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Genetic analysis for yield and physiological traits in developing rice hybrids for aerobic environment

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ABSTRACT

The present investigation was carried out to develop heterotic rice hybrids suitable for aerobic cultivation utilizing four cytoplasmic male sterile lines and twenty two testers. The CMS line IR 68888A was found to be a good general combiner for root length and shoot dry weight while the CMS line COMS 14A was found to be a good general combiner for relative water content, shoot dry weight, grain yield and harvest index. The male parents IR55838-B2-2-3-2-3, WGL 14 and IR 72875-94-3-3-2 were identified as good general combiners for most of the yield components and physiological traits. Good general combiners with respect to various physiological traits include PSBRC 80 for relative water content, root length, root dry weight, shoot dry weight, total dry matter production and harvest index; MTU 7029 for SPAD value; IR 36 for high harvest index and relative water content; IR 69715-72-1-3 for root length and root shoot ratio and MTU 9992 for shoot dry weight, total dry matter production and harvest index. Based on the high per se performance and high sca effects COMS 14A x IR55838-B2-2-3-2-3, IR 68888A x IR 72875-94-3-3-2, IR 68897A x IR 36 and IR 68897A x IR 59624-34-2-2 were identified as superior hybrids suitable for aerobic condition.

Key words : *aerobic rice, combining ability, physiological traits, yield improvement*

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 (IRRI, 1997) 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. By this the farmers can actually reduce the water requirement around 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.

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

Eighty eight hybrids along with four lines, 22 testers and two check hybrids viz., ADTRH 1 and CORH 2, were raised in randomized block design with two 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. Totally five irrigations were given to the aerobic treatment plot with an interval of eight days. The rainfall received during the entire crop period was also recorded.

In the vegetative stage five plants were selected randomly and tagged. Data were recorded at flowering and maturity stage for yield and physiological traits *viz.,* plant height, spikelet fertility, SPAD chlorophyll meter reading (SCMR), relative water content, shoot dry weight, root dry weight, root-shoot ratio, root length, total dry matter production, harvest index and grain yield per plant for both aerobic and flooded treatments. Observations for the A lines were recorded on the corresponding B lines. The mean data of these traits recorded for aerobic and flooded conditions were subjected to combining ability analysis proposed by Kempthorne (1957) and the results obtained for both conditions were compared and discussed.

RESULTS AND DISCUSSION

The analysis of variance revealed that the lines, testers and line x tester interaction was highly significant for all characters in both situations. The specific combining ability (sca) variance was higher than general combining ability (gca) variance for all the characters studied in both the conditions. In general the percentage contribution of testers was high for all the physiological traits when compared to the lines (Table1).

Information on physiological potential of the genotypes has more significance in the crop improvement programme to evolve varieties or hybrids suited for aerobic cultivation. In the present study, the potentiality of parents to produce better offsprings with reservoir of superior genes were evaluated based on *per se* performance and *gca* effects while evaluation of hybrids is based on the mean performance and significant *sca* effects since the genetic worth of the parents is decided on the basis of their specific combining ability to produce better effect in F_1 hybrids (Table 2).

The parental lines IR 68888A and IR69715-72-1-3 were considered as good general combiners for plant height as they showed highly significant negative *gca* effects combined with high *per se* performance under both conditions. In addition, the CMS line IR 68886A and two male parents viz., IR 71604-4-1-4-7-10-2-1-3 and PSBRC 80 were identified as good general combiners for plant height under aerobic condition indicating the presence of favourable alleles for semi dwarf plant type. Atlin *et al.*(2004) also reported that intermediate plant height would be favourable for aerobic conditions compared to tall varieties.

Hybrids with semi-dwarf plant type is preferable and highly productive. A total of 44 hybrids in flooded condition and 38 hybrids under aerobic condition recorded significantly lesser plant height. The hybrids IR 68888A x PR114 and IR 68886A x IR 71700-247-1-1-2 were the shortest under aerobic condition when compared to flooded condition. Wide range of *sca* effects for plant height in the hybrids was observed in flooded and aerobic conditions. A total of 32 hybrids under flooded and 23 hybrids under aerobic condition were found to be semi-dwarf in nature resulting from the parents with significant negative *sca* effects. Of the 23 hybrids, 12 hybrids had any one of the parent as a good general combiner for plant height. It was also observed that seven hybrids with significant negative *sca* effects were derived from low x low general combiners for plant height. The results are in conformity with the findings of Viswanathan Satheesh (2003) and Krishnan (2004). Reduction in plant height under aerobic condition due to moisture stress was also observed by Russo (2000) and Adriano *et al.* (2005).

Spikelet fertility is one of the important yield contributing characters that is mainly considered for yield improvement in rice hybrids. In aerobic condition, the line IR 68886A and 10 testers *viz.,* IR 36, IR55838-B2-2-3-2-3, IR 59624-34-2-2, IR60979-150-3-3-3-2, IR 62030-54-1-2-2, IR69715-72-1-3, MTU 5293, MTU 7029, MTU 9992 and WGL 14 were selected as good general combiners as they had desirable genes for spikelet fertility under aerobic condition which can be used as potential donors.

