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GENETIC ANALYSIS OF RICE (*Oryza sativa* L.) GENOTYPES UNDER AEROBIC CONDITIONS ON ALFISOLS

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SUMMARY

Ten popular low land rice genotypes were evaluated in 2007, 2008, and 2009 for variability, genetic divergence, stability and suitability under aerobic conditions on Alfisols. Results showed low variability in some of the growth and yield attributes like plant height, tillers/plant, spikelet length and harvest index, whereas high heritability (broad sense) estimates were observed for quantitative characters such as 1000-grain weight and grain yield. There was a significant and positive correlation of grain yield with number of tillers/plant (1.11), number of productive tillers/plant (0.99), number of grains/spikelet (0.84) and spikelet length (0.59), indicating that grain yield and these traits have the same physiological basis for expression. The pattern of constellations into 4 clusters indicated the existence of a significant amount of variability. The maximum intra-cluster distance (D: 0.773) was observed in cluster III and selection with this cluster may thus be useful. The yield attribute 1000-grain weight exhibited the maximum contribution to total genetic divergence (57.78%), followed by grain yield (15.56%), number of grains/spikelet (11.11%), straw yield (6.67%) and spikelet length (4.44%). On the other hand, the traits such as tillers/plant and harvest index failed to contribute toward genetic divergence. The stability analysis revealed that variety JGL-11727 consistently showed the highest agronomic performance.

Keywords: Aerobic rice, cluster analysis, stability, genetic divergence, genetic advance, heritability

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INTRODUCTION

Rice occupies a pivotal place in Indian agriculture. It is the staple food of two-thirds of the population, providing 43% of caloric requirement and 20-25% of agricultural income (Bhadru *et al*., 2012). India produced 104.3 million t of rice from an area of 44.0 million ha with a productivity of 2780 kg/ha in 2011-12 (GOI, 2013). The country is second in production next to China.

Of the many rice production systems prevailing, irrigated lowland rice comprises a major ecosystem. In Asia, more than 50% of all irrigation water is being used to grow rice (Barker *et al.,* 1999). The conventional lowland flooded transplanted rice technique consumes a lot of water. Keeping in view the ever increasing competition for irrigation water from other sectors and other crops, there is an imminent need to find an alternative rice production system with high water productivity (i.e., higher grain yield per unit of water used).

The aerobic rice system (ARS) is one such option. Here, rice is grown under non-puddled and non-flooded aerobic soil conditions (Tuong and Bouman, 2003). In this system, rice is sown directly into dry soil and irrigation is given to keep the soil sufficiently moist for good plant growth, but the soil is never flooded. Thus, in ARS, soils are kept aerobic almost throughout the rice-growing season. This production system is gaining importance in view of the reduced water use and increased productivity. In this system, the crop experiences moisture stress more frequently. Therefore, varieties that can tolerate moisture stress, particularly during the sensitive reproductive stage, have to be grown under aerobic conditions. Efforts have been made to identify location-specific varieties suitable for aerobic conditions in India and China, but, as soil type and weather conditions vary from one area to another, there is a possibility of variation in environments, thereby affecting the yield performance of cultivars. To some degree, the genotype by environment (GXE) interaction would have an influence on yield (Haryanto *et al.,* 2008; Suwarto and Nasrullah, 2011). In addition, yield performance may vary among genotypes, depending on how they are grown agronomically. Information on the suitability of rice varieties to aerobic conditions is scanty, especially on Alfisols (characterized by low water-holding capacity and poor soil fertility) under semi-arid climate. The adoption of the right variety/hybrid is critical to enhancing crop and water productivity. Hence, this study aimed to evaluate rice varieties for their suitability under aerobic conditions on Alfisols in the semi-arid climate of peninsular India.

To develop superior genotypes suitable for ARS, genetic variability and divergence studies are very important because they play a pivotal role in ensuring the success of a breeding program. In general, genetically diverse parents are used to obtain desirable recombinants in segregating generations. Multivariate analysis, an important tool for assessing genetic divergence, is utilized to assess genetic divergence along with the relative importance of different traits in total divergence.

