International Journal of Agricultural sciences ISSN: 2167-0447 Vol. 3 (7), pp. 586-595, September, 2013. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full length research paper

Aerobic Rice: Identification of suitable rice hybrids adaptability to aerobic condition in water-short areas

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Accepted 1 August, 2013

The investigation was carried out under aerobic condition using the line x testers mating design and studied for yield and its components traits. The objective of this study was carried out to identify the best combining parents and their hybrids suitable for aerobic cultivation. One hundred and thirty six hybrids along with eight lines, seventeen testers and one check CORH 3 were raised in randomized block design with two replications under aerobic condition. Nineteen hybrids showed desirable performance for all the yield traits. However, most of the hybrids involving aerobic and upland genotype as male parent exhibited hybrid vigor for yield and its component traits. Parental lines of the hybrids also had high per se performance for grain yield. Out of nineteen hybrids, five hybrids *viz.*, IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68888 A x MAS 26, TNAU CMS 2A x Vandana advocated for commercial exploitation since grain yield with its contributing characters manifested significantly for standard heterosis. Among this hybrid standard heterosis ranged from 78.77 percent in grain yield to -15.33 percent in flowering duration and showed marked variation in the expression of standard heterosis for yield component traits. Finally these hybrids as well as parents can be commercially exploited under aerobic condition.

Key words: Rice hybrids, heterosis, yield components, aerobic condition, water-short areas.

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop of India with world ranking first in area and second to china in production. At the current growth of population rice requirement increases dramatically, hence it is challenging task to ensuring food and nutritional security. In Asia, 17 million ha irrigated rice areas may experience "Physical water scarcity" and 22 million ha may have "Economic water scarcity" by 2025 (Tuong and Bouman, 2001). Therefore, a more efficient use of water is needed in rice production. Several strategies are being pursued to reduce rice water requirement, such as intensive rice farming in aerobic soil, referred to herein as aerobic rice, can greatly reduce the water input compared to that of flooded rice cultivation. Aerobic rice is a new way of cultivating rice that requires less water than lowland rice. It entails the growing of rice in aerobic soil, with the use of external inputs such as supplementary irrigation and fertilizers and aiming at high yields (Wang et al., 2002). Aerobic way of growing rice saves water by eliminating continuous seepage and percolation, reducing evaporation and eliminating wet land preparation (Castaneda et al., 2003).

The global water crisis threatens the sustainability of irrigated rice production in all the rice producing countries. For rice to be successful as an aerobic crop, it should tolerate intermittent water deficits and high soil impedance created due to aerobic conditions (Lafitte and Bonnett, 2002). Hence, specific aerobic rice cultivars with high yield potential and tolerance to water deficit are essential. The success of hybrid rice in breaking the yield barrier under irrigated condition provides an impetus to plant breeders to exploit it under aerobic condition. Hybrid rice with its vigorous and more active root system tolerates moderate stress caused due to limited irrigation water and therefore can be exploited under aerobic conditions. So far, there have been major efforts on this front keeping this in view; the present study was carried out to identify heterotic hybrids for aerobic conditions based on yield contributing traits in rice.

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MATERIALS AND METHODS

Eight Cytoplasmic Male Sterile (CMS) lines and 17 promising genotypes with desirable grain type, aerobic rice cultures and upland genotype used as tester in this study is depicted in Table 1. The released rice hybrid CORH 3 were used as standard check and also used as control check in flooded condition. The seed materials viz., aerobic rice cultures, upland genotype and quality lines were obtained from Directorate of rice research, Hyderabad, Central Rice Research Institute (CRRI) Cuttack, GKVK, Bangalore and Paddy Breeding Station, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore. Crossing work was done by clipping method. Crosses were effected between female and male parents in line x tester fashion and a total of 136 cross combination were obtained.

