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Combining Ability Analysis of Hybrid Rice (*Oryza sativa* L.) Parental Lines for Yield, Grain Quality and Grain Zinc Content

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ABSTRACT

Combining ability analysis assists in identifying parents with high general combining ability (GCA) effects and cross combinations with high-specific combining effect (SCA) to exploit heterosis and isolate pure lines from the progenies of heterotic hybrids. An experiment was conducted at the experimental field of the Genetics and Plant Breeding department, Bangabandhu Sheikh Mujibur Rahman Agricultural University during Aman season 2017-2018 using 25 hybrids obtained from 5 x 5, line x tester mating design. Analysis of variance of combining ability showed highly significant differences among the genotypes indicating wider genetic variability among genotypes. Significant General Combining Ability (GCA) and Specific Combining Ability (SCA) effects were obtained for all the characters studied except 50% flowering, panicle length, and grain breadth. Among the lines GAN46A, IR58A and IR62A showed significant GCA effects for grain yield, and most of the yield contributing traits could be used as good general combiner lines for improving the grain yield of rice. IR68A line is good general combiner for Zn and Fe content. Among testers, Hera5R, ACI1R and KataribhoghR testers are good general combiner for Zn and Fe content. Hera5R and ACI1R testers having positive GCA effect with yield (t/ha). IR58A x BU7R, IR58A x BHD1R, IR62A x Hera5R, BRRI1A x Hera5R, BRRI1A x BHD1R, BRRI1A x ACI1R, GAN46A x BU7R, GAN46A x BHD1R, GAN46A x ACI1R crosses are good specific combiner for zinc content with grain yield (t/ha).

Key words: Rice, Hybrid, CMS, Line X Tester, GCA, SCA

INTRODUCTION

Rice is abundantly produced and consumed in South and Southeast Asia and more than half of the global population consume rice as their staple food. However, rice is a poor source of micronutrients and vitamins. Thus, micronutrient deficiency particularly zinc and iron deficiency are acute in the poor people who mostly depend on rice for majority of their micronutrient requirements. In Bangladesh, 86.9% of 6-59-month-old children and 94.6% of Non-Pregnant Non-Lactating women (NPNL) suffer from micronutrient malnutrition; in particular, Zn and Fe insufficiency affect 31% and 15.1% of 6-59-month-old children and 43.4% and 14.1% of NPNL women (ICDDR, B 2022). The process of increasing the nutritional value of food crops using agronomic techniques, conventional or modern plant breeding and biotechnology is known as biofortification. Biofortification of staple food crops for enhanced micronutrient content through genetic manipulation is the best option available to alleviate hidden hunger with little recurring costs (Welch *et*

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al., 2004, Ortiz-Monasterio *et al.,* 2007). Through biofortification, it is attainable to economically combine high yield with the high micronutrient density trait in rice. It has become crucial for breeders to develop rice cultivars that have enhanced grain zinc content and high yield potentiality. In the history of rice improvement, one of the most significant breakthroughs is the development of hybrid rice varieties on a commercial scale utilizing male sterility and fertility restoration systems. The A, B, and R lines are the three breeding lines that form the foundation of the hybridization approach. A line is the cytoplasmic male sterile line where the male sterility is jointly controlled by recessive nuclear gene and sterile cytoplasmic factor. B line is an isogenic line of A line, the only difference in male sterility and fertility. R-line possesses a fertility restoration gene. (Islam *et al.*, 2015).

Combining ability analysis is an effective quantitative genetics tool for measuring ability of the parental lines to produce heterotic progenies for a particular trait either in specific or non-specific (general) combinations. There are two categories for combining ability: general combining ability (GCA) and specific combining ability (SCA). Diallel (Griffing, 1956) and line x tester (Kempthrone, 1956) matting designs are two of the statistical tools that can be used to determine the combining ability and gene action governing different quantitative traits. They offer reliable information about the general and specific combining abilities (GCA and SCA) of parents and their cross combinations, as well as assist in the estimation of various kinds of gene actions. Combining ability estimates play a major role in determining which parental lines are the best for developing hybrids. The combining ability studies are frequently used by plant breeders to evaluate genotypes for their parental usefulness and to assess the gene action involved in various characters to design an efficient breeding plan for further genetic improvement of the existing materials. Therefore, this study was undertaken to determine the combining ability and nature of gene action for grain zinc and iron content, yield and its different components.

MATERIALS AND METHODS

Experimental site and materials list

During Aman season 2018, the experiment was conducted at the research field and laboratory of the Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur. The experimental material comprised of five cytoplasmic male sterile (CMS) lines, hereafter A line and five restorer lines, hereafter R lines of rice with diverse genetic base. Zinc and iron enriched five A and five R lines (Table 1) were collected from department of Genetics and Plant Breeding, BSMRAU.

