313 × CR3005-230	8.14	-0.68	27.75 **	13.43	5.56	5.56	65.29 **	37.30 **	161.92 **	18.15 **	-1.39	60.13 **
CN1774-303-313 × JGL19618	3.20	-1.09	6.46	12.68	11.11	11.11	66.42 **	37.50 **	73.46 **	7.32 *	-17.23 **	34.41 **
CN1774-303-313× CN1448-5	11.55	3.41	11.31	-2.56	-9.52	5.56	13.42	3.05	30.00 *	11.61 **	3.76	68.49 **
HKR08-62 × CR3005-230	-2.98	-16.44 *	7.49	16.67	12.90	-2.78	55.14 **	9.48	108.85 **	8.21 *	-6.65	39.87 **
HKR08-62 × JGL19618	-5.59	-8.33	-9.54	3.12	-5.71	-8.33	33.01 *	29.91 *	6.92	23.51 **	-1.93	46.95 **
HKR08-62 × CN1448-5	-3.26	-3.79	-10.57	-9.86	-23.81 *	-11.11	28.39 *	13.06	16.5	10.22 **	6.44	59.49 **
Swarna × CR3005-230	7.04	-18.38 **	4.99	13.33	9.68	-5.56	68.50 **	29.44 **	146.92 **	10.33 *	8.60	21.86 **
Swarna × JGL19618	5.12	-11.46	-12.63	21.87 *	11.43	8.33	109.58 **	89.10 **	93.46 **	13.64 **	1.43	13.83 *
Swarna × CN1448-5	-12.89	-24.44 *	-30.54 **	4.23	-11.90	2.78	65.54 **	64.93 **	70.00 **	-11.11 **	-19.82 **	11.90 *

*Significant at p= 0.05, **Significant at p= 0.01

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Table 2. Contd.,

Crosses	Grain yield per plant (g)			Hulling recovery%			Milling recovery %			Head rice recovery %		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
Kavya × CR3005-230	74.02 **	23.76 **	193.01 **	-1.79	-2.41	-2.41	-3.30	-3.94	-2.64	6.69 *	5.36	8.06 *
Kavya × JGL19618	234.55 **	184.54 **	305.88 **	0.40	-0.60	-0.60	-5.61	-6.86	-4.33	1.57	-1.67	5.03
Kavya × CN1448-5	204.30 **	176.81 **	237.87 **	1.62	0.06	0.06	-4.39	-7.04	-7.04	28.54 **	1.01	1.01
MTU1075 × CR3005-230	135.40 **	82.76 **	332.72 **	-0.21	-0.85	-2.11	-3.58	-6.48	-5.21	22.91 **	2.72	5.34
MTU1075 × JGL19618	123.92 **	114.69 **	206.25 **	-0.58	-0.86	-2.83	-5.40	-8.83 *	-6.36	17.11 **	-3.70	2.87
MTU1075 × CN1448-5	62.79 **	57.30 **	105.88 **	-0.09	-0.37	-2.89	-2.86	-3.27	-7.85	55.62 **	42.41 **	-1.94
BPT5204 × CR3005-230	93.74 **	39.29 **	229.78 **	0.58	-0.43	-1.68	-0.21	-3.87	-2.57	11.59 **	8.01 *	10.77 **
BPT5204 × JGL19618	55.22 **	34.02 **	91.18 **	1.20	0.55	-1.44	-3.37	-7.51	-5.01	-1.07	-6.09	0.31
BPT5204 × CN1448-5	46.58 **	35.54 **	65.44 **	3.32	3.23	0.06	-2.30	-2.58	-7.99	30.10 **	3.79	-0.39
CN1774-303-313 × CR3005-230	-1.43	-14.60 *	102.21 **	-0.25	-1.22	-2.47	-10.08 *	-13.03 **	-11.85 *	-3.29	-9.97 **	-7.67 *
CN1774-303-313× JGL19618	129.77 **	109.32 **	263.24 **	-0.19	-0.80	-2.77	-35.46 **	-37.97 **	-36.29 **	-30.24 **	-36.26 **	-31.91 **
CN1774-303-313 × CN1448-5	145.77 **	109.32 **	263.24 **	-0.06	-0.12	-3.19	-21.83 **	-21.94 **	-26.07 **	5.48	-13.15 **	-23.24 **
HKR08-62 × CR3005-230	91.18 **	51.40 **	258.46 **	-0.62	-1.52	-2.77	-1.35	-4.81	-3.52	6.46 *	0.76	3.33
HKR08-62 × JGL19618	78.01 **	75.26 **	150.00 **	0.56	0.00	-1.99	-6.08	-9.95 *	-7.52	-1.05	-8.12 *	-1.86
HKR08-62 × CN1448-5	118.93 **	106.12 **	184.93 **	1.74	1.74	-1.38	0.83	0.72	-4.87	35.63 **	10.15 *	0.85
Swarna × CR3005-230	106.96 **	47.83 **	250.00 **	-5.06 **	-6.34 **	-7.52 **	-0.66	-4.81	-3.52	9.11 **	3.55	6.20
Swarna × JGL19618	112.65 **	81.96 **	159.56 **	0.62	-0.37	-2.35	-5.30	-9.82 *	-7.38	0.55	-6.38	0.00
Swarna × CN1448-5	56.25 **	43.07 **	74.63 **	0.44	0.00	-3.07	-2.71	-3.51	-8.87 *	12.30 **	-9.00 *	-16.19 **

