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Combining Ability for Yield and Yield Contributing Traits in Hybrid Rice

Gonya Nayak. P[1]*, Chandra Mohan. Y[2], Sujatha. M[3], Saida Naik. D[4] and Kiran Babu. T[2]

[1]Regional Agricultural Research Station, Polasa, Jagtial Telangana India.
[2]Institute of Rice Research, ARI, Rajendranagar, Telangana India.
[3]Department of Genetics and Plant Breeding, College of Agriculture, Rajendranagar, Telangana India.
[4]Department of Crop Physiology, Agricultural College, Jagtial, Telangana India.
(Professor Jayashankar Telangana State Agriculture University, Hyderabad Telangana India)

ABSTRACT

The key challenges for hybrid rice are the development of new rice hybrids with a competitive and comparable grain quality, with wider adaptability, suitable for irrigated areas, a further increase in yield potential and reduction in retail seed price. In this study forty hybrids of rice were developed by crossing four CMS lines and ten restorers in line x tester mating design for estimation of combining ability studies for various yield and yield contributing traits and to identify the best specific hybrid combinations. The pooled analysis of variance for combining ability over locations revealed the presence of significant differences among thelocations, parents and crosses which indicated the existence of adequate variation in the material under study. Among the lines, CMS 59B and among the testers, ZGY 1, RNR 2354, RNR 28359 and JGL 35126 were identified as promising based on their GCA effects for grain yield per plant and other important yield contributing characters.A total of six superior combinations viz., JMS 13A × RNR 2354, CMS 46A × JGL 34551, JMS 13A × ZGY 1, CMS 59A × IR 72, CMS 59A × JGL 35126 and CMS 59A × ZGY 1 have been identified as promising hybrids based on per se performance, positive SCA effects.The ratio of GCA to SCAvariances indicated that non-additive gene action was most prevalent for most of the characters under study.

Keywords: *Combining ability, GCA, SCA, gene action, hybrid rice and Yield.*

INTRODUCTION

Rice is a staple food for a significant portion of the world's population, particularly in Asia. It provides a major source of dietary calories and nutrition, meeting the energy requirements of millions of people.Rice plays a vital role in global food security, contributing to stable food supplies and mitigating hunger and malnutrition risks, especially in regions heavily reliant on rice as a primary food source.Rice production has witnessed substantial growth over the years, keeping pace with the increasing demand. Despite progress, challenges remain in achieving optimal productivity.The development of hybrid rice has been a significant milestone in rice breeding, providing enhanced productivity and other desirable traits.

Combining ability analysis is a valuable approach in plant breeding that helps assess the genetic potential of parental lines and predict the performance of their hybrids. The concept of combining ability was developed by Sprague and Tatum in 1942 [17] through preliminary studies with maize.This analysis involves the evaluation of both general combining ability (*GCA*) and specific combining ability (*SCA*) effects, which provide insights into the additive and non-additive genetic components contributing to important traits in rice.In the case of rice (*Oryza sativa*), combining ability analysis plays a crucial role in identifying superior combinations for developing high-yielding and desirable rice varieties and hybrids.

With this background present research problem was conducted in three locations to identify the best parents and hybrid combinations suitable for Telangana state.

MATERIAL AND METHODS

Experimental material for this investigation comprised four WA-based cytoplasmic male sterile (CMS) lines and ten elite proven restorer lines.During *Kharif*, 2020 four CMS lines and ten testers were planted in a crossing block with a spacing of 20 cm × 15 cm and crosses were performed in Line × Tester mating design to produce 40 hybrids. Three staggered sowings of the parents (females and males) were undertaken at an interval of 10 days to ensure synchronous flowering to make crosses.

A total of 40 hybrids along with 10 restorers, 4 'B' lines of corresponding male sterile lines and 2 checks were sown at three locations *viz.*,Regional Agricultural Research Station (RARS), Polasa, Jagtial (NTZ), Regional Sugarcane & Rice Research Station, Rudrur, Nizamabad (NTZ) and Rice Research Center ARI, Rajendranagar, (STZ)during *Rabi*, 2020-21 for estimation of *per se* performance, combining abilityand heterosis.

A completely randomized block design with three replications was followed. Top dressing was given with urea and need-based plant protection measures were undertaken for raising healthy seedlings. Each entry was planted in two rows of three meters in length with a spacing of 20 cm × 15 cm in three replications and all the package of practices were followed to raise a healthy crop.

Corresponding Author: **Gonya Nayak. P*
*Email Address: **pgonyanayak@gmail.com***

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Five plants were selected at random from each entry in each replication to record plant height, number of productive tillers per plant and panicle length. Observations were recorded for yield and yield-attributing traits at three locations. However 1000 grain weight were recorded on the random sample in each plot, whereas for days to 50% flowering the data was recorded on a whole plot basis. In the case of CMS lines, the observations were recorded on their respective maintainer (B) lines.

RESULTS AND DISCUSSIONS

1 Analysis of variance for combining ability

The material comprising 54 genotypes (4 CMS lines, 10 restorer lines and 40 hybrids) was evaluated during *rabi*2020-21 at three locations *viz*., Jagtial, Rudrur, and Rajendranagar for combining ability analysis. The pooled analysis of variance for combining ability over locations revealed the presence of significant differences among thelocations, genotypes, parents and crosses for all the characters studied (Table 1). Researchers like, [12] and [8] reported the significance of parents and crosses for all the characters studied. For parents *vs* crosses except panicle length, spikelet fertility, kernel breadth and kernel length breadth ratio all the characters were significant. The variance due to lines was significant for plant height, panicle length, head rice recovery, kernel length, kernel breadth and kernel length breadth ratio whereas, the variance due to testers was significant for plant height, panicle length, test weight, head rice recovery, kernel length, kernel breadth traits. The variance due to lines × testers was significant for the all characters studied. Parents × hybrids showed significant variance for nine characters *viz.,* indicating the superiority of hybrids and the presence of heterosis for the majority of the traits studied, [12] and [8] also noticed significant variances of line × tester effects for all the characters studied.

