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Combining ability analysis for morphological, physiological and root traits in aerobic rice

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ABSTRACT

Thirty hybrids generated from crossing five lines with six testers were studied along with parents for combining ability and gene action involved in expression of characters in aerobic rice. The gca and sca effects were significant for all the characters indicating the importance of both additive and non-additive genetic components. There was predominance of non-additive genetic components for expression of different traits in the present set of materials. Amongst the parental lines, IR 73718-3-1-3-3 and CT-6510-24-1-2 were best general combiners for grain yield along with other traits. The most specific combiners for grain yield and other traits were IR 67684A /CT-6510-24-1-2, IR 68885A / IR 73718-3-1-3-3, IR 70372A / PSBRC 80 and IR 70369A / IR 73718-3-1-3-3.

***Key words**: aerobic rice, combining ability, gene action, root traits*

Asia's food security depends largely on irrigated rice, which produces three quarters of all rice harvested. However, the increasing scarcity of fresh water threatens the sustainability of the irrigated rice ecosystem (Tuong and Bouman, 2002). Hence, growing rice aerobically like an irrigated upland crop, helps in sustaining rice production in Asia. For rice to be successful as an aerobic crop, it should tolerate intermittent water deficits and high soil impedance created due to aerobic conditions (Lafitte and Bennett, 2002). Therefore, any breeding programme towards the genetic improvement of rice for aerobic environment must emphasize on the morphological, physiological and root traits associated with the water uptake, maintenance of plant water status, and plant growth under water stress (Atlin and Lafitte, 2002). So far, there has been no major efforts on this front. Hybrid rice with its vigorous and more active root system tolerates moderate stresses caused due to limited irrigation water and therefore can be exploited under aerobic conditions (Virmani, 2001). Yield is a quantitative character and therefore selection of parents for hybridization is a complex problem. Combining ability analysis helps in identification of suitable parents for exploitation in breeding programmes. Keeping this in view, thirty rice hybrids along with their parents were evaluated to identify the lines with good combining ability and to identify good specific crosses based on the characters associated with water stress tolerance for exploitation of heterosis, under aerobic conditions.

MATERIALS AND METHODS

Five CGMS lines *viz.,* IR 67684A, IR 68885A, IR 68887A, IR 70369A and IR 70372A were crossed with six diverse testers *viz.,* PSBRC 80, PSBRC 82, CT-6510-24-1-2, APO (IR 55423-01), IR 73005-23-1-3-3 and IR 73718-3-1-3-3 during dry season 2006 and 2007 at Tamil Nadu Agricultural University to generate suffiecient amount of seeds. Crossing was done by adopting clipping method. The resultant hybrids were evaluated along with their parents and three standard checks ADTRH 1, CORH 2 and CT-6510-24-1-2 in a randomized block design, replicated thrice. Single seedling was transplanted hill^{-1}. The transplanted crop was maintained under flooded condition (2-3 cm water layer) for 15 days to ease the establishment of the crop. Thereafter, aerobic condition was imposed *i.e.* irrigation was applied to bring the soil water content in the root zone up to field capacity after it has reached a certain lower threshold (*e.g.,* half way between field capacity and wilting point) (Bouman, 2001). The recommended package of practices and plant protection measures for hybrid rice were adopted. Data were recorded on days to 50% flowering, number of productive tillers per plant, spikelet fertility, relative water content (RWC)at flowering, membrane integrity (% leakage) at flowering, leaf rolling, catalase activity, transpiration rate, stomatal conductance, root length, root volume, root dry weight and grain yield on five randomly selected plants per each replication. Days to fifty percent flowering was recorded on plot basis. For recording root characters plants were uprooted at the time of maturity and traits were measured. Transpiration rate and stomatal conductance were recorded using Steady State Porometer PMR 5. Standard procedures were followed for recording observations on RWC, leaf rolling and catalase activity. Data obtained were subjected to Line x Tester analysis (Kempthrone, 1957) to estimate general and specific combining ability effects and their respective variances.

RESULTS AND DISCUSSION

The analysis of variance for combining ability indicated that variances due to lines, testers and interaction effect (Line × Tester) were highly significant for all the characters (Table 1). This trend indicated the presence of both additive and non additive gene action. Further analysis of General combining ability (GCA)/ Specific combining ability (SCA) variance showed that the nature of gene action as non additive for all the traits. The *sca* variance was higher for all the characters (Table 1) indicating the role of non additive gene action, which results from dominance, epistasis and various other interaction effects with, non fixable genetic variation. The presence of greater non additive gene action offers scope for exploiting hybrid vigor through heterosis breeding and hence these parents can be further exploited for production of commercial hybrids. Malarvizhi (2005) also reported that non additive gene action was greater than additive gene action for yield and most of its components.