Evaluation of F_1 Hybrids and Parents under Aerobic Condition

Evaluation of F_1 hybrids and parents for yield traits under aerobic condition. One thirty six hybrids along with eight lines, seventeen testers and one check (CORH 3) were raised in a Randomized Block Design (RBD) with two replications under non-puddled and non- flooded aerobic soil, during Rabi, 2012 (Plate 1). Each treatment was accommodated in two rows of 1.5 m length with a spacing of 20 x 15 cm in each replication. A uniform population of 20 hills per treatment with single seedling was maintained in each replication. Normal agronomical practices and plant protection measures with external inputs such as supplementary irrigation and fertilizers were given at appropriate time. The hybrids along with their parents were maintained under irrigated condition up to 55 days. From the 56^{th} day onwards the treatment plot was maintained under aerobic condition. For every irrigation thereafter, soil sampling was carried out before and after irrigation to assess the soil moisture content. Irrigation was given only when hair line crack was noticed in the treatment plot and check was maintained under normal flooded condition till maturity (Mishra, 2004). The rainfall received during the entire crop period was recorded. Data were recorded on ten important yield contributing traits *viz.,* day to 50% flowering, plant height, pollen fertility percent, number of productive tillers per plant, panicle length, spikelet fertility, 100 grain weight, single plant yield, biological yield and harvest index.

RESULTS AND DISCUSSION

Information on yield potential of the genotypes has more Significance in the crop improvement programme to evolve varieties or hybrids suited for aerobic cultivation. Scope for exploitation of hybrid vigour will depend on the performance of hybrids and magnitude of heterosis. In rice, the phenomenon of hybrid vigour has been extensively exploited for enhancing the yield. Many workers have emphasized the usefulness of heterosis per cent as an important criterion for evaluation of hybrids. Therefore, the knowledge about the magnitude of heterosis would help in the selection of best cross combination. Among the three types of heterosis, standard heterosis is mainly considered by plant breeders for evaluation of hybrids with a view to getting superior hybrids performing well over the local standard varieties. Therefore, in the present study also, standard heterosis value was taken into account over CORH 3 for evaluation of hybrids. Here, the first five ranking hybrids with per se performance and standard heterosis for different yield characters under aerobic condition presented in Table 2.

Days to 50% Flowering

The hybrid with low per see performance for flowering is considered as desirable traits. A total of 67 hybrids under aerobic condition showed earliness for flowering. Days to 50% flowering in hybrid namely IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68888 A x MAS 26, IR 58025 A x 69726 and IR 68897 A x KMP 149 earliness for flowering under aerobic condition.

Negative heterosis is desirable for days to flowering because this will make the hybrids to mature earlier as compared to parents. The nature and magnitude of heterosis revealed that among 136 hybrids, a total 50 hybrid earlier flowering plants observed when compared to check CORH 3. Among them eight hybrids namely IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68888 A x MAS 26, TNAU CMS 2A x Vandana, COMS 24 A x IR 60199 R and IR 58025 A x IR 69726 R exhibited significant negative heterosis for days 50% to flowering compare to standard check. Heterosis in both negative and positive directions for days to flowering have also reported by Peng and Virmani (1991). Most data have indicated negative heterosis in days to flowering in hybrids (Mallick et al., 1978; Xu and Wang, 1980) found that days to maturity in hybrids depend on the male parent.

Plant Height

Semi- dwarf plant height (80 -100 cm) is desirable for recording high yield in rice variety as vigour in plant height may lead to unfavorable grain and straw ratios and below optimum yield due to lodging. Hybrids with semi-dwarf plant type is preferable and highly productive (Yadav, 2004). Based on the per se performance a total of 38 hybrids under aerobic condition recorded significantly shorter plant height.

Table 1. Details of parents used in the study.

LINES	Testers			Check
	RESTORER LINES:	AEROBIC RICE CULTURE:	UPLAND CULTURE:	(Flooded condition)
IR 79156 A	IR 69726 R	MAS 946 -1	ANJALI	
IR 68897 A	IR 60199 R	MAS 26	VANDANA	CORH 3
IR 58025 A	IR 10198 R	BI 33	VIRENDER	
IR 68888 A	IR 65912 R	BR 2655	ANNADA	
TNAU CMS 2A	IR 59669 R	KMP 149		
COMS 23 A	IR 21567 R			
COMS 24 A	IR 32809 R			
CRMS 31 A	CB 87 R			

Plate 1. Evaluation of parents and hybrids under aerobic condition.