Table 1. Pooled analysis of variance for combining ability for yield and yield components in rice

Source of Variation	Df	DFF	PH	PL	NPT	SF %	TW	GYP (g)
Replicates	2	13.05**	13.78**	3.00*	0.78	0.31	0.34	4.31
Environments	2	2647.49**	1763.79**	211.04**	70.30**	141.44**	103.73**	825.76**
Rep ×Env.	4	1.79	1.46	3.71**	1.59	2.91	0.255	1.39
Treatments	53	146.29**	428.11**	25.32**	18.96**	72.41**	65.39**	177.43**
Parents	13	195.71**	657.25	25.89**	30.95**	67.26**	101.31**	20.41**
Parent *vs* Crosses	1	991.38**	1038.78**	2.41	98.29**	1241.92	192.91**	2212.86**
Crosses	39	108.15**	336.08**	25.72**	12.93**	44.26**	50.14**	177.58**
Line effect	3	61.71	754.95**	95.39**	23.1	48.13	40.027	267.15
Tester effect	9	107.28	701.60**	45.18**	12.10	62.93	122.59**	177.56
Line × Tester effect	27	113.61**	167.69**	11.49**	12.08**	37.61**	27.12**	167.63**
Env× Treat	106	13.05**	23.78**	1.99**	3.48**	20.78**	5.18**	31.39**
Env× Parents	26	18.66**	15.78**	1.95**	3.35**	15.36**	5.83**	30.40**
Env× Parent *vs* Cross	2	9.88*	42.88**	0.36	2.86*	6.39	12.56**	332.84**
Env× Crosses	78	11.25**	25.96**	2.042**	3.54**	22.96**	4.78**	23.99**
Env× Line effect	6	2.57	68.07*	3.54	3.31	23.37	3.74	8.14
Env× Tester effect	18	10.63	24.71	2.49	4.06	20.16	3.34	36.69
Env× Line × Tester effect	54	12.43**	21.69**	1.72**	3.39**	23.85**	5.37**	21.53**
Error	318	2.260	2.81	0.703	0.73	3.38	0.88	3.77

**Significant at P=0.05 level ** Significant at P=0.01 level*

df =	Degrees of freedom
DFF =	Days to 50% flowering
PH =	Plant height (cm)
PL =	Panicle length (cm)
NPT=	No. of productive tillers per plant
SF =	Spikelet fertility (%)
TW =	1000 grain weight (g)
GYP=	Grain yield per plant (g)

Interaction effects of lines × testers × locations recorded significant differences for the characters days to 50% flowering, plant height, panicle length, number of productive tillers per plant, spikelet fertility, 1000 grain weight and grain yield per plant. Earlier researchers like, [12] and [8] also reported significant variances of lines × testers × locations for grain yield per plant and its attributes.This indicates the existence of wide variability within the material studied and there is a good scope for identifying promising parents and hybrid combinations.

2. Combining ability variances and gene action

The estimates of *GCA* and *SCA* variances in pooled analysis are presented inTable 2.General combining ability is associated with additive gene action, while specific combining ability is due to dominance and epistasis. In the present investigation *SCA* variances were higher than *GCA* variances in pooled analysis for most of the traits indicating the predominance of non-additive gene action.

A comparison of the magnitude of variance components due to *GCA* and *SCA* confirmed the nature of gene action in controlling the expression of traits. In the present investigation, it was found that *SCA* variances were higher than *GCA* variances for most of the characteristics like duration of 50% flowering, plant height (cm), panicle length (cm), productive tillers per plant, spikelet fertility (%), test weight (g) and grain yield per plant which indicated the predominance of non-additive gene action. It is evident from different studies, that predominance of non-additive gene action over the additive component is ideal for exploitation through heterosis breeding.

Similar to the present findings, certain workers reported the importance of non-additive components in rice for duration of 50% flowering, [9], plant height [8, 10and 22], panicle length [8, and 22], spikelet fertility per cent [22], 1000-grain weight [8, 9, 10, 22, 4,7 and 20], number of productive tillers per plant [8, 10, 7 and 20], and grain yield per plant [1, 8, 15, 9, 21, 10, 22, 4, 7 and 22] as in case of present study.

Table 2. Pooled estimates of general and specific combining ability variances and proportionate gene action in rice for thirteen characters.

Character	Source of Variation			Degree of dominance	Nature of Gene
	σ^2GCA	σ^2SCA	σ^2GCA/σ^2SCA	$\sigma^2SCA / (\sigma^2GCA)^{1/2}$	Action
Days to 50 % flowering	1.30	12.38	0.105	2.17	Non-Additive
Plant height (cm)	11.51	18.32	0.628	0.89	Non-Additive
Panicle length (cm)	0.47	1.30	0.362	1.17	Non-Additive
Number of productive tillers per plant	0.40	1.76	0.227	1.47	Non-Additive
Spikelet fertility (%)	3.11	6.54	0.476	1.02	Non-Additive
1000 grain weight (g)	1.64	5.12	0.320	1.24	Non-Additive
Grain yield per plant (g)	3.46	18.15	0.19	1.62	Non-Additive

Contrary to present findings, non-additive gene action was reported by some researchers for grain yield per plant [11 and 4]. The discrepancy among the results reported may be due to the differences in the material used for the studyand the environment tested.

The contribution of lines was recorded high for four traits *viz*., plant height, panicle length, test weight, and kernel breadth while the contribution of testers was high for characters *i.e.,* days to 50 per cent flowering, number of productive tillers, spikelet fertility, and grain yield per plant. The contribution of line × tester interaction was moderate for plant height, spikelet fertility, number of productive tillers per plant and grain yield per plant indicating the importance of these traits in determining the potentiality of the hybrids.

3. General and specific combining ability effects

The estimates of general combining ability (4 lines and 10 testers) and specific combining ability effects (40 hybrids) for different characters at three locations and pooled analysis are presented character-wise below.

1. Days to 50% flowering

a) *GCA-GCA* effects

In rice, genotypes with dominant genes having negative effects tend to be early in duration which is desirable. Among the four lines, CMS 23B recorded significant negative *GCA* effects at all locations and pooled over locations.Whereas CMS 46B showed significant positive *GCA* effects at all the locations and pooled analysis(Table 3). Among the testers, JGL 35126 and RNR 28411 recorded significant negative *GCA* effects at all the three locations and pooled. RNR 26085, RNR 28359 and JGL 34551 recorded significant positive *GCA* effects at all three locations and also in pooled data.

b) *SCA-SCA* effects

Out of the 40 hybrids studied desirable significant negative specific combining ability effects were exhibited by five crosses at Jagtial, Rudrur and Rajendranagar and seventeen crosses in pooled analysis. Five crosses *viz.*, JMS 13A × RNR 26085, CMS 23A × RNR 26085, CMS 23A × RNR 2354,CMS 46A × RNR 28359 and CMS 59A × JGL 35047 exhibited a negative significant effect at all the three locations and pooled analysis.The significant negative *GCA* and *SCA* effects were also reported by [8, 19, 7 and 15] for days to 50 % flowering.