Table 1. List of experimental materials showing grain zinc and iron content.

A line	Zn content	Fe content	R line	Zn content	Fe content
IR58A	43.20	18.17	Hera5R	38.90	12.28
IR62A	48.27	16.05	BU7R	37.33	14.63
IR68A	43.10	25.43	ACI1R	39.83	14.87
Gan46A	47.50	20.60	BHD1R	35.43	14.40
BRRI1A	39.40	52.80	KataribhoghR	33.33	12.83

Raising of parental materials and hybridization

Sowing of five A lines and five R lines was taken up to synchronize flowering. Crossing was done during Aman 2017. The CMS lines were used as female parents and the R lines were used as male parents. Using five A lines and five R lines as parents, total 25 cross combinations were made following line x tester mating design. Care was taken to obtain a good number of seeds per cross, so that they could be used for evaluation in field and also for evaluating grain zinc content. Also, the A lines were maintained by the corresponding B line in the field trial for generating data.

Evaluation of F1 progenies along with parents

During Aman 2018, the 10 parents along with 25 F1 seeds were evaluated. The experiment was laid out in a randomized complete block design (RCBD) with three replications in the field. At first seeds of each genotype were sown in the pot at laboratory then transplanted to the main field with the spacing of 20 x 20 cm as single seedling/hill.

Data Collection

Ten plants were selected randomly from each entry in each replication to record data on 19 physio-morphological traits. Data were collected on the following parameters: days to first flowering, days to 50% flowering, days to maturity, pollen fertility, plant height (cm), number of productive tillers per hill, panicle length (cm), number of tillers, filled spikelet, unfilled spikelet, straw yield, test weight (g), grain length (mm), grain breadth (mm), biomass content, harvest index, zinc content (ppm), iron content (ppm), grain yield ton per hectare.

Grain Iron and Zinc analysis

Analysis of Iron and Zinc content (ppm) of grain were done at brown condition in XRF (X-Ray Fluorescence Spectrometry) method in Harvest plus Laboratory, Bogura. XRF is a non-destructive analytical technique used to determine the elemental composition of materials. The rice samples were dehusked and kept clean before and after dehulling. Adequate samples were added to the cup (>3g). For sample analysis, Adequate samples were added to the cup (>3g). Before pouring the prepared (dehulled) sample to the plastic cups, the cups were cleaned and A4 µm film was placed over beveled edge of smaller plastic cup and then the larger secondary cup is placed over film. The larger cup is then pushed down and twisted. The samples are then held in plastic cups with plastic inserts. The samples were analyzed using glass standard instead of grain samples as standard. Total analysis time for each sample was around 120 seconds; scans were conducted in sample cups. Thus, from the XRF spectrum it is possible to determine the grain iron and zinc content present in the sample based on the energy of detected photons released.

Statistical Analysis

The GCA and SCA effects were determined using Excel and SAS software (SAS Institute 2008, SAS V9.2). The mean data were subjected to ANOVA and estimates of combing ability and their variances were performed as suggested by Kempthrone (1957).

Mathematical model for combining ability analysis is:

$$Yijk = \mu+gi+gj+sij+rk+eijk$$

Where, Yijk = any measurable character of the cross ixj in the kth replication

μ = population mean effect

gi = general combining ability effect of the female parent

gj = general combining ability effect of the male parent

sij = specific combining ability effect of (ixj)th cross

rk = effect due to Kth replication

eijk = environmental effect on (ijk)th individual

RESULTS AND DISCUSSIONS

Combining Ability

Tables 2 and 3 present the result of ANOVA for combining ability, estimates of GCA and estimates of SCA. The genotypes were found highly significant for all the traits except 50% flowering and grain breadth. Significant mean squares of the genotypes were obtained for the traits namely days to first flowering, days to maturity, plant height, tillers, productive tillers per plant, pollen fertility, panicle length, filled grain, unfilled grain, thousand grain weight, straw yield, grain length, biomass, harvest index, grain yield per plant, grain yield (t/ha), Zn content and Fe content. The ratio of GCA to SCA variances ranged from -0.024 to 0.097, which indicated that SCA values were higher than GCA values and thereby the non-additive gene actions predominated over the additive gene action for all the characters.

Singh *et al.,* (2018) found highly significant genotypic variance in hybrid rice. Parents and parents vs crosses were found highly significant for all the traits except plant height, which indicated that parents and parents vs crosses were significantly differed from each other. Crosses were found highly significant for all the traits except 50% flowering, panicle length, grain breadth, which indicated that crosses were significantly differed from each other. The A lines showed significant mean sum of square for days to maturity, tillers, filled grain, unfilled grain, grain length.