An estimate of genetic advance along with heritability is helpful in assessing the reliability of character for selection. Knowing the mechanisms underlying the correlations between different traits is fundamental for understanding the degree of integration of the phenotype and for resolving constraints imposed on evolutionary processes. Correlation determines the nature and magnitude of association among variables. All these measures are important to identify genetically distant parental combinations, aiming to use distinct gene sets in crossings to get superior hybrids and segregants. Keeping these in view, the present study aimed to evaluate 10 lowland genotypes for their suitability under aerobic conditions. Further, this study intended to determine the magnitude of environment and GXE interaction variance components and its contribution to yield and yield components on locally adapted rice cultivars and to look at the stability of these lowland genotypes under aerobic conditions.

MATERIALS AND METHODS

Experimental details

A field study was carried out during the 2007, 2008 and 2009 kharif at the Regional Agricultural Research Station, Acharya N.G. Ranga Agricultural University, Palem, in Andhra Pradesh. The experimental site has semi-arid climate, is within the southern Telangana zone (16^o 35' latitude, 78^o 1' longitude) and has an altitude of 642 m above sea level. The soil was Alfisol with low available N but high P and K. The plantmaterials consisted of 10 genotypes (JGL-11727, JGL-1798, JGL-3844, JGL-384, BPT-5204, Tellahamsa, RNR M-7, MTU-1010, MTU-1001, and JGL-3828) of lowland rice varieties developed at various research stations in Andhra Pradesh. These genotypes are diverse with respect to duration, yield potential, grain quality and tolerance for resistance to pests and diseases (Table 1). Among these genotypes, BPT-5204 (Samba Mahsuri), MTU-1010 (Cotton dora sannalu) and MTU-1001 (Vijetha) are considered mega varieties as they occupy very large areas in Andhra Pradesh and other states across the country. To test the performance of these genotypes under aerobic conditions, the study used a randomized block design with3 replications.Grains were line-sown with a spacing of 20 x 15 cm. A common fertilizer dose of 120 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1} was applied. The entire dose of P and half of the K were applied as basal. The other half of the recommended K was applied at the panicle initiation stage. Nitrogen was applied in three equally split doses at basal, active tillering, and panicle initiation stages. A plot size of 22.5 m^2 (5.0 m x 4.5 m) was maintained for each treatment. The seeds of the different genotypes were dibbled at a spacing of 20 cm x 15 cm. The recommended package of practices in terms of agronomic and need-based plant protection was followed to raise a good and healthy crop. Observations were recorded on 5 randomly chosen plants from the net plot of each and every treatment for quantitative traits. Grain and straw yield values recorded from the net plot (g/plot) were converted into hectare (kg/ha). Harvest index was calculated by dividing grain yield with biological yield (grain + straw yield). Irrigation was applied every 4-5 days, depending on soil moisture content (before hairline cracks develop) and was stopped at physiological maturity.

Meteorological data

During the 3-year experiment, 1206 mm rainfall was received (40 rainy days) in 2007, whereas the amount in 2008 was only 497.3 mm (29 rainy days) and that in 2009 was only 624.6 mm (27 rainy days). Rainfall in 2007 can be categorized as excessive as 86.5% more rainfall than normal (525 mm) was received during the crop growth period. In 2008, it was regarded adeficit (by 23.0%). Rainfall was normal in 2009. The 2009 rainfall distribution as deemed erratic as 376.6 mm of rainfall (60.3%) was received in 6 rainy days during the 39^{th} and 40^{th} meteorological weeks, which means that only 248 mm of rainfall (39.7%) was received in 25 rainy days during the crop growth period. This might have created stress during the 39^{th} and 40^{th} weeks. High evaporation rate (9.4 to 12.1 mm/d in 2009 and 8.7 to 8.9 mm/d in 2008) was recorded during the 25^{th} to 27^{th} standard weeks, which coincided with the germination phase. The corresponding values in 2007 were 3.2 to 6.1 mm/d. An evaporation of 6.8 to 9.5 mm/day was recorded during the 30^{th} and 32^{nd} weeks in 2009, more than that of the rate recorded in the corresponding period in 2008 and 2007. Low relative humidity (RH) (PM) 38.6 to 49.7% and 44.9 to 51.7% prevailed from the 25^{th} and 30^{th} standard week during 2008 and 2009, respectively as compared with 2007 (55.1 to 75.9%) in the corresponding period that coincided with germination and vegetative growth. Again, during the 43^{rd} and 44^{th} week, low RH (PM) prevailed in 2008 (37.1 and 22.6%) and 2009 (28.7 and 39.7%) as compared with 2007's 56.4 and 63.6%, which coincided with the milky stage.

