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Exploration of heterosis for yield and morpho physiological traits in hybrid rice (*Oryza sativa* L.) : A comparative study under flooded and aerobic conditions

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Abstract

The global water crisis threatens the sustainability of irrigated rice production in all the rice producing countries. Development of rice hybrids with high yield potential for aerobic conditions would be one of the exciting research to overcome the existing water crisis. Present investigation was carried out to identify the best combining parents and hybrids suitable for aerobic cultivation based on their physiological and yield contributing traits. One hundred and twenty hybrids along with four lines, 30 testers and two check hybrids *viz.*, ADTRH 1 and CORH 2, were raised in randomized block design in three replications under aerobic and flooded conditions. Data were recorded at vegetative (55-60 days), panicle initiation (75-80 days), flowering and maturity stage for physiological and quantitative traits for all the parents and hybrids included in the study. The hybrid COMS 14A x IR55838-B2-2-3-2-3 and COMS 14A x IR 36 showed superiority for number of productive tillers, panicle length, number of filled grains, spikelet fertility, total dry matter production and harvest index; the hybrid IR 68888 A x IR 72875-94-3-3-2 for number of productive tillers, spikelet fertility, relative water content, root dry weight, harvest index, root shoot ratio and IR 68897 A x IR 36 for number of productive tillers, panicle length, spikelet fertility, total dry matter production and harvest index. These four hybrids can be best utilized commercially for both flooded and water limited conditions. The parental lines involved in the above hybrids also had high per se performance for grain yield under aerobic condition. In general, higher yield was obtained in most of the hybrids under flooded condition. A few hybrids had equal performance under both conditions. The female parents IR 68888A and COMS 14A and the male parents IR55838-B2-2-3-2-3, IR 36, WGL 14 and WGL 32100 best suited for irrigated conditions also had good performance for most of the yield contributing traits and physiological parameters under aerobic condition. The hybrids developed from these parental lines were found superior for most of the yield and physiological traits under aerobic condition. Therefore these parental lines could serve as basic materials for developing high yielding hybrids suitable for water limited conditions.

Key words: CGMS system, heterosis, physiological and yield traits, aerobic condition

Introduction

The present food security depends largely on the irrigated rice production system and more than 75% of the rice supply comes from 79 million hectares of the irrigated land [1] which are predominantly found in Asia. More irrigated land is devoted to rice than to any other crop. But the global water crisis threatens the sustainability of irrigated rice production because water is becoming increasingly scarce. This increase in water scarcity now made the researchers to look for various ways of how to decrease the water use in rice production and increase the water use efficiency. Among the various water saving technologies available, aerobic rice technology is one of the best way to increase the food production. Using this technology, farmers can actually reduce the irrigation water requirement upto 50 % and can obtain yields of 4.5 to 6.5 t/ha. This new concept of "Aerobic Rice" combines the characteristics of both upland and high yielding lowland varieties with less water requirement and high response to inputs.

Significant yield advantage gained through the adoption and spread of hybrid rice technology had helped China to add about 350 million tonnes of extra rice to its food basket during 1976-1998 and enabled it to divert some of their rice areas to other commercial crops [2]. Hybrid rice technology had also shown increased yield, farmer profitability and better adaptability to stress environments such as water scarce

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and aerobic conditions. Development of rice hybrids with high yield potential for aerobic conditions would be one of the exciting research to be carried out to overcome the existing water crisis in India. Therefore, the present investigation was carried out to identify best combining parents and hybrids suitable for aerobic cultivation.

Materials and methods

Four cytoplasmic genic male sterile (CGMS) lines and 30 promising genotypes with desirable grain type and aerobic rice cultures were used for the study. The released rice hybrids ADTRH 1 and CORH 2 were used as standard checks. The seed materials *viz.,* aerobic rice cultures and quality lines were obtained from IRRI, Philippines and Paddy Breeding Station, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore.

The hybridization block, with four CGMS lines and 30 testers was raised to get sufficient hybrid seeds for evaluation under aerobic and flooded condition. Crossing was done by adopting clipping method. In the CGMS lines individual plants with complete pollen sterility was identified by observing the pollen grains under the microscope using one per cent Iodine potassium iodide stain. The spikelets were clipped off one third from the top without damaging the stigma, between 7.00 and 8.30 a.m. Immediately after clipping, the panicles were covered with butter paper covers. At the time of anthesis, panicles with fully opened spikelets were collected from the male parents and the pollen grains were dusted over the clipped panicles between 10.30 and 11.30 am. Crosses were effected between female and male parents in Line x Tester fashion and a total of 120 cross combinations were obtained. After 25 days, the matured panicles were harvested. The crossed seeds were dried and threshed separately by hand and kept in brown paper bags and properly stored for sowing in the next season.

Evaluation of F_1 hybrids and parents for yield traits under aerobic and flooded condition

One hundred and twenty hybrids along with four CGMS lines, 30 testers and two check hybrids *viz.*, ADTRH 1 and CORH 2, were raised in randomized block design with three replications under aerobic and flooded conditions. For each genotype single seedling per hill was planted at 20 x 20 cm spacing in three rows of 1.8m length consisting of thirty plants. Recommended fertilizer dose and cultural practices were adopted.

The hybrids along with their parents were sown in raised beds and 25 day old seedlings were transplanted in main field under puddled condition. Initially the aerobic and the control plots were maintained under irrigated condition upto 55 days. From 56th 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 the control plot was maintained under normal flooded condition till maturity [3]. The rainfall received during the entire crop period was also recorded.

The investigation was carried out under two situations *viz.,* aerobic and flooded condition simultaneously, using the line x tester mating design in three replications and studied for different biometrical and physiological traits *viz*., days to 50 per cent flowering, plant height, number of productive tillers per plant, panicle length, pollen fertility, number of spikelets per panicle, number of filled grains per panicle, spikelet fertility per cent, 100-grain weight, grain yield per plant, harvest index, chlorophyll content (using SPAD chlorophyll meter at flowering), relative water content at flowering, dry matter production, shoot dry weight, root dry weight, root: shoot ratio and root length.

The mean values of parents and hybrids pertaining to different biometrical traits and physiological traits were recorded. The percentage of heterosis over mid parent (relative heterosis), better parent (heterobeltiosis) and standard checks (standard heterosis) were estimated for all the hybrids for ten biometrical traits and seven physiological traits.