Among the 68 hybrids identified as best under aerobic condition, the hybrids COMS 14A x IR 62161-184-3-1-3-2, IR 68888A x WGL 32100, IR 68888A x IR 72875-94-3-3-2, IR 68897A x IR 55838-B2-2-3-2-3 and IR 68888A x MTU 9992 were found to have high *per se* performance for spikelet fertility. Also, 13 hybrid combinations showed equal performance for spikelet

Table 1. Analysis of variance for combining ability in flooded and aerobic condition for different physiological traits

Sources of variation		df	Mean Squares										
			Plant height	Spikelet fertility	SPAD Value	RWC (%)	TDMP (g $plant^{-1}$)	Shoot weight (g)	Root shoot ratio	Root dry weight (g $plant^{-1}$)	Root length (cm)	Harvest index	Grain yield
Replication	F	1	0.98	3.50	3.94	9.61	6.30	1.09	0.001	2.65	0.04	0.001	3.70
	A	1	2.95	6.70	7.25	6.38	8.63	2.48	0.001	1.86	3.01	0.0004	0.06
Hybrids	F	87	60.46	227.98	7.72	20.96	57.24**	58.46**	0.001	5.46	13.96	0.02	198.04
	A	87	60.03**	283.09	10.44	32.15**	41.23**	43.67**	0.002	6.01	10.03	0.019	169.68
Lines	F	3	99.14	252.71**	88.88**	27.33**	201.06**	305.21**	0.006	12.51**	88.76**	0.03**	169.58*
	A	3	28.72	313.59	59.92**	15.06	178.07**	241.68**	0.007	7.29	64.47**	0.002	65.68
Testers	F	21	122.85**	738.98**	8.09	21.53	139.42**	110.54**	0.001	8.91	23.34**	0.052**	631.82**
	A	21	133.32**	956.68**	10.68	59.70**	83.79**	60.84**	0.003	11.49*	15.80**	0.060	550.29**
LinesxTesters	F	63	37.82**	56.47**	3.73	20.46*	22.99*	29.35*	0.001	3.97	7.27	0.01**	54.80**
	A	63	37.10**	57.11**	8.00	23.78*	20.52*	28.51*	0.002	4.12	5.52	0.007	49.406**
Error	F	87	1.48	20.67	1.63	5.94	4.52	5.19	0.000	0.70	2.68	0.001	2.97
	A	87	3.01	9.23	1.48	6.76	4.38	6.14	0.000	1.07	2.20	0.001	2.73
σ^2 *gca*	F	-	0.27	2.07	0.048	0.006	0.414	7.79	0.001	0.018	0.081	0.001	1.73
	A	-	0.28	2.73	0.029	0.101	0.250	5.581	0.000	0.023	0.055	0.002	1.47
σ^2 *sca*	F	-	18.17	17.90	1.048	7.260	9.238	12.08	0.001	1.636	2.298	0.002	25.92
	A	-	17.04	23.94	3.259	8.510	8.074	11.18	0.001	1.527	1.658	0.003	22.52

F- Flooded condition ; A – Aerobic condition * Significance at 5% level; ** Significance at 1% level

Table 2. Best general and specific combiners for grain yield and physiological traits under aerobic condition

