Research Article

Genetic analysis to assess the physiological efficiency of parental lines in rice (*oryza sativa* L.)

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Abstract

Information on physiological potential of the genotypes is more important in the crop improvement programme, to evolve hybrids suitable for aerobic cultivation. Four CMS lines and 22 male parents were subjected to combining ability analysis and evaluated to identify the best combining parents for developing rice hybrids suitable for aerobic condition. The investigation was carried out under aerobic condition using the line x tester mating design in three replications and studied for different biometrical and physiological traits. The aerobic rice culture IR 72875-94-3-3-2 had high per se performance for grain yield, yield traits followed by higher harvest index, SPAD values, relative water content, total dry matter and root dry weight. The other genotype IR 71604-4-1-4-7-10-2-1-3 had superior performance for grain yield and for most of the yield contributing traits, relative water content and root length. The hybrids involving IR 72875-94-3-3-2 namely IR 68886A x IR 72875-94-3-3-2, IR 68888A x IR 72875-94-3-3-2 and COMS 14A x IR 72875-94-3-3-2 had higher grain yield under aerobic condition. Similarly PSBRC 80, the male parent best suited for aerobic condition had better performance for most of the traits like harvest index, high relative water content, total dry matter production, root dry weight and grain yield. PSBRC 82, the other aerobic culture also had, higher harvest index, leaf chlorophyll content, relative water content and grain yield. 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 had good performance for most of the yield contributing traits and physiological parameters under aerobic condition. The hybrids developed from these parental lines viz., IR 68888A x IR55838-B2-2-3-2-3, IR 68888A x IR 36, IR 68888A x WGL 14, IR 68888A x WGL 32100, COMS 14A x IR55838-B2-2-3-2-3, COMS 14A x IR 36, COMS 14A x WGL 14 and COMS 14A x WGL 32100 were found superior for most of the yield traits and physiological traits. Therefore, these parental lines could be best utilized for developing high yielding hybrids suitable for water limited conditions.

Key Words:
Rice hybrids – parental lines – combining ability- yield and physiological traits

Introduction

Rice is the most important cereal food grain of the world. The abundant water environment in which rice grows best, differentiates it from all other important crops. But water is becoming increasingly scarce. It has been frequently postulated that water will become the 'Oil' of the 21st century. For the existing water crisis in India, aerobic rice technology is one of the exciting research to increase the food production. Aerobic rice varieties have produced yields of 4 to 6 t/ha and water savings of around 50% compared with lowland rice. It takes about 4,000 litres of water to produce one kg of rice. Timing and control of water application is essential for success in aerobic rice but it deserves critical and thorough evaluation. Tuong and Bouman (2002) reported that farmers can actually reduce the water requirement from 20 to 30 per cent or even more and even increased yield by 20 %. With declining water availability for agricultural use, aerobic rice cultivation is expected to expand into the regions with intensive cropping and high productivity (Lafitte, 2002). As growing scarcity of fresh water will pose problems for rice production in future years, shifting gradually from traditional rice production system to grow rice aerobically, especially in water scarce irrigated lowlands, can mitigate the occurrence of water related problems.

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With aerobic rice, the future of rice farming looks better and planting rice itself remains viable and sustainable.

At the present situation, increasing the rice production, productivity and grain quality are the major challenges in rice research. Hybrid rice has unique advantage to meet this immense challenge. Hybrid rice technology has shown increased yield, farmer profitability and better adaptability to stress environments such as water scarce and aerobic conditions. The genetic improvement of rice for aerobic environments has not been understood well and there have been no major efforts in this front. Evaluation of physiological characters under aerobic condition, have not been much emphasized. Also, information on physiological potential of the genotypes is more important in the crop improvement programme to evolve varieties suited for aerobic cultivation. Keeping this in view, four CMS lines and 22 male parents were subjected to combining ability analysis and evaluated to identify the best combining parents for developing rice hybrids suitable for aerobic condition

Material and Methods

One hundred and twenty hybrids along with four CMS lines, 22 testers and two check hybrids were raised in randomized block design in two replications under aerobic 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 plots were maintained under irrigated condition for establishment of the seedlings and later on, it 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. The rainfall received during the entire crop period was also recorded. Details of weather conditions prevailed during the cropping period are collected from the meteorological observatory of Paddy Breeding Station, Department of Rice, Tamil Nadu Agricultural University, Coimbatore.

The investigation was carried out under aerobic condition using the line x tester mating design in two replications and studied for 17 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. Observations were recorded for the above 17 traits and subjected to combining ability analysis as suggested by Kempthorne (1957)

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. In the present study, selection of parents is based on the *per se* performance and *gca* effects for various morpho physiological traits and the results are discussed for the Tables 1 to 8.

Analysis of variance for combining ability

The analysis of variance for combining ability revealed that the lines differed significantly among themselves for days to 50 per cent flowering, panicle length and hundred grain weight in aerobic condition (Table 1). The testers also differed significantly for all the characters except for panicle length indicating wide variability among them for different characters. The line x tester interaction was significant for all the characters except for panicle length. Further, analysis of GCA/SCA variance indicated that the nature of gene action was non additive for all the characters, which results due to dominance, epistasis and other interaction effects with non fixable genetic variation. The presence of greater non-additive gene action offers scope for exploiting hybrid vigour through heterosis breeding and hence these parents can be further exploited for production of commercial hybrids (Panwar, 2005 and Tyagi et al., 2008).

