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RESEARCH ARTICLE :

Combining ability and heterosis prediction for grain yield of parental lines and hybrids for heat tolerance in rice (*Oryza sativa* L.)

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SUMMARY : Combining ability and heterosis studies conducted in three different temperature stress regimes at reproductive stage by adopting three different planting dates in fifty seven hybrid rice parental lines and different hybrid combinations. The temperature regimes were 39.8^0 C to 27.5^0 C at reproductive stage. From the results of ANOVA and kempthroren line x tester analysis, few hybrid combinations were found to be ideal for better parental lines development for heat tolerance with desirable traits. The elevated temperature at the time of flowering and maturity determines the yield *per se* of the genotypes. The hybrids adapted better than parental lines, showing the buffering nature and heterosis for stress tolerance. Under high temperature stress, the response of genotypes depended on developmental stage, but highest sensitivity was recorded at reproductive stage. Flowering stage was very sensitive to high temperature which cause pollen sterility ultimately leads to spikelet sterility. In hybrid rice seed production practices, the pollen fertility plays major role for cross pollination. The time of sowing, days to flowering, temperature at flowering time, combing ability with different CMS lines and significant positive heterosis were the crucial factors in determining the performance of hybrids to varying temperature. Hence it is necessary to select parental lines and cross combinations to identify future better hybrids. By keeping in view the above factors for different temperature stress within and across the environment.

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BACKGROUND AND OBJECTIVES

Rice (*O. sativa* L) is one of the major cereal crop cultivated in 150mha in all over the world and half of the world population was consumes rice every day. The world population will be about to 8.3 billion in 2030 and 9.3 billion in 2050. In the present situation the rate of rice production increases only 1.5% per year compared to increasing world population 2% per year. Abiotic stresses like drought, salinity, high temperature and cold are the severe problems throughout the rice cultivated environments in the world and many popular high yielding verities are not performed better yield potential under different abiotic stresses. Among these abiotic stresses high temperature stress at reproductive stage in rice was severe, which leads to loss of economic yield. The grain yield of rice reduced 10% for each 1ºC increase in temperature above the optimum temperature. in the philippenes (Peng *et al.*, 2004). Increase of mean night temperature (MNT) was more devastating than day time or daily mean temperatures. Most of the rice cultivated regions are already close to optimum temperatures for cultivation, According to the Intergovernmental panel on climate change (IPCC, 2007) the daily mean temperatures are increasing 1.8-4º C at the end of this century. Rice cultivation in coastal Andhra Pradesh in India may experience daytime temperature of 50ºC. The vegetative growth stage have benefit with elevated concentrations of CO_2 and moderate temperatures but high temperature during reproductive stage especially during anthesis will reduce grain yield by increase spikelet sterility. (Matsui *et al.,* 1997). Stake and Yoshida (1978) identified few heat tolerant genotypes capable of setting seed at high temperature upto 41ºC during flowering in both Indica and *Japonica* spp. The genotype Nagina 22 found heat tolerant but it is agronomically poor and has not been used in breeding.

In cultivated rice, flowering time depends on the climatic conditions, but flowering predominantly occurs between 1000 and 1200 h. To mitigate high temperature-induced spikelet sterility, two strategies have been proposed for rice breeding. One approach is to develop tolerant cultivars that can shed larger numbers of pollen grains or produce pollen capable of germinating on the stigma even under high temperatures. Another strategy is to confer an early morning flowering (EMF) trait to cultivated rice that ensures completion of fertilization before late morning or early noon high temperatures (Satake and Yoshida, 1978). High temperature can inhibit pollen germination and tube elongation in rice (Satake and Yoshida, 1978).

Anthesis is the most sensitive stage of rice to high temperatures (Yoshida *et al.,* 1981). The heat sensitive processes of anthesis- anther dehiscence, pollination, pollen germination, and to a lesser extent pollen tube growth—are completed within 45 min of the opening of a rice spikelet and fertilization is completed within 1.5 to 4 h. Spikelet tissue temperature of e$\geq$33.7°C for an hour at anthesis was sufficient to induce spikelet sterility (Jagadish *et al.*, 2007).