Results and discussion

Information on physiological 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. Here, the first five ranking hybrids for various quantitative and physiological characters with reference to *per se* performance, and standard heterosis are presented in Table 1.

A total of 51 hybrids under flooded and 67 hybrids under aerobic condition showed earliness for flowering. The hybrids with low *per se* performance for flowering is considered as a desirable trait. The days to 50 per cent flowering was similar in the hybrid combinations, IR 68886A x IR 36, IR 68886A x IR 71700-247-1-1-2, IR 68886A x PSBRC 80, IR 68897A x 77298-5-6, COMS14A x IR 71700-247-1-1-2 and COMS14A x 77298-12-7 under flooded and aerobic conditions.

In the present study, a total of 18 hybrids under flooded and 33 hybrids under aerobic condition showed earliness over the early check hybrid ADTRH1. It was observed that the hybrids which flowered earlier in the aerobic conditions showed delayed flowering under flooded condition. Based on *per se* performance *sca* effects and standard heterosis, two hybrids *viz.,* IR 68886A x IR 69715-72-1-3 and IR 68886A x IR 59624-34-2-2 were found to be superior under aerobic conditions for earliness. Exhibition of earliness under water stress conditions is a drought evading mechanism and such hybrids fits well for aerobic conditions.

Hybrids with semi-dwarf plant type is preferable and highly productive [4]. A total of 44 hybrids in flooded condition and 38 hybrids under aerobic condition recorded significantly shorter plant height. The hybrids IR 68888A x PR114 and IR 68886A x IR 71700-247-1-1-2 were the shortest under flooded and aerobic conditions respectively. In general, moisture stress results in reduced plant height under aerobic condition [5, 6].

Short stature of the plant confers resistance to lodging. Seventeen hybrids had significant negative standard heterosis under flooded and one hybrid (IR 68886A x IR 71700-247-1-1-2) under aerobic condition over the hybrid check ADTRH 1. Based on *per se* performance, *sca* effects and standard heterosis the hybrid IR 68886A x IR 71700-247-1-1-2, IR 68888A x PR 114 and IR 68888A x PSBRC 80 were found to have desirable plant height suitable for aerobic cultivation.

Number of productive tillers per plant is generally associated with higher productivity [7]. Twenty nine hybrids under flooded condition and 30 hybrids under aerobic condition had high per se performance for this trait. Among the 30 hybrids, five hybrids were found to have more number of productive tillers under aerobic condition (Table 1).

The magnitude of heterosis for number of productive tillers was found to be higher in 60 hybrids under flooded condition and 64 hybrids under aerobic condition over the hybrid check ADTRH1 while 11 hybrids under flooded and one hybrid under aerobic condition showed significant positive heterosis over the hybrid check CORH 2. Most of the hybrids except IR 68886A x PSBRC 80 under aerobic condition showed non significant positive heterosis over CORH2. Similar reports have already been published [8].

In general, number 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 in plants, which are exposed to aerobic condition at vegetative stage than the plants under flooding.

Panicle length is one of the yield contributing trait which is highly associated with number of spikelets per panicle and finally the yield [7]. There was a general reduction in panicle length under aerobic condition. A total of 44 hybrids in flooded and 46 hybrids under aerobic condition registered significantly higher panicle length (Table 1).

Heterosis for panicle length over the check hybrids was noticed in 60 hybrids under flooded and 46 hybrids under aerobic condition. Thirty hybrids in flooded and 22 hybrids under aerobic condition had significant positive heterosis over CORH 2. Significantly positive heterosis for panicle length was already reported [7].

The number of spikelets determines the proportion of spikelets, which produce grains [10]. In the present investigation more number of spikelets were produced in flooded condition. The mean performance of hybrids for number of spikelets per panicle was found to be superior in 74 hybrids in flooded and 58 hybrids in aerobic condition. Among the 58 hybrids, the 5 best hybrids which had superior performance for number of spikelets per panicle has been given in Table 1.

The extent of heterosis for this trait revealed superiority for 52 hybrids in flooded situation and 57 hybrids in aerobic condition over the check ADTRH 1 and 15 hybrids under flooded and five hybrids under aerobic condition over the check CORH2. Table 1 shows the first five ranking hybrids showing superior performance for number of spikelets per panicle. Based on *per se* performance, *sca* effects and heterosis, the hybrid IR 68888A x IR 555838-B2-2-3-2-3 was found superior under both flooded and aerobic conditions.

The number of filled grains determines the spikelet fertility which reflects on higher grain yield [4]. Sixty one hybrids in flooded and 60 hybrids in aerobic condition showed superior mean performance. Among them, a few hybrids were adjudged as best hybrids for aerobic conditions (Table 1).

Forty six hybrids under flooded and 57 hybrids under aerobic condition had significant positive heterosis

Table 1. Hybrids with desirable *per se* performance and standard heterosis for different traits in aerobic condition