Statistical analysis

The WINDOWSTAT version 9.1 software was used for statistical analysis. The ANOVA was based on a model given by Panse and Sukhatme (1967). The estimates of PCV and GCV were classified as low (< 10%), medium (10-20%), and high (> 20%) (Sivasubramanian and Madhavamenon, 1973). Heritability estimates (broad-sense) for yield components were done following Singh and Chaudhary (1985). They were categorized using the criteria of Robinson *et al.* (1949): 0-30% = low; 31-60% = moderate; > 60% = high. Genetic advance was estimated by adopting the method given by Johnson *et al.* (1955): > 20% = high; 10-20% = moderate; less than 10% = low.

To study the genetic divergence among the 10 genotypes used in the present investigation and to know the fluctuations in the clustering patterns of these genotypes, D^2 values (Mahalanobis, 1936) were calculated using the Tocher method described by Rao (1952) for grouping varieties into different clusters. Genetic divergence analysis using canonical (vector) method is some sort of multivariate analysis where canonical vectors and roots representing different axes of differentiation and amount of variation accounted for by each of such axes, respectively, were derived (Rao, 1952).

The genotypic and phenotypic correlation coefficients were calculated using the method of Al-Jibouri *et al.* (1958). Fasoulas (1980) stated that the stable genotypes interact less with environment and gave consistently high yield over a large environment, while the unstable cultivars displayed large G x E interactions. Eberhart and Russell (1966) defined a stable cultivar as one that shows high mean yield, a regression coefficient equal to unity (b_i = 0), and mean square deviation from regression (S^2d_i) close to zero. In interpreting the results of the present investigation, S^2d_i was considered as the measure of stability as suggested by Breese (1969). Then, the type of stability (measure of response or sensitivity to environmental changes) was determined on the basis of regression coefficient (b_i) and mean values (Finlay and Wilkinson, 1963). If b_i was equal to unity, a genotype is considered to have average stability (performance does not change with a change in environment). If the regression coefficient was significantly more than the average stability (sensitive to environmental changes but adaptable to favorable environments) and if b_i was less than unity, the genotype would have more than average stability (widely adaptable to different environments).

RESULTS AND DISCUSSION

Genetic parameters

Ten rice genotypes having diverse characteristic features were selected for the present investigation. The geographic origin, pedigree, morphological traits, and host plant resistance of these genotypes are detailed in Table 1.

Table 1. Pedigree and special characteristic features of 10 genotypes selected in the study.

No.	Variety	Developed at	Pedigree	Special features
1	JGL-1798 (Jagtial Sannalu)	RARS (ANGRAU), Jagtial, Karimnagar District, Andhra Pradesh, India	Samba Mahshuri/ Kavya	Resistant to gall midge
2	JGL-3844 (Jagtial Samba)	RARS (ANGRAU), Jagtial, Karimnagar District, Andhra Pradesh, India	Samba Mahsuri/ ARC 5984//Kavya	Resistant to gall midge
3	RNR 10754 (Tellahamsa)	ARI (ANGRAU), Rajendranagar, Hyderabad	HR 12/T(N)-1	Resistant to blast and bacterial leaf blight
4	MTU-1010 (Cotton dora sannalu)	APRRI and RARS (ANGRAU), Maruteru, Andhra Pradesh, India	MTU-077/ IR64	Tolerant of brown plant hopper and moderately resistant to blast
5	Polasa Prabha (JGL-384)	RARS (ANGRAU), Jagtial, Karimnagar District, Andhra Pradesh, India	BPT 5204/Kavya	Resistant to gall midge
6	JGL-11727 (Pranahitha)	RARS (ANGRAU), Jagtial, Karimnagar District, Andhra Pradesh, India	JGL-420/ Vijetha	Fine-quality rice, resistant to gall midge
7	JGL-3828 (ManairSona)	RARS (ANGRAU), Jagtial, Karimnagar District, Andhra Pradesh, India	Samba Mahsuri/ Aganni	Resistant to gall midge but susceptible to panicle mite and blast
8	RNR M-7 (Early Samba)	ARI (ANGRAU), Rajendranagar, Hyderabad, India	Mutant of BPT-5204	Mutant of BPT-5204 and resistant to blast
9	MTU-1001 (Vijetha)	APRRI and RARS (ANGRAU), Maruteru, Andhra Pradesh, India	Vajram/MTU-7014	Resistant to brown plant hopper and moderately resistant to blast
10	BPT-5204 (Samba Mahsuri)	ARS (ANGRAU), Bapatla, Guntur District, Andhra Pradesh, India	GEB-24/T(N)-1/ Mahsuri	Fine-quality rice with good cooking quality thus highly popular among consumers; susceptible to pests and diseases

