

## 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 testers and 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 is a key hub for rice production, which ranks first in the area and second only to China in production, is a key hub for rice production (Add Reference). 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) <sup>(1)</sup>.

Globally, about 167.20 million hectares of rice are planted, yielding 769.60 million tons with 4600 kg of productivity per hectare (FAO, 2019) <sup>(2)</sup>. 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<sup>-1</sup>, respectively (Directorate of Economics and Statistics, 2021) <sup>(3)</sup>.

### MATERIAL AND METHODS

The experimental inbred lines utilized for the present study consist of eight lines viz., CMS23A, CMS46A, CMS59A, JMS11A, JMS13A, JMS17A, JMS18A and CMS 64A, three testers viz., JGL 33124, KNM 7787 and RNR 21278 and the resultant 24 experimental hybrids.

Line x Tester mating design was used and developed 24 hybrids and the same were evaluated along simultaneously with the parents and three checks which includes two varietal checks 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

#### Analysis of variance

The results of the analysis of variance of the traits under investigation have been reported in

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theTable 1. It was observed that the variance due to treatments was found to be highly significant for all of the characters under investigation. The variance due to parents for all the characters under study indicated that there existed significant differences between the parents. The variance due to the crosses, variance due to the parents 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 be significant for all other characters while except non-significant for single plant yield. When the effects of parents were partitioned into lines, testers and line x tester effects, the interaction effects (lines x testers) were found to be significant for all the traits studied. This indicates that the material under investigation has adequate variability. The present findings are in concurrence with the findings of El-Shamey *et al.* (2022)<sup>(4)</sup> for parents, crosses and parents vs crosses, Nagamani *et al.* (2022)<sup>(5)</sup> for parents, testers, crosses, parents vs crosses and line x tester interactions.

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UNDER PEER REVIEW

**Table1. Analysis of variance for combining ability (Line x Tester) for yield and yield attributing traits in the rice genotypes.**

Source of variation	df	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productivetillers per plant	No. of filled grains per panicle	No. of unfilled grains per panicle	Spikelet fertility (%)	1000 grain-weight (g)	Grain yield per plant (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 (LvsT)	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**

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

\*Significant at 5 percent level \*\*Significant at 1 percent level

UNDER PEER REVIEW

## General combining ability effects and specific combining ability effects

The general combining ability (GCA) effects of eleven parents *i.e.*, eight lines and three testers and the specific combining effects (SCA) effects of 24 hybrid combinations were estimated according to the procedure given by Kempthorne, 1957<sup>(6)</sup> (Line x Tester mating design). The estimates of GCA effects of the parents *i.e.*, lines and testers on each character have been presented in the Table 2. and SCA effects of hybrids are presented in the Table 3.

### Days to 50% flowering

For this trait, the *gca* effects among the lines ranged from -4.53 (CMS59B) to 4.47 (CMS23B) while in testers, it ranged from -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 for early 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. Among them, 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 x JGL33124 (-5.14). Negative values provide the information that they are good combiners for early maturity. The findings are consistent and in accordance with the results reported by Malathi and Suresh (2019)<sup>(7)</sup> and Sari *et al.* (2020)<sup>(8)</sup>. The development of early maturing rice hybrids will therefore be successful using the identified lines and testers.

### Plant height (cm)

Among the parents, five lines have recorded significant *gca* effects and no tester reported 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 the development of dwarf and semi-dwarf hybrids and are ideal general combiners for dwarfness. Whereas, two lines *viz.*, CMS 46B (5.53) and CMS 23B (3.13) exhibited significantly positive *gca* effects.

**Table 2. Estimates of general combining ability (GCA) effects for lines and testers of the study for yield and yield attributing traits**

Source	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	No. of filled grains per panicle	No. of unfilled grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain yield per plant (g)
<b>Parents</b>									
<b>Lines</b>									
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**
<b>Testers</b>									

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 at 5 percent level \*\*Significant at 1 percent level

**Table 3. Estimates of specific combining ability (SCA) effects for yield and yield attributing traits in the experimental rice hybrids.**