*Significant at p= 0.05, **Significant at p= 0.01

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Table 2. Contd.,

Crosses	Kernel length (mm)			Kernel width (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	H_1	H_2	H_3
Kavya × CR3005-230	-5.83	-10.19 **	-10.19 **	1.37	-5.13	8.82 *	-7.81 **	-16.93 **	-16.93 **	-9.80 **	-14.18 **	-14.18 **
Kavya × JGL19618	-9.09 **	-12.04 **	-12.04 **	9.37 *	2.94	2.94	-17.05 **	-20.09 **	-13.77 **	-1.63	-9.70 **	-9.70 **
Kavya × CN1448-5	2.83	0.93	0.93	19.40 **	17.65 **	17.65 **	-12.43 **	-13.61 **	-13.61 **	-2.19	-4.29	0.00
MTU1075 × CR3005-230	-3.92	-7.55 *	-7.55 *	2.63	0.00	14.71 **	-5.36	-9.53 **	-20.41 **	-7.98 *	-14.79 **	-9.70 **
MTU1075 × JGL19618	-10.14 **	-12.26 **	-12.26 **	-4.48	-13.51 **	-5.88	0.16	-9.09 **	-1.90	1.57	-9.15 **	-3.73
MTU1075 × CN1448-5	-3.81	-4.72	-4.72	2.86	-2.70	5.88	-4.01	-8.62 **	-11.08 **	-5.67	-6.34	-0.75
BPT5204 × CR3005-230	3.74	-1.02	-1.02	1.41	-7.69 *	5.88	0.94	-3.92	-14.72 **	-1.28	-4.13	-13.43 **
BPT5204 × JGL19618	3.16	-2.97	-2.97	3.23	0.00	-5.88	-1.53	-10.26 **	-3.16	0.88	0.00	-14.93 **
BPT5204 × CN1448-5	-4.66	-11.54 **	-11.54 **	4.62	3.03	0.00	-7.82 **	-11.87 **	-14.24 **	-4.72	-13.57 **	-9.70 **
CN1774-303-313 × CR3005-230	-5.12	-12.82 **	-12.82 **	13.92 **	12.50 **	32.35 **	-16.85 **	-22.39 **	-28.16 **	-17.78 **	-25.50 **	-17.16 **
CN1774-303-313 × JGL19618	-4.59	-11.11 **	-11.11 **	11.43 **	-2.50	14.71 **	-15.55 **	-21.55 **	-15.35 **	1.92	-10.74 **	-0.75
CN1774-303-313 × CN1448-5	4.07	-1.71	-1.71	4.11	-5.00	11.76 **	2.33	-0.16	-2.85	-1.73	-4.70	5.97
HKR08-62 × CR3005-230	1.38	-7.56 *	-7.56 *	6.49 *	5.13	20.59 **	-3.09	-12.18 **	-13.29 **	3.76	-4.83	2.99
HKR08-62 × JGL19618	10.00 **	1.68	1.68	14.71 **	2.63	14.71 **	-2.91	-7.04 **	0.32	19.84 **	6.21	14.93 **
HKR08-62 × CN1448-5	11.21 **	4.20	4.20	-1.41	-7.89 *	2.94	14.77 **	13.94 **	12.50 **	5.96 *	4.14	12.69 **
Swarna × CR3005-230	6.38	2.04	2.04	10.81 **	5.13	20.59 **	-5.17	-6.18	-23.10 **	0.41	0.00	-9.70 **
Swarna × JGL19618	8.90 *	2.97	2.97	4.62	-2.86	0.00	1.33	-10.85 **	-3.80	6.90	3.33	-7.46 *
Swarna × CN1448-5	2.06	-4.81	-4.81	8.82 *	5.71	8.82 *	-4.15	-11.71 **	-14.08 **	1.54	-5.71	-1.49