Characters	Best general combiners		Best specific combiners
	Lines	Testers	
Plant height	IR 68888A	IR69715-72-1-3 IR 71604-4-1-4- 7-10-2 PSBRC 80 PR 114, MTU 7029 IR 62030-54-1-2-2	IR 68886Ax IR 71700-247-1-1-2 IR 68897 A x PSBRC 82 IR 68888A x PR 114 IR 68888A x PSBRC 80 IR 68886 A x IR 62030-54-1-2
Spikelet fertility	IR 68886A	IR 36 IR55838-B2-2-3-2-3 IR 59624–34-2-2 IR60979-150-3-3-3-2 IR 62030-54-1-2 IR69715-72-1-3 MTU 5293,MTU 7029 MTU 9992,WGL 14	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
SPAD at flowering	IR 68888A	MTU 7029	IR 68897 A x IR 62161-184-3-1-3-2 IR 68888AxIR 71700-247-1-1-2 IR 68888 Ax IR 72862-27-3-2-3 IR 68897 A x IR 36 IR 68888 A x IR 72875-94-3-3-2
Relative water content at flowering	IR 68897A	PSBRC 82 IR 36 MTU 7029 IR 69715-72-1-3 MTU 9992	COMS 14 A x IR 60979-150-3-2 IR 68897 A x IR 77298-12-7 IR 68886 Ax IR 71604-4-1-10-2 IR 68886 A x IR 59624 –34-2-2 IR 68886A x MTU 5293
Shoot dry weight	IR 68888A IR 68886A COMS 14A	MTU 9992 PSBRC 80 MTU 5293	IR 68886A x IR 72862-27-3-2-3 IR 68897 A x IR 59624 –34-2-2 COMS14 A x IR 77298-5-6 COMS14 Ax IR 60979-150-3-2 COMS14 A x PSBRC 80
Root shoot ratio	IR 68897A	IR 36, WGL 32100 IR55838-B2-2-3-2-3 IR60979-150-3-3-3-2 IR69715-72-1-3 IR 72875-94-3-3-2 IR 71604-4-1-4-7-10-2-1-3, PSBRC 82, IR 77298-5-6 IR 62030-54-1-2-2	IR 68897A x IR 60979-150-3-2 COMS14AxIR 71700-247-1-1-2 IR 68886 Ax IR 60979-150-3-2 IR 68888 A x PSBRC 80 COMS 14 A x IR 72862-27-3-2-3
Root dry weight	IR 68897A	IR55838-B2-2-3-2-3 IR 71604-4-1-10-2-1-3 IR 36 PSBRC 82 IR60979-150-3-3-3-2 WGL 32100	IR 68897AxIR 60979-150-3-3-2 COMS 14 A x IR 71700-247-1-2 IR 68886A x MTU 7029 IR 68888 A x PSBRC 80COMS 14 A x IR 36
Root length	IR 68886A COMS 14A	PSBRC 82 MTU 5293 PSBRC 80 IR69715-72-1-3 IR 77298-12-7 IR 71604-4-1-10-2-1-3 IR 72875-94-3-3-2	IR 68888A x IR69715-72-1-3 IR 68897AxIR 60979-150-3-3-2 COMS 14 A x MTU 7029 IR 68897 A x IR55838-B2-2-3-3 IR 68886 A x PSBRC 80

Contd...

Table 3 Contd...

Characters	Best general combiners		Best specific combiners
	Lines	Testers	
Total dry matter production	COMS 14A	MTU 5293 IR55838-B2-2-3-2-3 PSBRC 80 IR 36, PSBRC 82 IR 72875-94-3-3-2 WGL 14	IR 68886 A x IR 72862-27-3-2-3 IR 68897 A x IR 59624 –34-2-2 COMS 14 A x PSBRC 80 IR 68886 A x IR 77298-12-7 IR 68886 A x WGL 14
Harvest index	IR 68886A	IR 72875-94-3-3-2 IR55838-B2-2-3-2-3 IR69715-72-1-3, IR 36 IR 71604-4-1-10-2-1-3 MTU 9992,PSBRC 82 PSBRC 80, MTU 5293 IR 62030-54-1-2 WGL 32100, WGL 14 IR 59624 –34-2-2	IR 68886 A x IR 72862-27-3-2-3 IR 68897 A x IR 62161-184-3-1-3-2 IR 68897 A x IR 62030-54-1-2 IR 68888AxIR 71700-247-1-1-2 IR 68886 A x WCR 6
Grain yield per plant	IR 68886A COMS 14A	IR55838-B2-2-3-2-3 PSBRC 82 IR 72875-94-3-3-2 PSBRC 80, IR 36 IR69715-72-1-3 MTU 5293, MTU 9992 IR 62030-54-1-2 WGL 32100, WGL 14 IR 71604-4-1-4- 7-10-2 IR 62161-184-3-1-3-2 IR 59624 –34-2-2	IR 68886 A x IR 72862-27-3-2-3 IR 68897 A x IR 59624 –34-2-2 COMS14A x IR55838-B2-2-3-2-3 IR 68897 A x IR 62030-54-1-2 IR 68886 A x WCR 6 IR 68886 A x IR 77298-5-6 IR 68888AxIR 71700-247-1-1-2 COMS 14 A x PR114 COMS 14 A x MTU 7029 IR 68897 A x IR 36

fertility under both conditions indicating their ability to withstand water limited situations. The superior performance of these hybrids can be attributed due to the involvement 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. Wide range of *sca* effects was observed for spikelet fertility under both conditions. Five hybrids under flooded condition and 10 hybrids under aerobic condition showed significant positive *sca* effects. Out of the 10 hybrids, eight hybrids had atleast one parent as a good general combiner indicating the predominance of non additive gene action for expression of high spikelet fertility as reported by Bastian *et al.*(2004), Krishnan (2004) and Jeyaprakash and Balasubramanian (2004).

Chlorophyll meter quantifies the relative greenness of plants and it is one of the non-destructive method of measuring chlorophyll status (Watanabe *et al.,* 1980). The genotype MTU 7029 was identified as good general combiner with high mean performance under both aerobic and flooded conditions. The genetic nature of MTU 7029 with dark green leaves may be one of the reasons for the high *gca* and *per se* performance for this trait. This genotype MTU 7029 can be used as a potential donor for improving the chlorophyll status in the hybrids.

