Combining ability studies for yield and yield contributing traits in Rice (*Oryza sativa* L.)

ABSTRACT:

The current study was carried out at Agricultural Polytechnic, Polasa, Jagtial, during *Kharif*, 2021 and *Rabi*, 2021-22. Twenty-four (24) experimental hybrids were created using eight lines and three testersand randomized block design was utilized to evaluate them. The lines CMS 46B, CMS 23B, and the tester KNM 7787 showed significantly positive gca effects for grain yield per plant. The capacity to produce superior crosses from low-yielding parents is demonstrated by parents with strong sca effects and positive, significant gca effects for grain yield per plant.

Key words: Paddy, General Combining ability, Specific Combining ability, Gene action

INTRODUCTION:

One of the major cereal crops in the world and the staple food for half of the world's population is rice (Oryza sativa L.). India, which ranks first in the area and second only to China, is a key hub for rice production. The cultivation of rice is the most important grain crop and contributes significantly to India's national economy, accounting for 22% of global output (Bandumula, 2018) [1].

Globally, about 167.20 million hectares of rice are planted, yielding 769.60 million tons with 4600 kg of productivity per hectare (FAO, 2019) [2]. In India, rice has occupied 45.07 million hectares of land, yielding 122.27 million tons and producing 2713 kilograms per hectare. On a 2.31 Mha area, Telangana's production and productivity levels were 7.70 Mt and 3327 kg ha^{-1}, respectively(Directorate of Economics and Statistics,2021)[3].

MATERIAL AND METHODS

Theexperimental inbred linesutilizedforthepresentstudyconsistsofeightlines *viz.,*CMS23A,CMS46A,CMS59A,JMS11A,JMS13A,JMS17A,JMS18Aand CMS 64A, three testers *viz*., JGL 33124, KNM 7787 and RNR 21278 and the resultant24experimentalhybrids.

Line x Tester mating design was used and developed 24 hybrids and the samewere evaluated along simultaneously with the parents and three checks which includes two varietalchecks *viz.,* JGL 18047 (short duration variety with long slender grain type) and JGL24423 (most prominent variety with medium duration and long bold grain type) and one hybrid check *viz.,* 27 P 31 (medium duration with medium slender grain type) to delineate the general combining ability (*gca*) and specific combining ability effects (*sca*) for yield and yield attributing characters.

RESULTS AND DISCUSSION

Analysisofvariance

The results of the analysis of variance of the traits under investigation have beenreportedin theTable 1. It was observed that the variance due to treatments was found to behighlysignificant for all of the characters under investigation. The variance due to parents forall the characters under study indicated that there existed significant differences between theparents. The variance due to the crosses, variance due to theparents *vs*crosses were found highly significant for all the characters. The variance due to lines was significant for all the traits studied. Whereas, variance due to the testers was found to besignificant for all other characters while non-significant for single plant yield. When theeffectsofparentswerepartitionedintolines,testersandlinextestereffects,theinteraction effects (lines x testers) were found to be significant for all the traits studied.Thisindicates thatthematerialunderinvestigation has adequatevariability. The present findings are in concurrence with the findings ofEl-Shamey *et al.* (2022)[(4)] forparents, crosses and parents *vs* crosses, Nagamani *et al.* (2022)[(5)] for parents, testers,crosses,parents*vs* crosses and linextesterinteractions.

Table1.Analysisofvarianceforcombiningability(LinexTester)foryieldandyieldattributingtraitsinthericegenotypes.

Sourceofvariation	df	Days to 50%flowering	Plant height(cm)	Paniclelength(cm)	No. ofproductivetillers perplant	No. of filledgrains perpanicle	No. ofunfilledgrains perpanicle	Spikeletfertility(%)	1000 grain-weight (g)	Grain yieldperplant(g)
Replicates	2	0.085	2.23	0.03	0.02	34.26	35.94	2.42	0.61	0.04
Treatments	34	81.16**	57.54**	8.74**	4.88**	13501.09**	6565.75**	1587.01**	44.25**	240.48**
Parents	10	70.26**	65.69**	12.47**	2.35**	12327.54**	726.61**	67.05**	61.97**	57.91**
Parents(Lines)	7	21.47**	21.84**	7.98**	1.33**	4888.63**	508.58**	65.49**	65.49**	46.13**
Parents(Tester)	2	193.00**	252.03**	26.23**	1.00**	3076.35**	1344.83**	61.06**	1.57*	0.24
Parents(L*vs*T)	1	166.37**	0.01	16.41**	12.23**	82902.28**	1016.26**	89.99**	158.06**	255.64**
Parents*vs*Crosses	1	103.52**	116.34**	1.63**	1.68**	102877.04**	65837.77**	16960.22**	36.53**	1653.62**
Crosses	23	84.93**	51.44**	7.42 **	6.13 **	10125.42**	6527.46**	1579.44**	36.88**	258.42**