These were evaluated for 3 years under aerobic conditions on Alfisols and the mean values are presented in Table 2. The range of variation was maximum for grain yield (1702–3477 kg/ha), followed by straw yield (3068– 4277 kg/ha) and number of grains per spikelet (73–105). Variances and coefficients of variation indicated negligible differences between genotypic and phenotypic variance for some of the characters, namely, 1000-grain weight and harvest index. It means that the effect of environment on these characters is meager. On the other hand, characters such as straw yield, grain yield, number of productive tillers/plant, number of tillers/plant, and spikelet length were most affected by environment. For a meaningful comparison among characters for variability, standardization with respective mean values was calculated to get PCVs and GCVs. It is clear that the CV, which is a measure of the magnitude of variation, was highest for 1000-grain weight, productive tillers/plant, and grain and straw yield. Low variability was observed for some of the growth attributes such as plant height, number of tillers/plant, spikelet length, and harvest index. High heritability (broad sense) estimates were observed for quantitative characters such as 1000-grain weight and grain yield (Table 3). It revealed that dependence on phenotypic expression reflects the genotype's ability to transmit the genes to their offspring. Johnson *et al*. (1955) further suggested that high heritability, considered along with high genetic advance, is a more reliable predictor of the desired improvement for 1000-grain weight and grain yield. It further showed that these characters are amenable to improve for selection, particularly mass selection. Such values of high heritability and genetic gain may be attributed to the additive effect (Panse, 1957). Hence, selection in segregating generations for such characters would be highly effective.

Table 2. Mean performance of 10 rice genotypes in terms of yield and yield components under aerobic conditions, 2007-2009.

Character	Plant height (cm)	Tillers/ plant (no.)	Productive tillers/ plant (no.)	Spikelet length (cm)	Grains/ spikelet (no.)	1000-grain weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index
JGL-11727	63.19	15.04	12.28	16.07	105.11	20.00	3477	4175	0.45
JGL-1798	65.17	13.96	9.24	14.69	73.74	12.26	2608	3784	0.41
JGL-3844	54.50	11.24	9.16	16.10	80.50	14.43	2107	3279	0.39
JGL-384	52.89	12.37	9.38	15.41	89.11	12.89	2199	3284	0.39
BPT-5204	55.74	13.22	9.07	13.62	83.96	12.06	2414	4277	0.36
Tellahamsa	64.38	12.22	7.58	11.62	73.44	21.34	1702	3068	0.36
M-7	55.87	13.47	9.93	13.32	81.67	12.97	2565	3302	0.44
MTU-1010	57.36	13.32	11.49	14.70	98.78	21.46	2869	3764	0.43
MTU-1001	62.93	13.26	11.40	14.89	93.67	21.32	2916	3940	0.42
JGL-3828	57.64	12.39	8.22	14.18	89.11	13.77	2458	3482	0.41
Mean	58.97	13.05	9.77	14.46	86.91	16.25	2532	3635	0.41
CV	12.74	15.20	16.45	10.67	9.85	8.63	13	19	11.68
F ratio	3.24	2.53	7.90	6.97	13.09	80.39	19	3.38	3.71
F prob.	0.0024	0.014	0.00	0.00	0.00	0.00	0.00	0.0017	0.001
S.E	2.50	0.66	0.54	0.51	2.85	0.47	111	225	0.016
CD 5%	7.06	1.87	1.51	1.45	8.04	1.32	314	635	0.045
CD 1%	9.37	2.47	2.01	1.92	10.68	1.75	417	842	0.059

Table 3. Genetic parameters (PCV, GCV, and heritability) of yield and yield attributes of rice genotypes grown under aerobic conditions.