Based on the *per se* performance, 48 hybrids under flooded and 31 hybrids under aerobic condition were found superior and showed slight reduction in SPAD value when compared to flooded condition. The reduction in SPAD values was also reported by Maibangsa (1998) due to water stress in rice. With respect to *sca* effects, five hybrids under flooded condition and 10 hybrids under aerobic condition recorded significant positive *sca* effects. Of the ten hybrids with high *sca* effects, four hybrids resulted from the combination of high x high general combiners, while three hybrids were derived from the combination of differential *gca* effects of high x low and low x high combiners. Other three hybrids *viz.,* IR 68888A x IR

62161-184-3-1-3-2, IR 68886A x WGL14 and COMS 14A x PSBRC 82 resulted from low x low general combiners. The results indicate that additive and non-additive gene action played a major role in the expression of leaf chlorophyll content. Annadurai (2002) also reported similar results under water deficit conditions.

Relative water content is one of the measures which gives an idea of tissue water status. Considering both *per se* performance and *gca* effects, the line COMS14A and seven testers *viz.,* IR 36, IR55838-B2-2-3-2-3, IR 69715-72-1-3, PSBRC 80, PSBRC 82, WGL 14 and WGL 32100 had desirable genes and were adjudged as best general combiners under both conditions. Fifty six 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). Such reduction in RWC under was observed by Sairam and Dube (1984) under moisture stress conditions. Lawlor (1995) observed that changes in metabolic process with the cessation of photosynthesis and increased respiration in plants is due to reduced RWC. Significant positive *sca* effects were observed in nine hybrids under flooded and 10 hybrids in aerobic condition. Among the 10 hybrids, the hybrid COMS14A x IR 62161-184-3-1-3-2, resulted from combination of parents with high *gca* effects, while seven hybrids resulted from parents with differential *gca* effects and two hybrids IR 68886A x MTU 9992 and IR 68886A x IR 77298-5-6 from low x low general combiners, indicating the presence of additive and non additive gene action. Farshadfar *et al.* (2002) also reported non additive gene action for relative water content in their study under water stress conditions.

When considering aerobic and flooded conditions together, none of the genotypes had significant *gca* effect and *per se* performance for root dry weight. However, under aerobic condition IR 71700-247-1-1-2 and PSBRC 80 were identified as good general combiners coupled with high *per se* performance. Chang *et al.* (1972) observed that the drought resistant upland cultivars possessed longer and thicker root system and also concluded that selection for genotypes with high root weight could lead to improvement in other root traits.

Superior hybrids for root dry weight include 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. With respect to *sca* effects, significant positive performance was observed in 15 hybrids under flooded condition and seven hybrids under aerobic condition. The hybrid IR 68897A x IR 60979-150-3-3-3-2 was found to be highly suitable for aerobic situation. More root dry weight under water stress conditions was also reported by Robin (1997) and Michael Gomez *et al.* (2003).

Shoot dry weight is the major component that decides the total biomass of a plant. The genotypes COMS 14A, IR 68886A, MTU 9992 and PSBRC 80 had desirable genes and were identified as good general combiners for shoot dry weight. Significant positive *sca* effect for shoot dry weight was recorded by 15 hybrids in flooded and 10 hybrids under aerobic condition. Additive and non-additive gene action played a major role since four hybrids resulted from both the parents with high *gca* effects and remaining six hybrids were derived either from low x high or high x low combination of parents. High *sca* effects for this trait under water stress conditions were reported by Nilakantapillai (1998) and Kalita and Upadhaya (2000).

Genotypes with high root-shoot ratio is highly desirable under water limited situations. The genotypes IR 68897A. PSBRC 82, IR 71604-4-1-4-7-10-2-1-3, IR69715-72-1-3, WGL 32100 and IR 72875-94-3-3-2 had favourable genes for this trait and were identified as good general combiners. 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. When compared with flooded condition the root-shoot ratio was high in aerobic condition. This was in line with the findings of O'Toole and Chang (1979). High root to shoot ratio in drought resistant upland rice cultivars was also reported by Namuco *et al.* (1993) and Lu and Hua, (1994). Significant positive *sca* effect for root shoot ratio was displayed by 15 hybrids in flooded and 10 hybrids under aerobic condition. Out of ten hybrids under aerobic condition, two hybrids resulted from both the parents with high *gca* effects while four hybrids were derived from parents having low x high *gca* effects and the remaining four hybrids resulted from low x low general combiners. Additive and non-additive gene action played a major role for the expression of high root–shoot ratio.

Deep rooted cultivars extract more water than the shallow rooted genotypes (Puckridge and O'Toole, 1981). Generally, the parents and hybrids grown under aerobic condition had longer roots than the genotypes under flooded condition. Considering aerobic condition, the genotypes COMS 14A, IR 69715-72-1-3, IR 71604-4-1-4-7-10-2-1-3, IR 72875-94-3-3-2, PSBRC 82, and PSBRC 80 were identified as good general combiners for root length. The male parents those showed better performance for root length were specially bred for aerobic situation may be the reason. Lilley and Fukai (1994) reported that the cultivar with higher root length performed better than others under mild stress conditions.