The percentage contribution of testers was high in comparison to lines for all the traits except membrane integrity (% of leakage) at flowering, catalase activity at flowering and root length (Table 1) showing that testers were diverse for these characters and hence could be better utilized for heterosis breeding.

Table 1. Analysis of variance for combining ability for different morphological, physiological and root characters in aerobic rice

Source of variation	df	Days to 50 % flowering	No. of productive tillers plant^{-1}	Spikelet fertility (%)	Relative water content at flowering	Membrane integrity (% of leakage) at flowering	Leaf rolling (secs.)	Catalase activity at flowering (µg/g/minute)	Transpiration rate at flowering (mmol/m^2/sec)	Stomatal conductance at flowering (mmol/m^2/sec)	Root length (cm)	Root volume (cc)	Root dry weight (g)	Grain yield (g)
Replication	1	0.30	0.75	0.41	0.60	0.22	18.20	0.35	0.029	0.03	0.25	0.09	0.0001	2.48
Parents	10	97.28**	6.07**	28.99**	25.33**	23.92**	5611.74**	19.24**	0.282**	64.28**	19.77**	61.22**	1.169**	9.46**
Hybrids	29	97.61**	7.78**	2012.61**	20.25**	11.83**	4708.09**	51.87**	0.731**	65.22**	18.26**	111.17**	2.519**	64.28**
Parents Vs Hybrids	1	201.75**	19.65**	4178.43**	119.32**	199.30**	626.41**	129.17**	3.460**	21.71**	3.70*	896.36**	20.675**	114.66**
Lines	4	242.35**	3.82**	1979.49**	8.56**	18.25**	9431.05**	79.63**	0.212**	17.01**	21.57**	88.74**	1.312**	24.80**
Testers	5	220.54**	11.87**	5542.58**	26.46**	10.82**	7893.64**	28.10**	1.834**	169.23**	6.48**	188.50**	6.539**	147.04**
L x T	20	48.90**	7.63**	1312.13**	20.96**	10.96**	3283.82**	52.05**	0.597**	52.45**	20.07**	99.44**	1.919**	54.31**
Error	29	1.03	0.77	0.59	1.60	0.32	8.04	0.75	0.043	0.39	0.43	1.90	0.0887	0.98
σ^2 GCA	-	14.04	0.016	188.38	-0.265	0.27	413.73	0.14	0.032	3.13	-0.46	3.01	0.15	2.43
σ^2 SCA	-	23.93	3.42	655.77	9.68	5.32	1637.88	25.63	0.277	26.03	9.82	48.77	0.91	26.66
σ^2 GCA/ σ^2 SCA	-	0.58	0.01	0.28	-0.02	0.05	0.25	0.01	0.12	0.12	-0.05	0.06	0.16	0.09

*significant at 5 per cent level; ** significant at 1 per cent level

Estimates of *gca* effects (Table 2) revealed that male parents IR 73718-3-1-3-3 and CT-6510-24-1-2 were found to be good general combiners for grain yield. High *gca* effect of IR 73718-3-1-3-3 for grain yield was associated with its high *gca* effect for number of productive tillers per plant, spikelet fertility, RWC and root characters and significant negative *gca* effects for transpiration rate and stomatal conductance at flowering. Better combining ability of CT-6510-24-1-2 for grain yield was due to its high *gca* effect for number of productive tillers per plant, spikelet fertility and leaf rolling. Among the female parents, IR 67684 A and IR 70369A were the best general combiner for yield. High *gca* effects of IR 70369 A for grain yield may be associated with its high *gca* effects for spikelet fertility, root characters and physiological character like catalase, and negative *gca* effects for membrane integrity (% of leakage) and earliness. In IR 67684 A, high *gca* effects for yield and spikelet fertility were due to its negative *gca* effect for transpiration rate and stomatal conductance at flowering and positive *gca* effect for leaf rolling.

Earliness is a desirable trait for aerobic condition and parents showing good combining ability were IR 68885A, IR 68887A, IR 70369A, PSBRC 80 and CT-6510-24-1-2 (Table 2). These genotypes can be utilized for developing short duration hybrids. With respect to water stress tolerant traits, the CGMS line IR 70372A was a good general combiner for relative water content, leaf rolling, catalase activity, root volume, root length and root dry weight and tester PSBRC 80 for relative water content, membrane integrity, catalase activity at flowering, transpiration rate and stomatal conductance. Therefore, these genotypes with desirable genes for physiological and root traits can be used as potential donors for improvement of water stress tolerance.