Parameter	Plant height (cm)	Tillers/ plant (no.)	Productive tillers/ plant (no.)	Spikelet length (cm)	Grains/ spikelet (no.)	1000-grain weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index
General mean	58.97	13.05	9.77	14.46	86.91	16.25	2532	3635	0.41
Range lowest	52.89	11.24	7.58	11.62	73.44	12.06	1702	3068	0.36
Range highest	65.17	15.04	12.28	16.10	105.11	21.46	3477	4277	0.45
Var genotypic	14.01	0.67	1.98	1.58	98.46	17.33	227640	120622	0.00
Var phenotypic	70.45	4.61	4.57	3.96	171.74	19.30	339153	576825	0.00
GCV	6.35	6.27	14.41	8.69	11.42	25.62	18.85	9.55	6.42
PCV	14.23	16.45	21.87	13.76	15.08	27.04	23.00	20.89	13.33
h^2 (broad sense)	0.20	0.15	0.43	0.40	0.57	0.90	0.67	0.21	0.23
Genetic advance as % of mean (5%)	5.83	4.93	19.55	11.31	17.81	50.02	31.81	9.00	6.36

Correlation

Genotypic and phenotypic correlation coefficients were pooled over 3 years for 9 quantitative traits and these are presented in Table 4. Close agreement between genotypic and phenotypic correlation was not observed in most of the traits studied, indicating high environmental influence on the degree of association. Thus, reference was made only to genotypic correlation. In most of the cases, genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients.

Grain yield was significantly and positively correlated with number of tillers/plant (1.11), number of productive tillers/plant (0.99), harvest index (0.93), straw yield (0.86), grains/spikelet (0.84), spikelet length (0.59), and 1000-grain weight (0.28), indicating that grain yield and these traits have the same physiological basis for expression. The association between number of productive tillers/plant with other yield attributing traits and grain and straw yield was found to be highly significant and positive genotypically. Number of grains/spikelet was positively and significantly correlated with number of productive tillers/plant, spikelet length, 1000-grain weight, grain yield, straw yield, and harvest index. Spikelet length was positively and significantly associated with number of grains/spikelet, grain yield, and harvest index. Plant height had a highly significant positive correlation with tillers/plant (0.82), 1000-grain weight (0.59), grain yield (0.34), straw yield (0.33), and harvest index (0.32). On the other hand, plant height and spikelet length were significantly negatively correlated (Table 4).

Divergence

As to clustering, the 10 rice genotypes were grouped into four clusters (Table 5; Figure 1) based on the relative magnitude of the D^2 values. Among the clusters formed, clusters I to III had three genotypes each (I: JGL-384, JGL-3828, and JGL-3844; II: BPT-5204, RNR M-7, and JGL-1798; III: MTU-1010, MTU-1001, and JGL-11727) and are considered large. The fourth cluster was smaller; it has only 1 genotype (IV: Tellahamsa). The pattern of group constellations proved the existence of a significant amount of variability. The inter and intra-cluster distance (Table 6) revealed no genetic diversity among genotypes in clusters III and IV, indicating that unidirectional selection practiced in the past might have resulted in uniform features with less divergence among the genotypes. The maximum intra-cluster distance (D: 0.77) was observed in cluster III. Selection within this cluster may be done on the basis of the highest mean for desirable traits.

Table 4. Correlation matrix of traits of 10 rice genotypes grown under aerobic conditions (values in parentheses are genotypic correlation coefficients).

