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COMBINING ABILITY AND HETEROSIS STUDIES FOR SELECTING ELITE PARENTS AND HYBRIDS IN RICE (*Oryza* SATIVAL.)

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ABSTRACT

Combining ability and heterosis studies in rice with a set of 32 hybrids along with their parents (B and R lines) and standard checks viz., MTU 1010 and US 314 were evaluated for grain yield and related traits.The mean performance of the hybrids for most of the characters was higher than that of parents. The analysis of variance revealed significant differences among parents, lines and hybrids for most of the characters studied. Degree of dominance was more than unity for all the traits except for days to 50% flowering (0.72) plant height (0.68) and number of grains per panicle (0.68). SCA variances were higher than GCA variances for most of the characters, which indicated the predominance of non-additive gene action. The gca effects revealed that among the lines IET-19321 had significant gca effects in desired direction for several traits including yield. Among the testers, CMS 59A was a good general combiner. Among thirty two hybrids, CMS 59A x TP 30433, CMS 23A x TP 30433 and JMS13 x WGL 823 were found good specific combiners. Seventeen hybrids were recorded positive significant standard heterosis over variety (MTU 1010), whereas eight hybrids were recorded positive significant heterosis over hybrid check (US 314). Overall data revealed that CMS 23A x JGL 20649, JMS 13A x JGL 5614, CMS 64A x WGL 823, CMS 64A x IET 19321 and JMS 13A x WGL 823 were identified as potential hybrids with respect to all characters based on their sca and heterosis estimates.

INTRODUCTION

Rice is one of the foremost cereal crop feeding over more than half of world's population. But we are in the need to increase production to meet this growing population (Kumar *et al*., 2014). It is the only crop in the world that is grown in most fragile ecosystem and hence, second green revolution is possible only if rice research is undertaken vigorously. This in turn elucidates that we must reorient our research towards yield improvement. Theoretically, rice still has great yield potential to be tapped and there are many ways to raise rice yield, such as molecular breeding, new plant type and hybrid rice technology. Among three, the most effective and economical way to increase productivity is to develop hybrid varieties based on the fruitful experience gained in China (Galal Bakr Anis *et al*., 2017). Exploitation of heterosis for yield increase in rice through hybrid varieties becomes a practical option. This seems to be more effective, as commercial rice hybrid had been reported to exhibit 38% more yield compared to best commercial variety (Singh *et al*., 2013).

Exploitation of heterosis in rice has been considered as an important tool for breeding the present yield barriers. The study on the magnitude of heterosis is the most important prerequisite for undertaking any heterosis breeding program (Saravanan *et al*., 2008).

The first step in generating promising hybrids is the selection of desirable parents. The contribution of parents in a cross and nick well ability of parents in crosses can be assessed by biometrical methods through combining ability studies. Line × Tester analysis devised by Kempthorne (1957) is one of the effective mating design followed to estimate gca and sca which enables the effective screening of parental lines. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis (Sarker *et al*., 2002).The knowledge of combining ability is useful to assess nicking ability in self-pollinated crops and at the same time elucidate the nature and magnitude of gene actions involved, provides to the breeder about insight of nature and relative magnitude of fixable and non-fixable genetic variances *ie*. due to dominance or epistatic components (Pratap *et al*., 2013).

Commercial exploitation of heterosis in rice is being explored at present in many rice growing countries. The technology revolutionized the rice farming through boosting the yield from 35 to 40 q/ha from straight varieties of rice to the tune of 65 to 70 q/ha in rice hybrids. This helped the farmers in raising their economic status and helped in changing areas under straight varieties to rice hybrids in China (Yuan *et al*., 1989). In India so far 117 hybrids were released for cultivation (Anonymous, 2019).

For the exploitation of heterosis, it is imperative to study the magnitude of standard heterosis. Breeding strategies based on the selection of hybrids require expected level of heterosis as well as the specific combining ability (Satheesh kumar *et al*., 2016). It is also prerequisite to identify the parents having desirable general combining ability for various important traits. Keeping the context in view, the present investigation was aimed to study the combining ability of parents and identify heterotic crosses for grain yield and important yield attribute.

MATERIALS AND METHODS

The present investigation was conducted at Rice Research Center of Agricultural Research Institute, Hyderabad, Telangana, India, during Kharif, 2017. Experimental material consisting of 32 F1 hybrids obtained by line x tester mating generated by crossing 8 lines and 4 testers (Table 1). These hybrids along with 8 pollen parents (lines), 4 maintainer lines of CMS 23A, CMS 59A, CMS 64A and JMS 13A (testers) and 2 checks were grown in single row of 3 m length with 2 replications in RBD with spacing of 30 x 15 cm. Recommended agronomic practices were followed to raise a good crop.

Observations were recorded on 5 randomly selected plants for estimation of different traits *viz*., plant height (cm), number of productive tillers per plant, panicle length (cm), spikelet fertility (%) and grain yield per plant (g). However, days to 50% flowering was recorded on whole plot basis, whereas number of grains per panicle, 1000 grain weight (g), kernel length (mm), kernel breadth (mm), kernel length breadth ratio, hulling percent, milling percent and head rice recovery (%) were recorded on a random sample taken in each plot as per the standard procedures (SES, 2013). The character means of each replication was subjected for analysis of variance (Panse and Sukhatme, 1967), Combining ability analysis and the testing of significance of different genotypes was based on the procedure given by Kempthorne (1957) and also estimated the heterosis over the better parent, standard variety and standard hybrid (Fonseca and Patterson, 1968). Computer software Windostat version 9.1 has been used for analysis of data.

RESULTS AND DISCUSSION

The results showed that the mean performance of the hybrids for most of the characters was higher than that of parents. Among the thirty two hybrids, none of the hybrids was superior for all the characters studied. However, the hybrid CMS 23A x TP 30433 had better mean performance for majority of the characters barring number of grains per panicle and head rice recovery. Other hybrids, CMS 23A x JGL 20649 and CMS 59A x JGL 21071 were exhibited high mean performance for 10 characters and JMS 13A x IET19321, CMS 59A x IET 26106, CMS 59A x TP 30433, CMS 23A x JGL 5614, and CMS 64A x JGL 21071 were exhibited high mean performance for nine characters. In general, eighteen hybrids were superior for grain yield per plant.