2. Plant height (cm)

a) *GCA* effects

For the character plant height*, GCA* effects on negative side is more desirable in order to develop non-lodging and semi dwarf genotypes in rice. The line, JMS 13B and CMS 23B recorded significant negative *GCA* effect at all locations and pooled over locations (Table 3). Among the testers, RNR 2354, RNR 28359, IR 72 and JGL 35047 exhibited significant negative *GCA* effect at all the three locations as well as in pooled over locations. Significant positive *GCA* effects were observed in testers RNR 26085,JGL 34551 and RNR 28411 at all the three locations and when pooled over locations.

b) *SCA* effects

Out of the 40 crosses studied significant negative specific combining ability effects were exhibited by 13 crosses at Jagtial, 12 crosses at Rudrur, 13 crosses at Rajendranagar and 14 crosses in pooled analysis. Seven crosses that registered significant negative *SCA* effect at all the three locations and pooled over locations includes,JMS 13A × RNR 21571,JMS 13A × IR 72,JMS 13A × JGL 35047, CMS 23A × ZGY 1,CMS 23A × RNR 2354, CMS 23A × JGL 35126 and CMS 59A × RNR 28411.Significant negative *GCA* and *SCA* results were supported by [8, 3 and 7] for this trait.

Table 3 Individual location wise and pooled estimates of general and specific combining ability effects for Days to 50% flowering and plant height (cm)

Parent /Cross	Days to 50% flowering				Plant height (cm)			
Parent	JGL	RDR	RNR	POOLED	JGL	RDR	RNR	POOLED
LINES								
JMS 13B	0.07	0.02	-0.13	-0.01	-1.94**	-2.15**	-2.17**	-2.08**
CMS 23B	-1.43**	-1.18**	-0.73**	-1.11**	-2.47**	-1.19**	-2.17**	-1.94**
CMS 46B	0.90**	1.12**	0.58*	0.86**	-1.19**	-1.16**	2.06**	-0.10
CMS 59B	0.47	0.05	0.28	0.26	5.59**	4.50**	2.28**	4.13**
SE (Lines) (gi)	029	0.26	0.27	0.15	0.28	0.30	0.33	0.18
SE (gi-gj)	0.41	0.37	0.38	0.21	0.39	0.43	0.47	0.25
CD. 95%	0.58	0.52	0.54	0.30	0.55	0.61	0.66	0.35

TESTERS								
RNR 26085	2.43**	2.80**	2.26**	2.49**	6.28**	7.81**	4.12**	6.07**
ZGY 1	-0.65	-1.53**	1.18**	-0.34	-1.86**	-0.11	-3.32**	-1.76**
RNR 2354	2.35**	-0.37	-0.49	0.49*	-2.29**	-3.77**	-4.75**	-3.60**
RNR 28359	1.93**	1.72**	1.76**	1.80**	-2.39**	-3.45**	-4.07**	-3.31**
RNR 21571	-0.90	0.22	-0.83	-0.50*	-3.27**	-2.76**	0.88	-1.72**
IR 72	-0.40	0.47	-0.41	-0.11	-3.18**	-2.31**	-2.77**	-2.75**
JGL 35126	-3.82**	-3.28**	-3.33**	-3.48**	-2.07**	-2.73**	-0.80	-1.87**
JGL 35047	-0.90	0.97*	-1.16**	-0.36	-4.37**	-5.57**	-1.75**	-3.90**
JGL 34551	0.93*	1.72**	1.84**	1.49**	6.67**	6.25**	5.92**	6.28**
RNR 28411	-0.98*	-2.70**	-0.83	-1.50**	6.47**	6.65**	6.53**	6.55**
SE (Testers) (gj)	0.46	0.41	0.43	0.24	0.44	0.48	0.53	0.28
SE (gi-gj)	0.65	0.58	0.60	0.34	0.62	0.68	0.74	0.39
CD. 95%	0.91	0.82	0.85	0.48	0.87	0.96	1.05	0.55
CROSSES								
JMS 13A × RNR 26085	-2.90**	-2.10*	-2.29**	-2.43**	-2.70**	-4.11**	0.24	-2.19**
JMS 13A × ZGY 1	-1.48	1.90*	-2.20*	-0.59	5.94**	6.30**	4.51**	5.58**
JMS 13A × RNR 2354	5.52**	-0.60	0.46	1.79**	6.14**	2.93**	4.24**	4.44**
JMS 13A × RNR 28359	3.93**	5.32**	6.54**	5.26**	-1.46	-3.58**	-0.53	-1.86**
JMS 13A × RNR 21571	-3.23**	-1.18	-1.21	-1.88**	-3.85**	-2.84**	-7.36**	-4.68**
JMS 13A × IR 72	-1.40	-0.77	-0.96	-1.04*	-6.11**	-9.46**	-3.14**	-6.24**
JMS 13A × JGL 35126	-3.65**	-2.35**	-0.71	-2.24**	4.21**	8.43**	7.49**	6.71**
JMS 13A × JGL 35047	-1.23	-2.60**	0.13	-1.24*	-5.55**	-2.86**	-4.86**	-4.42**

**Significant at P=0.05 level ** Significant at P=0.01 level*

Table 3 (Contd.)