Significant positive *sca* effects for root length was observed in six hybrids under flooded condition and five hybrids under aerobic condition. Of the five hybrids, two hybrids resulted from the combination of high x high general combiners while the other hybrids resulted from high x low, low x high and low x low combiners. Predominance of additive and non-additive gene action had significant role in the expression of higher root length under aerobic condition. The contribution of favourable genes by the male parents of these hybrids may be one of the reasons for better expression of the hybrids for root length under aerobic condition.

Total dry matter production is an important parameter which indicates the photosynthetic efficiency of plants. In general, there was reduction in total dry matter production in the genotypes grown under aerobic condition (Fig 1and 2). It was also observed that most of the genotypes differed in their ability to produce high dry matter under aerobic condition (Table 3). Eight genotypes *viz.,* IR 36, IR55838-B2-2-3-2-3, IR 72875-94-3-3-2, MTU 5293, MTU 9992, PSBRC 80, PSBRC 82, and WGL 14 were found to have desirable alleles for dry matter production under aerobic condition. Similar results were reported by Chauhan *et al.* (1996) and Beser (1997). Simane *et al.*(1993) also observed higher reduction in dry matter accumulation in drought susceptible rice cultivars than that of tolerant cultivars.The *sca* effect for this trait was found to be highly significant in 11 hybrids under flooded condition and eight hybrids under aerobic condition. Though significant positive *gca* effect for dry matter was contributed by eight parents, only three parents produced hybrids *viz.,* COMS 14A x PSBRC 80, IR 68886A x WGL 14 and COMS 14A x MTU 5293 with

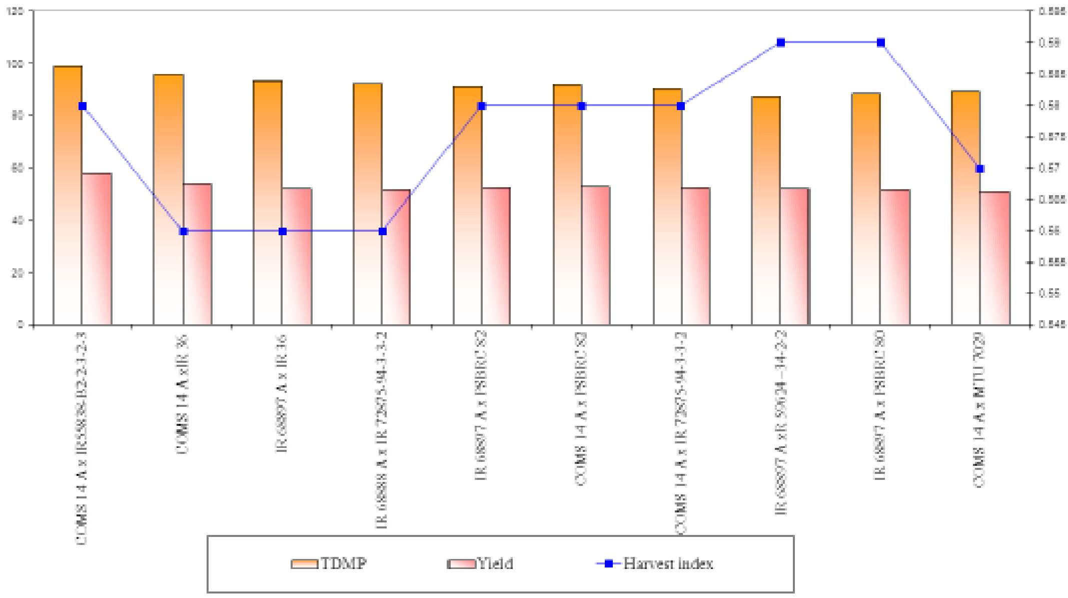


Fig. 1. Comparison of total dry matter, grain yield and harvest index under aerobic condition for high yielding hybrids

high *sca* effect from high x high general combiners while the other hybrids were produced from the high x low combination of parents which are controlled by additive and non-additive gene action. Similar results were reported by Souframanien *et al.*(1998a).

Harvest index, the partitioning efficiency of plants to divert the biomass towards the developing reproductive parts, was found to be relatively high in flooded condition than under aerobic condition (Fig 1 and 2). The genotypes COMS 14A, IR 36, IR55838-B2-2-3-2-3, IR 59624-34-2-2, IR 72875-94-3-3-2, WGL 14, MTU 9992 and WGL 32100 were found to have desirable genes for expression of high harvest index and were identified as good general combiners under aerobic and flooded conditions. The results are in conformity with reports of Sureka and Beser (1999).