The proportional contribution to total genetic variance by the testers was found to be higher for days to fifty per cent flowering, plant height, number of filled grains per panicle, spikelet fertility, grain yield, harvest index and total dry matter production. For other characters contribution from line x tester was higher. The testers exhibited higher GCA variance for the traits number of filled grains per panicle, spikelet fertility, days to 50 per cent flowering and relative water content in aerobic condition indicating the predominance of additive gene action. SCA variance due to lines x testers were significantly higher for days to 50 per cent flowering, panicle length, spikelet fertility, hundred grain weight, harvest index, SPAD values and relative water content in aerobic condition. These results indicate the predominance of non additive gene action for these traits under aerobic condition.

Per se performance and _gca_ effects of parents for yield and physiological traits

Evaluation of parents based on *per se* performance and *gca* effects separately might lead to contradiction in selection of promising parents since *per se* performance of parents was not always associated with high *gca* effects (Singh and Harisingh, 1985). Combination of both *per se* performance and *gca* effects will result in the selection of parents with good reservoir of superior genes. So, the parents were evaluated for high *per se* performance coupled with high *gca* effects.

For earliness, three CMS lines *viz.,*IR 68888A, IR 68897A and COMS 14 A and three male parents *viz.,* IR 62161-184-3-1-3-2, IR69715-72-1-3 and WCR 6 exhibited high mean performance combined with high *gca* effects (Table 2). Exhibition of earliness under water limited conditions is one of the drought evading mechanism as reported by Bhattacharya and Gosh (2004). Contribution of desirable alleles for earliness by these genotypes under aerobic condition is one of the desirable trait that can be utilized for developing short duration hybrids.

The parental lines *viz.,* IR 68888A, IR 68886A and IR69715-72-1-3, 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 (Tale 3). Atlin *et al.*(2004) also reported that intermediate plant height would be favourable for aerobic conditions compared to tall varieties.

More number of productive tillers is one of the important trait to increase the yield under aerobic system of rice production. High *per se* performance combined with positive significant *gca* effects were observed in the parents IR55838-B2-2-3-2-3, IR 72875-94-3-3-2, IR 71700-241-1-1-2 and WGL 32100 for number of productive tillers per plant (Table 4). Therefore, these genotypes possessing desirable alleles can be used as potential donors for improvement of number of productive tillers under aerobic condition. Nieuwenhuis *et al.* (2002) also quoted that in clay loam soil, the number of panicles are relatively high in aerobic condition due to the production of second generation tillers at reproductive stage.

Lengthy panicles are generally associated with higher number of spikelets per panicle resulting in higher productivity. The parents IR 72875-94-3-3-2, MTU 9992, WGL 14 and WGL 32100 were identified as good general combiners with high mean performance, indicating the presence of desirable genes for the expression of longer panicles (Table 5). Hence, these parents can be used in the breeding programme for improving panicle length under aerobic condition(Yadav *et al*., 1999).

Number of spikelets per panicle is one of the most important yield components that improves yield. High order *gca* effects in combination with high mean performance was exhibited by the male parents IR55838-B2-2-3-2-3, IR 72875-94-3-3-2, and WGL 14 for number of spikelets per panicle (Table 6). Fukai *et al.* (1991) reported that the number of spikelets determines grain number at anthesis and the proportion of spikelets that produce grains. This was further supported by Boonjung (1993) that the number of spikelets is directly related to the rate of assimilation between panicle initiation and anthesis, regardless of the alteration in assimilate production by water stress. Expression of desirable genes for this trait decides the grain filling per cent in hybrids which is due to the restoration ability of the male parents. The results indicated that these genotypes can be used as male parents to improve the number of filled grains in the hybrids.

With respect to spikelet fertility, the CMS line IR 68886A and 17 testers were selected as good general combiners. It was observed that few genotypes *viz.,* IR 71604-4-1-4-7-10-2-1-3, WCR 6, IR 77298-12-7 and IR 77298-5-6 which had high *gca* effect and mean, showed poor performance under aerobic conditions. The reduction in spikelet fertility in these genotypes may be due to the water stress in the aerobic condition (Ekanayake *et al.,*1989). Therefore, all the good general combiners identified under aerobic condition with desirable genes for spikelet fertility can be used as potential donors for hybrid rice breeding (Anandakumar *et al*., 2004).

Hundred grain weight, is one of the important characters that influence grain yield. The genotypes IR 68888A, COMS 14A, WGL 32100, WGL 14, IR55838-B2-2-3-2-3, IR 59624-34-2-2, IR 62161-184-3-1-3-2, IR 71700-247-1-1-2, MTU 5293, MTU 7029, and IR60979-150-3-3-3-2 were found to be good general combiners for this trait. These genotypes can be best utilized for developing good quality rice hybrids. Good general combiners with desirable alleles for 100 grain weight were reported by Yogameenakshi *et al.*(2003) under drought conditions. Cruz *et al.* (1986) also reported that a mild water stress at vegetative stage resulted in a linear decrease in 1000 grain weight but its influence on grain yield was not significant.