To overcome these problems it is requires to develop rice varieties with higher yield potential and greater stability. Heterosis breeding technology is one the important strategy to overcome these problems. Diversified maintainers and restorer lines using in heterosis breeding will help to get high level of heterotic hybrids. Rice hybrids will give 1.0-1.5 t/ha more yield (15-20%) compare to high yielding varieties. This experiment penetrating to study of combining ability and heterosis in rice hybrids in three different temperature regions to identify better hybrids for heat tolerance.

Plant materials :

Based on test cross evolution with CMS lines and morphological studies ten potential restorer lines were selected to attempt the line x tester analysis developed by Kempthoren, 1957. Four CMS lines were selected; one hybrid check and one varietal check were used. The list of male sterile lines, restorers and checks used in the study were given in Table A.

Table A : List of male sterile lines, effective restorers and checks used in the study

Sr. No.	Parental lines	Source
CMS Lines		
1	APMS6A	RARS, Maruteru (ANGRAU)
2	IR58025A	IRRI , Philippines
3	IR79156A	IRRI , Philippines
4	IR68897A	IRRI , Philippines
Restorer lines		
1	BCW-56	IIRR, Hyderabad
2	KMR-3	RARS, Mandya,KA
3	RPHR-1005	IIRR, Hyderabad
4	RPHR-517	IIRR, Hyderabad
5	IR40750R	IRRI , Philippines
6	C20R	IIRR, Hyderabad
7	IR-66R	IRRI , Philippines
8	Akshayadhan	IIRR, Hyderabad
9	IBL-57	IIRR, Hyderabad
10	RPHR-1096	IIRR, Hyderabad
Checks		
1	DRRH-3	IIRR, Hyderabad , Early duration, hybrid check
2	IR-64	IRRI , Philippines, Mid-early duration, varietal check

Resources and Methods

Experimental location :

The field experiment was carried out at experimental farm of Indian Institute of Rice Research (IIRR), Hyderabad, India (Latitute-17° 10'N, Longitude and Altitude 524msl) during *Rabi* 2015-16 in clay loam soil.

Crop management and data collection :

Crossing programme was attempted with four CMS lines and 10 restorer lines during *Kharif* 2015. Obtained forty hybrids (10 lines x 4 testers) along with 14 parents (10 'R' lines and 4 'B' lines of corresponding male sterile lines), one hybrid check and one varietal check were sown during *Rabi* 2015-16 at same location with 15 days interval difference to estimation of per se performance, combining ability, heterosis and stability. Based on hybridization, obtained F_1 hybrid seeds along with parents and checks treated with Carbendazim solution (0.1%) and only crossed seeds are allowed to germinate in petri dishes with blotting paper. Satisfactory germination was observed on the 4th and 5th day of soaking. The seedlings were transferred to small raised beds and sufficient care was taken to avoid water logging and complete drying up of the nursery beds.

Seed of parents and checks were soaked in water for 24 hours and incubated for 48 hours. The germinated seedlings were transferred to wet beds and proper care was taken to raise a healthy nursery. 25 days old seedlings were used for transplanting in the main field in a completely Randomized Block Design with two replications. Each entry was planted in a row of 0.6 mts length with a spacing of 20 x 15 cm and all the recommended package of practices was followed to raise a healthy crop. Similarly three sets of sowing and transplanting were done in 15 days interval difference for both hybrids and parental lines. Weather data were collected and presented in Table B.

Five plants were selected at random from each entry in each replication. Observations were recorded for yield and yield attributing traits at three environments. In case of CMS lines the observations were recorded on their respective maintainer (B) line. The observations days to fifty per cent flowering, plant height, panicle length, flag leaf area, panicle weight, number of reproductive tillers per plant, number of filled grains per panicle, spikelet fertility percentage, pollen fertility percentage, single plant yield, 1000 grain weight and grain yield per hector, per day productivity were recorded for the study. The data recorded on the material generated as per Line × Tester model of Kempthorne (1957), was subjected to analysis of variance as per the Line × Tester model. Heterosis was estimated for 40 hybrids for 12 characters based on Virmani hybrid rice breeding manual.