Significant positive *sca* effect for harvest index was displayed by 20 hybrids in flooded and 25 hybrids under aerobic condition. Out of the 25 hybrids under aerobic condition, 12 hybrids resulted due to interaction of positive alleles from good combiner and negative alleles from poor combiners. Predominance of additive and non-additive gene action played a major role. High *sca* effects for this trait under water stress conditions were reported by Annadurai (2002) and Yogameenakshi *et al.*(2003).

Grain yield, the economic output of the plant and the total contribution of all yield related traits was found to be high in the line COMS14A and 15 testers *viz.,* IR 36,IR55838-B2-2-3-2-3, IR 59624-34-2-2, IR 62030-54-1-2-2, IR 62161-184-3-1-3-2 IR 69715-72-1-3, IR 71604-4-1-4-7-10-2-1-3, IR 72875-94-3-3-2, MTU 5293, MTU 7029, MTU 9992, PSBRC 80, PSBRC 82, WGL 14 and WGL 32100 under aerobic condition and the lines IR 68886A and COMS 14 A and 14 testers had high *gca* effects for grain yield per plant under flooded condition. In general, higher yield was obtained in flooded condition when compared to aerobic situation (Fig 3). However, the line COMS 14A and 13 testers performed equally well under both conditions.

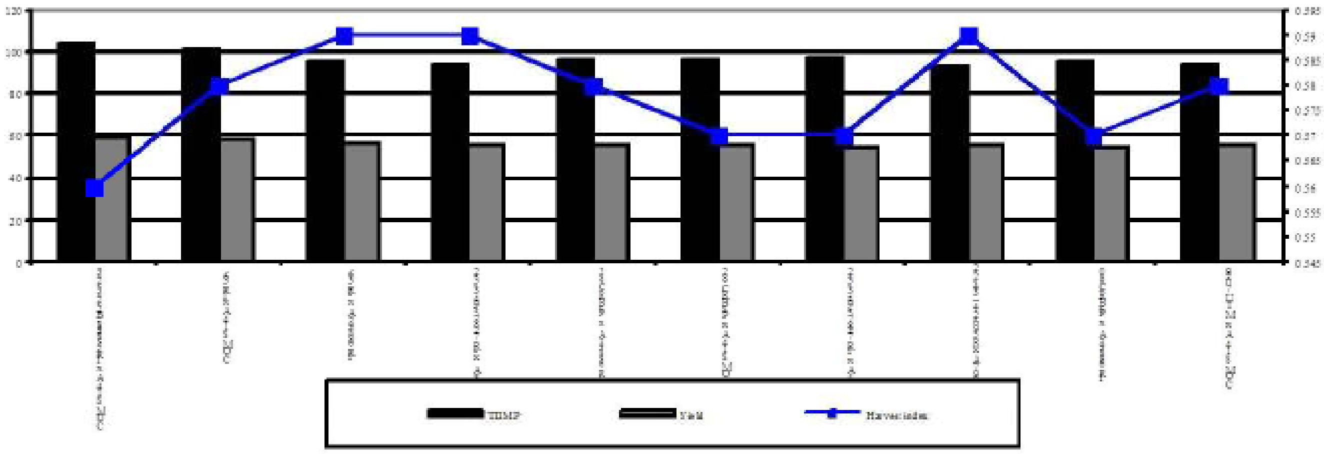
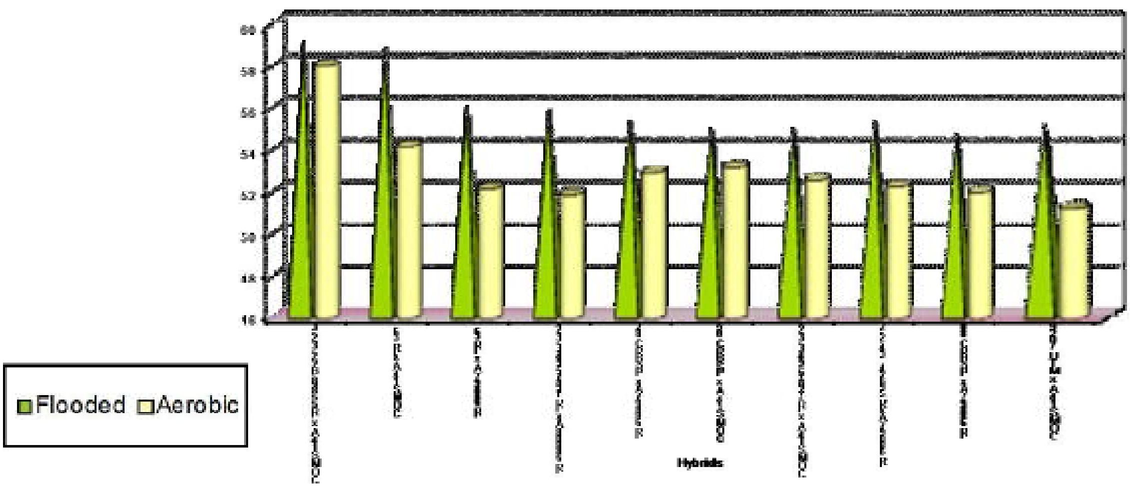


Fig. 2. Comparison of total dry matter, grain yield and harvest index under flooded condition for high yielding hybrids.