S.No.	Crosses	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	No. of filled grains per panicle	No. of unfilled grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain yield per plant (g)
1	CMS23A xRNR21278	-2.85**	-3.18**	-1.64**	-0.35	-43.22**	-2.78	-8.48**	-1.33**	-6.06**
2	CMS23A xJGL33124	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	CMS46A xJGL33124	3.86**	-1.75**	0.45 **	-0.03	20.56**	-41.64**	21.68**	3.53**	7.64**
6	CMS46A xKNM7787	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	CMS59A xJGL33124	1.19*	0.25	-0.08	-0.03	14.89**	-55.63**	17.20**	-0.85*	2.14**
9	CMS59A xKNM7787	-4.35**	-1.16	-0.04	0.25	-65.41**	92.93**	-35.63**	-0.64	-7.46**
10	JMS11A x RNR21278	-0.18	-1.42*	2.39**	0.12	-25.35**	-21.56**	1.05	1.64**	-0.32
11	JMS11A x JGL33124	-5.14**	-3.58**	-3.12**	-1.90**	32.63**	16.73**	2.76*	-0.03	-2.57**
12	JMS11A x KNM7787	5.32**	5.01**	0.73**	1.78**	-7.27**	4.83	-3.83**	-1.62**	2.89**
13	JMS13A x 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 at 5 percent level \*\*Significant at 1 percent level

Sixteen out of 24 hybrids recorded significant scaeffects. It was found that seven hybrids recorded significantly positive scaeffects while, nine hybrids recorded negative significant scaeffects. Highest and negative significantly negative scaeffect was recorded by the cross, JMS17A x KNM 7787 (-5.53) followed by JMS11A x JGL 33124 (-3.58). The cross combination, JMS 17A x KNM 7787 was recognized as the best specific combiner among all the crosses. Similar results were reported by Sari *et al.* (2020)<sup>(8)</sup> and Barhate *et al.* (2021)<sup>(9)</sup>.

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### **Panicle length (cm)**

Six lines and all the three testers (Parents) have shown significant gcaeffects for panicle length. The lines, JMS 11B (1.18), JMS 18B (0.68) and CMS46B (0.22) recorded positive significant gcaeffects while the testers, KNM7787 (0.74) recorded significantly positive gcaeffect. Hence, the line JMS 11B and the tester, KNM 7787 are identified as good general combiners for panicle length.

Among all the cross combinations, 19 hybrids reported significant scaeffects. 12 hybrids showed positive and significant scaeffects. The cross, JMS 11A x RNR21278 (2.39) recorded the highest positive significant scaeffect followed by CMS23A x JGL 33124 (1.75) and CMS64A x JGL 33124 (1.14). Among the crosses, JMS 11A x RNR21278 was identified as the best specific combiner for this trait. These results are in accordance with the findings of Ambikabath *et al.* (2019)<sup>(10)</sup> and Nagamani *et al.* (2022)<sup>(5)</sup>.

### **Number of productive tillers per plant**

Seven lines showed significant gcaeffects; Two lines out of eight showed significantly positive gcaeffects ranging from 1.87 (CMS 23B) followed by 1.35 (CMS 46B). Whereas in testers, only one tester *i.e.*, JGL 33124 (0.23) exhibited significantly positive gcaeffect. Hence, among the parents, the line CMS 23B and the tester, JGL 33124 were identified as good general combiners for number of productive tillers per plant.

Among the crosses, 13 hybrids have shown significant scaeffects. Six out of the total 24 crosses exhibited significantly positive scaeffects. The cross, JMS 11A x KNM7787 (1.78) followed by JMS17A x RNR21278 (1.55), CMS64A x JGL33124 (1.50) and CMS 46A x KNM 7787 (1.45) showed the highest significantly positive scaeffect. Among them the cross, JMS 11A x KNM 7787 was identified as the best specific combiner for number of productive tillers per plant. The findings are similar to the results of Patel *et al.* (2019)<sup>(11)</sup> and Salah *et al.* (2020)<sup>(12)</sup>.

### **Number of filled grains per panicle**

Among lines, CMS 23B (32.54) recorded the highest positive significant gcaeffect followed by CMS 46B (30.94) and JMS 11B (30.07) while in testers, KNM 7787 (20.01) exhibited significantly positive gcaeffect. Hence, among parents, the line, CMS23B and tester, KNM 7787 reported as good general combiners for number of filled grains per panicle.

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

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)<sup>(13)</sup>and Yuga*et al.* (2018)<sup>(14)</sup>.