Chlorophyll meter quantifies the relative greenness of plants immediately 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 combined with high mean performance (Table 7). Higher *per se* performance was observed in 12 parental lines under aerobic condition. However, the combined effect of high mean and high *gca* effect was observed only in MTU 7029. 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.

Relative water content is one of the measures which gives an idea of tissue water status. Maintenance of higher plant water status under drought plays a central role in stabilizing the various plant processes and yield (Kumar and Kujur, 2003). Considering both per se performance and gca effects, 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 were adjudged as best general combiners because of their superiority in relative water content. The results indicate the presence of favourable genes for high relative water content in these genotypes. Therefore, these parents with high relative water content can be used as potential donors which would result in rice hybrids with tolerance to water deficit conditions.

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 identified to have desirable alleles for dry matter production based on high *per se* performance and *gca* effects. Therefore, these genotypes can be utilized as potential donors for developing rice hybrids with high dry matter production. In general, there is a reduction in total dry matter production in the genotypes grown under aerobic condition. It was also observed that most of the genotypes differed in their ability to produce high dry matter under aerobic condition (Chauhan *et al*., 1996).

For root dry weight, the parents, IR 68897A, IR 36, IR55838-B2-2-3-2-3, IR 71700-247-1-1-2, IR60979-150-3-3-3-2, PSBRC 82, and WGL 32100 were identified as good general combiners coupled with high *per se* performance. Drought resistant upland cultivars possess longer and thicker root system therefore selection for genotypes with high root weight could lead to improvement in other root traits (Chang *et al.*,1972). Hence, these genotypes possessing desirable genes for this trait can be further exploited for developing rice hybrids with higher root weight suitable for cultivation under aerobic conditions.

For shoot dry weight, the genotypes COMS 14A, IR 68886A, IR 68888A, MTU 5293, MTU 9992 and PSBRC 80 had desirable genes and were identified as good general combiners for shoot dry weight (Kalita and Upadhaya, 2000) and the genotypes IR 68897A, PSBRC 82, IR69715-72-1-3, WGL 32100, IR 72875-94-3-3-2, IR 36, IR55838-B2-2-3-2-3, IR 71700-247-1-1-2, IR60979-150-3-3-3-2 and IR 62030-54-1-2-2 were identified to have favourable genes for root shoot ratio.

Deep rooted cultivars extract more water than the shallow rooted genotypes. Based on *per se* performance and significant *gca* effects, three lines *viz.,* COMS 14A, IR 68886A, IR 68888A and six testers *viz.,* IR 69715-72-1-3, IR 71700-247-1-1-2, IR 77298-12-7, MTU 5293, PSBRC 82, and PSBRC 80 were identified as good general combiners for root length. The genotype PSBRC 80 was found superior for total dry matter, shoot dry weight, root dry weight and root length. Lilley and Fukai (1994) indicated that the cultivars with higher root length performed better than others under mild stress conditions. The expression of favourable genes for higher root length in these genotypes can be best utilized in the breeding programmes for developing rice hybrids with high root length.

Wann (1978) found that water stress during the reproductive stage appeared to affect the reproductive physiology, by interfering with pollination, fertilization and grain filling. In the present study, the line COMS14 A 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, IR69715-72-1-3, IR 72875-94-3-3-2, MTU 5293, MTU 7029, MTU 9992, PSBRC 80, PSBRC 82, WGL 14, WGL 32100 had high *gca* effects and high *per se* for grain yield per plant under aerobic condition

Harvest index is the major determinant of yield due to its direct and indirect contribution from crop growth rate, leaf area index and N uptake activity (Reuben and Katuli,1990). Eight genotypes *viz.,* COMS 14A, IR 36, IR55838-B2-2-3-2-3, IR 59624-34-2-2, IR 62030-54-1-2-2, IR69715-72-1-3, IR 72875-94-3-3-2, IR 71700-247-1-1-2, IR 72862-27-3-3, MTU 7029, MTU 9992, PSBRC 80, PSBRC 82, WGL 14, and WGL 32100 were found to have desirable genes for expression of high harvest index. These genotypes also registered higher grain yield indicating that grain yield and harvest index are highly associated with each other (Surek and Beser,1999). Saxena *et al*. (1996) reported that genotypes having greater tolerance to water stress recorded higher number of grains, grain weight, grain yield and harvest index under drought condition.