It is observed that a total of fourteen crosses out of thirty crosses exhibited positive and significant *sca* effects for grain yield (Table 3). The promising specific combinations for grain yield and other traits were IR 67684A / CT-6510-24-1-2, IR 68885A / IR 73718-3-1-3-3, IR 70372A / PSBRC 80 and IR 70369A / IR 73718-3-1-3-3. It is observed that majority of the crosses with high *sca* effects for grain yield were involved with high/low combiners indicating additive x dominance type of gene interactions for expression of traits. Like wise crosses involving high/high general combiners showed high *gca* effects which could be due to predominance of additive x additive gene action. Also, a very few crosses having low/low general combiners showed high *sca* effects suggesting the epistatic gene action may be operating due to genetic diversity in the form of heterozygous loci. Thus in majority of the crosses, high *sca* effects for grain yield were attributed to additive and dominance gene actions and only few cases attributed to epistatic interactions. Similar result was reported by Pradhan and Singh (2008).

Negative estimates of *sca* are desirable for traits like earliness, membrane integrity (% of leakage), transpiration rate and stomatal conductance under aerobic condition. Cross combination showing desirable *sca* effects for earliness was IR 68885A/ IR 73718-3-1-3-3. Under stress, early maturing hybrids are desirable as they are more efficient in partitioning carbohydrate to the panicle and producing more yield per day ((Atlin and Lafitte, 2002). Plants maintaining high membrane integrity and function, low transpiration rate and stomatal conductance are desirable under water stress as they are associated with the conservation of leaf moisture (Premchandra *et al.,* 1990; O'Toole and Chang, 1979). In the present study, the hybrids IR 67684 A/CT 6510-24-1-2 and IR 70369 A/ IR 73718-3-1-3-3 exhibited desirable *sca* effect for these characters.

The root characters such as root volume, root length, and root thickness are positively correlated with the measures of water stress tolerance and plant recovery from stress and are used as selection criteria in the screening of water stress tolerant genotypes (O'Toole and Chang, 1979). Sorte *et al.* (1992) reported that a cultivar which partitions more of its dry weight in root can explore more soil volume for extracting water and thus can effectively sustain drought. Cross combination with high *sca* effects for root traits were IR 67684 A/CT 6510-24-1-2 and IR 68885 A/ IR 73718-3-1-3-3. The hybrid IR 67684 A/CT 6510-24-1-2 possessing favourable alleles for root characters was found to exhibit significant *sca* effect for morphological characters like productive tillers, spikelet fertility, RWC and physiological character like catalase activity. So it can de better utilized under aerobic condition.

From the study it is revealed that the importance of good x good general combiners exhibiting high *sca* effects can be utilized for improvement through single

Table 2. Estimates of general combining effects of parents

Name of Genotypes	Days to 50 % flowering	No. of productive tillers plant^{-1}	Spikelet fertility (%)	Relative water content at flowering	Membrane integrity (% of leakage) at flowering	Leaf rolling (secs.)	Catalase activity at flowering (μgg^{-1}minute^{-1})	Transpiration rate at flowering (mmolm^{-2}sec^{-1})	Stomatal conductance at flowering (mmolm^{-2}sec^{-1})	Root length (cm)	Root volume (cc)	Root dry weight (g)	Grain yield (g)	Combiner for yield
Female (lines)														
IR 67684 A	6.13**	-0.28	13.71**	0.14	1.06**	21.57**	-2.47**	-0.16**	-0.61**	-1.08**	-2.08**	-0.23**	1.35**	G
IR 68885 A	-3.13**	-0.02	-11.34**	0.40	0.21	-2.36**	2.57**	0.13	0.37*	-1.20**	-1.62**	-0.22**	-1.05**	L
IR 68887 A	-3.13**	-0.52*	-13.76**	-1.29**	1.47**	31.89**	-3.13**	-0.06	-0.95**	0.55**	-0.91*	-0.20*	-2.07**	L
IR 70369 A	-2.85**	-0.44	7.95**	-0.33	-1.27**	-27.22**	1.95**	-0.03	-1.23**	1.38**	4.22**	0.38**	1.15**	G
IR 70372 A	3.51**	0.71**	-6.41**	1.05**	-0.25	31.47**	1.43**	0.21**	0.86**	1.39**	1.94**	0.41**	0.59*	G
Male (Testers)														
PSBRC 80	-3.11**	0.68*	5.89**	1.50**	-0.95**	-28.84**	1.68**	-0.32**	-1.98**	0.36	-0.31	0.15	0.50*	G
PSBRC 82	1.14**	0.01	17.92**	1.39**	-0.71**	14.00**	1.58**	-0.08	-0.93**	-1.55**	-3.24**	-0.68**	-0.39	A
CT-6510-24-1-2	-0.69*	1.01**	20.00**	-1.08**	1.87**	46.83**	-1.49**	0.27**	3.73**	0.06	0.34	0.10	2.48**	G
Apo(IR 55423-01)	3.56**	-0.90**	-35.78**	-1.84**	0.04	-18.28**	1.41**	0.40**	0.39*	0.37	2.40**	0.74**	-5.29**	L
IR 73005-23-1-3-3	5.06**	0.34	-4.24**	0.09	-0.58**	-14.09**	-1.90**	-0.42**	-4.50**	-0.25	3.24**	0.65**	2.04**	G
IR 73718-3-1-3-3	1.64**	0.64*	16.96**	1.46**	-0.08	-15.46**	-0.87**	-0.36**	-2.83**	0.46*	4.49**	0.33**	3.86**	G