Among the 15 hybrids which showed high *per se* performance, the hybrid COMS 14A x IR55838-B2-2-3-2-3 out yielded the other hybrid combinations by recording 58.05 grams of grain yield per plant followed by the 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. In addition to yield, the hybrid COMS 14A x IR55838-B2-2-3-2-3 and COMS 14A x IR 36 showed superiority for spikelet fertility, total dry matter production and harvest index; the hybrid IR 68888 A x IR 72875-94-3-3-2 for spikelet fertility, relative water content, root dry weight, harvest index and root-shoot ratio and IR 68897 A x IR 36 for spikelet fertility, total dry matter production and harvest index. These four hybrids can be best utilized commercially for both conditions.

Significant positive *sca* effects for grain yield was recorded by 25 hybrids under flooded and 29



hybrids under aerobic condition (Table 3). Out of 29 hybrids under aerobic condition, nine hybrids were resulted from both the parents with superior *gca* effects indicating additive x additive gene action. High *sca* effects were also observed for grain yield in 16 hybrids, involving parents with differential *gca* effects, indicating non additive gene action. The remaining six hybrids resulted from low x low combining parents. Highest *sca* effect for grain yield was recorded under aerobic condition by the hybrid combination IR 68886A x IR 72862-27-3-2-3 followed by IR 68897A x IR 59624-34-2-2, COMS14A x IR55838-B2-2-3-2-3, IR 68897A x IR 62030-54-1-2-2 and IR 68886A x WCR 6. Significant positive *sca* effects for grain yield as observed in the present study was also reported by Kalita and Upadhaya (2000), Bastian *et al.*(2004) and Sabesan *et al.*(2004).

The parents with high x high general combining ability with more of favourable genes for the physiological traits would be of tremendous potential in the exploitation of heterosis for grain yield under aerobic condition. Therefore, the genotypes IR 68888A, COMS 14A, IR55838-B2-2-3-2-3, IR 36, IR 72875-94-3-3-2, WGL 14, WGL 32100, IR 59624–34-2-2, IR 71604-4-1-10-2-1-3, IR 62030-54-1-2 and MTU 9992 having desirable genes for specific traits can be used as potential donors in aerobic rice improvement.

Based on the high *per se* performance and high *sca* effects, the hybrids COMS 14A x IR55838-B2-2-

Table 3. Specific combining ability of hybrids with different gene effects under aerobic condition

Characters	Hybrids with significant sca effects	Hybrids		
		high x high gca effects	high x low or low x high	low x low gca effects
Plant height	23	4	12	7
Spikelet fertility	10	2	8	-
SPAD at flowering	10	4	3	3
Relative water content	10	1	7	2
Shoot dry weight	10	4	6	-
Root shoot ratio	10	2	4	4
Root dry weight	7	2	3	2
Root length	5	2	3	-
Total dry matter	8	3	5	-
Harvest index	25	4	12	9
Grain yield per plant	29	9	16	6
Type of gene action		Additive	Non additive	Epistatic

3-2-3, IR 68888A x IR 72875-94-3-3-2, IR 68897A x IR 36 and IR 68897A x IR 59624-34-2-2 were identified as superior hybrids and highly suitable for aerobic condition. Though reduction in grain yield was observed in most of the hybrids under aerobic condition few hybrids *viz.,* IR 68886A x IR 71604-4-1-4-7-10-2-1-3, IR 68886 A x IR 72875-94-3-3-2, IR 68888A x IR 36, IR 68888A x IR 72875-94-3-3-2, IR 68888A x IR 62030-54-1-2-2, IR 68888A x IR 71604-4-1-4-7-10-2-1-3, IR 68888A x PSBRC 82, IR 68897A x PSBRC 80, IR 68897A x IR 60979-150-3-3-2 and COMS 14A x WGL 32100 had equal performance for grain yield under aerobic as well as flooded conditions and these hybrids can be exploited commercially.

REFERENCES

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.

Annadurai A 2002. Heterosis for physiological traits in hybrid rice. Indian J. Genet., 62(4) : 331-333

Atlin GN, M Laza, M Amante and H R Lafitte 2004. Agronomic performance of tropical aerobic, irrigated and traditional upland rice varieties in three hydrological environments at IRRI. In: 4th International Crop Science Congress held at Australia.

Bastian CSD, Somanagoundra T Chandirahasan, R Ambika and P Rangasamy 2004. Line x Tester analysis of rice (*Oryza sativa* L.). In: Extended summaries of National Seminar on Hybrid Breeding in crop plants, March 3-4, 2004. Annamalai University, Annamalai Nagar, Tamil Nadu, India, pp. 36-37.