The analysis of variance revealed significant differences for all the characters studied for parents and hybrids. (Table 2). The variance due to hybrid was partitioned into variance due to lines, testers and lines × testers for all the characters. The variance due to lines was significant for all the characters. Variance due to testers was significant for all traits except the head rice recovery. The variance due lines × testers were significant for the six characters studied *viz*., days to 50% flowering, plant height, panicle length, number of grains per panicle, kernel length and kernel length breadth ratio. Parents × hybrids showed significant variance for nine characters indicating superiority of hybrids and presence of heterosis for almost all the traits studied. These results emphasized the importance of combining ability studies for indicating the variability in the material studied and there is a good scope for identifying promising parents and hybrid combinations for improving yield through its components.

In the present investigation, the degree of dominance was more than unity for all the traits except for days to 50% flowering (0.72), plant height (0.68) and number of grains per panicle (0.68) (Table 3). SCA variances were higher than GCA variances for most of the characters, which indicated the predominance of non-additive gene action. The traits *viz*., panicle length (0.86), number of productive tillers per plant (0.11), spikelet fertility % (0.14), 1000 grain weight (0.94), hulling percent (0.03), milling percent (0.1), head rice recovery % (0.42), grain yield per plant (0.13), kernel length (0.71), kernel breadth (0.55) and kernel length breadth ratio (0.5) shown non-additive gene action, while days to 50% flowering (1.94), plant height (2.17) and number of grains per panicle (2.18) exhibited additive gene action. The preponderance of non-additive type of gene actions for majority of the traits was earlier reported by Thakare *et al*. (2013).

The gca effect was significant and positive for IET 19321 (7.91) followed by JGL 21071 (3.37) and WGL 823 (2.66) among lines and CMS 64A (1.50) among testers for grain yield per plant. The gca effects revealed that among the lines IET 19321 had significant gca effects in desired direction for important traits *viz*., grain yield per plant, spikelet fertility %, 1000 grain weight, milling percent, and head rice recovery % (Table 4).

Table 1: Details of experimental material used for study

S. No	Genotype	Source	Features
	Lines		
1.	IET 19321	IIRR, Hyderabad	Medium duration, medium bold grain, high yield
2.	IET 26227	IIRR, Hyderabad	Medium duration, long bold grain
3.	WGL 823	RARS, Warangal	Medium duration, medium slender grain
4.	IET 26106	IIRR, Hyderabad	Mid early duration, dwarf, medium slender grain
5.	TP 30433	IRRI, Philippines	Short duration, long bold grain
6.	JGL 20649	RARS, Jagital	Short duration, long slender grain
7.	JGL 5614	RARS, Jagital	Medium duration, medium bold grain
8.	JGL 21071	RARS, Jagital	Short duration, long slender grain
	Testers		
1.	CMS 23B	IRRI, Philippines	Early duration, long bold grain
2.	CMS 59B	IRRI, Philippines	Mid early duration, long slender grain
3.	CMS 64B	IRRI, Philippines	Mid early duration, long slender grain
4.	JMS 13B	RARS, Jagital	Medium duration, medium slender grain

Table 2: Analysis of variance for different characters in rice

Source of variation	DF	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
Replications	1	8.30 *	52.1	0.86	0.9	1123	0.05	0.2	0.001	0.19	1.7	0.0003	0.00001	0.0004	5.45
Treatments	43	125.40**	187.20**	11.80**	7.00**	5705.50**	83.10**	18.40**	4.20**	7.80**	23.80**	0.98**	0.06**	0.45**	111**
Parents	11	151.40**	161.60**	6.30**	10.00 **	4482.10**	63.10**	21.60**	5.20**	10.40**	32.30**	1.30**	0.10**	0.0**	24.40**
Lines	7	170.40**	126.80**	7.20**	12.20**	2889.30**	56.30**	30.50**	7.80**	4.40*	45.00**	1.40**	0.16**	1.10**	35.40**
Testers	3	124.50**	274.70**	4.20**	7.50*	9661.40**	55.30**	7.80**	0.60**	27.90**	13.2	0.60**	0.08**	0.50**	6.90*
Line X Tester	1	99.20 **	65.30*	6.00**	2.3	93.5	134.20**	0.01	0.5	0.4	0.5	2.50**	0	0.40**	0.07
Parents X hybrids	1	602.50 **	1204.60**	14.00**	3.5	26569.40**	37.4	4.80*	12.70**	6.9	53.40**	0.07	0.03**	0.003	358**
Hybrids	31	100.80**	163.50**	13.70**	6.00**	5466.50**	91.70**	17.70**	3.60**	6.90**	19.80**	0.90**	0.04**	0.30**	133.70**
Error	43	1.8	13.9	0.4	2.6	852.5	12.1	1.09	1.5	1.9	4.9	0.03	0.001	0.01	1.7
Total	87	62.9	100.1	6.1	4.8	3254.2	47	9.6	2.8	4.8	14.2	0.5	0.03	0.23	55.75

*Significant at P=0.05 level ,**Significant at P=0.01 level;X1 =Days to 50% flowering,X2 = Plant height (cm), X3 =Panicle length (cm),X4 =No of productive tillers,X5 = No. of grains per panicle, X6 = Spikelet fertility(%),X7 =1000 grain weight (g), X8 =Hulling percent,X9 =Milling percent, X10 =Head rice recovery, X11 =Kernel length (mm),X12 =Kernel breadth (mm),X13 =Kernel length breadth ratio,X14 = grain yield per plant (g) SV = source of variation ,DF = degrees of freedom

Among the testers, CMS 59A was a good general combiner for the traits viz., grain yield per plant, spikelet fertility %, 1000 grain weight, panicle length and head rice recovery %. It was observed in certain instances that the lines and testers with good perse performance have not been good general combiners and vice versa, thus the association between perse performance and GCA effects was evident in the present study indicated the effectiveness of choice of parents based on perse performance alone was not appropriate for predicting the combining ability of the parents.