### **Number of unfilled grains per panicle**

Among the parents, five lines and all the three testers have shown significant gcaeffects. In lines, CMS46B(-38.91)followedbyCMS23B(-14.46)showedsignificantly negative gcaeffects. Whereas, among testers, KNM 7787 (-13.03) andRNR21278 (-5.24)showedsignificantlynegative gcaeffects.

Twenty-one hybrids exhibited significant scaeffects. Ten hybrids showed significantly positivescaeffectswhile eleven hybrids exhibited significantlynegativescaeffects. The highestnegativesignificantscaeffectwasexhibited 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 gcaeffects. The cross combination, CMS 59A x JGL 33124 wasidentifiedas the best specificcombination forthe character. CurrentfindingsisinconcurrencewiththereportsofRamesh *et al.*(2018)<sup>(13)</sup>.

### **Spikelet fertility(%)**

The gcaeffects 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 gcaeffects.

Twenty one hybrids exhibited significant scaeffects out of which ten hybridsexhibitednegativesignificantscaeffectsand11hybridsrecordedsignificantly positivescaeffects. The hybrid combination, JMS 17A x JGL 33124 (22.03) followedbyJMS13AxKNM7787(21.74),CMS46AxJGL33124(21.68)andJMS18Ax RNR21278(20.51)exhibitedthehighestpositiveandsignificantscaeffects.

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*et al.* (2020)<sup>(12)</sup>and

Mohan *et al.* (2021)<sup>(15)</sup>.

### **1000 grain weight(g)**

The *gca* effects for the trait revealed that seven lines and three testers exhibited significant *gca* effects. Among the lines, CMS 46B (4.24) showed the significantly positive *gca* effect followed by CMS 23B (3.27) and among the testers, KNM 7787 (1.64) exhibited positive and significant *gca* effect.

Among the hybrids, 18 cross combinations exhibited significant *sca* effects in which each nine crosses exhibited significantly positive *sca* effects while nine crosses exhibited 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 23A x KNM 7787 (2.83) and CMS 46A x KNM 7787 (2.45). These results are similar to the findings of Patel *et al.* (2019)<sup>(11)</sup> and Nagamani *et al.* (2022)<sup>(6)</sup>.

### **Grain yield per plant(g)**

All the parents, *i.e.*, eight lines and three testers exhibited significant *gca* effects for single plant yield. CMS 46B (9.98), CMS 23B (7.34) and JMS 11B (1.27) among lines and KNM 7787 (4.38) among testers exhibited positive significant *gca* effects.

Twenty two hybrids recorded significant *sca* effects. Thirteen hybrids exhibited significant positive effects and nine hybrids have shown significant negative effects. Highest positive significant effects are observed in hybrids, JMS 18A x RNR 21278 (10.37) followed by CMS 46A x KNM 7787 (8.35), CMS 46A x JGL33124 (7.64), CMS 23A x KNM 7787 (7.03) and JMS 13A x KNM 7787 (6.58).

CMS 46B among the lines and KNM 7787 among the testers were identified as good general combiners for grain yield per plant while, JMS 18A x RNR 21278 were identified as best specific combiners for the trait. The results are in agreement with the findings of Patel *et al.* (2019)<sup>(11)</sup> and Salah *et al.* (2020)<sup>(12)</sup> and Gupta *et al.*, 2024<sup>(16)</sup>.

In general, negative effects are desirable for days to 50% flowering to obtain early 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 good general combiner for spikelet fertility, number of unfilled grains per panicle, 1000 grain weight and grain yield per plant. CMS 23B was identified as good general combiner for number of productive tillers per plant, number of filled grains per panicle. CMS 59B was identified as good general combiner for days to 50% flowering. JMS 11B was identified as good general combiner for panicle length and JMS 17B was identified as good general combiner for plant height to develop dwarf and semi dwarf varieties.

Among testers, KNM 7787 was identified as good general combiner for

panicle length, number of filled grains per panicle, number of unfilled grains per panicle, spikelet fertility, 1000 grain weight and grain yield per plant. RNR 21278 was found to be good general combiner for days to 50% flowering and JGL 33124 was identified as good general combiner for number of productive tillers per plant.

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

## CONCLUSION

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

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**Comment [DS12]:** What about the 3 checks used? Did any of the crosses outperform the checks?

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