S.No.	Character	*Per se* performance	Standard heterosis over ADTRH 1	Standard heterosis over CORH 2
1.	Days to 50 % flowering	IR 68886A x IR69715-72-1-3 IR 68886A x IR 62161-184-3 IR 68897A x IR 59624 –34-2-2 COMS14A x IR 62161-184-3-1-3-2 IR 68886 A x IR 59624 –34-2-2	COMS 14 A x WCR 6 IR 68886 A x WCR 6 IR 68886A x IR69715-72-1-3 IR 68897 A x WCR 6 IR 68886 A x IR 62030-54-1-2	IR 68886 A x WCR 6 COMS 14 A x WCR 6 IR 68886A x IR69715-72-1-3 IR 68897 A x WCR 6 IR 68886 A x IR 59624 –34-2-2
2.	Plant height	IR 68886 A x IR 71700-247-1-1-2 IR 68888A x PR 114 IR 68888A x PSBRC 80 COMS 14 A x IR 77298-12-7 IR 68888 A x MTU 7029	IR 68886 A x IR 71700-247-1-1-2	-
3.	No. of productive tillers per plant	IR 68886A x PSBRC 80 IR 68886 Ax IR 72875-94-3-3-2 IR 68886 Ax WGL 32100 IR 68886 Ax IR 71604-4-1-10-2 IR 68897A x IR 72875-94-3-3-2	IR 68886 A x WCR 6 COMS 14 A x IR 77298-12-7 IR 68897 A x IR 72862-27-3-2-3 IR 68886 A xIR60979-150-3-3-3-2 IR 68897 A x IR 77298-5-6	IR 68886 A x WCR 6 COMS 14 A x IR 77298-12-7 IR 68897 A x IR 72862-27-3-2-3 IR 68886 A xIR60979-150-3-3-3-2 IR 68897 A x IR 77298-5-6
4.	Panicle length	IR 68886 A x WGL 14 IR 68886 A x WGL 32100 IR 68886 Ax IR 71604-4-1-10-2 IR 68886 A x IR 77298-5-6 IR 68886 A x MTU 9992	IR 68886 A x WGL 14 IR 68886 A x WGL 32100 IR 68886 Ax IR 71604-4-1-10-2 IR 68886 A x IR 77298-5-6 IR 68886 A x MTU 9992	IR 68886 A x WGL 14 IR 68886 A x WGL 32100 IR 68886 Ax IR 71604-4-1-10-2 IR 68886 A x IR 77298-5-6 IR 68886 A x MTU 9992
5.	No. of spikelets/ panicle	IR 68888 Ax IR55838-B2-3-2-3 IR 68886 A x WGL 14 IR 68888 A x IR 59624 –34-2-2 COMS 14 A x WGL 14 IR 68886 A x WGL 14	IR 68888 Ax IR55838-B2-3-2-3 IR 68888 A x WGL 14 IR 68886 A x IR 59624 –34-2-2 COMS 14 A x WGL 14 IR 68886 A x WGL 14	IR 68888 Ax IR55838-B2-3-2-3 IR 68888 A x WGL 14 IR 68886 A x IR 59624 –34-2-2 COMS 14 A x WGL 14 IR 68888 A x WGL 14
6.	No. of filled grains/panicle	IR 68888 A x IR55838-B2-2-3-2-3 IR 68888 A x IR 59624 –34-2-2 IR 68886 A x WGL 14 COMS 14 A x WGL 32100 COMS 14 A x WGL 14	IR 68888 A x IR55838-B2-2-3-2-3 IR 68886 A x IR 59624 –34-2-2 IR 68886 A x WGL 14 COMS 14 A x WGL 32100 COMS 14 A x WGL 14	IR 68888 A x IR55838-B2-2-3-2-3 IR 68886 A x IR 59624 –34-2-2 IR 68886 A x WGL 14 COMS 14 A x WGL 32100 COMS 14 A x WGL 14
7.	Spikelet fertility	COMS14A x IR 62161-184-3-1-3-2 IR 68888 A x WGL 32100 IR 68888 A x IR 72875-94-3-3-2 IR 68897 A x IR55838-B2-2-3-2-3 IR 68888 A x MTU 9992	COMS14A x IR 62161-184-3-1-3-2 IR 68888 A x WGL 32100 IR 68888 A x IR 72875-94-3-3-2 IR 68888 A x IR55838-B2-2-3-2-3 IR 68888 A x MTU 9992	COMS14A x IR 62161-184-3-1-3-2 IR 68888 A x WGL 32100 IR 68888 A x IR 72875-94-3-3-2 IR 68888 A x IR55838-B2-2-3-2-3 IR 68888 A x MTU 9992
8.	Hundred grain weight	COMS14A x WGL 32100 IR 68888A x MTU 7029 COMS14A x MTU 7029 COMS14A x IR 71604-4-1-10-2 COMS14A x IR 59624 –34-2-2	COMS14A x WGL 32100 IR 68888A x MTU 7029 COMS14A x MTU 7029 COMS14A x IR 71604-4-1-10-2 COMS14A x IR 59624 –34-2-2	COMS14A x WGL 32100 IR 68888A x MTU 7029 COMS14A x MTU 7029 COMS14A x IR 71604-4-1-10-2 COMS14A x IR 59624 –34-2-2
9.	SPAD at flowering	IR 68888 A x WCR 6 IR 68888 Ax IR 72862-27-3-2-3 IR 68888AxIR 71700-247-1-1-2 IR 68888 A x IR 77298-12-7 IR 68888 A x IR 77298-5-6	IR 68888 A x WCR 6 IR 68888AxIR 71700-247-1-1-2 IR 68888 A x IR 72862-27-3-2-3 IR 68888 A x IR 77298-12-7 IR 68888 A x IR 77298-5-6	IR 68888 A x IR 72862-27-3-2-3 IR 68888AxIR 71700-247-1-1-2 IR 68888 A x IR 77298-12-7 IR 68888 A x IR 77298-5-6 IR 68888 A x IR 72875-94-3-3-2
10.	Relative water content at flowering	IR 68897 A x WGL 14 IR 68886 Ax IR 71604-4-1-10-2 IR 68886 A x IR 59624 –34-2-2 IR 68897A x IR69715-72-1-3 IR 68888 A x IR 72875-94-3-3-2	IR 68897 A x WGL 14 IR 68886 Ax IR 71604-4-1-10-2 IR 68888 A x IR 59624 –34-2-2 IR 68888 A x IR 72875-94-3-3-2 IR 68897A x IR69715-72-1-3	IR 68897 A x WGL 14 IR 68886 Ax IR 71604-4-1-10-2 IR 68888 A x IR 59624 –34-2-2 IR 68888 A x IR 72875-94-3-3-2 IR 68897A x IR69715-72-1-3