The sca effects revealed that among thirty two hybrids, CMS 23A × JGL 20649 (15.53) recorded highest significant positive sca effect for grain yield followed by CMS 64A × IET 19321 (13.07), JMS 13A × JGL 5614 (11.23), CMS 59A × TP 30433 (7.67) and JMS 13A × IET 26227 (6.07) and were considered as desirable. Eleven hybrids recorded significant and negative sca effects for days to flowering and CMS 23A × IET 19321 (-5.40), CMS 64A × JGL 20649 (-4.06), CMS59A × IET 19321 (-4.0), CMS 59A × WGL 823 (-3.97) and JMS 13A × TP 30433 (-3.84) were considered to be highly desirable for earliness (Table 5).

Six hybrids viz., CMS 23A × TP 30433 (10.38), JMS 13A × WGL 823 (7.71), JMS 13A × JGL 21071 (6.67), CMS 59A × IET 26106 (5.94), CMS 59A × TP 3043 (5.2) and CMS 23A × IET 26106 (5.13) recorded significant positive sca effects for spikelet fertility (%).

Five hybrids viz., JMS 13A × JGL 20649 (3.72), CMS 23A × IET 26227 (3.27), CMS 64A × JGL5614 (3.21), CMS 23A × TP 30433 (2.44) and CMS 59A × TP 30433 (1.77) were having bold grains and recorded significant positive sca effects for1000 grain weight.Three lines viz., WGL 823 (-3.10), JGL 20649 (-2.36), JGL 21071 (-1.52), only one tester JMS 13A (-2.40) and seven hybrids viz., CMS 64A × TP 30433 (-2.46), JMS 13A × WGL 823 (-2.02), CMS 23A × IET 19321 (-1.73), CMS 59A × JMS 20649 (-1.71), JMS 13A × TP 30433 (-1.70), JMS 13A × JGL 5614 (-1.610) and CMS 64A × JMS 20649 (-1.53) were fine grain type and recorded significant negative gca and sca effects, respectively.

The sca effect was significant and positive for two hybrids viz., CMS 59A × TP 30433 (5.32) and CMS 59A × IET 26106 (3.96) for head rice recovery and identified as desirable.

CMS 59A × TP 30433 was found to be good specific combiner for traits viz., grain yield per plant, 1000 grain weight, spikelet fertility %, milling percent and head rice recovery and whereas CMS 23A x TP 30433 and JMS13 x WGL 823 were found to be good specific combiner for grain yield and other important traits.

Heterosis studies showed that the heterobeltiosis over better parent ranged from -41.18 to 65.99 % for grain yield (Table 6). Thirteen hybrids showed significant positive heterosis for this trait. Highest significant positive heterobeltiosis was recorded by CMS 64A x IET19321, CMS 23A x JGL 20649, CMS 64A x WGL 823 and JMS 13A x JGL 5614. The similar trend of heterosis was also reported by Padmavathi *et al.* (2013).

For standard heterosis over variety (MTU 1010) seventeen hybrids were recorded positive significant heterosis. Highest significant positive heterosis was recorded for CMS 64A ×IET-

Table 3: Estimates of general and specific combining ability variances and proportionate gene action in rice

Character	Source of variation			Degree of Dominance (σ2sca/σ^2gca)1/2	Nature of gene action
	σ^2 gca	σ^2sca	σ^2gca/σ^2 sca		
Days to 50% flowering	100.18	51.48	1.94	0.72	Additive
Plant height (cm)	129.68	59.58	2.17	0.68	Additive
Panicle length (cm)	8.08	9.66	0.86	1.074	Non additive
Number of productive tillers per plant	0.94	7.91	0.11	2.9	Non additive
Number of grains per panicle	4380.12	2003.53	2.18	0.68	Additive
Spikelet fertility (%)	23.98	162.42	0.14	2.6	Non additive
1000 grain weight (g)	12.97	13.78	0.94	1.03	Non-additive
Hulling percent	0.16	5.58	0.029	5.83	Non additive
Milling percent	1.02	10.35	0.099	3.17	Non-additive
Head Rice Recovery (%)	7.35	17.68	0.42	1.55	Non additive
Kernel length (mm)	0.73	1.02	0.71	1.18	Non additive
Kernel breadth (mm)	0.025	0.046	0.55	1.35	Non additive
Kernel length breadth ratio	0.2	0.04	0.5	1.41	Non additive
Grain yield per plant (g)	35.34	263.33	0.13	2.73	Non additive

Table 4: Estimates of general combining ability effects in lines and testers for yield and yield contributing characters in rice

Parents	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of productive tiller per plant	Number of grains per panicle	Spikelet fertility (%)	1000 grain weight (m)	Hulling percent	Milling percent	Head rice recovery %	Grain yield per plant (m)
LINES											
IET 19321	6.40**	7.70**	0.458	0.95	1.85	2.54*	1.53**	-0.334	2.11**	3.86 **	7.91**
IET 26227	0.4	-2.83*	-2.20**	-1.18*	-1.18	-3.60**	0.35	0.751	-0.3	-3.62**	-2.70**
WGL 823	-2.60**	-2.33	-2.20**	0.45	33.55**	4.21**	-3.10**	-0.31	-0.47	0.17	2.66**
IET 26106	4.00**	-6.33**	-1.40**	-0.18	-58.00**	-4.42**	0.59	-0.92*	-1.59**	0.24	-7.30**
TP30433	1.60**	-2	0.46	-0.18	-48.00**	-0.74	2.41**	-0.23	-0.39	0.55	-3.10**
JGL 20649	-9.60**	-0.89	3.77	-0.68	-0.70**	4.24**	-2.36**	0.75	0.57	-2.01*	-1.40**
JGL 5614	0.8	-7.58**	-1.80**	0.76	-8.67	-2.77*	2.09**	-0.06	-0.03	1.59	0.51
JGL 21071	-1.13 *	14.30**	2.83**	0.07	29.40**	0.54	-1.52**	0.36	0.11	-0.78	3.37**
TESTERS											
CMS 23A	-7.10**	-6.40**	-0.50**	0.38	43.0**	-0.52	0.85**	0.13	0.09	-1.01	0.25
CMS 59A	-0.22	5.11**	0.89**	0.41	-3.64	2.51**	1.41**	-0.42	0.3	1.14*	-2.00**
CMS 64A	2.88**	-0.39	0.08	-0.96*	-15.80*	0.6	0.14	0.12	0.32	-0.34	1.50**
JMS 13A	4.47**	1.67	-0.50**	0.16	30.80**	-2.59**	-2.40**	0.18	-0.08	0.2	0.53