The hybrids *viz.*, IR 68888 A x MAS 26, IR 68888 A x BI 33, CRMS 31 A x MAS 946 – 1, IR 58025 A x BI 33 and IR 68897 A x IR 21567 R were the shortest under aerobic conditions respectively. In general, moisture stress results in reduced plant height under aerobic condition (Russo, 2000). Short stature of the plant confers resistance to lodging. Shorter plant height is an important character of hybrid to withstand lodging. In the present study, three hybrids showed significant negative heterosis over mid-parent for plant height.

Two hybrids (IR 68888 A x MAS 26, and IR 68888 A x BI 33) had significant negative standard heterosis under aerobic condition over the hybrid check CORH 3. Based on per se performance, specific combining ability effects and standard heterosis the hybrid IR 68888 A x MAS 26, IR 68888 A x BI 33, CRMS 31 A x MAS 946 – 1, IR 58025 A x BI 33 and IR 68897 A x IR 21567 R were found to have desirable plant height suitable for aerobic cultivation. Plant observations are in close agreement with earlier reported by Nuruzzaman et al., (2002), Alam et al., (2004).

Pollen Fertility Percent

Pollen fertility is one of the constraints in hybrid rice breeding programme, which affects the yield considerably. However Pollen fertility in hybrids should be required as in pollen parent and or standard variety this indicates that the pollen parent in hybrid expressed full restoring capacity over a particular Cytoplasmic male sterile line. Therefore, hybrids having non- significant difference over both the parent (BP and SV) either in positive or negative direction would be beneficial trait. Sixty eight cross combination had positive but non – significant differences for standard heterosis as well as per

Table 2. Hybrids with desirable per se performance and standard heterosis for different aerobic condition traits.

S/No	CHARACTER	PER SE PERFORMANCE	STANDARD HETEROSIS OVER CORH 3
1.	**Days to 50% flowering**	IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68888 A x MAS 26, IR 58025 A x IR 69726 R.	IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68888 A x MAS 26, TNAU CMS 2A x Vandana.
2.	**Plant height**	IR 68888 A x MAS 26, IR 68888 A x BI 33, CRMS 31 A x MAS 946 – 1, IR 58025 A x BI 33, IR 68897 A x IR 215679 R.	IR 68888 A x MAS 26,IR 68888 A x BI 33
3.	**Pollen fertility percent**	IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, COMS 24 A x IR 60199 R.	IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, COMS 24 A x IR 60199 R, IR 68897 A x IR 21567 R, IR 58025 A x IR 69726 R
4.	**No. of productive tillers per plant**	IR 58025 A x IR 69726 R, IR 58025 A x BI 33, IR 68897 A x MAS – 946 -1, IR 68897 A x BR 2655, IR 68897 A x KMP 149	IR 68897 A x IR 21567 R , IR 58025 A x IR 69726 R, IR 58025 A x BI 33, IR 68897 A x MAS – 946 -1, IR 68897 A x BR 2655.
5.	**Panicle length**	IR 58025 A x BI33, IR 58025 A x IR 69726 R, IR 68897 A x BR 2655, IR 68897 A x KMP 149, TNAU CMS 2 A x MAS 26.	IR 68897 A x MAS 946 -1, IR 58025 A x BI33, IR 58025 A x IR 69726 R, CRMS 31 A x MAS 946 -1 , IR 68897 A x KMP 149.
6.	**Spikelet fertility**	IR 68897 A x KMP 149, IR 68897 A x IR 21567 R, TNAU CMS 2A x MAS 26, IR 58025 A x Anjali ,IR 68897 A x MAS – 946 -1,	IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68897 A x BR 2655, IR 68897 A x KMP 149 and IR 68897 A x IR 21567 R.
7.	**Hundred grain weight**	IR 68897 A x BR 2655, IR 68897 A x MAS – 946 -1, IR 58025 A x Anjali, CRMS 31 A x IR 59669 R, CRMS 31 A x BI 33	IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, TNAU CMS 2A x Vandana
8.	**Grain yield per plant**	CRMS 31 A x MAS 946 -1, IR 79156 A x MAS 946 -1, TNAU CMS 2A x MAS 26, IR 58025 A x Anjali, IR 58025 A x BI 33,	IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, TNAU CMS 2A x Vandana.
9.	**Biological yield**	IR 68897 A x KMP 149, IR 68888 A x BI 33, CRMS 31 A x MAS 946 – 1, IR 58025 A x BI 33, IR 68897 A x IR 21567 R.	IR 68888 A x MAS 26, IR 68888 A x BI 33, CRMS 31 A x MAS 946 – 1, IR 58025 A x BI 33 and IR 68897 A x IR 21567 R.
10.	**Harvest index**	IR 68897 A x KMP 149, IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26,	IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68897 A x BR 2655, IR 68897 A x KMP 149.