Heterosis over mid parent:

Heterosis was expressed as per cent increase or decrease observed in the F_1 over the mid-parent as per the following formula.

$$\text{Heterosis (\%) } (h_1) Z \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} x100$$

where,

$\overline{F_1}$ = Mean of F_1

$\overline{MP}$ = Mean of parents

Heterosis over better parent:

Heterobeltiosis was expressed as per cent increase or decrease observed in F_1 over the better parent as per the formula of Liang *et al*. (1971).

$$\text{Heterobetiosis (\%) } (h_2) Z \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} x\,100$$

where,

$\overline{BP}$ =Mean of better parent (for the characters like days to 50% flowering, earliness is desirable so the early parents are taken as better parents).

Heterosis over standard checks :

Standard heterosis was expressed as per cent

Table B : Month wise temperature, rainfall, sunshine, wind speed and evaporation details throughout the experiment

Month	Max Temp.	Min Temp.	Mean Temp.	Rainfall (mm) / days	Sunshine Hrs	Wind speed	Evaporation
January	27.5	8.4	17.9	-	8.9	2.4	2.6
February	30.2	16.0	23.1	7.0	8.7	3.4	2.7
March	36.6	18.7	27.6	-	8.8	3.5	2.9
April	38.7	23.9	31.3	4.0	8.2	4.3	5.0
May	39.8	24.6	32.2	4.0	8.3	4.5	5.2

increase or decrease observed in F_1 over standard checks.

$$\text{Standard heterosis (\%) } (h_3) = \frac{\bar{F}_1 - \text{Mean of check}}{\text{Mean of check}} \times 100$$

Test of significance of heterosis :

To test the significance for different types of heterosis needs computation of standard error (SEm). For relative heterosis and heterobeltiosis, SEm were calculated based on error mean squares (EMS) from the ANOVA tables consisting parents and crosses, whereas, EMS from the RBD ANOVA (σ^2e) table based on all treatments (parents, crosses and check) was used for standard heterosis.

OBSERVATIONS AND ANALYSIS

The results obtained from the present study as well as discussions have been summarized under following heads:

Analysis of variance for combining ability :

The material comprising of 57 genotypes (4 CMS lines, 10 restorer lines, 40 hybrids and two checks) was evaluated during *Rabi* 2015-16 at IIRR, Hyderabad with 15 days of interval difference in sowing and transplanting for line x tester analysis. The pooled analysis of variance for combining ability over environments revealed presence of significant differences among the environments, genotypes, parents, parents vs. crosses and crosses for all the characters studied (Table 1). Further partitioning of crosses x environments revealed that the interaction of lines x locations had significant differences for all the characters whereas testers x locations showed significance for plant height. Interaction effects of lines x testers x environments were recorded significant differences for all the characters.

Combining ability variances and gene action :

The estimates of GCA and SCA variances in pooled analysis are presented in Table. 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 all the characters except for days to 50% flowering, indicating the predominance of non-additive gene action. The results were represented in (Table 2).

General and specific combining ability effects :

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

The hybrids tend to be early in duration which is desirable with regard to days to 50% flowering. Among the four lines, two lines IR68897A and IR58025A recorded significant negative GCA effects at all environments and pooled over environments. Whereas the lines, APMS6A and IR-79156A showed significant positive GCA effects at all the environments and pooled analysis Among the 10 testers, RPHR-517, IR-66R and akshayadhan recorded significant negative GCA effects at all the three environments and pooled environments. The hybrids IR68897A X BCW-56, IR68897A X IR-66R and IR68897A X Akshayadhan were showed significant negative GCA effects at all the environments and pooled analysis.