Table 5: Estimates of specific combining ability effects in crosses for yield and yield contributing characters in rice

Hybrids	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of productive tillers per plant	Number of grains per panicle	Spikelet fertility (%)	1000 grain weight (m)	Hulling percent	Milling percent	Head rice recovery %	Grain yield per plant (m)
CMS 23A × IET 19321	-1.06	-0.61	-1.72**	-1.45	12.97	4.69	-1.73*	0.19	1.47	0.83	-2.38*
CMS 59A × IET 19321	2.53*	6.64*	2.67**	0.77	34.39	-2.89	0.99	0.31	2.10*	1.17	-4.02**
CMS 64A × IET 19321	-0.31	-5.86*	-2.02**	-0.85	-17.31	-2.93	-0.07	0.2	-1.87	0.15	13.07**
JMS 13A × IET 19321	-1.16	-0.17	1.07*	1.52	-30.05	1.14	0.8	-0.7	-1.7	-2.14	-6.67**
CMS 23A × IET 26227	-4.00**	0.14	-0.85	-0.57	4.87	0.45	-0.83	-0.31	0.08	-0.45	-6.64**
CMS 59A × IET 26227	-5.40**	4.39	0.04	0.4	-12.51	-1.5	0.01	0.06	-0.07	0.32	-1.03
CMS 64A × IET 26227	5.00**	-3.61	0.11	0.77	-9.01	-3.26	-0.45	-0.05	0.13	-0.71	1.61
JMS 13A × IET 26227	4.41**	-0.92**	0.7	-0.6	16.65	4.32	1.27	0.3	-0.11	0.84	6.07**
CMS 23A × WGL 823	-1.06	0.64	0.91	-1.95	-60.53**	-11.00**	3.27**	-1.5	-1.36	0.35	-10.33**
CMS 59A × WGL 823	-3.97**	-7.11	-1.46**	-0.98	31.39	-0.56	-0.63	-0.12	-0.74	-3.06	0.88
CMS 64A × WGL 823	-2.56*	-1.61	1.11*	0.4	43.19*	3.85	-0.62	0.18	-0.54	0.09	4.12**
JMS 13A × WGL 823	7.59**	8.08**	-0.55	2.52*	-14.05	7.71**	-2.02*	1.45	2.64*	2.63	5.33**
CMS 23A × IET 26106	-0.13	1.64	-1.02*	-1.57	11.57	5.13*	-1.26	1.35	-0.9	-3.88*	-0.62
CMS 59A × IET 26106	2.47*	-4.36	1.52**	-0.85	-20.11	5.94*	1.42	0.9	1.22	3.96*	5.79**
CMS 64A × IET 26106	0.37	-0.61	-0.42	0.27	17.29	4.61	1.22	1.2	1	1.28	4.23**
JMS 13A × IET 26106	-2.72**	3.33	-0.08	2.15	-8.75	-15.69**	-1.38	-3.45**	-1.32	-1.35	-9.40**
CMS 23A × TP 30433	-0.25	-0.92	-0.22	1.93	21.67	10.38**	2.44**	0.92	0.22	-0.45	4.68**
CMS 59A × TP 30433	0.34	-0.67	-2.33**	0.65	-16.11	5.20*	1.71*	1.46	2.52*	5.32**	7.69**
CMS 64A × TP 30433	3.75**	4.08	1.23*	-1.23	1.49	-6.73*	-2.46**	-0.74	0.63	-1.12	-8.11**
JMS 13A × TP 30433	-3.84**	-2.48	1.32**	-1.35	-7.05	-8.85**	-1.70*	-1.64	-3.36**	-3.75*	-4.25**
CMS 23A × JGL 20649	3.43**	-3.55	-1.53**	1.68	4.71	-0.94	-0.47	1.31	2.60*	2.53	15.53**
CMS 59A × JGL 20649	2.78**	6.45*	0.86	0.15	1.99	-2.13	-1.71*	-0.19	-1.7	-2.79	-3.85**
CMS 64A × JGL 20649	-4.06**	4.7	1.17*	1.52	17.72	1.53	-1.53*	0.37	-0.33	-0.64	-7.41**
JMS 13A × JGL 20649	-2.16*	-7.61**	-0.49	-3.35**	-24.42	1.54	3.72**	1.14	-0.57	0.9	-4.25**
CMS 23A × JGL 5614	2.06*	2.14	3.03**	2.99*	-7.7	-4.32	-0.54	1.59	-0.55	2.26	4.21**
CMS 59A × JGL 5614	2.66**	-1.61	-0.83	-2.04	-17.18	0.09	-1.07	-2.50**	-2.01*	-2.39	-7.27**
CMS 64A × JGL 5614	-2.19*	1.89	-1.27*	-0.66	-42.79*	1.08	3.21**	-0.66	0.44	-0.5	-8.17**
JMS 13A × JGL 5614	-2.53*	-2.42	-0.93	-0.29	67.67**	3.15	-1.61*	1.53	2.12*	0.63	11.23**
CMS 23A × JGL 21071	1	0.52	1.41**	-1.07	12.42	-4.38	-0.89	-0.92	-1.53	-1.19	-4.44**
CMS 59A × JGL 21071	-1.41	-3.73	-0.46	1.9	-1.86	-4.16	-0.73	0.04	-1.32	-2.52	1.81
CMS 64A × JGL 21071	0	1.02	0.11	-0.28	-10.56	1.88	0.69	-0.49	0.55	1.46	0.66
JMS 13A × JGL 21071	0.41	2.2	-1.05*	-0.6	-0.001	6.67*	0.92	1.37	2.31*	2.25	1.97*