Summary

Many parental lines had shown its physiological efficiency in expressing the yield potential in many of the cross combinations. However, few aerobic cultures like IR 72875-94-3-3-2, IR 71604-4-1-4-7-10-2-1-3, PSBRC 80 and PSBRC 82 had high *per se* performance for most of the yield contributing traits and morpho physiological traits. The hybrids *viz.,* IR 68886A x IR 72875-94-3-3-2, IR 68888A x IR 72875-94-3-3-2 and COMS 14A x IR 72875-94-3-3-2 involving the male parent IR 72875-94-3-3-2 had higher grain yield under aerobic condition (Table 8). The hybrid combination IR 68888A x IR 72875-94-3-3-2 having high yield potential and physiological efficiency for varied traits, is being under evaluation in advanced yield trials. Similarly, many hybrid combinations are under evaluation in advanced yield trials, with physiologically potential testers as one of its male parent. In addition to this, two female parents IR 68888A and COMS 14A and four male parents IR55838-B2-2-3-2-3, IR 36, WGL 14 and WGL 32100 had good performance for most of the yield contributing traits and physiological parameters under aerobic condition and had proved its ability that they can be used in the breeding programmes for developing rice hybrids suitable for aerobic condition.. The hybrids developed from these parental lines *viz.,* IR 68888A x IR55838-B2-2-3-2-3, IR 68888A x IR 36, IR 68888A x WGL 14, IR 68888A x WGL 32100, COMS 14A x IR55838-B2-2-3-2-3, COMS 14A x IR 36, COMS 14A x WGL 14 and COMS 14A x WGL 32100 were found superior for most of the yield and physiological traits under aerobic condition. Based on the suggestions given by several workers, that continuous flooding is not essential for higher grain yield but the practice of intermittent submergence at critical stages of crop gives better yield, these parental materials could be better utilized as valuable basic materials in developing high yielding rice hybrids for water limited conditions.

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Table 1. Analysis of variance for combining ability under aerobic condition for different biometrical traits

Source of variance	df	Days to 50% flowering	Plant height	No. of productive tillers plant^{-1}	Panicle length	No.of spikelets panicle^{-1}	No. of filled grains panicle^{-1}	Spikelet fertility per cent	100-grain weight
Replication	1	0.14	2.95	7.04	1.58	170.05	77.78	56.70	0.001
Hybrids	87	123.26**	60.03**	6.37**	5.19	1322.66	2570.72	283.09	0.104
Lines	3	283.08**	28.72	0.71	14.26**	937.20	698.22	313.59	1.20 **
Testers	21	310.71**	133.32**	10.19*	9.63	2492.57**	8148.84**	956.68**	0.11**
Lines x Testers	63	53.17**	37.10**	5.36**	3.28	951.04**	806.11**	57.11**	0.048**
Error	87	1.84	3.01	1.91	1.59	252.50	74.69	9.23	0.002
σ^2 *gca*	-	0.85	0.28	0.01	0.02	4.49	21.39	2.73	0.001
σ^2 *sca*	-	25.66	17.04	1.73	0.85	349.27	362.91	23.94	0.022

Source of variance	df	SPAD at flowering	RWC at flowering	Total dry matter pro-duction (g/ plant)	Shoot weight (g)	Root shoot ratio	Root dry weight (g/ plant)	Root length (cm)	Grain yield plant^{-1}	Harvest Index
Replication	1	127.25	176.38	8.63	2.48	0.001	1.86	3.01	0.06	0.0004
Hybrids	87	10.44	32..15	41.23	43.67	0.002	6.01	10.03	169.68	0.019
Lines	3	59.92	15.06	178.07	241.68	0.007	7.29	64.47	65.68	0.002
Testers	21	10.68	59.70	83.79	60.84	0.003	11.49	15.80	550.29**	0.060
Lines x Testers	63	8.00	23.78	20.52	28.51	0.002	4.12	5.52	49.406**	0.007
Error	87	1.48	6.76	4.38	6.14	0.000	1.07	2.20	2.73	0.001
σ^2 *gca*	-	0.029	0.101	0.250	5.581	0.000	0.023	0.055	1.47	0.002
σ^2 *sca*	-	3.259	8.510	8.074	11.18	0.001	1.527	1.658	22.52	0.003

* Significance at 5% level; **:Significance at 1% level

Table 2. *Per se* performance of lines for different yield and physiological traits

Sl. No.	Characters	IR 68886A	IR 68888A	IR 68897A	COMS 14 A	SE (L)	CD (P = 05)	CD (p= 01)
1.	Days to 50% flowering	83.00	88.50	91.00	92.50**	0.99	2.75	3.62
2.	Plant height (cm)	67.65	73.35	75.55**	81.45**	3.44	9.54	12.56
3.	No. of productive tillers plant^{-1}	11.00	11.00	12.00*	14.00**	0.90	2.49	3.27
4.	Panicle length (cm)	22.00	23.50**	21.75	23.45**	0.78	1.17	1.86
5.	No.of spikelets panicle^{-1}	130.00	144.50**	135.50	134.00	9.94	27.55	36.27
6.	No. of filled grains panicle^{-1}	117.00	119.00**	118.50	120.50**	6.74	18.69	24.61
7.	Spikelet fertility (%)	89.95**	82.70	87.25	90.05**	2.25	6.24	8.22
8.	100 grain weight (g)	1.88	2.04**	2.05**	1.96	0.03	0.08	0.11
9.	Grain yield plant^{-1} (g)	31.55**	29.30**	23.90	30.80**	1.16	3.22	4.23
10.	Harvest index	0.50**	0.41*	0.31	0.44**	0.02	0.05	0.07
11.	SPAD value	36.85	34.83	36.81	39.89**	0.84	2.33	3.07
12.	Relative water content (%)	67.18	68.88	68.91	70.85**	1.76	4.87	6.41
13.	Total dry matter production (g/ plant)	62.20	71.55**	77.35**	69.30	1.44	4.00	5.27
14.	Shoot dry weight (g)	49.90	59.61**	66.44**	58.87**	1.67	4.71	6.20
15.	Root : Shoot ratio	0.25**	0.20*	0.16	0.18	0.01	0.04	0.05
16.	Root dry weight (g/ plant)	12.30**	11.94**	10.91	10.43	0.71	1.96	2.58
17.	Root length (cm)	26.25**	26.40**	24.00	24.55	0.96	2.65	3.49