*Significant at p= 0.05, **Significant at p= 0.01

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Table 2. Contd.,

Crosses	Kernel breadth after cooking (mm)			Kernel elongation ratio			Alkali spreading value			Volume expansion ratio			Water uptake		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
Kavya × CR3005-230	8.86	7.50	7.50	-7.27 *	-9.58 *	-9.58 *	-5.26	-10.00	-10.00	-9.09	-9.09	-9.09	-2.97	-3.81	-3.81
Kavya × JGL19618	2.56	0.00	0.00	4.96	-2.68	-2.68	0.00	-30.00 *	-30.00 *	18.75	15.15	15.15	13.84	13.84	13.84
Kavya × CN1448-5	-4.65	-10.87	2.50	-7.52 *	-9.23 *	-5.75	-4.76	-9.09	0.00	28.36	26.47	30.30	-4.27	-16.67	12.46
MTU1075 × CR3005-230	7.32	2.33	10.00	-3.37	-5.06	-6.51	-10.00	-18.18	-10.00	13.85	12.12	12.12	11.51	4.63	17.30
MTU1075 × JGL19618	8.64	2.33	10.00	15.83 **	8.17	6.51	60.00 **	9.09	20.00	20.63	18.75	15.15	10.60	4.63	17.30
MTU1075 × CN1448-5	-3.37	-6.52	7.50	0.00	-2.58	1.15	0.00	0.00	10.00	-12.12	-14.71	-12.12	0.56	-7.95	24.22
BPT5204 × CR3005-230	1.27	0.00	0.00	-5.53	-7.36	-8.43 *	-4.76	-16.67	0.00	-1.59	-6.06	-6.06	-13.26	-19.37	-20.76
BPT5204 × JGL19618	-2.56	-5.00	-5.00	2.70	-4.26	-5.36	25.00	-16.67	0.00	4.92	3.23	-3.03	34.71	24.22	24.22
BPT5204 × CN1448-5	-4.65	-10.87	2.50	-0.57	-2.95	0.77	-13.04	-16.67	0.00	15.62	8.82	12.12	-22.71	-37.18 *	-15.22
CN1774-303-313 × CR3005-230	31.03 **	18.75 **	42.50 **	-13.15 **	-14.17 **	-16.48 **	5.88	0.00	-10.00	3.90	-9.09	21.21	17.92	15.85	13.84
CN1774-303-313× JGL19618	18.60 **	6.25	27.50 **	7.34	0.79	-1.92	83.33 **	37.50 *	10.00	-4.00	-18.18	9.09	47.07 *	43.25	43.25
CN1774-303-313 × CN1448-5	8.51	6.25	27.50 **	-5.52	-8.49 *	-4.98	-15.79	-27.27 *	-20.00	-5.13	-15.91	12.12	-0.90	-15.64	13.84
HKR08-62 × CR3005-230	19.10 **	6.00	32.50 **	-0.20	-0.80	-4.60	-10.00	-18.18	-10.00	19.40	17.65	21.21	0.00	-20.66	32.87
HKR08-62 × JGL19618	4.55	-8.00	15.00	7.59	1.59	-2.30	6.67	-27.27 *	-20.00	32.31 *	26.47	30.30	-7.12	-25.83	24.22
HKR08-62 × CN1448-5	-6.25	-10.00	12.50	-6.51	-9.96 *	-6.51	-27.27 *	-27.27 *	-20.00	17.65	17.65	21.21	-32.04 *	-38.64 *	2.77
Swarna × CR3005-230	12.64	2.08	22.50 **	-6.77	-10.41 *	-7.66	-20.00	-27.27 *	-20.00	6.67	-3.03	-3.03	-24.69	-32.97	-15.57
Swarna × JGL19618	2.33	-8.33	10.00	-4.88	-13.01 **	-10.34 *	20.00	-18.18	-10.00	27.59	19.35	12.12	3.83	-6.87	17.30
Swarna × CN1448-5	-12.77 *	-14.58 *	2.50	-1.11	-1.48	2.30	0.00	0.00	10.00	-4.92	-14.71	-12.12	-20.69	-23.33	3.46