LineEffect	7	81.58	96.94	4.32	9.87	7922.46	5863.73	1347.66	54.25	310.05
TesterEffect	2	207.18	3.30	10.28	2.63	8624.34	6373.57	1627.12	52.02	356.58
LinexTesterEff.	14	69.13**	35.57**	8.56**	4.75**	11441.33**	6881.32**	1688.52**	26.04**	218.56**
Error	68	0.37	1.02	0.07	0.15	18.75	38.94	4.19	0.33	0.15
Total	104	26.77	19.52	2.91	1.69	4426.74	2172.64	521.6	14.69	78.71

*Significant at5percent level**Significant at1percent level

Generalcombiningabilityeffectsand specificcombiningabilityeffects

The general combining ability (GCA) effects of eleven parents *i.e.,* eight linesandthreetestersandthespecificcombiningeffects(SCA)effectsof24hybridcombinations were estimated according to the procedure given by Kempthorne, 1957[(6)](Line x Tester matingdesign). The estimates of GCA effects of the parents *i.e.,* linesand testers on each character have been presented in the Table 2. and SCA effects ofhybridsare presented in the Table 3.

Daysto50%flowering

For this trait, the *gca*effects among the lines ranged from -4.53(CMS59B)to4.47(CMS23B)whileintesters,itrangedfrom-2.15(RNR21278)to 3.35 (KNM 7787). This implied that the line CMS 59B (-4.53) and tester, RNR 21278(-2.15) are good general combiners for days to 50% flowering since they recorded negative significant *gca*effects. The negative *gca*effects are desirable in breeding forearly maturity. Whereas, the lines CMS 23B (4.47), CMS 46B (3.81) and JMS 11B(0.81)showed positive significant *gca*effects.

Twenty one out of 24 hybrids have exhibited high significant *sca*effects. Amongthem, 11 hybrids showed positive significant *sca*effects while, 10 hybrids recorded significant negative *sca*effects. The cross combination, CMS 46A x RNR 21278(-6.18) exhibited the highest and significantly negative *sca*effect followed by JMS 11A xJGL33124(-5.14).Negativevaluesprovidestheinformationthattheyaregoodcombinersforearlymaturity. The findings are consistent and in accordance with the results reported by Malathi and Suresh (2019) [(7)] and Sari *et al.* (2020)[(8)]. The development of earlymaturingricehybridswillthereforebesuccessfulusingtheidentifiedlinesandtesters.

Plantheight(cm)

Among the parents, five lines have recorded significant *gca*effects and no testerreported significant *gca*effect for this trait. Among the lines, JMS 17B (-4.31), CMS59B (-3.97) and JMS 18B (-0.81) showed highly significant negative *gca*effects. Negative effects of the lines indicating that they could be effectively used in thedevelopment of dwarf and semi-dwarf hybrids and are ideal general combiners fordwarfness. Whereas, two lines *viz.,* CMS 46B (5.53) and CMS 23B (3.13) exhibitedsignificantlypositive*gca*effects.

Table2.Estimatesofgeneralcombiningability(GCA)effectsforlinesandtestersofthestudyforyieldandyieldattributingtraits