per se performance of these IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68888 A x MAS 26, COMS 24 A x IR 60199 R, IR 68897 A x IR 21567 R and IR 58025 A x IR 69726 R. Similar findings were reported by Tiwari et al., (2011).

Number of Productive Tillers per Plant

More panicle bearing tillers per plant is believed to be closely associated with high grain yield per plant resulting high productivity. Number of productive tillers plant is generally associated with higher productivity (Bhawana Joshi et.al*.,* 2004). Thirty four hybrids under aerobic condition had high per se performance for this trait. Among the 34 hybrids, five hybrids were found to have more number of productive tillers under aerobic condition (Table 2). The magnitude of heterosis for number of productive tillers was found to be higher in 33 hybrids under aerobic condition over the hybrid check CORH 3. Among 33 hybrids six hybrids namely IR 68897 A x IR 21567 R , IR 58025 A x IR 69726 R, IR 58025 A x BI 33, IR 68897 A x MAS – 946 -1, IR 68897 A x BR 2655 and IR 68897 A x KMP 149 showed significant positive heterosis over the hybrid check CORH 3. In general,numbers of productive tillers in the hybrids were lower in aerobic condition than under flooded situation. It was reported that the number of panicles were significantly lower

Table 3. Best parents identified based on per se performance in aerobic condition.

S.NO	Character	Per se performance
1.	**Days to 50% flowering**	IR 68897 A, IR 68888 A, IR 58025 A, MAS – 946 -1, BI 33, IR 65912 R, MAS 26, Vandana.
2.	**Plant height**	IR 68897 A, IR 68888 A, IR 58025 A, TNAU CMS 2A, COMS 24 A, CRMS 31 A, Vandana, BR 2655, MAS 946 -1, MAS 26, BI 33.
3.	**Pollen fertility percent**	IR 68897 A, , IR 68888 A, , IR 58025 A, TNAU CMS 2A, BI 33, IR 65912 R, MAS 26, Vandana, IR 60199 R, Anjali
4.	**No. of productive tillers per plant**	IR 68888 A, , IR 58025 A, TNAU CMS 2 A, MAS – 946 -1 BI 33, IR 65912 R, MAS 26, Vandana, IR 60199 R, Anjali, BR 2655, KMP 149, IR 59669 R
5.	**Panicle length**	IR 68897 A, IR 68888 A, , IR 58025 A, IR 65912 R, MAS 26, Vandana, IR 60199 R, Anjali, BR 2655, KMP 149, MAS 946 -1, MAS 26
6.	**Spikelet fertility**	IR 68897 A, IR 68888 A, IR 58025 A, TNAU CMS 2A, CRMS 31 A, MAS – 946 -1, BI 33, IR 65912 R, MAS 26, Vandana, IR 60199 R, Anjali, BR 2655.
7.	**Hundred grain weight**	IR 68888 A, IR 58025 A, TNAU CMS 2 A, COMS 24 A, CRMS 31 A, MAS – 946 -1, BI 33, IR 65912 R, MAS 26, Vandana, BR 2655, KMP 149.
8.	**Grain yield per plant**	IR 68897 A, IR 68888 A, IR 58025 A, TNAU CMS 2A, COMS 24 A, CRMS 31A ,MAS – 946 -1, BI 33, IR 65912 R, MAS 26, Vandana, IR 60199 R, Anjali, BR 2655, KMP 149, IR 21567 R, IR 69726 R ,IR 59669 R , BR 2655.
9.	**Biological yield**	IR 68897 A, IR 68888 A, IR 21567 R, IR 69726 R , IR 59669 R , BR 2655, MAS – 946 -1, BI 33, IR 65912 R, MAS 26.
10.	**Harvest index**	IR 68897 A, IR 68888 A, IR 58025 A, TNAU CMS 2A, COMS 24 A, CRMS 31 A, MAS – 946 -1 BI 33, IR 65912 R, MAS 26, Vandana, IR 60199 R, Anjali, BR 2655, KMP 149, IR 21567 R, IR 69726 R ,IR 59669 R , BR 2655.