Table 6: Heterobeltiosis and standard heterosis of hybrids for yield and yield contributing traits in rice

Cross	Days to 50% flowering			Plant height (cm)			Panicle length (cm)			Number of productive tillers per plant		
	HB	SVC	SHC	HB	SVC	SHC	HB	SVC	SHC	HB	SVC	SHC
CMS 23A × IET 19321	8.92 **	-4.47 **	-11.86 **	26.05 **	-2.81	-9.27 **	-17.24 **	-12.73 **	11.63 **	1.85	-5.17	10
CMS 59A × IET 19321	2.67	7.26 **	-1.03	15.89 **	13.39 **	5.85	2.59	8.18 **	38.37 **	4.92	10.34	28.00 *
CMS 64A × IET 19321	2.94 *	7.54 **	-0.77	21.45 **	-2.16	-8.67 **	-16.38 **	-11.82 **	12.79 **	-3.7	-10.34	4
JMS 13A × IET 19321	1.57	8.38 **	0	11.01 **	4.54	-2.42	-7.76 **	-2.73	24.42 **	4.76	13.79	32.00 *
CMS 23A × IET 26227	-2.55	-14.53 **	-21.13 **	15.13 **	-11.23 **	-17.14 **	-2.2	-19.09 **	3.49	-23.08 *	-13.79	0
CMS 59A × IET 26227	-12.30 **	-8.38 **	-15.46 **	6.28	2.38	-4.44	-4.85	-10.91 **	13.95 **	-16.92	-6.9	8
CMS 64A × IET 26227	2.14	6.70 **	-1.55	12.60 **	-9.29 **	-15.32 **	-3.06	-13.64 **	10.47 **	-23.08 *	-13.79	0
JMS 13A × IET 26227	1.05	7.82 **	-0.52	0.69	-5.18	-11.49 **	-1.04	-13.64 **	10.47 **	-24.62 *	-15.52	-2
CMS 23A × WGL 823	-2.55	-14.53 **	-21.13 **	16.25 **	-10.37 **	-16.33 **	-3.03	-12.73 **	11.63 **	0	-12.07	2
CMS 59A × WGL 823	-13.90 **	-10.06 **	-17.01 **	7.5	-7.13 *	-13.31 **	-10.68 **	-16.36 **	6.98 *	-9.84	-5.17	10
CMS 64A × WGL 823	-9.09 **	-5.03 **	-12.37 **	15.28 **	-7.13 *	-13.31 **	0	-10.00 **	15.12 **	17.02	-5.17	10
JMS 13A × WGL 823	2.93 *	8.10 **	-0.26	19.25 **	3.02	-3.83	-9.09 **	-18.18 **	4.65	7.94	17.24	36.00 **
CMS 23A × IET 26106	7.01 **	-6.15 **	-13.40 **	12.89 **	-12.96 **	-18.75 **	-6.73 *	-16.91 **	6.28	-12.28	-13.79	0
CMS 59A × IET 26106	3.89 *	4.47 **	-3.61 *	4.94	-8.21 *	-14.31 **	3.88	-2.73	24.42 **	-13.11	-8.62	6
CMS 64A × IET 26106	5.00 **	5.59 **	-2.58	12.06 **	-9.72 **	-15.73 **	-2.04	-12.73 **	11.63 **	-8.77	-10.34	4
JMS 13A × IET 26106	3.33 *	3.91 *	-4.12 **	9.14 *	-4.54	-10.89 **	-3.06	-13.64 **	10.47 **	1.59	10.34	28.00 *
CMS 23A × TP 30433	3.82 *	-8.94 **	-15.98 **	14.85 **	-11.45 **	-17.34 **	0	-7.27 **	18.60 **	16.36	10.34	28.00 *
CMS 59A × TP 30433	2.89	-0.56	-8.25 **	6.28	-1.3	-7.86 *	-3.88	-10.00 **	15.12 **	-3.28	1.72	18
CMS 64A × TP 30433	10.40 **	6.70 **	-1.55	21.72 **	-1.94	-8.47 **	7.84 **	0	27.91 **	-16.36	-20.69	-8
JMS 13A × TP 30433	3.47 *	0	-7.73 **	1.4	-5.83	-12.10 **	5.88 *	-1.82	25.58 **	-20.63	-13.79	0
CMS 23A × JGL 20649	-5.73 **	-17.32 **	-23.71 **	13.17 **	-12.74 **	-18.55 **	11.11 **	0	27.91 **	10.91	5.17	22
CMS 59A × JGL 20649	-1.53	-10.34 **	-17.27 **	33.88 **	5.83	-1.21	21.36 **	13.64 **	45.35 **	-9.84	-5.17	10
CMS 64A × JGL 20649	-6.13 **	-14.53 **	-21.13 **	25.96 **	-0.43	-7.06 *	24.24 **	11.82 **	43.02 **	0	-5.17	10
JMS 13A × JGL 20649	-1.84	-10.61 **	-17.53 **	14.75 **	-9.29 **	-15.32 **	15.15 **	3.64	32.56 **	-36.51 **	-31.03 **	-20
CMS 23A × JGL 5614	5.73 **	-7.26 **	-14.43 **	12.04 **	-13.61 **	-19.35 **	11.58 **	-3.64	23.26 **	-7.69	24.14 *	44.00 **
CMS 59A × JGL 5614	-3.21 *	1.12	-6.70 **	7.21	-6.91 *	-13.10 **	-6.80 *	-12.73 **	11.63 **	-33.33 **	-10.34	4
CMS 64A × JGL 5614	-5.08 **	-0.84	-8.51 **	13.40 **	-8.64 *	-14.72 **	-7.14 *	-17.27 **	5.81	-33.33 **	-10.34	4
JMS 13A × JGL 5614	-5.76 **	0.56	-7.22 **	2.99	-10.58 **	-16.53 **	-6.25 *	-18.18 **	4.65	-25.64 **	0	16
CMS 23A × JGL 21071	1.91	-10.61 **	-17.53 **	34.73 **	3.89	-3.02	11.32 **	7.27 **	37.21 **	-7.02	-8.62	6
CMS 59A × JGL 21071	-8.15 **	-5.59 **	-12.89 **	17.78 **	10.15 **	2.82	9.43 **	5.45 *	34.88 **	6.56	12.07	30.00 *
CMS 64A × JGL 21071	-3.26 *	-0.56	-8.25 **	35.92 **	9.50 **	2.22	8.49 **	4.55	33.72 **	-10.53	-12.07	2
JMS 13A × JGL 21071	-1.09	1.68	-6.19 **	20.09 **	12.31 **	4.84	1.89	-1.82	25.58 **	-14.29	-6.9	8