The negative heterotic values for plant height indicating short stature was desirable. The line, IR-68897A recorded significant negative GCA effect at all

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

	df	DFF	PH	NPT	PL	FLA	G/P	SPK (%)	SPY	TSW	PDP	YK/H	PW
Replicates	1	274.36**	0.05	54.25*	0.17	3.27	578.25	85.61	3.45	36.07*	145.74	7023.45	0.03
Crosses	39	84.37***	111.62***	10.40	4.87***	53.67***	2154.65***	67.97*	64.85**	7.38*	345.52**	8345.50**	0.48***
Line effect	3	944.33***	658.00***	112.56***	10.57**	272.11***	10456.19***	123.10	124.90	9.54	1654.16*	6548.00	3.01**
Tester effect	9	59.05	285.45***	7.15	11.75***	112.76***	2345.52	79.22*	75.97*	14.57**	398.18	9845.00	1.28*
L * T effect	27	34.74*	27.14*	6.81	2.24	28.54	1352.23**	59.47	45.03*	7.37	245.22	6584.50*	0.49***
Error	39	31.76	17.17	9.98	1.93	21.80	725.04	39.21	62.32	6.74	203.84	3845.25	0.23
Total	79	52.02	65.41	13.00	3.37	36.97	1436.72	61.39	56.62	5.75	287.79	5321.00	0.45

DFF-Days to fifty percentage flowering, PH-Plant height, NPT-Number of productive tillers, PL-Panicle length, FLA-Flag leaf area, G/P-Grains per panicle, SPK-Spikelet fertility, TSW-1000 seed weight, PDP-Per day productivity, YK/H-Yield kg per hector, PW-Panicle weight

Table 2 : Nature of gene action and degree of dominance for grain yield and its components in rice

Sr. No.	Character	Nature of gene action	Ratio of genetic component	Degree of dominance
1.	Days to 50% flowering	Addtive	11.6646	0.6151
2.	Plant height	Non-addtive	0.6548	0.9480
3.	Panicle length	Non-addtive	0.2654	1.5606
4.	Panicle weight	Non-addtive	0.1784	1.7844
5.	Flag leaf area	Non-addtive	0.2925	0.2829
6.	Number of productive tillers/plant	Non-addtive	0.2524	1.4637
7.	Number of filled grains per panicle	Non-addtive	0.2627	1.4853
8.	Spikelet fertility percentage	Non-addtive	0.1490	1.8965
9.	1000-grain weight	Non-addtive	0.5156	0.6666
10.	Grain yield per plant	Non-addtive	0.0587	2.8349
11.	Per day productivity	Addtive	1.9640	0.6503
12.	Yield kg/ h	Non-addtive	0.9845	0.6897

environments and pooled environments while the line IR58025A showed negative significant GCA effect at environment-1, environment-3 and pooled over environments. Other promising hybrids which scored significant negative SCA effects at two out of the three environments and pooled analysis were APMS6A X RPHR-517, IR58025A X RPHR-1005, IR58025A X RPHR-517, IR58025A X Akshayadhan, IR79156A X KMR-3, IR68897A X C-20R, IR68897A X IR-66R and IR68897A X Akshayadhan. Among the testers, RPHR-517, IR40750R, IR-66R and IBL-57 exhibited significant negative GCA effect at all the environments as well as in pooled over environments. These were found to be good combiners for producing dwarf plant types.

The positive heterotic values for panicle length were considered as desirable. For the trait panicle length, among the lines APMS6A line showed significant positive gca effect for all the environments and pooled analysis. The tester, KMR-3 showed significant positive gca effect at two environments and pooled analysis. Out of the 40 crosses studied significant positive specific combining ability effects were exhibited by APMS6A X RPHR-1005, APMS6A X IR40750R, APMS6A X Akshayadhan and IR79156A X RPHR-1096 at all the environments and pooled analysis.

For the trait panicle weight, Among the lines APMS6A line showed significant positive GCA effect for all the environments and pooled environments. The line IR58025A showed significant positive GCA effect at two environments and pooled analysis. The testers RPHR-1005 and IBL-57 showed significant positive GCA effect at environment-1, environment-2 and pooled analysis. Results revealed that the line APMS6A, testers RPHR-1005 and IBL-57 recorded significantly positive GCA effects and considered as good general combiners. These parents may be included in crossing programmes for improving this trait. The cross APMS6A x BCW-56 was found to be good specific combiner for panicle weight.