Table 1. *(Contd ....)*

11.	Root length	IR 68888A x IR69715-72-1-3 IR 68886 A x PSBRC 80 COMS 14 A x PSBRC 80 IR 68886A x IR69715-72-1-3 IR 68888 A x MTU 5293	IR 68888A x IR69715-72-1-3 IR 68886 A x PSBRC 80 COMS 14 A x PSBRC 80 IR 68886A x IR69715-72-1-3 IR 68888 A x MTU 5293	IR 68888A x IR69715-72-1-3 IR 68886 A x PSBRC 80 COMS 14 A x PSBRC 80 IR 68886A x IR69715-72-1-3 IR 68888 A x MTU 5293
12.	Shoot dry weight	IR 68886A x IR 72862-27-3-2-3 COMS14 A x PSBRC 80 COMS14 A x MTU 5293 IR 68886 A x WGL 14 IR 68886 A x IR 72875-94-3-3-2	IR 68886A x IR 72862-27-3-2-3 COMS14 A x PSBRC 80 COMS14 A x MTU 5293 IR 68886 A x WGL 14 IR 68886 A x IR 72875-94-3-3-2	IR 68886A x IR 72862-27-3-2-3 COMS14 A x PSBRC 80 COMS14 A x MTU 5293 IR 68886 A x WGL 14 IR 68886 A x IR 72875-94-3-3-2
13.	Root dry weight	IR 68897AxIR 60979-150-3-3-2 IR 68897 A x IR55838-B2-3-3 IR 68897 A x PSBRC 82 IR 68897 Ax IR 71604-4-1-10-2 IR 68888 A x IR 72875-94-3-3-2	IR 68897AxIR 60979-150-3-3-2 IR 68897 A x IR55838-B2-2-3-3 IR 68897 A x PSBRC 82 IR 68897 Ax IR 71604-4-1-10-2 IR 68888 A x IR 72875-94-3-3-2	IR 68897AxIR 60979-150-3-3-2 IR 68897 A x IR55838-B2-2-3-3 IR 68897 A x PSBRC 82 IR 68897 Ax IR 71604-4-1-10-2 IR 68888 A x IR 72875-94-3-3-2
14.	Root shoot ratio	IR 68897A x IR 60979-150-3-2 IR 68897 A x IR55838-B2-2-3-2-3 IR 68897 Ax IR 71604-4-1-10-2 IR 68886 Ax IR 60979-150-3-2 IR 68897A x IR 72875-94-3-3-2	IR 68897A x IR 60979-150-3-2 IR 68897 A x IR55838-B2-2-3-2-3 IR 68897 Ax IR 71604-4-1-10-2 IR 68886 Ax IR 60979-150-3-2 IR 68897A x IR 72875-94-3-3-2	IR 68897A x IR 60979-150-3-2
15.	Total dry matter production	COMS 14 A x MTU 5293 COMS 14 A x PSBRC 80 IR 68886 A x WGL 14 IR 68886A x IR 72862-27-3-2-3 IR 68886 A x IR 72875-94-3-3-2	IR 68886 A x IR 72875-94-3-3-2 IR 68886 A x IR 72862-27-3-2-3 IR 68886 A x WGL 14 COMS 14 A x PSBRC 80 COMS 14 A x MTU 5293	IR 68886 A x IR 72875-94-3-3-2 IR 68886 A x IR 72862-27-3-2-3 IR 68886 A x WGL 14 COMS 14 A x PSBRC 80 COMS 14 A x MTU 5293
16.	Grain yield/plant	COMS14A x IR55838-B2-2-3-2-3 COMS14A x IR 36 IR 68897 A x IR 36 IR 68888 A x IR 72875-94-3-3-2 IR 68897 A x PSBRC 82 COMS14A x IR 72875-94-3-3-2 IR 68897 A x IR 59624 –34-2-2 IR 68897 A x PSBRC 80 IR 68886 A x IR 72875-94-3-3-2 COMS14A x PSBRC 82	COMS14A x IR55838-B2-2-3-2-3 COMS14A x IR 36 IR 68897 A x IR 36 IR 68888 A x IR 72875-94-3-3-2 IR 68897 A x PSBRC 82 COMS 14 A x PSBRC 82 COMS14A x IR 72875-94-3-3-2 IR 68897 A x IR 59624 –34-2-2 IR 68897 A x PSBRC 80 COMS 14 A x MTU 7029	COMS14A x IR55838-B2-2-3-2-3 COMS14A x IR 36 IR 68897 A x IR 36 IR 68888 A x IR 72875-94-3-3-2 IR 68897 A x PSBRC 82 COMS 14 A x PSBRC 82 COMS14A x IR 72875-94-3-3-2 IR 68897 A x IR 59624 –34-2-2 IR 68897 A x PSBRC 80 COMS 14 A x MTU 7029
17.	Harvest index	COMS14A x IR55838-B2-2-3-2-3 COMS14A x IR 36 IR 68897 A x IR 36 IR 68897 A x IR 71604-4-1-10-2 IR 68897 A x IR 62030-54-1-2	COMS14A x IR 36 COMS14A x IR55838-B2-2-3-2-3 IR 68897 A x IR 71604-4-1-10-2 IR 68897 A x IR 36 IR 68897 A x PSBRC 80	COMS14A x IR 36 COMS14A x IR55838-B2-2-3-2-3 IR 68897 A x IR 71604-4-1-10-2 IR 68897 A x IR 36 IR 68897 A x PSBRC 80

over the check ADTRH I while 16 hybrids in flooded and 14 hybrids under aerobic condition had significant positive heterosis over CORH 2. Similar results with positive heterosis was already reported [4, 11]. Based on the mean, *sca* effects and heterosis, two hybrids IR 68888 A x IR 55838-B2-2-3-2-3 and IR 68888A x IR 59624-34-2-2 were found superior for more number of filled grains under aerobic conditions.

Spikelet fertility is one of the important yield contributing characters that is mainly considered for yield improvement in rice hybrids. A total of 65 hybrids under flooded condition and 68 hybrids under aerobic condition recorded higher *per se* performance for spikelet fertility. Among the 68 hybrids, 5 hybrids were found to have superior performance for spikelet fertility (Table 1). Thirteen hybrid combinations showed equal performance for spikelet fertility under both conditions indicating their ability to withstand water limited situations. The superior performance of these hybrids can be attributed due to the presence of aerobic rice cultivars like IR 71604-4-1-4-7-10-2-1-3, IR 72862-27-3-2-3, IR 71700-247-1-1-2, IR 72875-94-3-3-2 and PSBRC 82 as one of the parents.