Source	Days to 50%flowering	Plant height(cm)	Panicle length(cm)	No. ofproductivetillers perplant	No. of filledgrains perpanicle	No. of unfilledgrains perpanicle	Spikeletfertility(%)	1000 grain-weight(g)	Grain yieldperplant(g)
Parents									
Lines									
CMS23 B	4.47 **	3.13**	-0.48**	1.87**	32.54**	-14.46**	11.72**	3.27**	7.34**
CMS46 B	3.81 **	5.53**	0.22*	1.35**	30.94**	-38.91**	15.25**	4.24**	9.98**
CMS59 B	-4.53**	-3.97**	-1.05**	-0.45**	-23.79**	10.86**	-5.25**	-2.26**	-5.23**
JMS11 B	0.81**	0.16	1.18**	-0.38**	30.07**	-2.76	7.74**	-0.51*	1.27**
JMS13 B	-0.86**	0.03	-0.12	-0.18	-7.59**	-0.92	-3.79**	-1.41**	-2.55**
JMS17B	-2.53**	-4.31**	-0.25*	-0.62**	-13.33**	-6.39**	0.04	-0.66**	-3.10**
JMS18 B	-0.64**	-0.81*	0.68**	-0.38**	0.54	0.91	-1.77*	-0.29	-1.32**
CMS64 B	-0.53*	0.26	-0.18	-1.18**	-49.39**	51.67**	-23.94**	-2.37**	-6.40**
Testers									

RNR21278	-2.15**	0.12	-0.22**	-0.37**	-2.32*	-5.24**	1.67**	-1.21**	-1.54**
JGL33124	-1.19**	-0.42	-0.52**	0.23**	-17.69***	18.27**	-8.94**	-0.44**	-2.85**
KNM7787	3.35**	0.29	0.74**	0.15	20.01**	-13.03**	7.26**	1.64**	4.38**
CD95% GCA(Line)	0.408	0.69	0.18	0.26	2.98	4.24	1.37	0.38	0.25
CD95% GCA(Tester)	0.250	0.43	0.12	0.16	1.82	2.59	0.84	0.24	0.15

*Significant at5percent level**Significant at1percent level

Table3.Estimatesof specificcombiningability(SCA)effectsforyieldandyieldattributingtraitsintheexperimentalricehybrids.

S.No.	Crosses	Days to50% flowering	Plant height (cm)	Paniclelength(cm)	No. ofproductivetillers perplant	No. of filledgrains perpanicle	No. ofunfilled grains perpanicle	Spikeletfertility(%)	1000 grain-weight (g)	Grain yieldperplant(g)
1	CMS23A xRNR21278	-2.85**	-3.18**	-1.64**	-0.35	-43.22**	-2.78	-8.48**	-1.33**	-6.06**
2	CMS23AxJGL33124	1.19 **	3.85**	1.75**	0.83**	34.55**	35.39**	-1.82	-1.51**	-0.97**
3	CMS23A xKNM7787	1.65**	-0.66	-0.11	-0.48*	8.65**	-32.61**	10.31**	2.83**	7.03**
4	CMS46A xRNR21278	-6.18**	0.62	-0.84**	-1.42**	-80.22**	52.44**	-31.95**	-5.97**	-15.99**
5	CMS46AxJGL33124	3.86**	-1.75**	0.45 **	-0.03	20.56**	-41.64**	21.68**	3.53**	7.64**
6	CMS46AxKNM7787	2.32**	1.14	0.39*	1.45**	59.66**	-10.81**	10.27**	2.45**	8.35**
7	CMS59A xRNR21278	3.15**	0.92	0.13	-0.22	50.52**	-37.29**	18.43**	1.48 **	5.32**
8	CMS59AxJGL33124	1.19*	0.25	-0.08	-0.03	14.89**	-55.63**	17.20**	-0.85*	2.14**
9	CMS59AxKNM7787	-4.35**	-1.16	-0.04	0.25	-65.41**	92.93**	-35.63**	-0.64	-7.46**
10	JMS11Ax RNR21278	-0.18	-1.42*	2.39**	0.12	-25.35**	-21.56**	1.05	1.64**	-0.32
11	JMS11Ax JGL33124	-5.14**	-3.58**	-3.12**	-1.90**	32.63**	16.73**	2.76*	-0.03	-2.57**
12	JMS11Ax KNM7787	5.32**	5.01**	0.73**	1.78**	-7.27**	4.83	-3.83**	-1.62**	2.89**
13	JMS13Ax RNR21278	-0.52	-2.78**	-0.01	0.12	20.31**	-30.16**	16.52**	-0.86*	1.61**