The positive heterotic values for number of productive tillers were considered as desirable. Among the lines APMS 6A had significant positive general combining ability effect at all the three environments and pooled analysis. Among the 10 testers studied no tester showed positive significant effect at all three environments and pooled over environments. But two testers Akshayadhan and IBL-57 showed significant positive gca effect at two environments and pooled analysis. In the present study out of 40 hybrids evaluated, only five hybrids, APMS-6A X IR40750R, APMS6A X IBL-57, and IR58025A X KMR-3, IR79156A X BCW-56 and IR79156A X KMR-3 recorded significant positive sca effects at all environments and pooled analysis.

For the character number of filled grains per panicle, the line APMS6A recorded positive significant GCA effect at all the environments and pooled analysis. The line IR58025A had exhibited positive significant effect at two out of three environments as well as in pooled analysis. Among the testers, RPHR-1005 registered positive significant GCA effects at all the environments and pooled analysis. The hybrids, APMS-6A X BCW-56, APMS-6A X IBL-57, IR58025A X Akshayadhan and IR79156A X Akshayadhan were registered positive significant SCA effect for all the three environments and pooled analysis. Three hybrids exhibited negative significant SCA effect at all environments and pooled analysis.

Among the lines studied, APMS6A and IR79156A had positive significant GCA effects for spikelet fertility

(%) at all the environments and in pooled analysis, while the line, IR58025A had exhibited positive significant effect at two out of three environments as well as in pooled analysis. Among the testers, tester RPHR-1096 registered positive significant GCA effects at all the environments and pooled analysis. The hybrids APMS6A X RPHR-517 and IR58025A X IR-66R recorded significant positive sca effects at three environments and in pooled analysis. The hybrids, APMS-6A X BCW-56, IR58025A X BCW-56, IR79156A X IR-66R, IR79156A X Akshayadhan and IR68897A X RPHR-1005 recorded significant positive SCA effects at two environments and in pooled analysis.

Out of five lines for the trait 1000 grain weight, the GCA effects of lines APMS6A recorded positive significant general combining ability at all the three environments and pooled analysis. Among the testers IR-66R, Akshayadhan and IBL-57 registered positive significant GCA effects at all the environments and pooled over environments. The hybrids APMS6A X Akshayadhan, IR79156A X IR40750R, IR79156A X Akshayadhan and IR68897A X C20R exhibited positive significant specific combining ability for 1000 grain weight at all the environments and pooled analysis.

The line, APMS6A registered significant positive general combining ability effects at all the three environments and over environments. The line IR58025A recorded significant positive gca effects at environment-2 and pooled analysis. Among the 10 testers studied, RPHR-1005, Akshayadhan and IBL-57 manifested significant positive GCA effects at all the environments and pooled analysis for grain yield per plant. For grain yield per plant, the hybrids APMS-6A X RPHR-1096, IR58025A X RPHR-1005, IR58025A X RPHR-517, IR79156A X IR-66R and IR68897A X RPHR-1005 exhibited significant positive effects at all the environments and pooled analysis.

For flag leaf area, among the four lines, APMS6A registered significant positive general combining ability effects at all the three environments and over environments. Among the 10 testers, RPHR-1005 and IBL-57 showed significant positive general combining ability effects at all the three environments and over environments. The hybrids APMS6A X IR40750R, APMS6A X Akshayadhan, IR58025A X Akshayadhan and IR79156A X C20R exhibited significant positive effects at all the environments and pooled analysis.