* Significance at 5% level; **: Significance at 1% level

Table 3. General combining ability effects of lines for different yield and physiological traits

Sl. No.	Characters	IR 68886A	IR 68888A	IR 68897A	COMS 14 A	SE (L)	CD (P = 05)	CD (P= 01)
1.	Days to 50% flowering	3.71 **	-1.97 **	-1.13 **	-0.61 **	0.20	0.57	0.76
2.	Plant height (cm)	1.08 **	-0.88 **	-0.10	-0.10	0.26	0.73	0.97
3.	No. of productive tillers $plant^{-1}$	-0.02	0.18	-0.06	-0.10	0.21	0.58	0.77
4.	Panicle length (cm)	0.79 **	-0.25	-0.02	-0.53 **	0.19	0.53	0.71
5.	No.of spikelets $panicle^{-1}$	3.53	-3.52	4.41	-4.43	2.39	6.71	8.91
6.	No. of filled grains $panicle^{-1}$	-0.04	4.78 **	0.23	-4.97 **	1.30	3.65	4.85
7.	Spikelet fertility (%)	3.47 **	0.68	-2.44 **	-1.71 **	0.46	1.28	1.71
8.	100 grain weight (g)	0.14 **	-0.02 **	0.10 **	-0.21 **	0.01	0.02	0.02
9.	Grain yield $plant^{-1}$ (g)	-0.06	0.31	-1.60 **	1.35 **	0.25	0.70	0.93
10.	Harvest index	-0.00	-0.00	-0.00	0.01 **	0.01	0.01	0.01
11.	SPAD value	-0.48*	1.68**	-0.99**	-0.21	0.18	0.51	0.68
12.	Relative water content (%)	-0.19	-0.71	0.65	0.25	0.39	1.10	1.46
13.	Total dry matter production (g/ plant)	1.29**	0.30	-2.93**	1.34**	0.32	0.88	1.17
14.	Shoot dry weight (g)	1.23 **	0.69 *	-3.48 **	1.55 **	0.37	0.74	0.98
15.	Root : Shoot ratio	-0.002 **	-0.01 **	0.02 **	-0.01 **	0.01	0.01	0.01
16.	Root dry weight (g/ plant)	0.06	-0.39*	0.54**	-0.21	0.16	0.44	0.58
17.	Root length (cm)	0.61**	0.44*	-1.81**	0.76**	0.22	0.63	0.83

* Significance at 5% level; **:Significance at 1% level

Table. 4. Mean performance of testers for different biometrical traits

S. No	Parents	Days to 50% flowering	Plant height (cm)	No. of productive tillers plant^{-1}	Panicle length (cm)	No.of spikelets panicle^{-1}	No. of filled grains panicle^{-1}	Spikelet fertility (%)	100 grain weight (g)	Grain yield plant^{-1} (g)	Harvest Index
1	IR 36	94	78.15	11	25.00**	134	122.5	91.55**	2.29**	34.60**	0.45**
2	IR55838-B2-2-3-2-3	106.00**	86.85**	14.00**	24.25**	162.50**	145.50**	89.60**	1.88	34.80**	0.47**
3	IR 59624–34-2-2	85.5	84.40**	12.50**	24.25**	209.50**	143.00**	92.10**	1.94	31.75**	0.47**
4	IR 60979-150-3-3-3-2	113.50**	72.45	11	23.75**	133.5	122.5	91.85**	1.93	25.2	0.32
5	IR 62030-54-1-2-2	94	74.7	10.5	23.25	128	119.5	93.35**	1.87	25.1	0.36
6	IR 62161-184-3-1-3-2	94	81.45**	11	22.75	154.50**	131.00**	84.8	2.33**	28.2	0.41
7	IR 69715-72-1-3	96.5	76.2	11.5	25.00**	120.5	110.5	91.70**	1.94	26.6	0.37
8	IR 71700-247-1-1-2	100.5	81.90**	11.5	24.25**	136	119	87.4	1.86	33.80**	0.47**
9	IR 71604-4-1-10-2-1-3	99	76.8	10	24.00**	159.00**	135.50**	85.25	1.9	25.75	0.38
10	IR 72862-27-3-3	97. 00	73.05	10.5	24.15**	141	129.00**	91.50**	1.94	31.30**	0.45**
11	IR 72875-94-3-3-2	100	84.9	13.00**	23.75**	157.00**	138.50**	88.2	2.19**	36.95**	0.50**
12	IR 77298-5-6	99	83.3	11	25.00**	146	125	85.65	1.99**	36.90**	0.54**
13	IR 77298-12-7	99	87.40**	11	20.6	142	122.5	86.65	2.01**	36.40**	0.57**
14	MTU 5293	118.50**	83.10**	12.00**	22.85	123	114	92.70**	2.22**	27.2	0.39
15	MTU 7029	116.00**	73.35	12.00**	21	161.50**	147.00**	91.00**	1.76	27.35	0.39
16	MTU 9992	107.50**	75.35	13.50**	24.75**	113	104	92.00**	2.04**	39.10**	0.51**
17	PSBRC 80	97.5	76.5	12.50**	23.1	146	125	85.7	2.26**	23.25	0.52**
18	PSBRC 82	101	79.8	13.50**	24.00**	152.50**	134.50**	88.15	2.39**	32.30**	0.48**
19	PR 114	111.00**	74.2	10	23.65	159.00**	137.00**	86.2	2.14**	26.4	0.4
20	WGL14	111.50**	85.3	12.00**	24.00**	168.50**	154.50**	91.75	1.44	32.05**	0.45**
21	WGL 32100	101.5	84.10**	13.50**	25.25**	141	123.5	87.55	1.6	34.30**	0.46**
22	WCR 6	95	80.45**	10.5	22.6	134	117	87.35	2.00**	24.25	0.37
	SE (T)	0.992	3.443	0.897	0.783	1.938	1.744	2.252	0.029	1.16	0.018
	CD (P = 05)	2.751	2.543	0.487	2.169	2.547	1.692	2241	0.081	3.215	0.05
	CD (P = 01)	3.621	3.563	0.273	2.855	3.261	2.605	3215	0.106	4.231	0.066