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

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Table 3. Promising crosses with estimates of heterosis, GCA and SCA effects for yield and quality traits in rice (*Oryza sativa* L)

S. No	Characters	No. of crosses showing heterosis			Range			Average heterosis		Heterobeltiosis		Standard heterosis		GCA of Heterotic cross	SCA of the Heterotic cross
		H1	H2	H3	H1	H2	H3	Top crosses	H1	Top crosses	H2	Top crosses	H3	H2	H2
1	Days to 50% flowering	7	13	9	-12.16 to 5.67	-18.10 to 3.54	-16.11 to 3.79	CN1774-303 × CR3005-230	-12.16**	BPT5204× JGL19618	-18.10**	CN177-303× CR3005-230	-16.11**	L× M	H
								Kavya × CR3005-230	-11.49**	Kavya× CR3005-230	-14.22**	Kavya× CR3005-230	-14.22**	H× M	M
								MTU1075 × CR3005-230	-10.24**	BPT5204× CN1448	-13.79**	HKR08-62× JGL19618	-13.27**	H× M	L
								BPT5204 × JGL19618	-7.99**	CN177-303× CR3005-230	-13.66**	MTU1075× CR3005-230	-12.80**	L× M	H
								BPT5204× CN1448-5	-7.62**	MTU1075× CR3005-230	-13.21**	HKR08-62× CN1448-5	-12.32**	L× L	H
2	Effective tillers	8	4	7	-20.67 to 45.84	-21.57 to 24.01	-21.06 to 37.96	HKR08-62× CR3005-230	45.84**	SWARNA × CR3005-230	24.01**	BPT5204× JGL19618	37.96**	M× H	L
								SWARNA × CR3005-230	42.71**	HKR08-62× CR3005-230	22.53**	SWARNA× CR3005-230	34.29**	L× H	H
								BPT5204× JGL19618	31.06**	SWARNA × CN1448-5	18.04**	HKR08-62× CR3005-230	32.70**	M× H	L
								SWARNA × CN1448-5	30.66**	BPT5204× JGL19618	11.04**	SWARNA × CN1448-5	16.91**	M× L	H
								BPT5204 × CR3005-230	18.20**			BPT5204× CR3005-230	14.99**		
3	Plant height	-	-	2	-0.47 to 32.74	-1.04 to 11.76	-10.14 to 48.86	-	-	-	-	BPT5204× CN1448-5	-10.14**	H× H	L
												SWARNA× CN1448-5	-8.21**	H× H	H
4	Panicle length	7	1	9	-6.03 to 16.68	-8.45 to 11.24	-1.99 to 30.46	CN1774-303 × JGL19618	16.68**	HKR08-62× CR3005-230	11.24**	CN1774-303× JGL19618	30.48**	-	-
								CN1774-303× CN1448-5	15.86**			CN1774-303× CR3005-230	29.58**	-	-
								SWARNA× CR3005-230	13.08**			CN1774-303× CN1448-5	27.37**	-	-
								CN1774-303× CR3005-230	12.56**			HKR08-62× CR3005-230	24.50**	H× H	L
								SWARNA× JGL19618	12.40**			Kavya× CR3005-230	17.00**	-	-