The testers (R lines) exhibited significant mean sum of square for thousand seed weight, grain length. Lines x testers differed significantly due to its significant mean sum of square for all the traits except 50% flowering, tillers, panicle length, filled grain, grain breadth. Significant GCA variance and SCA Variance were obtained for all the characters studied except panicle length, grain breadth indicated both additive and non-additive gene action were involved for these traits. The result is in agreement with Kumar *et al.,* (2007) who observed preponderance of both additive and non-additive gene effects were almost equally important for grain yield per plant, grain length, and grain length: breadth ratio.

General Combining Ability

The fixable GCA effect is described as the inherent genetic value of the parent for an attribute resulting from additive gene effects (Simmonds, 1989). Negative GCA effects are desirable for days to flowering, days to maturity and plant height while positive GCA effects are desirable for other like Zn and Fe content traits included in the study. Table 3 presents GCA effects of the parents. None of the CMS lines was observed to be good general combiner for all the traits studied. GAN46A exhibited significant negative GCA effect for days to first flowering, days to 50% flowering indicated as a good general combiner parent for early flowering. Venkatesan *et al.,* (2008) reported that the line IR 58029-99-3-1-3 and tester BR4828-2-2-1 recorded negative GCA effects for days to 50 percent of flowering. Tiwari *et al.,* (2011) also observed higher GCA effects for this trait of flowering. Line IR62A showed significant negative GCA effect for days to maturity. GAN46A line had significant positive GCA effects for tillers and productive tillers per hill. In this study,

Table 2. Analysis of variance of combining ability of 10 parental lines 25 crosses for yield and its contributing traits of rice.

Source	df	DFF	50% F	DM	PH(cm)	NT	NPT	PF(%)	PL(cm)	FS	UFS	TSW
Replications	2	0.07	0.70	0.37	96.839	14.010	15.80	2.67	6.27	538.695	90.64	1.32
Treatments	34	94.57**	106.02	38.10**	724.623**	82.077**	111.53**	2370.84**	51.91**	2793.237**	1173.91**	49.38**
Parents	9	200.82**	172.91	131.35**	2039.094**	119.541**	45.17**	4346.28**	159.66**	1833.541	344.13*	106.65**
Parents vs Crosses	1	14.41**	1209.65	34.74**	63.149	1114.97**	2819.16**	6234.21**	222.64**	1.524	11573.52**	42.60**
Crosses	24	58.06**	34.96	3.27**	259.258**	24.991**	23.60**	1469.07**	4.40	3269.444**	1051.75**	28.18**
Lines	4	109.41	75.51	6.85*	159.047	69.347**	44.85	1432.62	8.50	7569.767*	2105.49*	30.31
Testers	4	39.31	18.05	4.35	228.080	12.647	8.91	1825.62	2.65	2137.900	1004.55	69.29**
Lines x Testers	16	49.91**	29.05	2.10**	292.105**	16.988	21.96**	1389.05**	3.81	2477.250	800.12**	17.38**
σ^2GCA		0.204**	0.148	0.029**	-0.821**	0.20^{0}**	0.041**	2.001**	0.015	19.805**	6.291**	0.270**
σ^2SCA		16.36**	9.173	0.594**	61.111**	2.048**	4.705**	462.667**	-0.621	480.476**	223.059**	5.375**
σ^2GCA/σ^2SCA		0.012	0.016	0.048	-0.013	0.097	0.008	0.004	-0.024	0.041	0.028	0.050
Error	68	0.831	1.53	0.32	108.773	10.843	7.85	1.04	5.67	1035.823	130.94	1.25

Source	df	SY (g)	GL(mm)	GB(mm)	BM (g/p)	HI (%)	GY (g/p)	GY (t/ha)	Zn (ppm)	Fe (ppm)
Replications	2	4.03	0.06	3.32	12.93	3.01**	2.76	0.15	0.49	1.02
Treatments	34	263.93**	1.69**	4.61	868.48**	629.74**	492.17**	39.13**	362.32**	220.77**
Parents	9	232.44**	1.93**	0.13	1047.84**	124.25**	723.49**	36.88**	210.85**	452.60**
Parents vs. Crosses	1	342.86**	1.33**	22.32*	402.29**	1916.23**	1193.53**	15.36**	3213.88**	1881.82**
Crosses	24	272.44**	1.62**	5.56	820.65**	765.70**	376.20**	40.97**	300.31**	64.63**
Lines	4	288.00	2.22*	5.48	841.23	187.54	285.48	31.09	112.18	9.70
Testers	4	88.00	4.36**	4.28	677.86	1606.99	731.05	79.61	300.02	105.39
Lines x Testers	16	314.67**	0.78**	5.89	851.20**	699.92**	310.16**	33.78**	347.42**	68.17**
σ^2GCA		-1.056**	0.021**	-0.008	1.645**	1.251*	1.651**	0.180**	-1.178**	-0.089**
σ^2SCA		104.019**	0.215**	0.618	230.427**	240.241*	102.543**	11.193**	115.218**	22.555**
σ^2GCA/ σ^2SCA		-0.010	0.097	-0.012	0.007	0.005	0.020	0.020	-0.010	0.003
Error	68	2.61	0.14	4.04	4.64	8.64	2.53	0.20	1.76	0.51