Character		Plant height (cm)	Tillers/ plant (no.)	Productive tillers/ plant (no.)	Spikelet length (cm)	Grains/spikelet (no.)	1000-grain weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index
Plant height (cm)	P	1.00	0.06	-0.044	-0.10	0.10	0.33**	0.07	0.09	-0.04
	G	(1.00)	(0.821)**	(0.21)	(-0.28)**	(-0.14)	(0.59)**	(0.34)**	(0.33)**	(0.32)**
Tillers/plant (no.)	P		1.00	0.49**	0.00	0.14	0.06	0.32**	0.35**	0.02
	G		(1.00)	(0.78)**	(0.23)	(0.65)**	(0.24)	(1.11)**	(0.96)**	(1.096)**
Productive tillers/plant (no.)	P			1.00	0.19	0.39**	0.31**	0.47**	0.36**	0.118
	G			(1.00)	(0.69)**	(0.92)**	(0.49)**	(0.99)**	(0.70)**	(1.045)**
Spikelet length (cm)	P				1.00	0.25*	-0.09	0.29**	-0.08	0.35**
	G				(1.00)	(0.63)**	(-0.08)	(0.59)**	(0.50)**	(0.49)**
Grains/spikelet (no.)	P					1.00	0.36**	0.56**	0.24*	0.29**
	G					(1.00)	(0.47)**	(0.84)**	(0.64)**	(0.77)**
1000-grain weight (g)	P						1.00	0.26*	0.12	0.09
	G						(1.00)	(0.28)**	(0.08)	(0.33)**
Grain yield (kg/ha)	P							1.00	0.47**	0.55**
	G							(1.00)	(0.86)**	(0.93)**
Straw yield (kg/ha)	P								1.00	-0.45**
	G								(1.00)	(0.62)**
Harvest index	P									1.00
	G									(1.00)

P: Phenotypic G: Genotypic

Table 5. Clustering pattern among 10 rice genotypes grown under aerobic conditions (Tocher method).

No.	Genotypes (no.)	Genotype name
1	3	JGL-384, JGL-3828, JGL-3844
2	3	BPT-5204, M-7, JGL-1798
3	3	MTU-1010, MTU-1001, JGL-11727
4	1	Tellahamsa

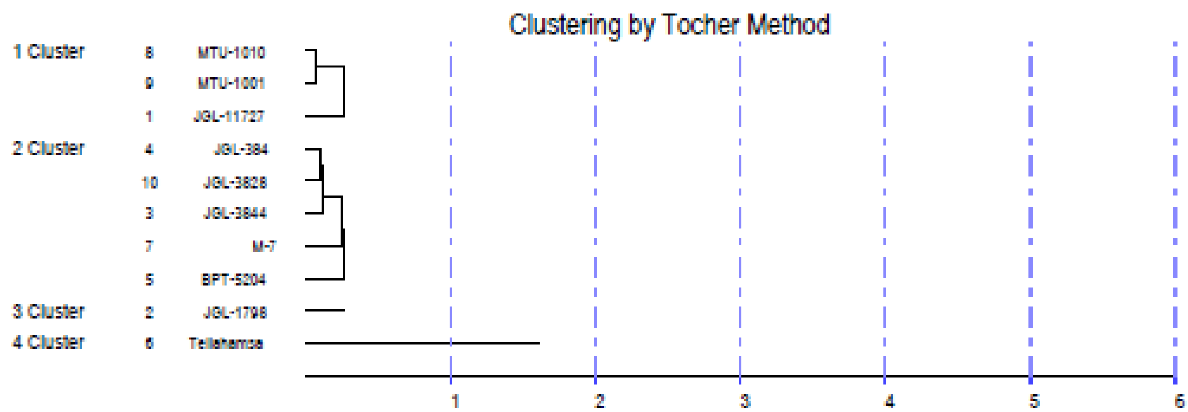

Figure 1. Dendrogram showing clustering patterns of 10 rice genotypes grown under aerobic conditions (Tocher method).

Table 6. Inter and intra-cluster distances (Tocher method) of 10 rice genotypes grown under aerobic conditions.

Cluster	I	II	III	IV
I	0.773	5.529	7.510	5.838
II		0.750	1.317	6.500
III			0.000	8.769
IV				0.000

The relative divergence of each cluster from other clusters (inter-cluster divergence) indicated a high order of divergence between clusters II and IV (D: 8.77), followed by that between clusters II and III (D: 7.51), and between III and IV (D: 6.50). Hybridization between genotypes from these clusters will result in maximum hybrid vigor and the highest number of useful segregants for metric traits. Hybridization between genetically distant genotypes to generate promising breeding material has been suggested by Vivekanandan and Subramanian (1993).