G-Good combiner, L-Poor combiner, A-Average Combiner
* Significant at 5 per cent level
** Significant at 1 per cent level

Table 3. Estimates of specific combining ability of crosses for various characters

Name of Genotypes	Days to 50 % flowering (µgg^{-1}minute^{-1})	No. of productive tillers plant^{-1} (mmolm^{-2}sec^{-1})	Spikelet fertility (%)	Relative water content at (mmolm^{-2}sec^{-1})	Membrane integrity (% of leakage)	Leaf rolling (secs.)	Catalase activity at flowering	Transpiration rate at flowering	Stomatal conductance at flowering (g)	Root length (cm)	Root volume (cc)	Root dry weight	Grain yield (g)	Combiner foryield
IR 67684 Ax PSBRC 80	-5.89**	1.35*	1.10*	1.21	-0.25	29.25**	3.28**	0.20	-2.12**	2.18**	2.58*	0.34	0.31	GxG
IR 67684 Ax PSBRC 82	3.86**	-1.03	-16.61**	2.08*	0.31	-13.89**	-4.28**	0.16	-1.21**	-0.42	-2.80**	-0.64**	-3.19**	GxA
IR 67684 Ax CT-6510-24-1-2	0.19	5.27**	23.18**	6.80**	-4.12**	-48.28**	8.26**	-1.00**	-7.72**	4.40**	12.20**	1.65**	9.12**	GxG
IR 67684 A x Apo(IR 55423-01)	1.44	0.08	42.22**	3.59**	-2.5**	-10.64**	7.43**	0.23	-3.04**	-0.10	4.39**	0.21	3.24**	GxL
IR 67684 A x IR 73005-23-1-3-3	2.44**	-0.56	-15.13**	-2.87**	-0.40	-17.85**	-6.80**	0.05	0.46	2.40**	-2.79**	0.02	-4.61**	GxG
IR 67684 A x IR 73718-3-1-3-3	3.36**	-6.56**	-53.72**	-9.18**	7.05**	-13.18**	-7.64**	1.04**	11.74**	-8.25**	-18.30**	-2.36**	-12.99**	GxG
IR68885Ax PSBRC 80	4.40**	-0.95	-50.01**	1.73	2.80**	-19.52**	-1.21	0.95**	12.60**	-0.61	-1.89	-0.26	-7.96**	LxG
IR 68885 A x PSBRC 82	*2.71***	*0.02*	*13.22***	*0.55*	*0.41*	*6.15***	*0.21*	*-0.43***	*-2.06***	*-4.24***	*0.60*	*0.01*	*0.69*	*LxA*
IR68885A x CT-6510-24-1-2	-5.95**	-0.24	28.20**	-2.21*	-2.42**	21.31**	-0.34	-0.49**	-6.87**	-4.41**	10.25**	-1.48**	2.64**	LxG
IR 68885AxApo(IR 55423-01)	3.80**	-0.18	-7.19**	-3.60**	1.48**	-23.35**	3.31**	0.33**	-3.48**	0.35	3.09**	0.74**	4.34**	LxL
IR68885Ax IR 73005-23-1-3-3	3.80**	-0.42	12.69**	1.09	-0.34	1.23	-4.53**	0.01	1.14**	2.59**	6.25**	0.71**	2.31**	LxG
IR68885Ax IR 73718-3-1-3-3	-9.79**	2.69**	21.69**	2.25*	-2.68**	83.61**	3.02**	-0.03	-4.57**	3.18**	9.25**	0.98**	6.04**	LxG
IR68887Ax PSBRC 80	-4.54**	-0.19	19.56**	2.46**	-0.24	-19.77**	3.35**	-0.66**	1.94**	0.72	3.90**	-0.21	0.52	LxG
IR68887A x PSBRC 82	-5.79**	1.31*	12.40**	-1.49	0.90*	18.65**	0.07	0.66**	1.54**	3.71**	4.89**	0.49	2.33**	LxA