Legend: DFF=Days to first flowering, 50%F=Days to fifty percent flowering, DM=Days to maturity, PF=Pollen fertility, PH=Plant height (cm), NPT=Number of Productive Tillers per hill, PL=Panicle Length(cm), NT=Number of tillers, FS= Filled spikelet, UFS= Unfilled spikelet, SY= straw yield, TSW=Test Weight(g), GL=Grain Length (mm), GB=Grain Breadth (mm), BM= Biomass, HI= Harvest Index, Zn=Zinc Content (ppm), Fe=Iron Content (ppm), GY= Grain Yield ton per hectare.

Table 3. General combining ability (GCA) effects of parents (lines and testers) for yield and its contributing traits of rice.

Parent	Days to first flowering	50% Flowering	Days to maturity	Plant Height	Tillers	Productive tillers	Pollen fertility	Panicle length	Filled grain	Unfilled grain	1000 grain weight	Straw yield	Grain length	Grain breadth	Bio-mass	Harvest Index (%)	Zn content	Fe content	Grain yield/plant	Grain yield (t/ha)
Lines																				
IR58A	-0.15	0.21	-0.11	-0.72	-1.59	-1.39	0.24	0.74	15.33	-6.64	1.15*	-3.47**	0.42**	1.07	-3.66**	5.06**	-0.37	-1.12**	-0.19	-0.06
IR62A	0.39	0.01	-0.77**	-1.59	-1.59	-0.99	11.64**	-0.83	18.93	1.83	0.21	-4.80**	-0.25	-0.25	-9.61**	-2.07	-1.93**	0.43	-4.81**	-1.59**
IR68A	3.85	3.15	1.09**	4.35	-1.32	-1.32	-15.36**	-0.03	-34.2*	19.23**	-2.33**	4.53**	0.23	-0.30	1.32	-3.38*	4.49**	0.83*	-3.22**	-1.06**
GAN46A	-3.7**	-3.19**	-0.11	2.01	3.15*	2.35*	3.24**	-0.66	-11.33	-11.71*	-0.15	-0.80	-0.53**	-0.36	1.22	2.27*	-2.41**	-0.54*	2.02**	0.67**
BRRI1A	-0.35	-0.19	-0.11	-4.05	1.35	1.35	0.24	0.77	11.27	-2.71	1.12*	4.53**	0.13	-0.17	10.74**	-1.88	0.22	0.40	6.20**	2.05**
SE	0.235	0.319	0.147	2.693	0.850	0.723	0.264	0.615	8.310	2.955	0.289	0.417	0.095	0.519	0.556	0.759	0.343	0.184	0.411	0.114
SE(gi-gi)	0.333	0.451	0.207	3.808	1.202	1.023	0.373	0.870	11.52	4.178	0.409	0.590	0.135	0.734	0.787	1.073	0.485	0.260	0.581	0.162
Testers																				
Hera5R	-0.41	-0.25	-0.11	-2.52	1.35	1.08	-3.76**	-0.19	-0.20	4.43	-1.91**	3.20**	0.73**	0.95	7.45**	0.48	2.45**	1.20**	4.25**	1.40**
BU7R	2.45**	1.88**	0.63	-2.85	-0.19	-0.65	-4.76**	-0.49	-9.40	9.63*	0.44	1.87*	-0.08	-0.32	-7.44**	-16.0**	-6.71**	-3.18**	-9.30**	-3.07**
KataribhoghR	0.45	-0.19	0.49*	-3.05	0.35	0.48	8.64**	0.11	-5.87	2.49	0.70	-2.13	0.19	-0.27	-2.80**	7.04**	2.64**	1.27**	-0.66	-0.22
BHD1R	-1.9**	-0.99	-0.51*	5.08	-1.12	-0.72	-13.7**	-0.06	-5.07	-5.77	-2.25**	-0.80	-0.76**	-0.21	-4.01**	-2.25*	-2.41	-2.35**	-3.21**	-1.06**
ACI1R	-0.55	-0.45	-0.51*	3.35	-0.39	-0.19	13.64**	0.64	20.53	-10.77*	3.01**	-2.13**	-0.08	-0.15	6.79**	10.7**	4.03**	3.06**	8.92**	2.94**
SE	0.235	0.319	0.147	2.693	0.850	0.723	0.264	0.615	8.310	2.955	0.289	0.417	0.095	0.519	0.556	0.759	0.343	0.184	0.411	0.114
SE(gi-gi)	0.333	0.451	0.207	3.808	1.202	1.023	0.373	0.870	11.75	4.178	0.409	0.590	0.135	0.734	0.787	1.073	0.485	0.260	0.581	0.162

IR62A and GAN46A lines also exhibited significant positive GCA effects for pollen fertility.