14	JMS13Ax JGL33124	-3.47**	-0.25	-1.12**	-0.10	-86.91**	61.08**	-38.26**	-1.53**	-8.18**
15	JMS13Ax KNM7787	3.98**	3.04**	1.13**	-0.02	66.59**	-30.92**	21.74**	2.39**	6.58**
16	JMS 17A x RNR 21278	4.15**	3.85**	0.93**	1.55**	-21.95**	44.94**	-17.61**	1.68**	4.31**
17	JMS 17A x JGL 33124	0.19	1.68*	0.42 *	-0.36	55.43**	-38.39**	22.03**	-0.33	4.56**
18	JMS 17A x KNM 7787	-4.35**	-5.53**	-1.34**	-1.18**	-33.47**	-6.543	-4.43 **	-1.35**	-8.87**
19	JMS 18A x RNR 21278	6.26**	3.85 **	1.19**	1.12**	85.18**	-23.33**	20.51 **	3.24**	10.37**
20	JMS 18A x JGL 33124	-3.03**	-1.92*	0.58**	0.10	-29.24**	10.44 **	-7.09 **	1.28**	-0.42
21	JMS 18A x KNM 7787	-3.24**	-1.93*	-1.77**	-1.22**	-55.94**	12.88**	-13.41 **	-4.52**	-9.96**
22	CMS 64A x RNR 21278	-3.85**	-1.82*	-2.14**	-0.88**	14.72**	17.76 **	1.534	0.11	0.75 **
23	CMS 64A x JGL 33124	5.19**	1.72*	1.14**	1.50**	-41.91**	12.01**	-16.51**	-0.56	-2.18**
24	CMS 64A x KNM 7787	-1.35**	0.11	0.99**	-0.62**	27.19**	-29.77**	14.97**	0.46	1.43**
	CD 95% SCA	0.71	1.19	0.33	0.45	5.16	7.35	2.38	0.66	0.45

*Significant at5percent level**Significant at1percent level

Sixteen out of 24 hybrids recorded significant *sca*effects.It was foundthat seven hybridsrecorded significantly positive*sca*effects while, nine hybrids recordednegative significant *sca*effects. Highestand negative significantly negative *sca*effect was recordedby thecross,JMS17A x KNM 7787(-5.53)followed by JMS11A x JGL 33124(-3.58). The cross combination, JMS 17A x KNM 7787 was recognized asthe bestspecific combiner amongall the crosses. Similar results were reported by Sari *et al.*(2020)(8)andBarhate *et al.*(2021)(9).

Paniclelength (cm)

Six lines and all the three testers (Parents)have shown significant *gca*effects for panicle length. The lines, JMS 11B (1.18), JMS 18B (0.68) and CMS46B (0.22) recorded positive significant *gca*effects while the testers, KNM7787 (0.74) recorded significantly positive *gca*effect. Hence, the line JMS 11B and thetester,KNM 7787areidentified asgoodgeneral combinersforpaniclelength.

Among all the cross combinations, 19 hybrids reported significant *sca*effects.12 hybrids showed positive and significant *sca*effects.The cross, JMS 11A x RNR21278(2.39)recorded thehighestpositivesignificant*sca*effectfollowed byCMS23A x JGL 33124 (1.75) andCMS64Ax JGL 33124(1.14).Among the crosses,JMS 11A x RNR21278wasidentifiedas the bestspecificcombiner forthistrait. These results are in accordance with the findings of Ambikabathy*et al.*(2019)(10) and Nagamani*etal.* (2022)(5).

Numberofproductivetillersperplant

Seven lines showed significant *gca*effects; Two lines out ofeight showed significantly positive *gca*effects ranging from 1.87 (CMS 23B) followedby 1.35 (CMS 46B). Whereas in testers, only one tester *i.e.,* JGL 33124 (0.23) exhibitedsignificantly positive *gca*effect. Hence, among the parents, the line CMS 23B and thetester, JGL 33124 were identified as good general combiners for number of productivetillersperplant.

Among the crosses, 13 hybrids have shown significant *sca*effects. Six out of thetotal 24 crosses exhibited significantly positive *sca*effects. The cross, JMS 11A x KNM7787(1.78)followedbyJMS17A xRNR21278(1.55),CMS64A xJGL33124(1.50) and CMS 46A x KNM 7787 (1.45) showed the highest significantly positive *sca*effect.Among them the cross, JMS 11A x KNM 7787 was identified as the best specificcombinerfornumberofproductivetillers per plant. The findings are similar to the results of Patel *et al.*(2019)(11) and Salah*et al.* (2020)(12).