* Significance at 5% level; **:Significance at 1% level

Table 5. *Per se* performance of testers for different physiological traits

S. No.	Parents	SPAD value	Relative water content (%)	Total dry matter production (g/ plant)	Shoot dry weight (g)	Root : Shoot ratio	Root dry weight (g/ plant)	Root length (cm)
1	IR 36	37.00	71.66	73.55	63.51	0.16	10.05	27.55
2.	IR55838-B2-2-3-2-3	36.56	70.99	72.85	63.43	0.15	9.41	24.45
3.	IR 59624–34-2-2	37.19	68.88	67.30	58.40	0.15	8.90	26.05
4.	IR 60979-150-3-3-3-2	33.98	65.88	78.20	70.10	0.12	8.10	25.20
5.	IR 62030-54-1-2-2	38.26	67.36	70.85	60.26	0.18	10.59	24.40
6.	IR 62161-184-3-1-3-2	37.48	66.17	69.30	58.75	0.18	10.55	25.00
7.	IR 69715-72-1-3	34.23	71.15	71.60	57.89	0.24	13.72	26.10
8.	IR 71700-247-1-1-2	33.26	79.45	75.30	61.49	0.23	13.82	25.70
9.	IR 71604-4-1-10-2-1-3	32.08	73.75	67.75	60.51	0.12	7.23	25.80
10.	IR 72862-27-3-3	34.48	77.25	69.80	59.34	0.18	10.47	25.20
11.	IR 72875-94-3-3-2	74.43	36.85	74.90	60.82	0.23	14.08	24.15
12.	IR 77298-5-6	78.68	37.60	68.60	58.55	0.17	10.05	25.90
13.	IR 77298-12-7	62.75	35.55	64.30	52.89	0.22	11.41	23.00
14.	MTU 5293	62.23	33.95	70.90	57.98	0.22	12.92	24.45
15.	MTU 7029	62.12	37.35	71.55	61.14	0.17	10.41	23.20
16.	MTU 9992	66.40	34.24	77.35	66.96	0.16	10.39	26.15
17.	PSBRC 80	72.35	34.83	73.15	61.27	0.19	11.88	24.65
18.	PSBRC 82	73.46	35.85	66.30	55.93	0.19	10.38	25.10
19.	PR 114	64.15	36.47	64.70	52.85	0.23	11.85	24.65
20.	WGL14	71.02	36.34	78.80	67.46	0.17	11.34	26.05
21.	WGL 32100	70.78	34.33	73.70	64.63	0.14	9.07	26.90
22.	WCR 6	52.20	34.31	65.35	56.32	0.16	9.03	24.00
	SE (T)	0.841	1.758	1.443	1.670	0.014	0.707	0.958
	CD (P = 05)	2.332	4.872	4.000	4.712	0.038	1.960	2.654
	CD (P = 01)	3.069	6.413	5.265	6.202	0.050	2.581	3.494

* Significance at 5% level; **:Significance at 1% level

Table 6. General combining ability effects of testers for different biometrical traits (cont..)