5	Flag leaf length	3	2	5	-9.68 to 49.81	-8.33 to 43.76	-17.77 to 43.76	MTU1075× CR3005-230	49.81**	MTU1075× CR3005-230	43.76**	MTU1075× CR3005-230	43.76**	L× H	L
								MTU1075× JGL19618	25.37**			MTU1075× JGL19618	37.15**	L× L	L
										Kavya × CN1448-5	17.47**	CN1774-303× JGL19618	27.75**	H× L	L
								Kavya × CN1448-230	18.26**			Kavya × JGL19618	20.41**	H× L	H
												Kavya× CN1448-5	17.47**	H× L	L
6	Flag leaf width	-	1	-	-9.36 to 31.83	-23.81 to 30.0	-5.56 to 30.0			SWARNA× CR3005-230	-23.81**	-	-	L× L	L
7	Filled grains /panicle	16	14	16	-12.70 to 140.08	1.93 to 118.85	6.92 to 170.77	Kavya × CN1448-230	140.08**	Kavya × CN1448-5	118.85**	MTU1075× JGL19618	170.77**	H× L	L
								SWARNA × CN1448-5	108.58**	MTU1075× CR3005-230	93.64**	CN1774-303× JGL19618	161.92**	H× H	H
								MTU1075× CR3005-230	96.59**	MTU1075× CN1448-5	56.37**	SWARNA× JGL19618	146.92**	H× L	L
								BPT5204× CN1448-5	94.79**	BPT5204× CN1448-5	54.97**	Kavya× JGL19618	136.15**	H× L	H
								MTU1075× CN1448-5	85.98**	MTU1075× JGL19618	41.94**	Kavya× CN1448-5	118.85**	H× L	L
8	Test weight	11	-	12	-16.14 to 23.51	-29.95 to 8.60	-7.40 to 68.49	HKR08-62× CN1448-5	23.5**	-	-	HKR08-62× CR3005-230	68.49**	-	-
								CN1774-303× JGL19618	18.15**			CN1774-303× JGL19618	60.13**	-	-
								MTU1075× CR3005-230	17.32**			SWARNA× CR3005-230	59.49**	-	-
								Kavya × CN1448-5	14.53**			MTU1075× CR3005-230	40.51**	-	-
								SWARNA× CN1448-5	13.64**						
9	Yield / plant	17	17	18	-1.43 to 234.55	-14.60 to 184.54	65.49 to 333.72	Kavya × JGL19618	234.55**	Kavya × JGL19618	184.54**	MTU1075× CR3005-230	332.72**	H× L	H
								Kavya × CN1448-5	204.30**	Kavya × CN1448-5	176.81**	Kavya× JGL19618	305.38**	H× L	H
								CN1774-303× CN1448-5	148.77**	MTU1075× JGL19618	114.69**	CN1774-303× JGL19618	263.24**	H× L	H
								MTU1075× CR3005-230	135.40**	CN1774-303× CN1448-5	109.32**	HKR08-62× CR3005-230	258.46**	H× L	L
								CN1774-303× JGL19618	129.77**	HKR08-62× CN1448-5	106.12**	SWARNA× CR3005-230	250.00**	L× L	L
10	Hulling percent	-	-	-	-5.06 to 3.2	-6.34 to 3.23	-7.52 to 0.06	-	-	-	-	-	-	-	-
11	Milling recovery	-	-	-	-35.46 to 0.83	-37.97 to 0.72	-36.29 to -2.64	-	-	-	-	-	-	-	-