Table 6: Continued

Cross	Number of grains per panicle			Spikelet fertility (%)			1000 grain weight (g)			Hulling percent		
	HB	SVC	SHC	HB	SVC	SHC	HB	SVC	SHC	HB	SVC	SHC
CMS 23A × IET 19321	3.27	33.25	-27.47 *	-0.35	-2.1	0.67	-2.64	-4.84	6.61	0.52	0	-1.03
CMS 59A × IET 19321	34.36 *	73.35 **	-5.64	-5.33	-7	-4.36	11.70 *	9.65 *	22.84 **	0.52	-0.52	-1.54
CMS 64A × IET 19321	17.89	52.11 *	-17.2	-7.46	-9.09 *	-6.51	1.65	-0.64	11.31 *	1.58	0	-1.03
JMS 13A × IET 19321	-21.22 *	53.56 **	-16.41	-6.5	-8.14 *	-5.54	-5.9	-8.02	3.04	-1.04	-1.03	-2.05
CMS 23A × IET 26227	4.89	27.37	-30.66 **	-12.65 **	-13.28 **	-10.82 **	-1.64	-6.07	5.22	1.25	0.73	-0.31
CMS 59A × IET 26227	16.84	41.89 *	-22.76 *	-11.47 **	-12.10 **	-9.61 *	2	0.13	12.18 *	1.04	0.52	-0.51
CMS 64A × IET 26227	29.33	57.06 **	-14.51	-15.45 **	-16.05 **	-13.67 **	-3.17	-7.53	3.59	1.56	1.04	0
JMS 13A × IET 26227	-5.69	83.84 **	0.07	-10.69 **	-11.33 **	-8.82 *	-6.94	-11.13 *	-0.45	1.55	1.56	0.52
CMS 23A × WGL 823	-36.28 **	5.67	-42.48 **	-9.79 *	-17.18 **	-14.84 **	2.21	-3.16	8.49	-1.56	-2.07	-3.08 *
CMS 59A × WGL 823	15.95	92.28 **	4.67	6.01	-2.67	0.08	-16.40 **	-17.94 **	-8.07	0	-1.03	-2.05
CMS 64A × WGL 823	28.40 *	112.93 **	15.91	8.94 *	0.01	2.84	-14.39 **	-23.50 **	-14.30 **	1.58	0	-1.03
JMS 13A × WGL 823	-5.08	85.03 **	0.72	3.78	0.73	3.59	-24.48 **	-40.91 **	-33.80 **	1.65	1.66	0.62
CMS 23A × IET 26106	-26.45	-7.39	-49.59 **	-9.24 *	-9.12 *	-6.54	-10.28 *	-6.91	4.28	1.25	0.73	-0.31
CMS 59A × IET 26106	-22.42	-2.31	-46.82 **	-5.11	-4.98	-2.29	3.53	7.42	20.34 **	0.52	-0.52	-1.54
CMS 64A × IET 26106	7.39	35.22	-26.39 *	-8.58 *	-8.46 *	-5.87	-2.75	0.91	13.04 *	2.11	0.52	-0.51
JMS 13A × IET 26106	-34.38 **	27.9	-30.38 **	-33.83 **	-33.75 **	-31.87 **	-24.61 **	-21.78 **	-12.37 *	-5.19 **	-5.18 **	-6.15 **
CMS 23A × TP 30433	16.26	6.13	-42.23 **	13.45 **	0.5	3.35	3.89	17.50 **	31.63 **	1.56	1.04	0
CMS 59A × TP 30433	-7.41	7.19	-41.65 **	10.84 *	-1.81	0.97	3.22	16.74 **	30.78 **	2.09	1.04	0
CMS 64A × TP 30433	19.88	31.66	-28.33 *	-5.97	-16.70 **	-14.34 **	-18.03 **	-7.29	3.86	0.52	-1.04	-2.06
JMS 13A × TP 30433	-30.29 **	35.88	-26.03 *	-20.07 **	-22.42 **	-20.22 **	-24.98 **	-15.15 **	-4.95	-2.08	-2.07	-3.08 *
CMS 23A × JGL 20649	31.55	58.97 **	-13.46	7.78	-6.32	-3.67	-11.84 *	-16.48 **	-6.43	-1.54	-0.52	-1.54
CMS 59A × JGL 20649	51.56 **	83.15 **	-0.3	10.05 *	-4.34	-1.63	-17.98 **	-19.48 **	-9.8	-0.82	0.21	-0.82
CMS 64A × JGL 20649	70.80 **	106.40 **	12.35	12.22 **	-2.46	0.3	-15.28 **	-24.30 **	-15.19 **	0.52	1.56	0.52
JMS 13A × JGL 20649	-3.32	88.46 **	2.59	-3.04	-5.88	-3.22	12.08 *	-12.30 *	-1.76	1.54	2.59	1.54
CMS 23A × JGL 5614	-9.1	12.66	-38.67 **	-6.55	-17.51 **	-15.17 **	8.65	2.94	15.32 **	1.03	2.08	1.03
CMS 59A × JGL 5614	6.81	32.39	-27.94 *	2.52	-9.50 *	-6.93	5	3.07	15.47 **	-4.62 **	-3.62 *	-4.62 **
CMS 64A × JGL 5614	3.57	28.36	-30.13 **	1.4	-10.49 **	-7.95 *	25.14 **	16.35 **	30.34 **	-1.74	-0.72	-1.74
JMS 13A × JGL 5614	8.29	111.08 **	14.9	-9.03 *	-11.70 **	-9.20 *	-9.79	-16.13 **	-6.04	1.02	2.07	1.02
CMS 23A × JGL 21071	8.43	51.06 *	-17.77	-13.36 **	-14.01 **	-11.57 **	-9.84	-14.58 **	-4.31	-1.54	-0.52	-1.54
CMS 59A × JGL 21071	20.31	67.61 **	-8.76	-9.83 *	-10.50 **	-7.97 *	-9.74 *	-11.40 *	-0.74	-1.03	0	-1.03
CMS 64A × JGL 21071	25.43	74.74 **	-4.88	-5.35	-6.06	-3.4	-0.12	-10.76 *	-0.02	-1.02	0.01	-1.02
JMS 13A × JGL 21071	-1.73	91.56 **	4.27	-3.62	-4.34	-1.63	-1.59	-20.92 **	-11.41 *	1.34	2.39	1.34