IR58A and BRRI1A lines showed positive GCA effects for thousand grain weight indicating these two lines might be good general combiners for test weight. For biomass content, BRRI1A line exhibited the highest positive significant value indicating to be a good general combiner for the trait. IR68A line showed significant positive GCA effects for Zn and Fe content along with grain yield (t/ha) which indicates that the line is a good general combiner for Zn and Fe content as well as for grain yield (t/ha).

None of the testers was observed to be good general combiner for all the traits studied. BHD1R showed significant negative GCA effects whereas KataribhoghR showed positive GCA effects for days to maturity. So, BHD1R was a useful general combiner for early maturity. The tester line KataribhoghR exhibited significant positive GCA effects for pollen fertility reflecting good general combining ability for this trait. For test weight, ACI1R was good general combiner as it showed significant positive effects. Hera5R and ACI1R showed significant positive GCA effects for biomass content, which indicated that these two testers were good general combiners for biological yield of rice.

Among testers KataribhoghR and ACI1R showed significant positive GCA effects for harvest index % which indicated that it was good general combiner for this trait. For grain length, Hera5R showed significant positive GCA effects indicating a good general combiner for long grain. Tester Hera5R, ACI1R and KataribhoghR showed significant positive GCA effects for Zn and Fe content of grain and grain yield (t/ha) also. So, these lines might be used as good general combiner for Zn and Fe content along with grain yield (t/ha).

Specific Combining Ability

The performance of hybrid combinations is measured by the specific combining ability (SCA), which is a non-additive gene action related to dominance, over dominance, and epistatic effects. (Dianga et al., 2020). Choosing hybrids based on SCA effects would maximize their heterotic effect. Negative SCA effects are desirable for days to flowering, days to maturity and plant height while positive SCA effects are desirable for the other like Zn and Fe content traits. Table 4 presents SCA effects of the hybrids. None of the hybrids was observed to be good specific combiner for the all the traits studied. The cross combinations GAN46A x BU7R, BRRI1A X BU7R, IR58A x KataribhoghR, IR68A x KataribhoghR, BRRI1A x KataribhoghR, IR68A x ACI1R, GAN46A x ACI1R showed significant negative SCA effects for days to first flowering, days to 50% flowering, days to maturity indicating to be good specific combiners for early maturity. Among these cross combinations GAN46A x BU7R showed highest negative SCA effects and was detected as the best specific combiner for these traits. GAN46A x KataribhoghR, BRRI1A x KataribhoghR cross combinations showed the highest significant positive SCA effects for plant height. So, these crosses were the best specific combiners for producing taller plants. IR58A x BHD1R showed the highest significant positive SCA effects for productive tillers per hill and might be considered as the best specific combiner hybrid.