In case of per day productivity APMS6A registered significant positive general combining ability effects at all the three environments and over environments. Among the 10 testers studied, RPHR-1005, Akshayadhan and IR-66R manifested significant positive GCA effects at all the environments and pooled analysis for per day productivity. For per day productivity, five crosses at environment-1, 13 crosses at environment-2, 6 crosses at environment-3 and 16 crosses in pooled analysis registered positive sca effect specific combining ability. The hybrids APMS-6A X RPHR-1005, IR58025A X KMR-3, IR79156A X KMR-3 and IR79156A X IR40750R exhibited significant positive effects at all the environments and pooled analysis. Among lines, APMS6A while in testers, IBL-57 and IR-66R were recorded significant positive gca effects for per day productivity. Based on per se performance, SCA effects and the corresponding gca status of parents, two crosses *viz.*, IR79156A X KMR-3 and IR79156A X IR40750R were identified as best specific cross combinations for per day productivity. The line, APMS6A registered significant positive general combining ability effects at all the three environments and over environments for yield kg/ha. Among the 10 testers studied, RPHR-1005, Akshayadhan, RPHR-517 and IBL-57 manifested significant positive GCA effects at all the environments and pooled analysis for grain yield per plant. The hybrids APMS-6A X RPHR-1005, APMS6A X RPHR-517, IR58025A X KMR-3, IR58025A X Akshayadhan, IR79156A X IR40750R and IR68897A X KMR-3 exhibited significant positive effects at all the environments and pooled analysis.

Heterosis estimation :

For days to fifty percentage of flowering in pooled analysis, seven hybrids recorded significant negative heterosis ranging from -16.67 (APMS6A X RPHR-517) to -0.46 per cent (IR68897A X BCW-56) over the mid parental value. Two hybrids exhibited significant negative standard heterosis with a range from -7.14 (APMS6A X RPHR-517) to -3.81 per cent (APMS6A X RPHR-1005) over the check DRRH-3. Only seventeen hybrids exhibited significant negative mid parent heterosis in pooled analysis for plant height. The significant negative standard heterosis was recorded in 3 hybrids, with a range of -7.14 (APMS6A X C20R) to -3.81 per cent (APMS-6A X 40750R), when compared with check DRRH-3, while only 3 hybrids expresses negative heterosis over varietal check, IR-64.

Pooled analysis over the locations for panicle length revealed that 31 hybrids expressed significant positive average heterosis ranging from 3.16 (APMS6A X IR-66R) to 30.77 per cent (IR68897A X BCW-56). Twenty six hybrids recorded significant positive standard heterosis varied from 1.10 (APMS6A X IR40750R) to 13.19 per cent (IR58025A X RPHR-1005) and 32 hybrids ranged from 0.62 (APMS6A X IR-66R) to 27.16 per cent (IR58025A X RPHR-1005) over DRRH-3 and IR-64, respectively. Pooled analysis over the environments for panicle weight revealed that sixteen hybrids expressed significant positive mid parent heterosis ranging from 3.51 (IR79156A X BCW-56) to 51.55 per cent (IR58025A X KMR-3. The range of significant positive standard heterosis varied from 5.78 (IR58025A X IR40750R) to 43.40 per cent (APMS-6A X RPHR-1005) and from 6.40 (IR79156A X KMR-3) to 59.74 per cent (IR58025A X KMR-3) over DRRH-3 and IR-64, respectively. As many as 11 hybrids over DRRH-3 and 22 hybrids over IR-64 were excelled superiority in desirable direction.

In pooled analysis, the range of average heterosis for number of productive tillers per plant was from -9.77 (IR68897A X KMR-3) to 21.84 per cent (IR68897A X IR-66R) and twenty hybrids recorded significant positive heterosis. Only eighteen crosses exhibited significant positive standard heterosis ranged from 0.48 (IR58025A X KMR-3) to 16.48 per cent (IR68897A X IR-66R) over DRRH-3 and thirty one hybrids recorded significant positive standard heterosis ranged from 2.48 (IR58025A X IBL-57) to 27.78 (IR79156A X C20R) over check, IR-64. Flag leaf area in pooled analysis over the environments revealed that eight hybrids expressed significant positive mid parent heterosis ranging from 4.17 (IR68897A X IBL-57) to 50.00 per cent (APMS6A X RPHR-1005). The range of significant positive standard heterosis varied from 3.85 (APMS6A X IR40750R) to 30.77 per cent (APMS-6A X RPHR-517) and from 4.35 (APMS6A X IBL-57) to 47.83 per cent (APMS6A X Akshayadhan) over DRRH-3 and IR-64, respectively. Only 6 hybrids over DRRH-3 and 8 hybrids over IR-64 were excelled superiority in desirable direction.