Table 6: Continued

Cross	Milling percent			Head rice recovery (%)			Grain yield per plant (m)		
	HB	SVC	SHC	HB	SVC	SHC	HB	SVC	SHC
CMS 23A × IET 19321	-1.1	5.29 *	2.88	1.26	0.63	5.92	17.44 **	25.08 **	9.19 *
CMS 59A × IET 19321	4.02 *	6.47 **	4.02 *	5.03	4.37	9.86 **	5.38	12.23 **	-2.03
CMS 64A × IET 19321	-2.3	0	-2.3	1.26	0.63	5.92	65.99 **	76.78 **	54.32 **
JMS 13A × IET 19321	-1.72	0.59	-1.72	-1.38	-2	3.16	5.81	12.69 **	-1.62
CMS 23A × IET 26227	-6.19 **	-0.12	-2.41	-10.82 **	-12.50 **	-7.89 *	-27.56 **	-21.05 **	-31.08 **
CMS 59A × IET 26227	-0.59	-0.01	-2.3	-6.37	-8.12 *	-3.29	-18.75 **	-11.46 **	-22.70 **
CMS 64A × IET 26227	-1.17	-0.59	-2.88	-10.19 **	-11.87 **	-7.24 *	-0.57	8.36 *	-5.41
JMS 13A × IET 26227	-1.17	-0.59	-2.88	-7.00 *	-8.75 *	-3.95	9.38 *	19.20 **	4.05
CMS 23A ×WGL 823	-8.29 **	-2.36	-4.60 *	-2.46	-5.63	-0.66	-12.54 **	-15.79 **	-26.49 **
CMS 59A ×WGL 823	1.21	-1.18	-3.45	-2.64	-7.50 *	-2.64	18.87 **	11.15 **	-2.97
CMS 64A ×WGL 823	0.61	-1.76	-4.02 *	4.82	-5	-0.01	56.86 **	32.82 **	15.95 **
JMS 13A ×WGL 823	7.49 **	3.06	0.69	9.17 *	-0.38	4.86	37.20 **	33.59 **	16.62 **
CMS 23A × IET 26106	-9.17 **	-3.3	-5.52 **	-8.91 *	-11.87 **	-7.24 *	-13.74 **	-16.41 **	-27.03 **
CMS 59A × IET 26106	2.41	0	-2.3	8.55 *	3.13	8.55 *	-1.28	-4.33	-16.49 **
CMS 64A × IET 26106	1.2	-1.18	-3.45	7.64 *	-3.12	1.97	5.75	2.48	-10.54 **
JMS 13A × IET 26106	-1.81	-4.12 *	-6.32 **	2.74	-6.25	-1.32	-41.18 **	-42.72 **	-50.00 **
CMS 23A ×TP 30433	-6.08 **	-0.01	-2.3	-3.1	-6.25	-1.32	17.36 **	13.00 **	-1.35
CMS 59A ×TP 30433	5.39 *	3.53	1.15	11.19 **	5.63	11.19 **	22.52 **	14.55 **	0
CMS 64A ×TP 30433	1.8	0	-2.3	6.38	-6.25	-1.32	-13.67 **	-22.76 **	-32.57 **
JMS 13A ×TP 30433	-3.59	-5.29 *	-7.47 **	-0.68	-9.37 **	-4.6	-11.45 **	-13.78 **	-24.73 **
CMS 23A × JGL 20649	-1.66	4.70 *	2.3	-2.46	-5.63	-0.66	57.56 **	51.70 **	32.43 **
CMS 59A × JGL 20649	0.11	-1.07	-3.34	-5.66	-10.37 **	-5.66	-10.26 *	-16.10 **	-26.76 **
CMS 64A × JGL 20649	1.19	-0.01	-2.3	2.83	-9.38 **	-4.61	-0.18	-15.48 **	-26.22 **
JMS 13A × JGL 20649	1.19	-0.01	-2.3	2.74	-6.25	-1.32	-6.2	-8.67 *	-20.27 **
CMS 23A × JGL 5614	-6.63 **	-0.59	-2.88	-1.85	-0.62	4.6	27.33 **	22.60 **	7.03
CMS 59A × JGL 5614	-3.49	-2.36	-4.60 *	-5.56	-4.37	0.66	-17.42 **	-20.74 **	-30.81 **
CMS 64A × JGL 5614	-0.93	0.23	-2.07	-4.94	-3.75	1.31	-8.23	-11.92 **	-23.11 **
JMS 13A × JGL 5614	1.74	2.94	0.57	-2.47	-1.25	3.95	49.13 **	45.20 **	26.76 **
CMS 23A × JGL 21071	-7.74 **	-1.77	-4.03 *	-6.33	-9.37 **	-4.6	5.96	4.64	-8.65 *
CMS 59A × JGL 21071	-1.18	-1.18	-3.45	-3.29	-8.12 *	-3.29	17.71 **	16.25 **	1.49
CMS 64A × JGL 21071	0.59	0.59	-1.72	2	-4.37	0.66	25.86 **	24.30 **	8.51 *
JMS 13A × JGL 21071	3.41	3.41	1.03	4.13	-2.38	2.76	26.96 **	25.39 **	9.46 *

* Significant at 0.05% level, **Significant at 0.01% HB = Heterobeltiosis SVC = standard varietal check (MTU 1010) SHC = standard hybrid check (US 314)

Table 7: Top 5 ranking hybrids based on heterosis over varietal and hybrid check and sca effect.