The cross combinations viz. IR58A x Hera5R, BRRI1A x Hera5R, IR58A x BU7R, BRRI1A x BU7R, IR58A x BHD1R, IR62A x BHD1R, IR68A x BHD1R, IR68A x KataribhoghR, GAN46A x ACI1R showed significant positive SCA effects for pollen fertility and might be selected as good specific combiner hybrids. Among these hybrids, IR58A x BHD1R showed highest positive significant value for these traits and could be considered as the best specific combiner. The cross combinations viz. BRRI1A x BU7R, IR58A x BHD1R, IR58A x KataribhoghR showed significant positive SCA effects for filled grain per panicle and were considered to be good specific combiner hybrids for the trait. In this study, IR58A x Hera5R, IR62A x Hera5R, GAN46A x BU7R, IR58A x BHD1R, IR62A x KataribhoghR, BRRI1A x KataribhoghR, GAN46A x ACI1R crosses are positively significant for Zn content of grain. The significant high SCA effect for Zn content was reported by Pradeep Kumar and Reddy (2009). Again, IR62A x Hera5R, GAN46A x BU7R, BRRI1A x BU7R, IR58A x BHD1R, IR62A x KataribhoghR, BRRI1A x KataribhoghR, GAN46A x ACI1R crosses are positively significant for Fe content which indicates that these crosses are good specific combiners. In another finding, IR58A x BU7R, IR58A x BHD1R, IR62A x Hera5R, GAN46A x BU7R, GAN46A x BHD1R, GAN46A x ACI1R, BRRI1A x BHD1R, BRRI1A x Hera5R, BRRI1A x ACI1R crosses showed good specific combining ability for grain yield (t/ha). The hybrids viz. IR62A x Hera5R, GAN46A x BU7R, GAN46A x ACI1R have been obtained showing best specific combining ability for grain Zn and Fe content and grain yield (t/ha). Both yield and grain Zn are genetically complex traits and are hugely influenced by external environmental factors (Zaw *et al*. 2019). There was no direct effect of Zn on yield, indicating that combining high yield potential and high grain-Zn content is possible in order to develop successful Zn-biofortifed rice varieties (Calayugan *et al*. 2021). Rao et., al. reported that germplasm screening for their zinc content in brown and polished rice using ED-XRF revealed wide genetic variability, and evaluation of mapping populations indicated the possibility of favourable recombination of high zinc content and yield. Recently, zinc enriched high yielding rice variety BRRI dhan102 BRRI has developed. The variety has high zinc content 25.5 mg/kg with the average yield of 8.10 t/ha (Kader et., al. 2023).

The crosses between good general combiners may not always give good SCA effects in their cross combinations. Findings of a study on combining ability effects, high specific combiners involved low×low, low ×high, average×low, average×average, high×average and high×high combining parents. In crosses with high×low and low×low general combiners, Jinks (1956) described severe SCA effects caused by over-dominance and epistasis. In crosses involving high vs. low general combiners for yield components, mutual cancellation of heterosis components, especially dominance and its interaction, resulting in unfavorable SCA effects. Crossing two parents with low general combiners produces high performance, attributable to complementary gene activity (Al-Mamun *et al*., 2022). For example, although the crosses GAN46A x BU7R, BRRI1A x BU7R, IR58A x KataribhoghR, BRRI1A x KataribhoghR, IR68A x ACI1R were made among low x low, low x low, low x high, low x high, high x high general combiner parents for days to first flowering and days to 50% flowering, respectively, their SCA effects were high for these traits. The cross between low x low general combiners (GAN46A x BU7R, BRRI1A x BU7R) exhibited high SCA effects for days to maturity. Also, the crosses BRRI1A x KataribhoghR were made among low x high general combiner parents, showed high SCA effects for plant height. The crosses GAN46A x BU7R, IR58A x BHD1R, BRRI1A x BHD1R were made among low x low general combiners for zinc content, their SCA effects were high for these traits. On the other hand, the crosses between low x high general combiners, (IR62A x KataribhoghR, GAN46A x ACI1R, and BRRI1A x KataribhoghR) exhibited high SCA effects for grain zinc content.