Numberoffilledgrains perpanicle

Among lines, CMS 23B (32.54) recorded the highest positive significant *gca*effect followed by CMS 46B (30.94) and JMS 11B (30.07) while in testers, KNM 7787(20.01) exhibited significantly positive *gca*effect. Hence, among parents, the line, CMS23B and tester, KNM 7787 reported asgood generalcombinersfor number offilledgrains perpanicle.

Twenty fourhybrids exhibited significant *sca*effects while, elevenhybrids exhibited significantly negative effects and all the remaining thirteen hybridsexhibited significant and positive *sca*effects. Among these thirteen hybrids, JMS 18A xRNR21278(85.18)followedbyJMS13AxKNM7787(66.59),CMS46AxKNM 7787(59.66)andJMS17AxJGL33124(55.43)exhibitedthehighestsignificantly positive*sca*effects.

In terms of the number of grains per panicle, the good general combiners wereCMS 23B among lines and KNM 7787 among testers and the best specific combinerwasJMS 18AxRNR 21278. These findings are in concurrence with results reportedby Ramesh *et al.*(2018)(13)and Yuga*et al.* (2018)(14).

Numberofunfilledgrains perpanicle

Among the parents, fivelines and allthe three testers have shown significant*gca*effects.Inlines,CMS46B(-38.91)followedbyCMS23B(-14.46)showedsignificantly negative *gca*effects. Whereas, among testers, KNM 7787 (-13.03) andRNR21278 (-5.24)showed significantlynegative*gca*effects.

Twenty-one hybrids exhibited significant *sca*effects. Tenhybrids showed significantly positive*sca*effectswhile eleven hybrids exhibited significantlynegative*sca*effects.Thehighestnegativesignificant*sca*effectwasexhibited by the cross, CMS 59A x JGL 33124 (-55.63) followed by CMS 46A x JGL33124(-41.64),JMS17Ax JGL33124 (38.39)and CMS59AxRNR 21278(-37.29).

For number of unfilled grains per panicle, CMS 46B among lines and KNM7787 among testers are identified as the good general combiners due to their highsignificantly negative *gca*effects. The cross combination, CMS 59A x JGL 33124 wasidentifiedas the best specificcombination forthe character.Currentfindingisinconcurrencewiththereportsof Ramesh *et al*.(2018)(13).

Spikeletfertility(%)

The *gca*effects of parents revealed that three lines CMS 46B (15.25), CMS 23B(11.72) and JMS 11B (7.74) and two testers *i.e.,* KNM 7787 (7.26) and RNR 21278(1.67)exhibited significantlypositive *gca*effects.

Twenty one hybrids exhibited significant *sca*effects out of which tenhybridsexhibitednegativesignificant*sca*effectsand11hybridsrecordedsignificantly positive*sca*effects. The hybrid combination, JMS 17A x JGL 33124 (22.03) followedbyJMS13AxKNM7787(21.74),CMS46AxJGL33124(21.68)andJMS18Ax RNR21278(20.51)exhibitedthehighestpositiveandsignificant*sca*effects.

Based on combining ability effects, the parents, CMS 46B among lines andKNM7787amongtesterswererecognized asgoodgeneralcombinersforspikeletfertility. The hybrid combination, JMS 17A x JGL 33124 was recognized as the bestspecificcombiner forspikelet fertility. These findings are in consonance with results of Salah*etal.* (2020)(12)and

Mohan *et al.* (2021)[15].

1000grain weight(g)

The *gca*effects for the trait revealed that seven lines and three testers exhibitedsignificant*gca*effects.Amongthelines,CMS46B(4.24)showedthesignificantly positive *gca*effect followed by CMS 23B (3.27) and among the testers, KNM 7787(1.64)exhibited positiveand significant*gca*effect.

Among the hybrids, 18 cross combinations exhibited significant*sca*effects inwhich each nine crosses exhibited significantly positive *sca*effects while nine crossesexhibited significant negative *sca*effect and thus it is evident that the trait, 1000 grain-weight is under the control of non-additive gene action. The cross, CMS 46A x JGL33124 (3.53) exhibited the highest positive *sca*effect followed by JMS 18A x RNR21278(3.24),CMS 23Ax KNM 7787(2.83)andCMS 46Ax KNM7787(2.45). These results are similar to the findings of Patel *et al.* (2019)[11] and Nagamani *etal.* (2022)[5].