S. No	Parents	Days to 50% flowering	Plant height (cm)	No. of productive tillers plant^{-1}	Panicle length (cm)	No.of spikelets panicle^{-1}	No. of filled grains panicle^{-1}	Spikelet fertility (%)	100 grain weight (g)	Grain yield plant^{-1} (g)	Harvest Index
1	IR 36	-0.84	3.91**	0.48	0.28	-5.78	15.65**	6.28**	0.12**	9.44 **	0.11**
2	IR55838-B2-2-3-2-3	4.66**	6.94**	1.63 **	0.73	31.60 **	38.4**	7.64**	-0.07**	7.86 **	0.07**
3	IR 59624–34-2-2	-8.46**	-4.35**	0.07	-0.39	10.85	18.53**	6.14**	-0.04**	2.61 **	0.03**
4	IR 60979-150-3-3-3-2	3.66**	1.39*	-0.65	0.69	3.1	6.28*	3.64**	-0.06**	-2.88 **	-0.01
5	IR 62030-54-1-2-2	-7.46**	-0.95	0.41	-0.44	5.97	11.53**	4.96**	-0.01	3.54 **	0.05**
6	IR 62161-184-3-1-3-2	-10.09**	0.36	-0.29	0.42	7.22	13.9**	6.23**	-0.09**	2.61 **	-0.02
7	IR 69715-72-1-3	-6.21**	-3.39**	0.6	-0.02	4.22	15.03**	6.93**	0.13**	4.69 **	0.06**
8	IR 71700-247-1-1-2	3.41	3.3**	0.97*	0.51	-20.65	6.28*	4.36**	-0.06**	4.10 **	0.07**
9	IR 71604-4-1-10-2-1-3	2.79**	-5.09**	0.07	-0.93 *	-26.53	-59.1**	-19.10**	0	-12.23 **	-0.12**-
10	IR 72862-27-3-3	2.04**	1.85**	-2.08 **	-0.94 *	-36.03**	-68.6**	21.80**	0.36**	-10.39 **	0.12**
11	IR 72875-94-3-3-2	4.16**	8.95**	2.38 **	1.27 **	13.47 *	20.15**	6.89**	0.21**	8.55 **	0.08**
12	IR 77298-5-6	1.91**	-2.62**	-1.70 **	0.44	-4.28	-49.6**	-21.46**	0	-13.90 **	-0.14
13	IR 77298-12-7	1.41**	-4.92**	-1.95 **	0.18	-7.53	-41.72**	-17.37**	0.06**	-16.64**	-0.17**
14	MTU 5293	7.91**	2.33**	-0.4	0.44	7.22	12.53**	4.64**	-0.09**	3.60**	0.01
15	MTU 7029	9.66**	-4.02**	-0.13	-2.06 **	-2.4	6.53*	5.61**	-0.28**	2.50**	0.04**
16	MTU 9992	6.41**	0.33	0.06	0.92 *	0.72	12.4**	7.88**	-0.01	4.60**	0.04**
17	PSBRC 80	-7.34**	-2.4**	0.21	-0.82	8.22	10.28**	0.33	0	7.04**	0.07**
18	PSBRC 82	1.54**	3.84**	-0.27	0.31	8.72	16.9**	6.53**	0.03	9.19**	0.09**
19	PR 114	-5.46**	-3.64**	0.02	-0.4	-26.90 **	-13.1**	5.04**	0.03*	-2.81**	-0.02**
20	WGL14	5.79**	4.79**	0.9	1.62 **	35.85 **	42.78**	7.11**	-0.06**	1.99**	0.02*
21	WGL 32100	2.41**	-2.5**	1.26 *	1.27 **	9.85	31.4**	**6.9****	-0.29**	1.76**	0.03
22	WCR 6	- 11.90**	-4.14**	-1.57 **	-3.06 **	-16.90**	-46.47**	-17.35**	0.14**	-15.19**	-0.18**
	SE (T)	0.48	0.614	0.489	0.445	5.618	3.0555	1.074	0.015	0.584	0.009
	CD (P = 05)	1.344	1.719	1.369	1.247	15.731	8.556	3.008	0.042	1.656	0.024
	CD (P = 01)	1.785	2.283	1.819	1.656	20.896	11.364	3.995	0.056	2.173	0.032

* Significance at 5% level; **:Significance at 1% level

Table 7. General combining ability effects of testers for different physiological traits