Pooled analysis for number of filled grains per panicle revealed that the significant heterobeltiosis was recorded in 13 hybrids with a range from 1.49 (APMS6A X IBL-57) to 38.73 per cent (APMS-6A X C20R). The significant positive standard heterosis was recorded in 30 hybrids with a range from 1.44(IR79156A X RPHR-517) to 27.82 (APMS-6A X KMR-3) when compared with check DRRH-3, for the character number of filled grains per panicle. For the trait of spikelet fertility in pooled analysis, the significant positive average heterosis was recorded in 13 hybrids, which ranged between 2.65 (APMS6A X Akshayadhan) to 76.86 per cent (IR79156A X Akshayadhan). The significant positive standard heterosis was recorded in 24 hybrids with a range from 1.63 (APMS6A X C20R) to 75.06 (APMS-6A X RPHR-1096) when compared with check DRRH-3.

For the trait of 1000 seed weigh in pooled analysis, the significant positive average heterosis was recorded in 21 hybrids, which ranged between 0.75 (IR79156A X Akshayadhan) to 8.64 per cent (APMS6A X IR-66R). The significant positive standard heterosis was recorded in 21 hybrids with a range from 0.61 (IR68897A X IBL-57) to 5.34 per cent (APMS6A X IR-66R) when compared with check DRRH-3.

In pooled analysis for single plant yield, the significant positive average heterosis was recorded in 15 hybrids, which ranged between 0.36 (IR58025A X Ashayadhan) to 76.55 per cent (IR79156A X IR40750R). The significant positive standard heterosis was recorded in 5 hybrids with a range from 0.27 (APMS6A X Ashayadhan) to 5.88 (IR58025A X RPHR-1005) when compared with check DRRH-3. Six hybrids recorded significant positive standard heterosis over check, IR-64. For the trait of per day productivity in pooled analysis, average heterosis for per day productivity ranged from -2.23 (IR79156A X KMR-3) to 37.23 per cent (IR79156A X Akshayadhan) and 10 crosses recorded significant positive heterosis. Only 11 hybrids showed significant positive heterosis for per day productivity ranging from 1.81 (IR68897A X KMR-3) to 75.58 per cent (IR68897A X C20R). 17 hybrids were more than the per day productivity over the check, DRRH-3 as revealed by significant positive standard heterosis and 13 hybrids over the check, IR-64.

For the trait of yield kg per hector in pooled analysis, the significant positive average heterosis was recorded in 14 hybrids, which ranged between 0.94 (IR68897A X RPHR-1096) to 24.84 per cent (IR79156A X IR66R). The significant positive standard heterosis was recorded in 5 hybrids with a range from 1.12 (APMS6A X Ashayadhan) to 6.76 (APMS6A X BCW-56) when compared with check DRRH-3. Five hybrids recorded significant positive standard heterosis over check, IR-64.

In rice, genotypes with dominant genes having negative effects tend to be early in duration which is desirable with regard to days to 50% flowering. Among the four lines, one line IR-68897A recorded significant negative gca effects at all locations and pooled over locations. Upadhyay and Jaiswal (2015) also found that the line IR-68897A was the best general combiner for earliness. The significant negative GCA and SCA effects also reported by Tiwari *et al.*(2011); Ghara *et al.* (2012) and Latha *et al.* (2013) for days to 50 % flowering. For the character plant height, GCA effects in negative side is more desirable to develop non-lodging and semi dwarf genotypes in rice. Priyanka *et al.* (2014) reported that the line, IR-68897A recorded significant negative GCA effect at all locations and pooled locations and similar results obtained with us. For the trait number of productive tillers per plant APMSA6A revealed positive significance revealed additive and additive × additive genetic component of variance which are fixable and this character could be easily improved. Similar results were reported by Salgotra *et al.* (2009) and Padmavathi *et al.* (2012) for this trait. APMS 6A had positive significant gca effects for spikelet fertility (%) at two locations and in pooled analysis, while the line, PUSA 5A was significantly negative. Shyam *et al.* (2012) reported positive GCA effect of the line APMS 6A for spikelet fertility (%). Grain yield for plant was significantly correlates yield tons per hector and many hybrid combinations are showed positive significances. Chakraborty *et al.* (2009) and Priyanka *et al.* (2014) also reported significant positive sca effects for grain yield from high x high GCA status.