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S. No	Characters	No. of crosses showing heterosis			Range			Average heterosis		Heterobeltiosis		Standard heterosis		GCA of Heterotic cross	SCA of the Heterotic cross
		H1	H2	H3	H1	H2	H3	Top crosses	H1	Top crosses	H2	Top crosses	H3	H2	H2
12	Head rice recovery	11	3	2	-30.24 to 55.62	-36.26 to 42.41	-23.24 to 10.77	MTU1075× CN1448-5 HKR08-62× CN1448-5 BPT5204× CN1448-5 Kavya × CN1448-5 MTU1075× CR3005-230	55.63** 35.63** 30.10** 28.54** 22.91**	MTU1075× CN1448-5 HKR08-62× CN1448-5 BPT5204× CR3005-230	42.41** 10.15** 8.01**	BPT5204× CR3005-230 Kavya× CR-3005-230	10.77** 8.06**	H× L H× L H× H	H L L
13	Kernel length	3	-	-	-10.14 to 11.21	-12.26 to 4.20	-12.82 to 4.20	HKR08-62× CN1448-5 HKR08-62× JGL19618 SWARNA× JGL19618	11.21** 10.00** 8.90**	-	-	-	-	-	-
14	Kernel width	-	3	-	-1.41 to 19.40	-7.89 to 17.65	-5.88 to 32.35	-	-	MTU1075× JGL19618 HKR08-62× CN1448-5 BPT5204× CR3005-230	-13.51** -7.89** -7.69**	-	-	H× H L× L H× L	H L L
15	Length/ Breadth ratio	1	1	1	-17.05 to 14.77	-22.39 to 13.94	-28.16 to 12.50	HKR08-62× CN1448-5	14.77**	HKR08-62× CN1448-5	13.94**	HKR08-62× CN1448-5-2	12.50**	H× H	L
16	Kernel length after cooking	2	-	2	-17.78 to 19.84	-25.50 to 6.21	-14.93 to 14.93	HKR08-62× JGL19618 HKR08-62× CN1448-5	19.84** 5.96**	-	-	HKR08-62× JGL19618 HKR08-62× CN1448-5	14.93** 12.69**	- -	- -
17	Kernel breadth after cooking	1	1		-12.77 to 31.03	-14.58 to 18.75	2.50 to 42.50	SWARNA× CN1448-5	-12.77**	SWARNA× CN1448-5	-14.58**	-	-	-	-
18	Kernel elongation ratio	1	1	-	-13.15 to 15.83	-14.17 to 13.0	-16.48 to 6.51	MTU1075× JGL19618	15.83**	-	-	-	-	-	-
19	Alkali spreading value	2	1	-	-27.27 to 83.33	-30.00 to 37.50	-30.0 to 20.0	CN1774-303× JGL19618 MTU1075× JGL19618	83.33** 60.00**	CN1774-303× JGL19618	-	37.50**	-	L× L	L
20	Volume expansion ratio	1	-	-	-12.12 to 32.31	-18.18 to 26.47	-12.12 to 30.30	HKR08-62× JGL19618	32.31*	-		-	-	-	-
21	Water uptake	1	-	-	-32.04 to 47.07	-38.64 to 43.25	-20.76 to 43.25	CN1774-303× JGL19618	47.07**	-		-	-	-	-

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