Table 2. Best parents identified based on *per se* performance in aerobic condition

S.No.	Character	*Per se* performance
1.	Days to 50 % flowering	IR 68888[A], IR 68886[A], COMS14 A IR 59624–34-2-2, IR 36 IR 62030-54-1-2-2, IR 62161-184-3-1-3-2 IR 69715-72-1-3, IR 71604-4-1-10-2-1-3 IR 72862-27-3-3, IR 72875-94-3-3-2 IR 77298-5-6, IR 77298-12-7, PSBRC 80, WCR 6
2.	Plant height	IR 68888[A], IR 68886A IR 36, IR60979-150-3-3-3-2 IR 62030-54-1-2-2, IR69715-72-1-3 IR 71604-4-1-4-7-10-2, IR 72862-27-3-2-3 MTU 7029, MTU 9992, PSBRC 80, PR 114
3.	Number of productive tillers per plant	COMS 14A, IR 68897A IR55838-B2-2-3-2-3, IR 59624–34-2-2 IIR 72875-94-3-3-2, MTU 5293, MTU 7029, MTU 9992, PSBRC 80, PSBRC 82, WGL 14, WGL 32100
4.	Panicle length	IR 68888A, COMS14 A IR 36, IR55838-B2-2-3-2-3, IR 59624–34-2-2 IR60979-150-3-3-3-2, IR 69715-72-1-3 IR 71700-247-1-1-2, IR 71604-4-1-10-2-1-3 IR 72862-27-3-3, IR 72875-94-3-3-2, IR 77298-5-6, MTU 9992, PSBRC 82, WGL 14, WGL 32100
5.	Number of spikelets per panicle	IR 68888A, IR 68897A IR 59624–34-2-2, IR55838-B2-2-3-2-3, PR 114, WGL 14 IR 62161-184-3-1-3-2, IR 71604-4-1-10-2-1-3, IR 72875-94-3-3-2, MTU 7029, PSBRC 80, PSBRC 82
6.	Number of filled grains per panicle	IR 68888A, COMS 14A IR55838-B2-2-3-2-3, IR 59624–34-2-2, IR 62161-184-3-1-3-2 IR 71604-4-1-4-7-10-2, IR 72862-27-3-2-3, IR 72875-94-3-3-2 MTU 7029, PSBRC 82, PR 114, WGL 14
7.	Spikelet fertility	COMS 14A, IR 68886A IR 36, IR55838-B2-2-3-2-3, IR 59624–34-2-2, WGL 14 IR60979-150-3-3-3-2, IR 62030-54-1-2, IR69715-72-1-3 IR 72862-27-3-2-3, MTU 5293, MTU 7029, MTU 9992
8.	Hundred grain weight	IR 68886[a], COMS14 A IR55838-B2-2-3-2-3, IR 59624–34-2-2, IR60979-150-3-3-3-2 IR 62030-54-1-2, IR 69715-72-1-3, IR 71700-247-1-1-2 IR 71604-4-1-10-2-1-3, IR 72862-27-3-3, IR 77298-5-6 MTU 7029, WGL 14, WGL 32100
9.	Grain yield per plant	COMS 14A, IR 68888A, IR 68886A IR 36, IR 59624–34-2-2, IR55838-B2-2-3-2-3, IR 77298-5-6 IR 71604-4-1-10-2-1-3, IR 72862-27-3-2-3, IR 72875-94-3-3-2 IR 77298-12-7, MTU 9992, PSBRC 82, WGL 14, WGL 32100
10.	Harvest index	IR 68888A, COMS 14A, IR 68886 A IR 36, IR55838-B2-2-3-2-3, IR 59624–34-2-2, WGL 32100 IR 71700-247-1-1-2, IR 72862-27-3-2-3, IR 72875-94-3-3-2 IR 77298-5-6, IR 77298-12-7, MTU 9992, WGL 14, PSBRC 80, PSBRC 82
11.	SPAD chlorophyll meter reading	COMS 14A IR 36, IR55838-B2-2-3-2-3, IR 59624–34-2-2, IR 77298-5-6 IR 62161-184-3-1-3-2, IR 62030-54-1-2-2, IR 72875-94-3-3-2 MTU 7029.PSBRC 82, WGL 14, PR 114

Table 2. *(Contd ....)*

12.	Relative water content at flowering	COMS14 A IR 36, IR55838-B2-2-3-2-3, IR 69715-72-1-3 IR 71700-247-1-1-2, IR 71604-4-1-10-2-1-3, WGL 32100 IR 72862-27-3-3, IR 72875-94-3-3-2, PSBRC 82, WGL 14 IR 77298-5-6, MTU 5293, PSBRC 80
13.	Total dry matter production	IR 68888A, IR 68897A IR 36, IR55838-B2-2-3-2-3, IR60979-150-3-3-3-2 IR69715-72-1-3, IR 71700-247-1-1-2 IR 72875-94-3-3-2 MTU 7029, MTU 9992 WGL 14, PSBRC 80, WGL 14, WGL 32100
14	Shoot dry weight	IR 68888A, IR 68897A, COMS 14A IR60979-150-3-3-3-2, IR 72875-94-3-3-2 IR 71700-247-1-1-2, IR 71604-4-1-4-7-10-2-1-3, PSBRC 80 MTU 7029,MTU 9992, IR 36,WGL 14, WGL 32100
15.	Root shoot ratio	IR 68888A, IR 68886A IR69715-72-1-3, IR 62161-184-3-1-3-2, IR 72862-27-3-3 IR 71700-247-1-1-2, IR 72875-94-3-3-2, IR 77298-12-7 PSBRC 80, PSBRC 82, PR 114
16.	Root dry weight	IR 68888A, IR 68886A IR 69715-72-1-3, IR 71700-247-1-1-2, IR 72875-94-3-3-2 IR 77298-12-7, MTU 5293,WGL 14, PSBRC 80,PR114
17.	Root length	IR 68886A, IR 68888A IR 59624–34-2-2, IR60979-150-3-3-3-2, IR69715-72-1-3, IR 71700-247-1-1-2, IR 71604-4-1-10-2-1-3 IR 72862-27-3-3, IR 77298-5-6, IR 36 MTU 9992, WGL 14, WGL 32100

The extent of heterosis was found to be high in 29 hybrids under aerobic condition over the check CORH2 and positive but non significant heterosis was observed in the hybrids under flooded condition (Table 1). Hybrids with high standard heterosis was reported for spikelet facility[7].

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 that in the 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 [12].