in plants, which are exposed to aerobic condition at vegetative stage than the plants under flooding. Results for significantly high number of productive tillers per plant are in conformity with those obtained by Manual and Palanisamy (1989); Annadurai, (2002); Sonie et al., (2005).

Panicle Length

Generally, larger panicle is associated with high number of grains panicle resulting into higher productivity; therefore, hybrids with positive heterosis for Panicle length are desirable. There was a general reduction in panicle length under aerobic condition. The present study evealed that based on the per see performance a total of 46 hybrids under aerobic condition registered significantly higher panicle length. Heterosis for panicle length over the check hybrid was noticed in 46 hybrids under aerobic condition. Twenty hybrids under aerobic condition had significant positive heterosis over CORH 3. Significantly positive heterosis for panicle length was already reported by Vivekanandan et al., (1991), Singh et al*.,* (1992); Bhawana J (2004).

Spikelet Fertility Percent

Spikelet fertility percent is very important in hybrid breeding programme. Since this trait has a direct bearing on the yield, hence manifestation of heterosis in positive direction is desirable for this trait. The number of spikelets determines the proportion of spikelets, which produce grains (Boonjung, 1993). Spikelet fertility is one of the important yield contributing characters that is mainly considered for yield improvement in rice hybrids. The mean performance of hybrids for spikelet fertility was found to be superior in 58 hybrids under aerobic condition.

Table 4. Mean performance and standard heterosis for yield and its components traits in promising hybrids.

Genotype	No. of productive tillers per plant	Plant height	Days to 50% flowering	Panicle length	Grain yield per plant
LINES					
IR 68897 A	21.33	84.40	79.30	28.37	37.68
IR 68888 A	19.70	83.66	70.70	25.80	38.28
IR 58025 A	19.30	85.33	65.34	26.66	42.88
TNAU CMS 2A	23.33	101.70	69.00	28 .52	32.68
TESTERS					
MAS 946-1	20.33	100.34	65.00	28.62	39.72
BI 33	20.40	121.00	61.33	30.87	42.88
IR 65912 R	18.70	98.26	70.10	27.13	41.97
MAS 26	19.60	101.26	70.69	28.17	42.88
VANDANA	23.42	92.00	68.21	31.33	39.78
HYBRIDS					
IR 68897 A X MAS – 946 -1	26.30 66.89	101.66 -15.01[a] **	62.01 -15.36 [a] **	42.57 21.01 [a] **	59.25 78.77 [a] **
IR 68888 A X BI 33	25.67 57.12 [a] **	103.71 -13.47 [a] **	70.12 -12.35 [a] **	39.33 20.02 [a] **	58.12 73.12 [a] **
IR 58025 A X IR 65912 R	24.30 52.41 [a] **	110.60 -12.65 [a] **	68.21 -12.65 [a] **	34.33 18.89 [a] **	57.12 68.12 [a] **
IR 68888 A X MAS 26	26.22 65.89[a]**	112.00 -13.64 [a] **	71.60 -15.05 [a] **	40.33 19.88 [a] **	58.56 78.67 [a] **
TNAU CMS 2A X Vandana	25.78 58.72 [a] **	114.21 -13.12 [a] **	60.21 -13.05 [a] **	36.21 18.81 [a] **	57.89 69.88 [a] **

[a] Standard heterosis over CORH3, **Significant at 1% level

Among the 58 hybrids, the 5 best hybrids namely IR 68897 A x KMP 149, IR 68897 A x IR 21567 R, TNAU CMS 2 A x MAS 26, IR 58025 A x Anjali , IR 68897 A x MAS – 946 -1 which had superior performance for spikelet fertility has been given in Table 2.Eighteen hybrids combination showed equal performance for spikelet fertility compared to check under flooded conditions (CORH 3) indicating their ability to withstand water limited situations. The superior performance of these hybrids due to presence of aerobic cultures like MAS 946 -1, MAS 26, BI 33, BR 2655 and KMP 149 and upland cultivars like Anajli, vandana one of the male parent.