S. No.	Parents	SPAD value	Relative water content (%)	Total dry matter production (g/ plant)	Shoot dry weight (g)	Root : Shoot ratio	Root dry weight (g/ plant)	Root length (cm)
1	IR 36	0.08	2.63**	2.99**	2.09	0.01 **	0.90*	-1.51**
2	IR55838-B2-2-3-2-3	-1.02	2.13*	3.45**	1.24	0.03 **	2.21**	0.04
3	IR 59624–34-2-2	0.73	1.17	0.42	0.81	-0.01 **	-0.4	-0.01
4	IR 60979-150-3-3-3-2	-0.14	-7.63**	-1.82**	-2.82 **	0.028 **	0.99**	-1.46**
5	IR 62030-54-1-2-2	-1.44**	-0.78	-0.01	-0.142 **	0.002 **	0.13	-2.23**
6	IR 62161-184-3-1-3-2	-0.46	0.5	-0.71	-0.502 **	-0.03 **	0.21	-1.45**
7	IR 69715-72-1-3	0.71	2.57**	0.17	-0.41 **	0.01 **	0.57	2.58**
8	IR 71700-247-1-1-2	-0.32	0.88	-2.00**	-3.561 **	0.03 **	1.57**	1.28*
9	IR 71604-4-1-10-2-1-3	0.01	-5.35**	-5.70**	-4.70 **	-0.02 **	-1.00**	-1.45**
10	IR 72862-27-3-3	0.72	-1.65	-1.21	0.52	-0.02 **	-1.73**	-0.72
11	IR 72875-94-3-3-2	-0.73	1.62	4.34**	2.48	0.02 **	-1.87**	-0.62
12	IR 77298-5-6	0.34	-0.34	-6.23**	-5.44 **	0.01 **	-0.80*	-0.73
13	IR 77298-12-7	0.81	-2.98**	-4.75**	-3.48**	-0.01 **	-1.27**	1.14*
14	MTU 5293	0.86*	-0.16	5.65**	5.28 *	-0.01 **	0.41	2.30**
15	MTU 7029	1.01*	0.07	-1.47*	0.49	-0.03 **	-1.96**	-0.4
16	MTU 9992	-0.36	-0.75	2.58**	3.29 *	-0.02 **	-0.71	-0.21
17	PSBRC 80	0.92*	1.88**	2.92**	3.06 *	-0.01 **	-0.15	1.99**
18	PSBRC 82	-1.65**	2.27*	2.85**	1.44	0.02 **	1.41**	2.17**
19	PR 114	-1.56**	-1.96*	-1.27	-0.14 **	-0.02 **	-1.14**	-0.82
20	WGL14	-0.84	4.23**	3.00**	2.97	-0.01 **	0.03	-0.47
21	WGL 32100	-1.11*	1.87*	-0.23	-1.02 **	0.01 **	0.79*	0.75
22	WCR 6	3.45**	-0.21	-2.97	-1.45 **	-0.02 **	-1.53**	-1.11*
	SE (T)	0.43	0.92	0.74	0.88	0.01	0.37	0.53
	CD (P = 05)	1.21	2.57	2.07	1.74	0.01	1.03	1.47
	CD (P = 01)	1.6	3.42	2.75	2.31	0.02	1.36	1.95

Table 8. Promising hybrid combinations identified under aerobic condition

Sl.No.	Hybrids	*Per se*		*gca* effects		*gca* reaction	Grain yield (g)	% of yield increase over check
		Line	Tester	Line	Tester			
1.	IR 68886 A x IR 36	31.55**	34.60**	-0.06	9.44 **	L x H	49.3	22.5
2.	IR 68886 A x IR55838-B2-2-3-2-3	31.55**	34.80**	-0.06	7.86 **	L x H	46.9	16.5
3.	IR 68886 A x IR 59624 –34-2-2	31.55**	31.75**	-0.06	2.61 **	L x H	45.75	13.64
4.	IR 68886 A x IR69715-72-1-3	31.55**	26.6	-0.06	4.69 **	L x H	49.4	22.7
5.	IR 68886 A x IR 71604--4- 7-10-2	31.55**	25.75	-0.06	-12.23 **	L x L	49.55	23.08
6.	IR 68886 A x IR 72862-27-3-2-3	31.55**	31.30**	-0.06	-10.39 **	L x L	46.7	16
7.	IR 68886 A x IR 72875-94-3-3-2	31.55**	36.95**	-0.06	8.55 **	L x H	51	26.68
8.	IR 68886 A x MTU 7029	31.55**	27.35	-0.06	2.50**	L x H	47.75	18.6
9.	IR 68886 A x MTU 9992	31.55**	39.10**	-0.06	4.60**	L x H	46.85	16.37
10.	IR 68886 A x PSBRC 80	31.55**	23.25	-0.06	7.04**	L x H	49.05	21.7
11.	IR 68886 A x PSBRC 82	31.55**	32.30**	-0.06	9.19**	L x H	50.4	25.19
12.	IR 68888 A x IR 36	29.30**	34.60**	0.31	9.44 **	L x H	46.85	16.37
13.	IR 68888 A x IR55838-B2-2-3-2-3	29.30**	34.80**	0.31	7.86 **	L x H	49.4	22.7
14.	IR 68888 A x IR 62161-184-1-3-2	29.30**	28.2	0.31	2.61 **	L x H	47.7	18.48
15.	IR 68888 A x IR 71604-7-10-2-1-3	29.30**	25.75	0.31	-12.23 **	L x L	48.75	21.09
16.	IR 68888 A x IR 72875-94-3-3-2	29.30**	36.95**	0.31	8.55 **	L x H	54.9	36.36
17.	IR 68888 A x MTU 5293	29.30**	27.2	0.31	3.60**	L x H	49.6	23.2
18.	IR 68888 A x MTU 9992	29.30**	39.10**	0.31	4.60**	L x H	46.3	15
19.	IR 68888 A x PSBRC 80	29.30**	23.25	0.31	7.04**	L x H	49	21.71
20.	IR 68888 A x PSBRC 82	29.30**	32.30**	0.31	9.19**	L x H	50	24.19
21.	IR 68888 A x WGL 14	29.30**	32.05**	0.31	1.99**	L x H	49.25	22.33
22.	IR 68888 A x WGL 32100	29.30**	34.30**	0.31	1.76**	L x H	49	21.71