Grain weight is one of the important traits that decides the final grain yield. Forty six hybrids under flooded condition and 43 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 hybrid combinations *viz.,* COMS14A x WGL 32100, IR 6888A x MTU 7029, COMS14A x MTU 7029, COMS14A x IR 71604-4-1-4-7-10-2-3 and COMS14A x IR 59624-34-2-2 were identified as the superior combinations 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 [13]. Water stress at booting, and heading to flowering stages also effects number of productive tillers, grain number per plant and 1000 grain weight.

With respect to heterosis, desirable negative significance was recorded by 20 hybrids in flooded condition and 40 hybrids under aerobic condition over ADTRH1 while 79 hybrids under flooded and 69 hybrids under aerobic condition had negative significance for grain weight over CORH2. The hybrids which showed low *per se* performance also showed negative heterosis for this trait.

Chlorophyll meter reading which determines the leaf greenness, is an indirect method of determining the N content and chlorophyll content of the leaf [14]. Based on the *per se* performance, 48 hybrids under flooded and 31 hybrids under aerobic condition were found superior. In general, all the hybrids under aerobic condition showed slight reduction in chlorophyll content when compared to flooded condition. The reduction in SPAD values was observed due to water stress in rice [15].

The extent of heterosis was found highly positive and significant in six hybrids under flooded condition and five hybrids in aerobic condition over the check hybrid ADTRH1 while six hybrids under flooded and nine hybrids in aerobic condition registered positive significance over CORH2. The hybrids which had superior performance with respect to heterosis also had higher *per se* performance. Based on *per se* performance, *sca* effects and heterosis, two hybrids viz., IR 68888A x IR 72862-27-3-2-3 and IR 68888A x IR 71700-247-1-1-2 were found suitable for aerobic condition.

Relative water content is one of the most important trait which determines the leaf water status of a genotype under water stress conditions [16]. Relative water content is associated with the yielding ability of plants under aerobic condition [17]. In the present study, 56 hybrids under flooded and 51 hybrids under aerobic condition had high *per se* performance for RWC. Twenty two hybrids had lower RWC under aerobic condition and the reduction was more pronounced in the hybrid combination IR 68897A x IR 60979-150-3-3-3-2 (57.55 per cent). This may be due to marked changes in plant metabolic process with the cessation of photosynthesis and much increased respiration was observed under reduced RWC [18].

High standard heterosis was found in 61 hybrids under flooded and 40 hybrids under aerobic condition over the check hybrid ADTRH 1 while 44 hybrids each under both flooded and aerobic conditions over the check CORH 2. The same hybrids which showed superior performance for relative water content also showed higher standard heterosis. The results are in accordance with the findings of Yogameenakshi *et al.* [19]. The overall performance revealed that the hybrids IR 68886A x IR 71604-4-1-4-7-10-2-1-3 and IR 68886A x IR 59624-34-2-2 were highly suitable for aerobic condition.

Root characteristics in rice are genetically controlled but they are also strongly affected by soil conditions and crop management practices [20]. Deep root system ensures greater extraction of water held deep in the soil profile which in turn maintains leaf water potential during drought periods [21]. In the present study, 46 hybrids each under flooded and aerobic condition displayed higher root length. Generally, the root length was more in the hybrids under aerobic condition. Genotypes with higher root length tend to have high leaf water potential and delayed leaf death by maintaining favourable plant water status resulting in higher grain yield under water limited conditions. The hybrids with higher root length performed better than others under aerobic conditions [22].

Under drought conditions, the most effective defense mechanism available to rice plant is the good root system, consisting of deep and mostly thick roots that enables the plants to avoid the adverse effects of internal water deficit [23]. High *per se* performance for root dry weight was observed in 54 hybrids under flooded and 58 hybrids under aerobic condition. The root dry weight under aerobic condition was found higher than under flooded condition, irrespective of the hybrid combinations. Superior hybrids for root dry weight includes IR 68897A x IR 60979-150-3-3-3-2, IR 68897A x IR 55838-B2-2-3-2-3, IR 68897A x PSBRC 82, IR 68897A x IR 71604-4-1-4-7-10-2-1-3 and IR 68888A x IR 72875-94-3-3-2 which also had higher standard heterosis over the check hybrids ADTRH 1 and CORH 2.

Total dry matter production is an important parameter which indicates the photosynthetic efficiency of plants. The maintenance of higher biomass or dry matter during water limited situation can be viewed as one of the criteria to decide drought tolerance. The yield advantage in hybrid rice genotypes is mainly because of dry matter increase rather than harvest index [24]. The present investigation showed that 66 hybrids under flooded and 70 hybrids under aerobic condition had higher biomass. In general, there was obvious reduction of dry matter in aerobic condition when compared to flooded condition.

However, two hybrids *viz.,* COMS14A x IR 77298-12-7 and COMS14A x IR 72862-27-3-2-3 had dry matter on par with flooded condition. Among the 70 hybrids that performed well under aerobic condition, the hybrids COMS14A x MTU 5293, COMS 14A x PSBRC 80, IR 68886A x WGL 14, IR 68886A x IR 72862-27-3-2-3 and IR 68886A x IR 72875-94-3-3-2 had superior performance for total dry matter. It may be due to the involvement of superior parental lines which also had higher *per se* performance for harvest index under water limited conditions.

COMS 14A x IR 55838-B2-2-3-2-3

IR 68888A x IR 72875-94-3-3-2

IR 68897A x IR 59624-34-2-2

IR 68897A x IR 36

Fig. 1. High yielding hybrids under aerobic condition

High heterosis for dry matter was observed in 82 hybrids under flooded condition and 76 hybrids in aerobic condition over the check ADTRH1 while 48 hybrids in flooded and 34 hybrids under aerobic condition over CORH2. The hybrids which had superior *per se* performance also had higher standard heterosis under aerobic condition. Based on the high *per se* performance, and heterosis, three hybrids *viz.,* IR 68886A x IR 72862-27-3-2-3, COMS14A x PSBRC 80 and IR 68886A x WGL 14 were found to be highly suitable for aerobic condition with respect to total dry matter production

Harvest index, the partitioning efficiency of plants to divert the biomass towards the developing reproductive parts, was found to be high in flooded condition than under aerobic condition. Based on *per se* performance 56 hybrids each under flooded and aerobic condition were found to have higher harvest index. In 10 hybrids, the *per se* performance was found to be similar under both conditions. The parents involved in these hybrids include the female parents IR 68886A, IR 68888A, IR 68897A and the male parents IR 59624-34-2-2, WGL 14, IR 72875-94-3-3-2, PR 114, IR 71700-247-1-1-2, MTU 9992 and PSBRC 82. Among the parental lines, IR 72875-94-3-3-2, IR 71700-247-1-1-2 and PSBRC 82 are specially bred for aerobic situations, also had equal performance for harvest index.