JMS 13A × JGL 34551	-1.07	0.32	-1.54	-0.76	-2.99**	-0.56	-5.16**	-2.90**
JMS 13A × RNR 28411	5.52**	2.07*	1.79*	3.13**	6.38**	5.75**	4.56**	5.56**
CMS 23A × RNR 26085	-5.40**	-9.23**	-8.69**	-7.78**	2.69**	2.77**	4.82**	3.43**
CMS 23A × ZGY 1	-0.32	0.43	2.39**	0.84	-2.30*	-2.88**	-4.45**	-3.21**
CMS 23A × RNR 2354	-6.32**	-1.73*	-2.61**	-3.55**	-8.10**	-8.76**	-5.42**	-7.43**
CMS 23A × RNR 28359	0.10	-0.48	-2.53**	-0.97*	1.27	2.93**	0.17	1.46**
CMS 23A × RNR 21571	3.60**	0.68	1.73*	2.00**	4.04**	0.44	2.85**	2.44**
CMS 23A × IR 72	3.43**	0.77	3.98**	2.73**	5.48**	6.63**	1.80	4.64**
CMS 23A × JGL 35126	2.85**	-2.48**	-3.78**	-1.14*	-8.19**	-6.93**	-5.570**	-6.90**
CMS 23A × JGL 35047	4.93**	5.60**	6.39**	5.64**	2.94**	5.62**	1.08	3.21**
CMS 23A × JGL 34551	0.10	3.18**	3.06**	2.11**	1.40	0.52	9.35**	3.76**
CMS 23A × RNR 28411	-2.98**	3.27**	0.06	0.11	0.77	-0.34	-4.63**	-1.40*
CMS 46A × RNR 26085	5.93**	6.47**	7.34**	6.58**	0.05	-0.39	-6.25**	-2.20**
CMS 46A × ZGY 1	-0.98	-2.87**	-3.91**	-2.59**	-4.77**	-4.95**	-1.02	-3.58**
CMS 46A × RNR 2354	-0.32	0.97	1.43	0.69	0.96	1.85	-2.35*	0.15
CMS 46A × RNR 28359	-3.90**	-6.78**	-6.16**	-5.61**	-2.31*	-1.52	0.97	-0.95
CMS 46 A × RNR 21571	1.93*	1.05	3.09**	2.03**	0.50	1.08	4.18**	1.92**
CMS 46A × IR 72	-1.57	-0.86	-0.66	-1.03*	-2.16*	-0.60	-0.33	-1.03
CMS 46A × JGL 35126	1.52	6.22**	5.26**	4.33**	0.70	2.01*	-3.43**	-0.24
CMS 46A × JGL 35047	-0.73	-0.70	-3.91**	-1.78**	2.70**	1.89	1.18	1.92**
CMS 46A × JGL 34551	-0.90	-4.12**	-1.91*	-2.31**	5.53**	1.83	1.08	2.81**
CMS 46A × RNR 28411	-0.98	0.63	-0.58	-0.31	-1.20	-1.20	5.97**	1.19*
CMS 59A × RNR 26085	2.37*	4.87**	3.64**	3.63**	-0.04	1.74	1.19	0.97
CMS 59A × ZGY 1	2.78**	0.53	3.73**	2.35**	1.14	1.52	0.96	1.21*
CMS 59A × RNR 2354	1.12	1.37	0.73	1.07*	1.00	3.98**	3.53**	2.84**
CMS 59A × RNR 28359	-0.13	1.95*	2.14*	1.32**	2.50**	2.17*	-0.62	1.35*
CMS 59A × RNR 21571	-2.30*	-0.55	-3.61**	-2.15**	-0.69	1.32	0.33	0.32
CMS 59A × IR 72	-0.47	0.87	-2.36**	-0.65	2.79**	3.43**	1.68	2.63**
CMS 59A × JGL 35126	-0.72	-1.38	-0.78	-0.96	3.28**	-3.52**	1.51	0.42
CMS 59A × JGL 35047	-2.97**	-2.30**	-2.61**	-2.63**	-0.09	-4.64**	2.59*	-0.71
CMS 59A × JGL 34551	1.87*	0.62	0.39	0.96	-3.93**	-1.80	-5.27**	-3.67**

CMS 59A × RNR 28411	-1.55	-5.97**	-1.28	-2.93**	-5.96**	-4.20**	-5.89**	-5.35**
SE (Sij)	0.92	0.82	0.85	0.49	0.88	0.96	1.05	0.55
SE (Sij-Sik)	0.92	0.82	0.86	0.49	0.88	0.96	1.05	0.55
SE (Sij-Skl)	1.30	1.16	1.21	0.69	1.24	1.36	1.49	0.78
CD. 95%	1.83	1.64	1.71	0.96	1.75	1.92	2.10	1.09
*Significant at P=0.05 level ** Significant at P=0.01 level								

3. Panicle length (cm)

a) *GCA effects*

For the trait panicle length, the line CMS 46B exhibited significant positive GCA effect at Jagtial, Rajendranagar and CMS 59B exhibited significant positive GCA effect at all the three locations and pooled analysis(Table 4). Three testers viz.,RNR 26085, JGL 35126 and RNR 28411 expressed positive significant GCA effects at Jagtial and Rudrur locations and 5 testers in pooled analysis. One tester (RNR 26085) exhibited significant positive GCA effect at all the three locations and pooled analysis.

b) *SCA effects*

Among the 40 crosses studied, 8 at Jagtial, 5 at Rudrur, 6 at Rajendranagar and 12 in pooled analysis had significant positive SCA effects for panicle length. Two crosses viz., JMS 13A × 35126 and CMS 59A × IR 72 recorded significant positive SCA effects at all the three locations and pooled analysis for panicle length.

4. Number of productive tillers per plant

a) *GCA effects*

Among the lines JMS 13B had significant positive general combining ability effects at all the three locations and also in pooled analysis. CMS 23B had significant positive general combiner at Jagtial and pooled analysis. While the line CMS 46B and CMS 59B had significant negative effect for number of productive tillers per plant in pooled analysis. Among the 10 testers studied, RNR 21571, IR 72, JGL 35126 and RNR 28411showed positive significant effect at Jagtial location, RNR 21571 and IR 72 at Rudrur, RNR 2354 at Rajendranagar and RNR 21571 and IR 72, recorded positive significant GCA effects at Jagtial, Rudrur and pooled over locations (Table 4).

b) *SCA effects*

Number of productive tillers per plant is an important character that contributes directly to the grain yield. In this study, out of 40 hybrids evaluated, 5 at Jagtial, 8 at Rudrur, 8 at Rajendranagar and 9 in pooled analysis had significant positive SCA effects for number of productive tillers per plant. Two hybrids viz., CMS 23A × RNR 26085 and CMS 59A × RNR 28411 recorded positive significant SCAeffects at all the three locations and also in pooled. Similar results were reported by [18 and 14] for this trait.