Grainyieldperplant(g)

All the parents, *i.e.,* eight lines and three testers exhibited significant *gca*effectsfor single plant yield. CMS 46B (9.98), CMS 23B (7.34) and JMS 11B (1.27) amonglinesandKNM7787(4.38)amongtesterexhibited positivesignificant *gca*effcts.

Twenty twohybridsrecorded significant*sca*effects.Thirteenhybrids exhibited significant positive effects and nine hybrids have shown significantnegative effects. Highest positive significant effects are observed in hybrids, JMS18A x RNR 21278 (10.37) followed by CMS 46A x KNM 7787 (8.35),CMS 46A xJGL33124 (7.64), CMS23A x KNM7787 (7.03)andJMS13A xKNM7787 (6.58).

CMS 46B among the lines and KNM 7787 among the testers were identified asgood general combiners for grain yield per plant while, JMS 18A x RNR 21278 wereidentifiedas best specificcombiners for thetrait. The results are in agreement with the findings ofPatel *et al.* (2019)[11]and Salah *et al.*(2020)[12].and Gupta et al, 2024[16].

In general, negative effects are desirable for days to 50% flowering to obtainearly maturing types. Whereas, positive effects are desirable for the other characters.From the above findings it is understood that the line, CMS 46B was found to be goodgeneral combiner for spikelet fertility, number of unfilled grains per panicle, 1000 grainweightandgrainyieldperplant.CMS23Bwasidentifiedasgoodgeneralcombinerfor number of productive tillers per plant, number of filled grains per panicle. CMS59Bwas identified asgoodgeneralcombiner for days to 50% flowering.JMS 11B wasidentified as good general combiner for panicle length and JMS 17B was identified asgoodgeneralcombinerforplantheight todevelopdwarf andsemidwarfvarieties.

Among testers, KNM 7787 was identified as good general combiner for paniclelength,number of filledgrainsperpanicle,number ofunfilledgrainsperpanicle,spikelet fertility, 1000 grain weight and grain yield per plant. RNR 21278 was found tobe good general combiner for days to 50% flowering and JGL 33124 was identified asgoodgeneralcombinerfornumberofproductivetillers perplant.

The cross combinations, CMS 46A x RNR 21278 and JMS 11A x JGL 33124were identified as good specific combiners for days to 50% flowering.Though thecross, JMS 17A x KNM 7787 and JMS 11A x JGL 33124 were identified as goodspecific combiners for dwarfness, the crosses, JMS 11A x KNM 7787, CMS 23A x JGL33124, JMS 17A x RNR 21278 and JMS 18A x RNR 21278 were found to be goodspecific combiners for the trait, plantheight to achieve higher yield. The cross, JMS11A x RNR 21278 was identified as good specific combiner for panicle length. JMS11A x KNM 7787, JMS 17A x RNR 21278 and CMS 64A x JGL 33124 were identifiedas good specific combiners for number of productive tillers per plant. The crosses, JMS18A x RNR 21278 followed by JMS 13A x KNM 7787 were identified as good specificcombiners for number of filled grains per panicle. The crosses, CMS 59A x JGL 33124followed by CMS 46A x JGL 33124 crosses were identified as good specific combinersfor number of unfilled grains per panicle. JMS 17A x JGL 33124 followed by JMS 13Ax KNM 7787 and CMS 46A x JGL 33124 wereidentified as good specific combinersfor spikelet fertility. CMS 46A x JGL 33124, JMS 18A x RNR 21278 crosses wereidentified as the best specific combiners for 1000 grain weight. JMS 18A x RNR 21278,CMS46AxKNM7787,CMS46AxJGL33124,CMS23AxKNM7787andJMS 13Ax KNM7787wereidentifiedasbestspecificcombinersforgrainyieldperplant.