S. No.	Hybrids	Grain yield /plant (g)	Heterosis over varietal check (%)	Heterosis over hybrid check (%)	sca Effect
1	CMS 64A x IET 19321	57.1	76.78	54.32	13.07
2	CMS 23A x JGL 20649	49	51.7	32.43	15.53
3	JMS 13A x JGL 5614	46.9	45.2	26.76	11.23
4	JMS 13A x WGL 823	43.15	33.59	16.62	5.33
5	CMS 64A x WGL 823	42.9	32.82	15.92	4.12

19321 followed by CMS 23A × JGL 20649, JMS 13A × JGL 5614, JMS 13A × WGL 823 and CMS 64A × WGL 823. Eight hybrids were recorded positive significant heterosis viz., CMS 64A x IET19321, CMS 23A x JGL 20649, CMS 23A x IET 26106, JMS 13A x WGL 823, CMS 64A x WGL 823 over standard hybrid check (US 314). Among these CMS 23A x JGL 20649, CMS 64A x IET-19321, CMS 23A x TP 30433, CMS 23A x JGL 5614 and CMS 64A x JGL 21071 were identified as potential hybrids with respect to all characters based on their perse performance and heterosis estimates. Out of 32 hybrids, four hybrids reported as best for grain yield based on standard heterosis while two hybrids showed significant negative heterosis for earliness and plant height (Thirumalai *et al.*, 2017). Marked variation in the expression of heterobeltiosis and standard heterosis for yield and yield components was observed for all cross combinations. These finding are also consistent with those of Saravanan *et al.* (2008), Kumar *et al.* (2012), Singh *et al.* (2013), Sharma *et al.* (2013), Pratap *et al.* (2013) Bhati *et al.* (2015) Satheesh kumar *et al.* (2016) and Galal Bakr Anis *et al.* (2017).

REFERENCES

Anonymous. 2019. Hybrid rice progress report. All India Coordinated Rice Improvement Project. ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad.

Bhati, P.K., Singh, S.K., Singh, R., Sharma, A and Dhurai, S.Y. 2015. Estimation of heterosis for yield and yield related traits in rice (Oryza sativa L). *SABRAO J. Breeding and Genet*.**47(4):** 467-474.

Fonseca, S and Patterson F.L. 1968. Hybrid vigor in a seven-parent diallel cross in common winter wheat (Triticum aestivum L). *CropSci*.**8:** 85.

Galal Bakr Anis, Ahmed Ibrahem El-Sherif, Hytham Freeg and Elsaed Farok Arafat. 2017. Evaluation of some hybrid combinations for exploitation of two-line system heterotic in rice (Oryza sativa L). International *J. Bio-Sci Agriculture and Technology*. **8(1):** 1-8.

Kempthorne, O. 1957. An introduction genetic statistic. John Wiley and Sons, New York.

Kumar Chetan, M.R., Devaraju and Prasad, S.R. 2012. Characterization of rice hybrids and their parental lines based on morphological traits. *Oryza*. **49(4):** 302-304.

Kumar, S., Dwivedi, S.K., Singh, S.S., Jha, S.K., Lekshmy, S.,

Padmavathi, Satyanarayana, P.V. and Lal Ahamed, M. 2013. Heterosis studies in rice hybrids (Oryza sativa L.) over locations.*The Bioscan* **8(4):**1321-1325.

Panse, V.G and Sukhatme, P.V. 1967. Statistical Methods for Agricultural Workers, 2nd Edition, Indian Council of Agricultural Research, New Delhi.

Pratap, N., Raj Shekhar, P. K. Singh and S. K. Soni. 2013. combining ability, gene action and heterosis using CMS lines in hybrid Rice (Oryza Sativa L.). *The Bioscan* **8(4):** 1521-1528.

Saravanan, K.T., Sabesan and Kumar, S.T. 2008. Heterosis for yield and yield components in rice (Oryzasativa L). *Advances in Plant Science.* 21(1): 119-121.

Sarker, U., Biswas, P.S., Prasad, B.and Khaleque, M.M.A. 2002. Heterosis and genetic analysis in rice hybrid. *Pakistan J. Biol. Sci.,* **5(1):** 1-5.

Satheesh kumar, P., Saravanan, K and Sabesan, T. 2016. Selection of superior genotypes in rice (Oryza sativa L.) through combining ability analysis. *International J. of Agri. Sci.* **12(1):** 15-21.

SES (Standard Evaluation System for Rice) 5th Edition. 2013. IRRI, Manila, Philippines.

Sharma, S.K., Singh, S.K., Nandan, R., Amita Sharma., Ravinder Kumar., Kumar, V and Singh, M.K. 2013. Estimation of heterosis and inbreeding depression for yield and yield related traits in rice (Oryza sativa L). *Molecular Plant Breeding.* **29(4):** 238-246.

Singh, S.K., Vikash Sahu, Amita Sharma and Pradeep Bhati Kumar. 2013. Heterosis for yield and yield components in rice (Oryza sativa L). *Bioinfolet.* **10(2B):** 752-761.

Thakare, I. S., Patel, A. L. and Mehta, A. M. 2013. Line × Tester analysis using CMS system in rice (Oryza Sativa L.). *The Bioscan* **8(4):**1379-1381.

Thirumalai, T., Palaniraja, K. and Vennila, S. 2017. Assessment of heterotic effecs in rice (Oryza sativa L.) coastal saline environment. *Plant Archives* **17(2):** 1501-1504.

Yogita Shrivas., Parmeshwar Sahu., Deepak Sharma and Nidhi Kujur. 2016. Heterosis and combining ability analysis for grain yield and its component traits for the development of red rice (Oryza Sativa L.) hybrids. *The Ecoscan: Special issue*, Vol. IX: PP.475-485.

Yuan, L. P., Virmani, S. S and Mao, C. X. 1989. Hybrid rice - achievements and future outlook. In: Progress in irrigated rice research. IRRI, Manila, Philippines, PP.219-235.