Early maturing hybrids are desirable as they produce more yields per day and fit well in multiple cropping systems. Majority of the hybrids exhibited significant negative values of heterosis and heterobeltiosis imply early flowering in hybrids. Higher magnitude of negative standard heterosis for earliness was reported by Kumar Babu *et al.* (2010), Palaniraja *et al.* (2010) and Tiwari *et al.* (2011). Both positive and negative standard heterosis was observed by Gouri Shankar *et al.* (2010). Short stature is an important trait in rice to withstand lodging especially under high input management, hail storm and high rainfall areas. Hence, heterosis in negative direction is treated as desirable in the present study. Both positive and negative heterosis was observed over mid parent, better parent and standard checks. In case of standard heterosis, similar nature was reported Gouri Shankar *et al.* (2010), Tiwari *et al.* (2011) and Padmavathi *et al.* (2012).

Hybrids are generally characterized by having larger panicles indicating their efficiency in partitioning of assimilates to reproductive parts. Earlier workers Chandirakala *et al.* (2010) and Padmavathi *et al.* (2012) reported positive standard heterosis for panicle length. Standard heterosis of both positive and negative nature was observed in their studies by Singh *et al.* (2007) and Parihar and Pathak (2008). In case of panicle length Standard heterosis of both positive and negative nature was observed in their studies by Singh *et al.* (2007). Number of productive tillers per plant will directly contribute towards grain yield. In the present investigation, majority of the hybrids recorded significant positive heterosis and heterobeltiosis. Rosamma and Vijayakumar (2007); Gouri Shankar *et al.* (2010); Kumar Babu *et al.* (2010) and Tiwari *et al.* (2011) reported both positive and negative standard heterosis in their studies as in the case of present study suggesting methods of exploiting both additive and non-additive gene effects.

Spikelet fertility and pollen fertility were the most important traits for heat tolerance. High number of pollen was directly correlates highest spikelet fertility. Positive standard heterosis for spikelet fertility percentage was desirable. Both positive and negative standard heterosis for spikelet fertility was reported by Kumar Babu *et al.* (2010); Tiwari *et al.* (2011) and Padmavathi *et al.* (2012) whereas negative heterosis for this trait was observed by Pandya and Tripathi (2006). Grain yield is a complex quantitative character controlled by many genes interacting with the environment and is the product of many factors called yield components. Selection of parents based on yield alone often misleading. Hence, the knowledge about relationship between yield and its contributing characters is needed for an efficient selection strategy for development of high yielding variety. Both positive and negative heterosis over standard check reported by Singh *et al.* (2007); Gouri Shankar *et al.* (2010); Kumar Babu *et al.* (2010b); Tiwari *et al.* (2011) and Padmavathi *et al.* (2012).

It was observed in few cases, the lines and testers with good per se performance were not necessarily be the good general combiners and *vice versa*, thus, choice of parents must be based on both per se performance and GCA effects of parents.

Conclusion :

Global temperatures are increasing rapidly due to climate change, so we need to develop rice varieties and hybrids tolerance to high temperature stress to get food security. By using conventional breeding method, heterosis is one of the better option to increase the vigour, growth and yield of the rice crop. Heterosis and specific combining ability for pollen fertility, spikelet fertility and grain yield under heat tolerance was desirable. In most cases, high temperature tolerance at the grain-filling stage is also required. Information on the reaction of rice cultivars to high temperature under various field conditions is needed. Higher pollen shedding trait is also important and can be incorporated into high yielding susceptible genotypes can pay way for further breeding.

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