CONCLUSION

The lines, CMS 46B, CMS 23B and the tester, KNM 7787 showed significantpositive *gca*effects for grain yield per plant. Parents having positive significant *gca*effects for grain yield per plant, emphasizing their capability of producing superiorcrosses from low yielding parents, with high *sca*effects. The pedigree method can beused to exploit superior crosses with high xhigh *gca*effects. Whereas, biparentalmating and recurrent selection methods can be used to develop the obtained bettercrosseswith high xlowand lowxlow *gca*effects.

REFERENCES

1. Bandumula, N. 2018. Rice production in Asia: Key to global food security. *Proceedingsof the National Academy of Sciences, India Section B: Biological Sciences*. 88(4):1323-1328.
2. FAOSTAT, 2019. Agricultural production year book. (*http:// faostat.fao.org*). Food andAgricultural Organisation, Rome,Italy.
3. DES, D. 2021. Directorate of Economics and Statistics. *Department of Agriculture,Cooperation and Farmers welfare, GovernmentofIndia*.
4. El-Shamey, E.A., Sakran, R.M., ElSayed, M.A., Aloufi, S., Alharthi, B., Alqurashi, M.,Mansour, E and Abd El-Moneim, D. 2022. Heterosis and combining ability forfloral and yield characters in rice using cytoplasmic male sterility system. *SaudiJournal of Biological Sciences*. 29 (5): 3727-3738.
5. Nagamani,V.,Shivakumar,NandNagaraja,T.E.2022.Estimationofcombiningabilityandh eterosisforyieldanditscomponenttraitsforidentificationofpromising red rice (*Oryza*

sativa L.) hybrids developed from new WA-basedCMS lines and red kernel breeding lines. *Electronic Journal of Plant Breeding*.13(1): 146-154.

6. Kempthorne, O. 1957. An Introduction to Genetic Statistics. John Wiley and Sons Inc:Newyork.
7. Malathi, D and Suresh, S. 2019. Combining ability analysis for quantitative traits inaerobicrice(*Oryzasativa*L.).*JournalofPharmacognosyandPhytochemistry*.8(2): 40-43.
8. Sari, W.K., Nualsri, C., Junsawang, N and Soonsuwon, W. 2020. Combining ability andheritability for yield and its related traits in Thai upland rice (*Oryza sativa* L.).*Agricultureand NaturalResources*. 54 (3): 229-236.
9. Barhate, K.K., Borole, D.N and Misal, R.A. 2021. Combining ability analysis for yieldand other associated traits in rice (*Oryza sativa* L.). *Journal of PharmacognosyandPhytochemistry*. 10 (3): 390-393.
10. Ambikabathy, A., Banumathy, S., Gnanamalar, R.P., Arunchalam, P., Jeyaprakash, P.,Amutha, R and Venkatraman, N.S. 2019. Heterosis and combining ability foryield and yield attributing traits in rice. *Electronic Journal of Plant Breeding*. 10(3):1060-1066.
11. Patel, U.M., Faldu, G.O., Patel, P.B and Patel, S.N. 2019. Combining ability analysis inrice (*Oryza sativa* L.). *International Journal of Pure and Applied Bioscience*. 7(3):362-368.
12. Salah, M.H.G., Diaa, A.E., Ehab, M.R.M and Mohamed, M.E.M. 2020. Combiningability and heterosis studies for some economic traits in rice (*Oryza sativa* L.).*ResearchJournal of Biotechnology*. 15 (1): 101-111.
13. Ramesh, C., Raju, C.D., Raju, C.S and Varma, N.R. 2018. Combining ability and geneaction in hybrid rice. *International Journal of Pure and Applied Bioscience*. 6(1):497-510.
14. Yuga, M., Kimani, P., Kimani, J.M., Nzuve, F.M., Olubayo, M.F and Muthomi, J.W.2018. Combining ability and heterosis for agronomic and yield traits in *indica*and*japonica*ricecrosses.*Journal ofAgriculturalScience.*10(12):92-103.
15. Mohan, Y., Krishna, L and Singh, T. 2021. Combining ability and heterosis studies forgrain yieldinrice(*Oryzasativa*L.).*JournalofCropand Weed*.17(2):245-254.

16. Gupta, P., Pachuri, A., Deepak, G., Sahu, J.K., Kavitha, C., Sao, A and Bhagat, V. 2024. Heterotic analysis (*Oryza sativa* L.) in drought tolerant rice accessions. Journal of Advances in Biology and Biotechnology. 27(3): 34.46.