The extent of heterosis result for this trait revealed that 34 hybrids expressed heterosis in desired direction with positive non-significant under aerobic condition. Among 34 hybrids, five hybrids namely, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68897 A x BR 2655, IR 68897 A x KMP 149 and IR 68897 A x IR 21567 R was found to be high and positive significant heterosis under aerobic condition over the check CORH 3. Table 2 shows the first five ranking hybrids showing superior performance for number of spikelets per panicle.

Under aerobic condition there was a general reduction in spikelet fertility level in most of the hybrid combinations. But few hybrid combinations showed spikelet fertility percent equal to standard check CORH 3 under flooded conditions. The involvement of aerobic cultivars as parents in the hybrids may be one of the reasons. Earlier studies also suggested that the spikelet fertility is a reliable parameter for the mass screening of genotypes for yield performance under water deficit situations (Garrity and O'Toole, 1994).

Based on per se performance, specific combining ability effects and heterosis,, the hybrids *viz.*, IR 68897 A x KMP 149 and IR 68897 A x IR 21567 R was found superior under aerobic conditions. Positive heterosis over better parent and standard variety was reported by Virmani *et al*. (1981) they concluded that heterosis in yield was primarily due to increased fertile spikelets

Plate 2. First five ranking promising hybrids based on yield performane under aerobic condition.

IR 68897 A X MAS – 946 -1

IR 68888 A X BI 33

IR 58025 A X IR 65912 R

IR 68888 A X MAS 26

TNAU CMS 2A X Vandana

per panicle. These result conformity with results obtained by Viraktamath (1987) and Singh (2000) who reported hybrids possess significantly lower tiller number than mid parent, better parent and check variety.

100 Grain Weight

The 100 grain weight is one of the important common traits which influence the yield. Based on the mean performance hybrids for 100 grain weight was found to be superior in 38 hybrids among one hundred thirty six hybrids. Among the 58 hybrids, the five best hybrids *viz*., IR 68897 A x BR 2655, IR 68897 A x MAS – 946 -1, IR 58025 A x Anjali, CRMS 31 A x IR 59669 R and CRMS 31 A x BI 33 which had superior performance for 100 grain weight has been given in Table 2. The standard heterosis over the check for twelve most promising crosses were IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, TNAU CMS 2A x Vandana, COMS 24 A x IR 60199 R CRMS 31 A x MAS 946 -1, IR 79156 A x MAS 946 -1, TNAU CMS 2A x MAS 26, IR 68897 A x IR 21567 R , IR 58025 A x IR 69726 R and CRMS 31 A x IR 59669 R . Heterosis with respect to 100 grain weight in positive and negative direction have also been reported by Virmani *et al*. (1981), Lokaprakash *et al.*(1992) and Tiwari *et al.* (2011).

Grain Yield

Rice, being a self-pollinated crop, the commercial exploitation of hybrid vigour depends on magnitude of heterosis for grain yield. Grain weight is one of the important traits that decide the final grain yield. It is multiplicative end product of several basic components of yield (Grfius, 1959). Forty three hybrids under aerobic condition displayed high per se performance for hundred grain weight. Most of the hybrids under aerobic condition showed lesser grain weight but few hybrids showed equal performance under both conditions. The hybrids CRMS 31 A x MAS 946 -1, IR 79156 A x MAS 946 -1, TNAU CMS 2A x MAS 26, IR 58025 A x Anjali, IR 58025 A x BI 33, TNAU CMS 2 A x Anjali, IR 58025 A x Vandana, IR 68897 A x BR 2655, IR 68897 A x KMP 149, IR 58025 A x IR 69726 R and CRMS 31 A x IR 59669 R showed superior mean performance compare to check CORH3. Some of the hybrid combinations were identified as the superior s with reference to grain quality based on low mean performance. The reduction in grain yield in rice with water stress was mainly due to decrease in the number of filled grains per panicle and 1000-grain weight depending on severity of stress (Surek and Beser 1986). Water stress at booting, and heading to flowering stages also effects number of productive tillers, grain number per plant and 1000 grain weight.