Significant positive heterosis for this trait was found in 55 hybrids under flooded and 63 hybrids in aerobic condition over the check ADTRH1 and 27 hybrids in flooded and 47 hybrids in aerobic condition over CORH 2. The hybrids which showed superior *per se* performance for harvest index also showed superior heterosis under aerobic condition indicating their greater tolerance to water stress.

Shoot dry weight is the major component that decides the total biomass of a plant. For shoot dry weight, 22 hybrids under flooded and 15 hybrids under aerobic condition exhibited higher *per se* performance. The hybrids IR 68886A x IR 72862-27-3-2-3, COMS14A x PSBRC 80, COMS14A x MTU 5293, IR 68886A x WGL 14 and IR 68886A x IR 72875-94-3-3-2 had high shoot dry weight under aerobic condition.

Significant positive heterosis for this trait was found in 81 hybrids under flooded and 53 hybrids in

Table 3. Best parents identified for biometrical and physiological traits in aerobic condition

S.No.	Parents	Characters
1.	IR 68886A	Panicle length, number of spikelets per panicle, pikelet fertility, hundred grain weight, root length
2.	IR 68888A	Days to 50% flowering, plant height, number of productive tillers per plant, number of filled grains per panicle, root length, shoot dry weight
3.	COMS 14A	Days to 50% flowering, number of productive tillers, grain yield per plant, harvest index, relative water content, shoot dry weight
4.	IR55838-B2-2-3-2-3	Number of productive tillers, panicle length, number of spikelets per panicle, number of filled grains per panicle, spikelet fertility, hundred grain weight, grain yield per plant, harvest index, relative water content, total dry matter production, root dry weight
5.	WGL 14	Panicle length, number of spikelets per panicle, number of filled grains per panicle, spikelet fertility, hundred grain weight, grain yield per plant, harvest index, relative water content, total dry matter production
6.	IR 72875-94-3-3-2	Number of productive tillers per plant, panicle length, number of spikelets per panicle, number of filled grains per panicle, grain yield per plant, harvest index, total dry matter production, root shoot ratio
7.	MTU 9992	Number of productive tillers, panicle length, shoot dry weight, spikelet fertility, grain yield, harvest index, total dry matter production
8.	IR 59624-34-2-2	Days to 50% flowering, number of filled grains per panicle, spikelet fertility, hundred grain weight, grain yield per plant, harvest index
9.	IR69715-72-1-3	Days to 50% flowering, plant height, spikelet fertility, relative water content, root length, root shoot ratio
10.	WGL 32100	Number of productive tillers per plant, panicle length, hundred grain weight, grain yield per plant, relative water content

aerobic condition over the check ADTRH1 and 52 hybrids in flooded and 47 hybrids in aerobic condition over CORH2. The same hybrids which showed superior *per se* performance for shoot dry weight also showed superior heterosis under aerobic condition indicating their greater tolerance to low moisture stress. The present study revealed that the hybrids IR 68886A x IR 72862-27-3-2-3 and COMS14A x PSBRC 80 are promising under aerobic conditions.

Genotypes with high root to shoot ratio is highly desirable under water limited situations. Under water deficit conditions, presence of deep root system ensures greater extraction of water from deep in the soil profile and therefore maintains high leaf water potential [21] In the present study, constant increase in root- shoot ratio was observed under aerobic condition. It might be an adaptive mechanism of plants to extract water from the deeper layers of soil. This helps in the maintenance of water status in tissues. Thirteen hybrids under flooded and 21 hybrids under aerobic condition exhibited higher *per se* performance for root shoot ratio. Few hybrids exhibited superior performance for root shoot ratio under aerobic condition (Table 1). When compared with flooded condition the root shoot ratio was high in aerobic condition.

Significant positive heterosis for this trait was found in one hybrid under flooded and 44 hybrids in aerobic condition over the check ADTRH1 and two hybrids IR 68897A x IR 71604-4-1-4-7-10-2-1-3 and IR 68897A x IR 60979-150-3-3-3-2 in flooded and one hybrid IR 68897A x IR 71604-4-1-4-7-10-2-3 in aerobic condition over CORH2. From the above results, the hybrid IR 68897A x IR 60979-150-3-3-3-2 was found highly suitable for aerobic condition.

Finally, with reference to grain yield, the economic output of the plant and the total contribution of all yield related traits was found to be high in 62 hybrids under flooded condition and 60 hybrids under aerobic condition. Among them, 30 hybrids under flooded and 15 hybrids under aerobic condition were found to be high yielding, by registering grain yield of more than 50 grams per plant. Among the 15 hybrids which showed superior performance, the hybrid COMS 14A x IR55838-B2-2-3-2-3 out yielded the other hybrid combinations by recording 58.05 grams per plant followed by hybrids COMS 14A x IR 36, IR 68897A x IR 36, IR 68888A x IR 72875-94-3-3-2 and IR 68897 A x PSBRC 82. The parental lines involved in the above hybrids also had high *per se* performance for grain yield under aerobic condition. Among the above five hybrids, four hybrids *viz.,* COMS 14A x IR55838-B2-2-3-2-3, COMS 14A x IR 36, IR 68897A x IR 36 and IR 68888A x IR 72875-94-3-3-2 recorded higher yield under both aerobic and flooded situations. In addition to yield, these hybrids also showed superiority for other characters also. The hybrid COMS 14A x IR55838-B2-2-3-2-3 and COMS 14A x IR 36 showed superiority for number of productive tillers, panicle length, number of filled grains, spikelet fertility, total dry matter production and harvest index; the hybrid IR 68888 A x IR 72875-94-3-3-2 for number of productive tillers, spikelet fertility, relative water content, root dry weight, harvest index, root shoot ratio and IR 68897 A x IR 36 for number of productive tillers, panicle length, spikelet fertility, total dry matter production and harvest index.