Beser N 1997. Trakya Bolgesnde legisik ekim ve Sulame Yontemlerini Celtikte (*Oryza sativa* L.) verim ve verm unsurtari ice kalite karakterlerine etkisi. Ph.D. Thesis, submitted to Trakya University, Edrine, Turkey.

Chang TT, G Loresto and O Tagumpay 1972. Agronomic and growth characteristics of upland and lowland rice varieties. In: Rice Breeding, pp. 645-661, IRRI, Los Banos, Philippines.

Chauhan JS, TB Moya, RK Singh and CV Singh 1996. Growth and development under different soil moisture regimes in upland rice (*Oryza sativa* L.). Indian J. Plant Physiol., 1: 270-272.

Farshadfar E, A Afarinesa and J Sutka 2002. Inheritance of drought tolerance in Maize. Cereal Research Communications. 30: 285-290.

IRRI (International Rice Research Institute),1997. Rice Almanac, second edition, IRRI, Los Banos, Philippines.181p.

Jeyaprakash P and P Balasubramanian 2004. Combining ability analysis for traits influencing drought tolerance in rainfed rice. In: Extended summaries of National Seminar on "Hybrid Breeding in Crop Plants" March 3-4, 2004. Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India pp 38-59.

Kalita VC and LP Upadhaya 2000. Line x Tester analysis of combining ability in rice under irrigated low land condition. Oryza, 37: 15-19.

Kempthorne O 1957. An introduction to genetic statistics. John Wiley and Sons, Inc. New York, pp. 458-471.

Krishnan V 2004.Studies on the development of improved grain quality hybrids through three line breeding in rice (*Oryza sativa* L.) Ph.D Thesis, Tamil Nadu Agricultural University , Coimbatore

Lawlor DW 1995. The effects of water deficit on photosynthesis. In: Environment and Plant Metabolism : flexibility and accumulation. (Ed.) Smirnoff, N. Bios Scientific Publishers Ltd., UK. pp. 129-160.

Lilley JM and S Fukai 1994. Effect of timing and severity of water deficit on four diverse rice cultivars. III. Phenological development, Crop growth and grain yield. Field crops Res., 37: 225-234.

Lu F and HJ Hua 1994. A study on the main drought resistant index of land rice. Acta. Agriculturae Boreali Sinica., 9: 7-12.

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.

Michael Gomez S, P Rangaswamy and N Nadarajan 2003. Assessing the best combiners in rice (*Oryza sativa.L.*) suitable for drought prone areas of Tamil Nadu. Res. on Crops., 4(1): 79-84.

Namuco OS, KT Ingram and LT Fuentes 1993. Root characteristics of rice genotypes with different drought responses. Int. Rice Res. Notes., 18: 38-39.

Nilakanta pillai 1998. Genetic studies on semi dry rice (*Oryza sativa* L.) Ph.D thesis, Tamil Nadu agricultural University, Coimbatore.

O'Toole JC and TT Chang 1979. Drought resistance and cereals- Rice: A case study. In: Stress Physiology in

Crop Plants. (Ed.). H. Mussell and R. Staphes, Johnwiley and Sons, Inc: 373-405.

Puckridge DW and O'Toole JC 1981. Dry matter and grain production of rice using a line source sprinkler in drought studies. Field Crops Res., 3: 303-319

Robin S 1997. Genetic analysis of yield, yield components and physiological attributes related with drought tolerance in rice (*Oryza sativa* L.) Ph.D Thesis, Tamil Nadu Agricultural University, Coimbatore.

Russo S 2000. Preliminary studies on rice varieties adaptability to aerobic irrigation. Cahiers Options Méditerranéennes, 15:35-39.

Sabesan T, K Saravanan and J Ganesan 2004. Studies on combining ability through Line x Tester analysis in rice (*Oryza sativa* L.). In: Extended summaries of 'National Seminar on hybrid breeding in crop plants', March 3-4, 2004, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India. pp. 24-25.

Simane B, JM Pea Cock and PC Struik 1993. Differences in developmental plasticity and growth rate among drought resistant and susceptible cultivars of durum wheat (*Triticum turgidum* var. *durum*). Plant Soil., 157: 155-166.

Souframanien J, P Rangasamy, P Vaidyanathan and M Thangaraj 1998. Combining ability for drought resistant characters in hybrid rice (*Oryza sativa* L.). Indian J. Agric. Sci., 68(10): 687-689.

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.

Viswanathan Satheesh 2003. Development of improved grain quality hybrids through three line breeding in rice (*Oryza sativa* L.) M.Sc. (Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore.

Watanabe S, Y Hataaka and K Inada 1980. Development meter: Structure and performance. Jpn. J. Crop Sci., 49: 89-90.

Yogameenakshi P, NNadarajan and A Sheeba 2003. Evaluation of varieties and land races for drought tolerance in rice. Indian J. Genet., 63 (4) : 299-303.