In the present investigation in respect to heterosis, 46 hybrids under aerobic condition had negative significance for grain yield over CORH3. Some of the hybrids was found to be significant higher in nineteen hybrid viz., IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, TNAU CMS 2A x Vandana, COMS 24 A x IR 60199 R, CRMS 31 A x MAS 946 -1, IR 79156 A x MAS 946 -1, TNAU CMS 2A x MAS 26, IR 58025 A x Anjali, IR 58025 A x BI 33, TNAU CMS 2A x Anjali, IR 58025 A x Vandana, IR 68897 A x BR 2655, IR 68897 A x KMP 149,COMS 24 A x IR 60199 R, IR 68897 A x IR 21567 R , IR 58025 A x IR 69726 R and CRMS 31 A x IR 59669 R under aerobic condition. These findings were in close agreement with the earlier findings by Amudha (2008); Malarvizhi et al., (2009); Bagheri, Jelodar (2010); Rahimi et al., (2010); Tiwari et al., (2011).

Biological Yield

In general 40 hybrids were found to be superior performance under aerobic condition. Top five cross combination in relation to based on per se performance, sca effects and standard heterosis for biological yield were IR 68888 A x MAS 26, IR 68888 A x BI 33, CRMS 31 A x MAS 946 – 1, IR 58025 A x BI 33 and IR 68897 A x IR 21567 R were found to have desirable plant height suitable for aerobic cultivation compare to check CORH 3. These findings earlier reported by Peng, Virmani (1991); Virmani et al., (1993).

Harvest Index

Harvest index which indirectly influences the grain yield through controlling the mechanism of distribution of photosynthesis to economic and non – economic organs as such is not a yield component. Therefore, it is an important consideration for genetic improvement. Based on the per se performance a total 35cross combination performed well under aerobic condition. Results revealed that, among 35 cross combination,five crosses having positive heterosis and remaining some of the hybrids showed negative heterosis over check CORH 3.The positive heterosis was also reported by Virmani et al., (1982). The significant and negative heterosis over better parent for harvest index over standard variety by Sarwagi and Srivastava (1998).

Finally, with reference to grain yield, the economic output of the plant and the total contribution of all yield related traits were found to be high in 60 hybrids under aerobic condition. Among them, 19 hybrids under aerobic condition were found to be high yielding, by registering grain yield of more than 50 grams per plant. Among the 19 hybrids which showed superior performance, the hybrid out yielded the other hybrid combinations by recording 56.05 grams per plant followed by hybrids *viz.*,
IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, TNAU CMS 2A x van-

dana, COMS 24 A x IR 60199 R, CRMS 31 A x MAS 946 -1, IR 79156 A x MAS 946 -1, TNAU CMS 2A x MAS 26, IR 58025 A x Anjali, IR 58025 A x BI 33, TNAU CMS 2A x Anjali, IR 58025 A x Vandana, IR 68897 A x BR 2655, IR 68897 A x KMP 149, COMS 24 A x IR 60199 R, IR 68897 A x IR 21567 R , IR 58025 A x IR 69726 R and CRMS 31 A x IR 59669 R . Parental lines involved in the hybrids also had high per se performance for grain yield and yield contributing traits under semi-arid tropics stress tolerant traits under aerobic condition (Table 3).Among the above nineteen hybrids, five hybrids viz., IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R, IR 68888 A x MAS 26, TNAU CMS 2A x Vandana recorded higher yield under aerobic situations over standard check CORH 3. In addition to yield, these hybrids also showed superiority for other characters also. The hybrid viz., IR 68897 A x MAS 946 -1, IR 58025 A x BI33, IR 58025 A x IR 69726 R and showed superiority for number of productive tillers, panicle length, spikelet fertility, 100 grain weight and harvest index; the hybrid IR 68897 X BR 2655 and IR 68897 A x IR 21567 R for number of productive tillers, panicle length, spikelet fertility and harvest index.