With respect to standard heterosis, 67 hybrids under flooded condition and 60 hybrids under aerobic condition showed significant positive heterosis over ADTRH 1 and 56 hybrids in flooded and 58 hybrids under aerobic condition over the check CORH 2. The hybrids COMS14A x IR55838-B2-2-3-2-3, COMS14A x IR 36, IR 68897A x IR 36, IR 68888A x IR 72875-94-3-3-2 and IR 68897A x PSBRC 82 were identified as the best hybrids for grain yield under aerobic condition. Positive heterosis for grain yield in rice has been reported earlier [4, 7, ,25, 26]. These hybrids can be best utilized commercially for both flooded and water limited conditions (Fig. 1).

References

1. **IRRI (International Rice Research Institute).** 1997. Rice Almanac, second edition, IRRI, Los Banos, Philippines.181p.
2. Directorate of Rice Research, Progress Report, 1998-99, Hyderabad, India. Pp: 27-28.
3. **Mishra B.** 2004. Rice Research in India-Major achievements and future thrust. In: Winter school on “Advances in hybrid rice technology”, Eds. Viraktamath, B.C., M. Ilyas Ahmed and B. Mishra, Directorate of Rice Research, Hyderabad.
4. **Yadav L. S., D. M. Maurya, S. P. Giri and S. B. Singh.** 2004. Nature and magnitude of heterosis for growth, yield and yield components in hybrid rice. Oryza, **41**: 1-3.
5. **Russo S.** 2000. Preliminary studies on rice varieties adaptability to aerobic irrigation. Cahiers Options Méditerranéennes, **15**: 35-39.
6. **Adriano S., D.Bartolomeo X. Cristos and M. Andrea.** 2005. Antioxidant defences in olive trees during drought stress: changes in activity of some antioxidant enzymes. Functional Plant Biology, **32**: 45-53.
7. **Bhawana Joshi, H. Singh and M. P. Pandey.** 2004. Study on heterosis and inbreeding depression in rice (*Oryza sativa* L.). Oryza, **41**: 64-67.
8. **Annadurai A.** 2002. Heterosis for physiological traits in hybrid rice. Indian J. Genet., **62**: 331-333.
9. **Nieuwenhuis J., B. A. M. Bouman and A. Castaneda.** 2002. Crop - water responses of aerobically grown rice: preliminary results of pot culture experiments. In: Water- Wise Rice Production. pp. 177-185. Bouman, B.A.M. Hengdijik, H.Hardy, P.S. Bindrabab, ST.P. Toung and J.K. Ladha (eds.). IRRI.
10. **Boonjung H.** 1993. Modelling growth and yield of upland rice under water limiting conditions. Ph.D. Thesis, The University of Queens land.
11. **Sathya A., G. Kandasamy and J. Ramalingam.** 1999a. Heterosis in hybrid rice. Crop Res., **18**: 243-246.
12. **Garrity D. P. and O’Toole J. C.** 1994. Screening rice for drought resistance at the reproductive stage. Field Crops Research, **39**: 99-110.
13. **Surek H. and N. Beser.** 1999. The effect of water stress on grain and total biological yield and harvest index in rice (*Oryza sativa* L.). Cahiers Options Méditerranéennes, **40**: 61-67.
14. **Shaobing Peng, F. V. Garcia, R. C. Laza and K. G. Cassman.** 1993. Adjustments for specific leaf weight improves chlorophyll meter’s estimate of rice leaf. Nitrogen Concentration. Agron. J.**, 85**: 987-990.
15. **Maibangsa S.** 1998. Morpho-physiological, biochemical and molecular mechanisms of water stress tolerance in rice (*Oryza sativa* L.). Ph.D. Thesis, submitted to TamilNadu Agricultural University, Coimbatore, India.
16. **Blum A.** 2002. Drought tolerance – is it a complex trait. In: Field Screening for drought tolerance in crop plants with emphasis of rice. (Ed.). N.P. Saxeena and J.O’Toole pp. 17-22. ICRISAT, Patancheru, India.
17. **Lafitte R.** 2002. Relationship between leaf relative water content during reproductive stage water deficit and grain formation in rice. Field Crop Res., **76**: 165-174.
18. **Lawlor D. W.** 1995. The effects of water dificit on photosynthesis. *In*: Environment and Plant Metabolism : Flexibility and accumulation, Smirnoff N. (ed.), Bios Scientific Publishers Ltd., U.K. pp. 129-160.

19. **Yogameenakshi P., N. Nadarajan and A. Sheeba.** 2003. Evaluation of varieties and land races for drought tolerance in rice. Indian J. Genet., **63**: 299-303.

20. **Hasegawa S., M.Thangaraj and J. C. O'Toole.** 1984. Root Behaviour: Field and Laboratory studies for rice and non rice crops. International workshop on Physical Aspects of Soil Management In: Rice-Based Cropping Systems (PASMIRCS). International Rice Research Institute, Philippines.

21. **Fukai S. and M. Cooper.** 1995. Development of drought resistance cultivars using physio morphological traits in rice. Field Crop Res., **40**: 67-86.

22. **Mambani B. and Lal R.** 1983. Response of upland rice varieties fo stress 1. Relation between root system development and plant water potential. Plant Soil, **73**: 59-72.

23. **Chang T. T., G. C. Loresto, J. C. Toole and J. L. Armenta - Soto.** 1982. Strategy and methodology of breeding rice for drought prone areas. *In*: Drought resistance in crops with emphasis on rice, IRRI, Los Banos, Philippines: 217-244.

24. **Yamauchi M.** 1994. Hybrid Rice Technology: New Developments and further prospects, IRRI, Manila, Phillippines.

25. **Guha Sarkar C. K., F. U. Zaman and A. K. Singh.** 2001. Heterosis for yield and yield attributes in WA type rice hybrids (*Oryza sativa* L.) on multilocation. Crop Res., **22**: 262-266.

26. **Raju C. H. S., M. V. B. Rao, A. Sudarshanam and G. L. K. Reddy.** 2008. Heterosis and inbreeding depression for yield and kernel characters in rice. Oryza, **42**: 14-19.