Table 4. Continued

Crosses	TSW	GL(mm)	GB (mm)	BM(g/p)	HI (%)	Zn(ppm)	Fe(ppm)	GY(g/p)	GY(t/ha)
IR58Ax Hera5R	2.05**	-0.76**	4.43*	-2.44	-8.06**	3.13**	1.05	-4.58**	-1.51**
IR62A x Hera5R	-0.36	0.45*	-1.30	2.04	14.42**	12.15**	5.26**	5.24**	1.73**
IR68A x Hera5R	-0.42	0.15	-1.11	-11.32**	4.17	0.54	1.34*	-5.46**	-1.80**
GAN46A x Hera5R	1.13	-0.70**	-0.97	-6.36**	-7.00**	-16.17**	-7.14**	-5.83**	-1.92**
BRRI1A x Hera5R	-2.40**	0.85**	-1.04	18.09**	-3.53	0.35	-0.52	10.62**	3.51**
IR58A x BU7R	1.25	0.22	-0.98	9.77**	5.12**	1.05	-1.47*	6.31**	2.08**
IR62A x BU7R	-1.56*	-0.24	0.25	-14.90**	-7.15**	-13.33**	-6.36**	-6.37**	-2.10**
IR68A x BU7R	-0.69	0.39	0.11	3.79*	-1.32	0.83	-0.44	1.66	0.55
GAN46A x BU7R	2.47**	0.01	0.18	11.83**	15.20**	10.11**	5.08**	11.03**	3.64**
BRRI1A x BU7R	-1.47*	-0.38	0.45	-10.49**	-11. 86**	1.34	3.20**	-12.62**	-4.17**
IR58A x BHD1R	2.45**	0.28	0.51	31.92**	4.20	4.05**	2.11**	16.46**	5.43**
IR62A x BHD1R	-1.87**	-0.52*	0.36	19.48**	-26.53**	-6.49**	-2.11**	0.01	0.00
IR68A x BHD1R	2.48**	0.18	0.37	-23.21**	11.66**	-3.01*	-2.10**	-9.34**	-3.08**
GAN46A x BHD1R	-1.77*	-0.20	-0.21	4.54*	6.47*	-0.71	0.23	6.41**	2.11**
BRRI1A x BHD1R	2.85**	-0.20	0.59	4.02*	4.55	2.98*	0.79	5.89**	1.94**
IR58A x KataribhoghR	0.60	0.17	-1.23	-5.34**	2.60	-6.21**	-1.40*	0.53	0.17
IR62A x KataribhoghR	-3.65**	-0.10	0.00	-22.86**	8.07**	11.66**	3.51**	-7.66**	-2.53**
IR68A x KataribhoghR	-1.31	-0.07	-1.10	-4.94**	-2.71	2.60*	1.13	-4.41**	-1.46**
GAN46A x KataribhoghR	1.77*	0.82**	0.43	0.67	-23.53**	-17.80**	-7.70**	-9.46*	-3.12**
BRRI1A x KataribhoghR	-1.53*	-0.36	0.30	-4.29*	15.21**	12.93**	5.54**	1.58	0.52
IR58A x ACI1R	-2.59**	0.44*	-1.12	2.95	3.04	-0.57	0.70	2.15	0.71
IR62A x ACI1R	1.00	-0.12	0.25	-14.77**	-26.68**	-15.81**	-6.56**	-16.90**	-5.58**
IR68A x ACI1R	0.14	0.18	0.07	-15.97**	19.12**	2.15	0.42	-2.10	-0.69
GAN46A x ACI1R	-1.71	-0.04	0.37	16.72**	7.26**	12.20**	6.25**	11.92**	3.93**
BRRI1A x ACI1R	3.16**	-0.46*	0.44	11.07**	-2.74	2.03	-0.80	4.93**	1.63**
SE (sij)	0.646	0.213	1.160	1.244	1.697	0.766	0.411	0.918	0.256
SE(sij-skl)	0.914	0.301	1.641	1.759	2.400	1.084	0.581	1.299	0.362

*and** indicate significance at 5% and 1% levels respectively

Legend: DF=Days to flowering, 50%F= Fifty Percent Flowering, DM=Days to Maturity, PF(%)=Pollen Fertility, PH=Plant Height(cm), NT=Number of tillers, PT=Number of Productive Tillers per hill, PL=Panicle Length(cm), FS= Filled Spikelet, UFS= Unfilled spikelet, SY= Straw Yield (g), TSW=Test Weight(g), GL=Grain Length(mm), GB=Grain Breadth(mm), BM= Biomass content (g/p), HI (%)= Harvest Index, Zn=Zinc Content(ppm), Fe=Iron Content(ppm), GY= Grain Yield (t/ha).

Table 4. Specific Combining Ability (SCA) effects of 5 X 5 line-tester progenies for yield and its contributing traits of rice.