IR68887A x CT-6510-24-1-2	9.05**	-1.88**	-39.10**	-0.50	2.11**	-13.94**	-5.04**	0.40**	4.75**	1.10*	-9.23**	-0.71**	-4.97**	LxG
IR 68887A xApo (IR 55423-01)	6.30*	-0.38	-9.02**	-0.23	0.57	50.40**	-2.98**	-0.73**	-2.82**	0.46	-6.06**	-0.60**	3.61**	LxL
IR68887Ax IR 73005-23-1-3-3	-6.20**	0.23	18.82**	-1.96*	-2.43**	33.23**	6.53**	0.39**	0.77	0.28	-2.47**	1.28**	5.56**	LxG
IR68887Ax IR 73718-3-1-3-3	-0.79	-.09	16.25**	-0.81	-0.11	-41.64**	-4.03**	-0.26	-1.18*	1.30**	2.66**	-0.24	-1.92**	LxG
IR 70369A x PSBRC 80	2.68**	-1.43*	9.62**	-0.83	0.49	-14.40**	-0.05	0.07	-3.92**	-1.04*	-3.48**	-1.40**	3.70**	GxG
IR 70369Ax PSBRC 82	1.93**	-0.16	-7.20**	-0.27	-0.67	-19.49**	-2.75**	-0.17	3.32**	-0.63	-6.29**	0.98**	0.38	GxA
IR70369AxCT-6510-24-1-2	-1.24	-1.46*	2.49**	-2.79**	0.50	56.43**	0.20	0.48**	1.19*	-0.06	-0.44	0.76**	-5. 13**	GxG
IR 70369Ax Apo (IR 55423-01)	-2.49**	0.14	-14.52**	-0.43	1.18**	-24.24**	-0.59	0.35**	4.47**	1.37**	-5.50**	-0.50*	3.61**	GxL
IR70369A x IR 73005-23-1-3-3	-2.49**	0.60	-9.44**	-0.64	1.60**	-18.90**	0.76	-0.33**	-1.58**	0.01	3.91**	0.02	0.65	GxG
IR 70369Ax IR 73718-3-1-3-3	-1.07	2.11**	-0.18	1.49*	-4.21**	-23.03**	5.21**	-0.94**	-4.57**	0.78	11.29**	0.56*	5.72**	GxG
IR 70372Ax PSBRC 80	0.32	2.96**	19.22**	1.80*	-3.16**	46.00**	3.35**	-0.85**	-3.07**	-3.67**	-4.95**	0.81**	6.13**	GxG
IR70372A x PSBRC 82	-1.93**	0.13	9.44**	0.07	0.76	-49.92**	0.07	0.24**	5.66**	2.31**	0.33	0.14	1.15	GxA
IR70372Ax CT-6510-24-1-2	-2.60**	-1.32*	-30.83**	1.89*	4.68**	-34.76**	-5.07**	0.13	2.73**	0.21	3.59**	-1.09**	-6.42**	GxG
IR70372A x Apo (IR55423-01)	-6.85**	0.81	8.06**	-1.12	-0.30	23.33**	-2.90**	-0.04	1.97**	-0.36	3.03**	-0.01	-1.01**	GxL
IR70372Ax IR 73005-23-1-3-3	7.15**	-0.56	7.26**	-1.78	1.74**	6.16**	6.53**	0.01	-1.58**	-2.54**	2.19*	-0.47*	0.67	GxG
IR70372AxIR 73718-3-1-3-3	6.07**	0.05	16.31**	2.89**	-2.64**	-16.97**	-4.03**	0.12	-0.98**	4.05**	-2.81**	0.61**	1.87**	GxG

plant selections in segregating generations. But in crosses having high *sca* effects due to good x poor general combiners have to be improved through population improvement. The crosses showing high *sca* effects involving poor x poor general combiners may be exploited for heterosis breeding programme.

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