Table 4 Individual location wise and pooled estimates of general and specific combining ability effects for panicle length and number of productive tillers per plant

Parent /Cross	Panicle length (cm)				Number of productive tillers per plant			
Parent	**JGL**	**RDR**	**RNR**	**POOLED**	**JGL**	**RDR**	**RNR**	**POOLED**
LINES								
JMS 13B	-0.62**	0.05	-0.54**	-0.37**	0.38*	0.62**	0.89**	0.63**
CMS 23B	-1.01**	-1.01**	-1.43**	-1.18**	0.40**	0.02	0.16	0.19*
CMS 46B	0.53**	-0.11	0.49**	0.30**	-0.67**	-0.37*	-0.17	-0.41**
CMS 59B	1.19**	1.08**	1.48**	1.25**	-0.1	-0.27	-0.87**	-0.42**
SE (Lines) (gi)	0.15	0.14	0.16	0.08	0.14	0.16	0.15	0.08
SE (gi-gj)	0.21	0.20	0.23	0.12	0.20	0.23	0.21	0.12
CD. 95%	0.30	0.28	0.32	0.17	0.29	0.33	0.30	0.17
TESTERS								
RNR 26085	1.83**	2.65**	2.29**	2.26**	-0.77**	-0.37	0.04	-0.37*
ZGY 1	-1.79**	-0.94**	-1.12**	-1.29**	-0.35	0.46	0.04	0.05
RNR 2354	-1.43**	-0.66**	-1.50**	-1.20**	-0.77**	0.46	0.88**	0.19
RNR 28359	0.60*	0.06	0.42	0.36*	-0.68**	-0.04	0.04	-0.23
RNR 21571	-1.04**	-1.16**	-0.55*	-0.91**	1.07**	0.96**	0.46	0.83**
IR 72	-0.38	-0.36	-0.05	-0.27	1.65**	0.96**	0.04	0.88**
JGL 35126	1.15**	0.52*	0.12	0.60**	0.73**	-0.46	-0.29	-0.006
JGL 35047	-0.35	-1.82**	-0.50	-0.89**	-0.60*	0.04	0.12	-0.14
JGL 34551	0.40	0.75**	0.47	0.54**	-0.93**	-1.54**	-0.96**	-1.14**
RNR 28411	1.01**	0.97**	0.42	0.80**	0.65**	-0.46	-0.38	-0.06
SE (Testers) (gj)	0.24	0.22	0.25	0.14	0.23	0.26	0.24	0.14
SE (gi-gj)	0.34	0.31	0.36	0.19	0.32	0.37	0.34	0.20
CD. 95%	0.48	0.44	0.51	0.27	0.46	0.52	0.48	0.27
CROSSES								
JMS 13A × RNR 26085	-2.13**	-0.59	-0.57	-1.10**	-2.37**	-1.46**	-1.31**	-1.71**
JMS 13A × ZGY 1	0.56	0.20	0.13	0.30	0.55	1.38*	2.36**	1.43**

JMS 13A × RNR 2354	0.86	0.80	1.42**	1.03**	0.63	1.71**	0.53	0.96**
JMS 13A × RNR 28359	0.14	0.14	0.86	0.38	-0.45	-0.13	-0.31	-0.29
JMS 13A × RNR 21571	-0.96	-1.51**	-0.71	-1.06**	1.47**	-1.46**	-1.39**	-0.46
JMS 13A × IR 72	-2.95**	-1.91**	-2.23**	-2.37**	1.55**	0.21	1.36**	1.04**
JMS 13A × JGL 35126	1.46**	2.05**	1.86**	1.79**	0.47	-0.04	-0.64	-0.07
JMS 13A × JGL 35047	-0.28	-0.75	-1.36*	-0.79	0.8	0.46	0.28	0.51
JMS 13A × JGL 34551	1.17*	0.38	0.41	0.65*	-1.53**	-0.96	-0.64	-1.04**

**Significant at P=0.05 level ** Significant at P=0.01 level*

Table 4 (Contd.)

JMS 13A × RNR 28411	2.12**	1.20**	0.19	1.17**	-1.12*	0.29	-0.23	-0.35
CMS 23A × RNR 26085	-0.72	0.34	0.21	-0.06	1.93**	2.14**	1.76**	1.94**
CMS 23A × ZGY 1	1.44**	0.43	0.61	0.83**	0.85	-1.69**	-1.24*	-0.69*
CMS 23A × RNR 2354	0.44	0.59	-0.13	0.30	0.6	-0.03	-0.74	-0.06
CMS 23A × RNR 28359	0.15	-0.44	-0.39	-0.23	0.18	0.81	0.42	0.47
CMS 23A × RNR 21571	0.85	-0.06	0.44	0.41	-0.9	1.48**	1.01*	0.53
CMS 23A × IR 72	-0.71	0.85	-1.05*	-0.30	-0.15	-1.53**	-1.58**	-1.08**
CMS 23A × JGL 35126	-1.07*	0.30	-0.22	-0.33	-1.23**	-1.44**	-1.24*	-1.30**
CMS 23A × JGL 35047	0.17	-0.62	-0.01	-0.16	-0.9	-0.28	0.68	-0.17
CMS 23A × JGL 34551	0.48	-0.30	1.06*	0.41	-0.9	-0.03	0.43	-0.17
CMS 23A × RNR 28411	-1.03*	-1.08*	-0.52	-0.89**	0.52	0.56	0.51	0.53
CMS 46A × RNR 26085	0.29	0.61	-0.50	0.13	0.33	-1.46**	-1.24*	-0.79**
CMS 46A × ZGY 1	-0.59	-0.27	-0.73	-0.53	-0.08	-0.29	0.43	0.02
CMS 46A × RNR 2354	1.18*	0.66	0.92	0.92**	-0.33	0.71	1.93**	0.77**
CMS 46A × RNR 28359	-0.85	-0.24	-0.60	-0.56*	-0.42	0.21	0.76	0.18
CMS 46 A × RNR 21571	-0.28	1.51**	0.53	0.59*	-0.5	2.54**	2.68**	1.57**
CMS 46A × IR 72	1.99**	-0.65	1.20*	0.85**	-1.42**	1.21*	-0.58	-0.26
CMS 46A × JGL 35126	-0.23	-1.63**	-0.97	-0.94**	0.5	-1.04	-0.91	-0.48
CMS 46A × JGL 35047	-0.16	0.21	0.18	0.08	0.83	-0.54	-1.66**	-0.45
CMS 46A × JGL 34551	0.49	0.07	0.45	0.33	1.83**	0.71	0.43	0.99**
CMS 46A × RNR 28411	-1.83**	-0.28	-0.47	-0.86**	-0.75	-2.04**	-1.83**	-1.54**
CMS 59A × RNR 26085	2.56**	-0.35	0.87	1.03**	0.1	0.78	0.79	0.56
CMS 59A × ZGY 1	-1.42**	-0.36	-0.02	-0.60*	-1.32**	0.61	-1.54**	-0.75**
CMS 59A × RNR 2354	-2.48**	-2.04**	-2.21**	-2.24**	-0.9	-2.39**	-1.71**	-1.67**
CMS 59A × RNR 28359	0.56	0.54	0.14	0.41	0.68	-0.89	-0.88	-0.36
CMS 59A × RNR 21571	0.39	0.06	-0.26	0.06	-0.07	-2.56**	-2.29**	-1.64**
CMS 59A × IR 72	1.67**	1.70**	2.08**	1.81**	0.02	0.11	0.79	0.36
CMS 59A × JGL 35126	-0.16	-0.72	-0.66	-0.51	0.27	2.53**	2.79**	1.86**
CMS 59A × JGL 35047	0.28	1.16*	1.19*	0.87**	-0.73	0.36	0.71	0.11
CMS 59A × JGL 34551	-2.14**	-0.15	-1.91**	-1.40**	0.6	0.28	-0.21	0.22
CMS 59A × RNR 28411	0.74	0.17	0.80	0.57*	1.35**	1.19*	1.54**	1.36**
SE (Sij)	0.48	0.44	0.51	0.28	0.46	0.52	0.48	0.28
SE (Sij-Sik)	0.48	0.44	0.51	0.28	0.46	0.52	0.48	0.28
SE (Sij-Skl)	0.68	0.63	0.73	0.39	0.65	0.74	0.68	0.40
CD. 95%	0.96	0.89	1.03	0.55	0.92	1.05	0.96	0.56
*Significant at P=0.05 level ** Significant at P=0.01 level								