Crosses	DF	50% F	DM	PH(cm)	NT	PT	PF (%)	PL(cm)	FS	UFS	SY(g)
IR58A x Hera5R	0.81	0.05	0.11	6.32	-0.15	0.25	25.76**	-0.31	1.53	9.37	2.13*
IR62A x Hera5R	-0.05	-0.08	-0.63	-5.35	0.39	0.65	-38.24**	-0.34	-2.93	7.84	-3.20**
IR68A x Hera5R	-0.05	-0.01	-0.49	-0.81	-1.15	-1.48	-1.64*	-0.11	1.20	-18.69**	-5.87**
GAN46A x Hera5R	-1.05	-0.75	0.51	9.12	1.92	1.85	-6.64**	0.69	20.80	0.24	-0.53
BRRI1A x Hera5R	0.35	0.79	0.51	-9.28	-1.01	-1.28	20.76**	0.06	-20.60	1.24	7.47**
IR58A x BU7R	-0.05	-0.08	0.77*	4.19	0.52	0.19	9.36**	1.43	-10.40	6.57	3.47**
IR62A x BU7R	6.41**	5.45**	0.71*	-3.48	0.39	0.59	-9.64**	-1.27	-35.53	4.71	-8.53**
IR68A x BU7R	3.41**	2.19**	0.17	1.05	-2.15	-2.88	-1.04	0.29	-14.40	20.17**	2.13*
GAN46A x BU7R	-5.59**	-4.55**	-0.83*	4.65	0.25	-0.21	-8.04**	-0.57	17.20	-13.23	0.80
BRRI1A x BU7R	-4.19**	-3.01**	-0.83*	-6.41	0.99	2.32	9.36**	0.13	43.13*	-18.23*	2.13*
IR58A x BHD1R	-1.05	-0.01	1.17**	-0.75	3.79	4.59**	37.36**	2.09	38.60*	9.97	15.47**
IR62A x BHD1R	0.95	2.05**	1.31**	-2.55	-0.75	-0.55	8.96**	-0.84	-17.93	10.77	19.47**
IR68A x BHD1R	4.95**	1.99*	-0.69*	-9.95	-2.35	-2.55	20.96**	0.13	-14.00	-14.96*	-13.87**
GAN46A x BHD1R	4.55**	3.65**	0.51	-5.95	-0.48	0.12	-9.64**	-1.24	-20.20	17.97*	-1.87
BRRI1A x BHD1R	-0.45	-0.61	-0.49	-1.88	2.12	3.12	0.36	0.79	10.53	-21.29**	-1.87
IR58A x KataribhoghR	-5.19**	-3.88**	-1.09**	10.25	2.59	2.19	-38.64**	0.29	42.07*	-18.83**	-5.87**
IR62A x KataribhoghR	0.35	-0.15	-0.69*	2.99	-3.28	-3.68*	-28.64**	-1.67	-48.73*	13.04	-15.20**
IR68A x KataribhoghR	-1.59**	-0.55	0.11	-21.75	0.45	0.52	2.76**	-1.07	-24.80	-3.23	-0.53
GAN46A x KataribhoghR	1.95**	1.19	0.51	16.65*	0.25	-0.01	-2.24**	0.79	25.40	18.64**	10.13**
BRRI1A x KataribhoghR	-4.45**	-3.68**	-0.63	12.92*	-2.35	-3.75**	8.76**	0.73	9.07	-12.09	-5.87**
IR58A x ACI1R	6.01**	4.45**	0.11	0.99	-3.41	-3.15	0.76	-0.34	-8.40	6.11	0.80
IR62A x ACI1R	-0.85	-1.68*	-0.63	-3.35	-2.21	-2.08	1.76**	-1.21	-9.20	-10.43	2.13*
IR68A x ACI1R	-3.85**	-3.61**	-0.49	4.19	1.92	1.79	-6.64**	-0.14	20.60	9.04	-13.87**
GAN46A x ACI1R	-2.85	-0.35	0.51	2.12	0.65	0.79	3.36**	0.99	-3.80	9.97	4.80**
BRRI1A x ACI1R	1.55**	1.19	0.51	-3.95	3.05	2.65	0.76	0.69	0.80	-14.69*	6.13**
SE (sij)	0.526	0.714	0.328	6.021	1.901	1.617	0.590	1.375	18.582	6.607	0.933
SE(sij- skl)	0.744	1.009	0.464	8.516	2.689	2.287	0.834	1.945	26.278	9.343	1.319

*and** indicate significance at 5% and 1% levels respectively

CONCLUSIONS

Among the lines, IR58A, IR62A and GAN46A showed significant GCA effects for grain yield, and most of the yield contributing traits, could be used as good general combiner lines for improving the grain yield of rice. IR68A line was found as good general combiner for Zn and Fe content. Among testers, Hera5R, ACI1R and KataribhoghR testers were good general combiner for Zn and Fe content having positive GCA effect with yield (t/ha). The combinations, IR62A x Hera5R, GAN46A x BU7R, BRRI1A x BHD1R, IR62A x KataribhoghR, BRRI1A x KataribhoghR, GAN46A x ACI1R were good specific combiner for Fe content along with grain yield (t/ha). The CMS lines namely GAN46A, IR58A and IR62A might be recommended as good general combiner for improving grain yield in hybrid breeding. Similarly, among the testers, Hera5R, ACI1R and KataribhoghR testers were obtained as good general combiner for Zn and Fe content along with grain yield (t/ha). On the other hand, the hybrids *viz.* IR58A x BHD1R, IR62A x Hera5R, GAN46A x BU7R, GAN6A x ACI1R were found suitable for heterosis breeding for Zn content and grain yield (t/ha). Finally, IR62A x Hera5R, IR62A x KataribhoghR, GAN46A x BU7R, GAN46A x ACI1R, BRRI1A x BHD1R, BRRI1A x KataribhoghR crosses could be recommended as good specific combiners for Fe content and grain yield (t/ha).

AUTHORS’ CNTRIBUTION

URS, NAI and MSR formulated the idea; coordinated the research; URS and NAI developed methodology; URS, NAI and MSR provided scientific insights; URS collected data; URS and NAI carried out analysis; URS and NAI did the writings for all version of the manuscript; URS, NAI, MSR and MAK performed critical review and editing; All authors read and approved the final manuscript.

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DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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