With respect to standard heterosis, 58 hybrids superior under aerobic condition over the check CORH 3. The per see performance and standard heterosis as the indices of heterotic vigour in short listed five hybrids for five yields and its component its depicted in Table 4. It appear hybrid vigour in yield where due to significance high yield components, namely productive tillers per plant, plant height, days to 50% flowering, panicle length and grain yield. Grafius (1959) suggested that there is no separate gene system for yield per se and that the yield is an end product of the multiplication interaction between the yield components. This was confirmed by the present investigation where none showed hybrid vigor for yield alone. In five crosses, the heterotic effect in yield was along with hybrid vigor for namely productive tillers per plant, plant height, days to 50% flowering, panicle length and grain yield thus, it is obvious that hybrid vigor for yield is the result of interaction of simultaneous increase in the expression of yield components.

The five hybrids showned highly significsnt increase in yield with a standard heterosis 78.77 percent due to indirect effect of its contributing components namely productive tillers per plant(66.89 percent), plant height(-15.01 percent), days to 50% flowering(-15.36 percent), and panicle length(21.01 percent). For plant height and days to 50% flowering negative heterosis were desirable, but for the rest of the characters positive characters were desirable. Degree of heterosis varied from cross to cross and from character to character as observed in this study from 24.30 to 26.30 for productive tillers per plant , from 101.66 to 114.21 for plant height, from 62.01 to 71.60 for days to 50% flowering, from 34.33 to 42.57 for panicle length and from 57.12 to 59.25 for grain yield in terms of mean performance and from 52.41 percent to 66.89 percent for productive tillers per plant , from -15.01 to -12.65 percent for plant height, from -15.36 to -12.01 percent for days to 50% flowering, from 18.81 to 21.01 percent for panicle length and from 68.12 to 78.77 percent for grain yield for standard heterosis against CORH 3.

Among the yield components highest heterosis effect was for productive tillers per plant (66.89 per cent) followed by panicle length (21.01 percent). Similar result was observed by Mandal (1982). The major yield components in rice are number of panicles plant-1, spikelet number panicle-1, spikelet fertility percentage and 1000-grain weight (Virmani and Edwards, 1983). There are many reports showing evidence of significant positive high parent heterosis and standard heterosis for yield and yield components. Although the hybrids had fewer effective panicles per square meter, they had significantly more filled grains per panicles and larger seeds (Virmani et al., 1981). Significant positive mid parent, high parent and standard heterosis were observed for one or more of yield components in a number of crosses (Luat et al., 1985; Peng and Virmani, 1994). Virmani et al. (1981) observed negative heterosis for panicle number per square meter. Most crosses showing significant standard heterosis for yield were found to be possessing heterosis for more than one component (Maurya, Sing, 1978; Virmani et al., 1982). Results obtained in China and at IRRI indicate that heterotic F1 combinations usually show an increased sink size through an increase in spikelet per panicle, spikelet fertility percentage and 1000-grain weight (Virmani and Edwards, 1983).

Maximum variation was observed in heterobeltiosis and standard heterosis for yield among hybrids followed by grain number panicle-1. F1 rice hybrids are useful not only for their high grain yield per cropping season. The results indicated the possibility of obtaining more heterotic hybrids only in specific cross combinations. With appropriate choice of parental lines it appears possible to develop F1 rice hybrid possessing distinct yield superiority over the best-inbred lines. Yield components should be considered to increase the yield through selections. According to Swaminathan et al. (1972), heterobeltiosis of more than 20% over better parent could offset the cost of hybrid seed. Thus, the crosses showing more than 20% of heterobeltiosis viz., IR 68897 A x MAS – 946 -1, IR 68888 A x BI 33, IR 58025 A x IR 65912 R , IR 68888 A x MAS 26, TNAU CMS 2A x Vandana may be exploited for hybrid rice production (Plate 2). These hybrids can be best utilized commercially in water limited conditions.

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