5. Spikelet fertility (%)

a) *GCA* effects

Among the lines studied, CMS 59B showed significant positive *GCA* effect at Jagtial, Rudrur, and pooled analysis. Among the testers, ZGY 1 showed significant positive at all locations (except Jagtial) and pooled, JGL 35126 showed significant positive *GCA*effect at all locations (except Rajendranagar) and pooled, JGL 34551 showed significant positive *GCA*effect at all three locations and pooled.

(b) *SCA* effects

Out of 40 hybrids tested 9 at Jagtial, 8 at Rudrur, 10 at Rajendranagar and 7 in pooled analysis had significant positive specific combining ability effects for spikelet fertility percentage(Table 5). Four hybrids *viz.,* CMS 23A × RNR 28359, CMS 23A × IR 72, CMS 46A × JGL 35047 and CMS 59A × RNR 26085 have recorded significant positive effects at two locations and in pooled analysis for spikelet fertility percentage.

6. 1000 grain weight (g)

a) *GCA* effects

Among the lines, CMS 46B had positive significant *GCA*effect at all the locations (except Rajendranagar) and pooled for 1000 grain weight and JMS 13B had negative significant *GCA*effect at all the three locations and pooled (Table 5). Among the testers, RNR 26085, ZGY 1, RNR 28359, IR 72 and RNR 28411 registered positive significant *GCA* effects at all the locations and pooled over locations while, three testers exhibited negative significant effects.

b) *SCA* effects

Evaluation of the hybrids for 1000 grain weight revealed that 8 crosses at Jagtial, 13 crosses at Rudrur, 9 at Rajendranagar and 12 in pooled analysis registered significant positive *GCA* effects (Table 5). Three crosses *viz.* JMS 13A × JGL 35047, CMS 23A × RNR 2354 and CMS 46A × JGL 35126 showed positive significant *SCA*effects at all three locations and pooled over locations.On contrast four crosses at all three locations as well as in pooled over locations showed significant negative *SCA* effects.

The significant positive, negative *GCA* and *SCA* effects were reported by [16] for this trait.

Table 5 Individual location wise and pooled estimates of general and specific combining ability effects for spikelet fertility (%) and 1000 grain weight

Parent /Cross	Spikelet fertility (%)				1000 grain weight (g)				Grain Yield (g)			
Parent	**JGL**	**RDR**	**RNR**	**POOLED**	**JGL**	**RDR**	**RNR**	**POOLED**	**JGL**	**RDR**	**RNR**	**POOLED**
LINES												
JMS 13B	-0.29	-0.73*	1.34**	0.11	-1.03**	-1.33**	-0.57**	-0.98**	0.51	0.58*	0.64	0.57**
CMS 23B	-0.57	0.42	0.03	-0.04	0.01	0.63**	0.24	0.29**	-2.67**	-2.25**	-1.74**	-2.22**
CMS 46B	-0.70	-0.88**	-1.20**	-0.93**	0.52**	0.73**	0.31	0.52**	0.23	-0.78**	-0.20	-0.25
CMS 59B	1.56**	1.19**	-0.18	0.85**	0.49**	-0.03	0.02	0.16	1.93**	2.46**	1.30**	1.89**
SE (Lines) (gi)	0.37	0.29	0.33	0.19	0.17	0.14	0.19	0.09	0.40	0.30	0.40	0.21
SE (gi-gj)	0.52	0.41	0.47	0.27	0.24	0.20	0.27	0.13	0.56	0.40	0.57	0.30
CD. 95%	0.74	0.58	0.67	0.38	0.35	0.38	0.38	0.18	0.80	0.51	0.78	0.43
TESTERS												
RNR 26085	1.493 *	-1.70**	-0.004	-0.07	1.31**	1.24**	0.64*	1.06**	-3.67**	-2.74**	-3.73**	-3.38**
ZGY 1	0.234	1.60**	2.02**	1.28**	1.59**	0.93**	1.79**	1.43**	3.25**	3.63**	0.84	2.57**
RNR 2354	-1.96**	0.56	-0.54	-0.65*	-3.56**	-3.61**	-2.04**	-3.07**	1.61*	2.10**	1.07	1.59**
RNR 28359	0.63	-1.52**	1.10*	0.07	0.84**	1.48**	1.04**	1.12**	1.29*	1.60**	0.27	1.06**
RNR 21571	-1.02	-1.01*	-3.17**	-1.73**	0.79**	0.43	0.35	0.52**	-2.90**	-6.46**	0.14	-3.07**
IR 72	-0.25	-1.90**	-2.88**	-1.67**	1.01**	1.07**	1.25**	1.11**	-2.17**	-1.99**	0.23	-1.31**
JGL 35126	1.74**	3.79**	0.49	2.01**	-0.24	-0.81**	-1.70**	-0.91**	3.57**	4.08**	1.18	2.94**
JGL 35047	-1.51*	0.06	0.61	-0.28	0.34	-0.44	-0.01	-0.03	-2.76**	-2.66**	1.49*	-1.31**
JGL 34551	1.83 **	1.01*	2.52**	1.78**	-3.41**	-2.89**	-3.40**	-3.23**	1.04	2.62**	-0.47	1.06**
RNR 28411	-1.20 *	-0.87	-0.16	-0.74	1.33**	2.60**	2.08**	2.00**	0.762	-0.17	-1.03	-0.15
SE (Testers) (gj)	0.58	0.46	0.53	0.30	0.27	0.22	0.30	0.14	0.63	0.40	0.64	0.34
SE (gi-gj)	0.83	0.65	0.75	0.43	0.39	0.31	0.43	0.20	0.89	0.56	0.90	0.48
CD. 95%	1.17	0.99	1.06	0.60	0.55	0.44	0.60	0.29	1.26	0.80	1.23	0.68
CROSSES												
JMS 13A × RNR 26085	-1.57	2.00 *	2.31*	0.92	-0.91	-0.11	-2.00**	-1.01**	-2.52	-1.26	-1.66	-1.82**
JMS 13A × ZGY 1	-1.21	1.4	0.29	0.16	1.04	2.16**	3.88**	2.36**	3.86**	3.89**	4.47**	4.07**
JMS 13A × RNR 2354	-1.02	2.58 **	1.91	1.16	-1.71**	-1.37**	0.78	0.77*	9.03**	4.45**	7.11**	6.86**
JMS 13A × RNR 28359	-2.08	-2.85 **	-2.33*	-2.42**	0.49	1.34**	-1.03	0.26	-5.55**	-7.12**	-3.83**	-5.50**
JMS 13A × RNR 21571	4.81**	-0.93	-1.12	0.92	1.91**	-0.60	0.85	0.72*	-3.49**	-5.64**	-0.43	-3.19**
JMS 13A × IR 72	2.44*	-4.08 **	-5.81**	-2.48**	0.82	-0.98*	-0.44	-0.20	-3.59**	-2.72**	-4.46**	-3.59**
JMS 13A × JGL 35126	1.58	1.68	3.55**	2.27**	-2.63**	-4.24**	-4.80**	-3.89**	1.97	3.24**	0.93	2.05**
JMS 13A × JGL 35047	-1.90	-1.83	2.99**	-0.24	2.19**	2.16**	3.78**	2.71**	7.67**	9.65**	2.29	6.53**

**Significant at P=0.05 level ** Significant at P=0.01 level*

Table 5 (Contd.)

JMS 13A × JGL 34551	1.20	-0.61	-4.51**	-1.31*	-0.26	1.28**	-1.87**	-0.28	-7.097**	-6.67**	-2.66*	-5.47**
JMS 13A × RNR 28411	-2.24	2.63 **	2.71*	1.03	-0.93	0.36	0.86	0.09	-0.29	2.19**	-1.76	0.05
CMS 23A × RNR 26085	2.44*	-0.71	-1.54	0.06	-0.38	0.96*	-0.07	0.17	2.62*	1.03	1.85	1.83**
CMS 23A × ZGY 1	-4.33**	-0.75	1.03	-1.35*	1.14*	0.07	-0.55	0.22	-2.07	-2.65**	-2.89*	-2.53**
CMS 23A × RNR 2354	-2.48*	-1.34	-0.78	-1.53*	3.76**	4.47**	3.51**	3.91**	-5.23**	-3.58**	-2.58*	-3.80**
CMS 23A × RNR 28359	1.57	5.30 **	3.68**	3.52**	-1.85**	-1.65**	1.63**	-0.62	4.59**	5.71**	4.51**	4.94**
CMS 23A × RNR 21571	-2.32	-3.77 **	0.49	-1.87**	-1.06	-0.83	-1.45*	-1.11	1.32	5.78**	-1.15	1.98**

CMS 23A × IR 72	1.68	4.88 **	2.53*	3.03**	-1.62**	0.53	0.99	-0.03	-0.52	-0.19	-2.05	-0.92
CMS 23A × JGL 35126	1.26	-1.14	-3.38**	-1.09	-0.07	0.91*	-0.34	0.17	-4.23**	-2.99**	-3.53**	-3.58**
CMS 23A × JGL 35047	1.54	-2.81 **	-0.26	-0.51	-2.88**	-1.89**	-2.66**	-2.50**	0.47	-6.92**	4.23**	-0.74
CMS 23A × JGL 34551	-2.09	2.28 *	1.17	0.41	0.47	-2.31**	-2.07**	-1.31**	3.94**	3.83**	1.19	2.99**
CMS 23A × RNR 28411	2.73*	-1.95 *	-2.95**	-0.72	2.50**	-0.27	1.02	1.08**	-0.89	-0.01	0.42	-0.16
CMS 46A × RNR 26085	-3.29**	-1.81	-5.38**	-3.50**	0.07	0.26	1.25*	0.53	2.72*	3.25**	0.51	2.16**
CMS 46A × ZGY 1	-0.26	1.09	0.33	0.39	-2.94**	-1.80**	-2.70**	-2.48**	-2.87*	-3.05**	-4.36**	-3.43**
CMS 46A × RNR 2354	-1.31	-2.27 *	1.02	-0.85	-0.16	-0.83	-0.64	-0.54	3.50**	4.35**	0.55	2.80**
CMS 46A × RNR 28359	-1.56	-0.69	-1.75	-1.34*	1.10*	0.91*	0.05	0.69*	2.53*	-0.69	0.18	0.67
CMS 46 A × RNR 21571	0.02	1.10	-1.58	-0.15	0.53	-0.07	-1.86**	-0.47	-1.52	-8.10**	0.88	-2.91**
CMS 46A × IR 72	-2.68*	1.25	2.93**	0.50	-0.03	0.23	-1.09	-0.30	-0.32	-5.39**	-0.48	-2.06**
CMS 46A × JGL 35126	1.73	0.53	3.92**	2.06**	2.05**	2.23**	2.22**	2.17**	-1.56	1.36	0.13	-0.02
CMS 46A × JGL 35047	4.74**	5.20 **	-0.19	3.25**	0.54	-0.8	-0.37	-0.21	-4.49**	1.21	-2.94*	-2.08**
CMS 46A × JGL 34551	2.64*	-2.52 **	0.60	0.24	0.35	-1.12*	3.22**	0.82**	6.01**	7.89**	6.15**	6.68**
CMS 46A × RNR 28411	-0.03	-1.88 *	0.08	0.61	-1.51**	0.99*	-0.09	-0.20	-4.02**	-0.82	-0.62	-1.82**
CMS 59A × RNR 26085	2.42*	0.52	4.60**	2.52**	1.23*	-1.10*	0.82	0.31	-2.81*	-3.02**	-0.69	-2.17**
CMS 59A × ZGY 1	5.81**	-1.74	-1.65	0.80	0.75	-0.44	-0.63	-0.11	1.07	1.81*	2.78*	1.89**
CMS 59A × RNR 2354	4.80**	1.03	-2.16*	1.22**	-1.90**	-2.27**	-3.64**	-2.61**	-7.29**	-5.22**	-5.08**	-5.87**
CMS 59A × RNR 28359	2.08	-1.76	0.40	0.24	0.26	-0.60	-0.65	-0.33	-1.57	2.10*	-0.86	-0.11
CMS 59A × RNR 21571	-2.51*	3.60 **	2.20*	1.10	-1.38*	1.50**	2.47**	0.86**	3.69**	7.97**	0.71	4.12**
CMS 59A × IR 72	-1.44	-2.05 *	0.35	-1.05	0.83	0.22	0.54	0.53	4.42**	8.30**	6.98**	6.57**
CMS 59A × JGL 35126	-4.57**	-1.07	-4.10**	-3.24**	0.65	1.1*	2.92**	1.55**	3.81**	-1.61*	2.47*	1.56*
CMS 59A × JGL 35047	-4.38**	-0.57	-2.55*	-2.50**	0.16	0.53	-0.74	-0.01	-3.65**	-3.93**	-3.57**	-3.72**
CMS 59A × JGL 34551	-1.75	0.85	2.75*	0.61	-0.55	2.15**	0.72	0.77*	-2.85*	-5.05**	-4.68**	-4.19**
CMS 59A × RNR 28411	-0.46	1.19	0.16	0.30	-0.05	-1.08*	-1.79**	-0.97**	5.19**	-1.356	1.95	1.93**
SE (Sij)	1.17	0.92	1.07	0.61	0.55	0.44	0.60	0.29	1.26	0.80	1.28	0.69
SE (Sij-Sik)	1.17	0.92	1.07	0.61	0.55	0.44	0.60	0.29	1.26	0.80	1.28	0.69
SE (Sij-Skl)	1.66	1.30	1.51	0.87	0.78	0.63	0.86	0.41	1.79	1.13	1.81	0.97
CD. 95%	2.33	1.83	2.13	1.21	1.09	0.89	1.21	0.58	2.52	1.59	2.45	1.36
*Significant at P=0.05 level ** Significant at P=0.01 level												

7. Grain yield per plant (g)

a) *GCA* effects

Among the lines, CMS 59B registered significant positive general combining ability effects at all the three locations and over locations while the lines CMS 23B exhibited negative significant effect.Among the 10 testers studied, ZGY 1, RNR 2354, RNR 28359 and JGL 35126 manifested significant positive *GCA* effects at two locations and pooled analysis for grain yield per plant.The tester, JGL 34551 at Rudrur and pooled analysis recorded significant positive general combining ability effects.

b) *SCA* effects

For grain yield per plant, 14 crosses at Jagtial, 15 crosses at Rudrur, 8 crosses at Rajendranagar and 16 crosses in pooled analysis recorded significant positive specific combining ability effects (Table 4.19). The hybrids recorded positive significant *SCA* effects
at all three locations and pooled over locations includes JMS 13A × ZGY 1, JMS 13A × RNR 2354, CMS 23A × RNR 28359, CMS 46A × JGL 34551, CMS 59A × ZGY1 and CMS 59A × IR 72. The positive significant *GCA* and *SCA* effects was reported by [6, 5, 2, 19, 16 and 23].

Among lines, CMS 59B was good general combiner for grain yield per plant, panicle length andspikelet fertility. Whereas JMS 13B was good general combiner for plant height and number of productive tillers per plant. Out of ten testers four were found to be good general combiners for various yield and yield attributing charactersas ZGY 1 for grain yield per plant, spikelet fertility and 1000 grain weight; RNR 2354 for grain yield per plant and plantheight;RNR 28359 for grain yield per plant, plant height, 1000 grain weight,; JGL 35126 for grain yield, days to fifty percent flowering, plant height, panicle length and spikelet fertility.

It was observed in certain instances that the lines and testers with good *per se* performance have not been good general combiners and *vice versa*, thus the association between *per se* performance and *GCA* effects was evident in the present study indicated the effectiveness of choice of parents based on *per se* performance alone was not appropriate for predicting the combining ability of the parents.

Among the crosses, the five best specific combiners identified based on *SCA* effects and corresponding mean performance, being JMS 13A × RNR 2354for grain yield per plant, panicle length, number of productive tillers per plant and1000 grain weight; CMS 46A × JGL 34551for grain yield per plant, days to 50% flowering, number of productive tillers per plant and1000 grain weight; JMS 13A × ZGY 1for grain yield per plant,number of productive tillers per plant and1000 grain weight;CMS 59A × IR 72for grain yield per plant, panicle length and 1000 grain weight; CMS 59A × JGL 35126for grain yield per plant, number of productive tillers per plant and 1000 grain weight.

SUMMARY AND CONCLUSIONS

The pooled analysis of variance for combining ability over locations revealed the presence of significant differences among thelocations, parents and crosses which indicated the existence of adequate variation in the material under study. The ratio of *GCA* to *SCA*variances indicated that non-additive gene action was most prevalent for most of the characters under study.

Among the lines, CMS 59B and among the testers, ZGY 1, RNR 2354, RNR 28359 and JGL 35126 were identified as promising based on their *GCA* effects for grain yield per plant and other important yield contributing characters.

In pooled analysis significant positive *SCA* effects were obtained in 16 hybrids for grain yield per plant, 9 hybrids for a number of productive tillers per plant, four hybrids for spikelet fertility percentage and three hybrids for 1000 grain weight. Total six superior combinations *viz.*, JMS 13A × RNR 2354, CMS 46A × JGL 34551, JMS 13A × ZGY 1, CMS 59A × IR 72, CMS 59A × JGL 35126 and CMS 59A × ZGY 1 have been identified as promising hybrids based on *per se* performance, positive *SCA* effects. F_1 seed production of these hybrids can be taken place to conduct the front line demonstrations in farmer's fields for acceptance and commercial release of hybrids.

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