Looking at the contribution of individual characters to divergence (Table 7), it was seen that 1000-grain weight gave the maximum contribution to total genetic divergence (57.78%), followed by grain yield (15.56%), number of grains/spikelet (11.11%), straw yield (6.67%), and spikelet length (4.44%). On the other hand, traits such as number of tillers plant^{-1} and harvest index failed to contribute toward genetic divergence.

Table 7. Contribution of each character to divergence in 10 rice genotypes grown under aerobic conditions (Tocher method).

Source	Number of times ranked first	Contribution (%)
Plant height	1	2.22
Number of tillers/ha	0	0.00
Number of productive tillers/ha	1	2.22
Spikelet length	2	4.44
Number of grains/spikelet	5	11.11
1000-grain weight	26	57.78
Grain yield	7	15.56
Straw yield	3	6.67
Harvest index	0	0.00

Table 8. Cluster means of 10 rice genotypes grown under aerobic conditions (Tocher method).

Cluster no.	Plant height (cm)	Tillers/ plant (no.)	Productive tillers/ plant (no.)	Spikelet length (cm)	Grains/ spikelet (no.)	1000-grain weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index
I	61.16	13.87	11.72	15.22	99.19	20.93	3087	3960	0.43
II	55.33	12.54	9.15	14.53	84.89	13.22	2349	3525	0.40
III	65.17	13.96	9.24	14.69	73.74	12.26	2608	3784	0.41
IV	64.38	12.22	7.578	11.62	73.44	21.34	1702	3068	0.37

Thus, the 4 characters (1000-grain weight, grain yield, number of grains/spikelet, and straw yield) were important as they have contributed 91.12% toward divergence. Nayak *et al*. (2004) and Bardhan and Thangavel (2011) also reported that the choice of parents mainly depends on the contribution of characters toward divergence.

There was a wide range of variation in the cluster mean value for most of the characters under study. A perusal of data in Table 8 revealed that cluster I recorded the highest means for traits such as number of productive tillers/plant (11.72), spikelet length (15.22 cm), number of grains/spikelet (99.19 g), grain yield (3087 kg/ha), straw yield (3960 kg/ha), and harvest index (0.43). For cluster III, it was number of tillers/plant (13.96) and for cluster IV, these were plant height (64.38 cm) and 1000-grain weight (21.34 g). On the other hand, the lowest means were observed for plant height (55.33 cm) and productive tillers (9.15) in cluster II and tillers/plant (12.22), spikelet length (11.62cm), number of grains/spikelet (73.44), grain yield (1702), straw yield (3068), and harvest index (0.37) in cluster IV.

Earlier studies reported that clustering patterns of genotypes from different sources/origin clustered together. Chaturvedi and Maurya (2005) and Sabesan and Saravanan (2008) indicated no association between geographic distribution of genotypes and genetic divergence. The possible reason for the grouping of genotypes from different regions into one cluster could be the free exchange of germplasm among the breeders of different regions or the unidirectional selection practiced by breeders in tailoring promising cultivars to different regions. Genotypes from the same center of origin were distributed in the different clusters (Kandamoorthy and Govindarasu, 2005; Senapathi and Sarkar, 2005; Sabesan *et al*., 2009; and Banumathy *et al*. 2010), which may be due to differential adaptation to varying agro-ecosystems.

Stability

The stability measure was calculated according to Eberhart and Russell (1966). Here, ideal genotypes would have a high mean yield performance over wider environments, a coefficient of regression equal to 1 and the deviation of mean square from regression approaching zero. This method was used because of its simplicity and ability to minimize interaction between genotypes and their environment. Weather conditions in 2007 were favorable, while those in 2009 were least favorable. This has a bearing on the performance of rice genotypes as indicated by the following environmental indices for seed yield: 680.77 in 2007, -70.0 in 2008, and -610.77 in 2009.

The ANOVA (Table 9) revealed that genotypes and environments were significant for number of productive tillers/plant, spikelet length, number of grains/spikelet, 1000-grain weight, grain yield, and harvest index, indicating the diversity among the genotype and environment studies. The G x E interactions were significant for 2 characters, 1000-grain weight and harvest index, implying differential behavior of genotypes under 3 environments for these characters. A significant variation due to environment (linear) was observed for all 9 characters (Table 9) studied, revealing considerable additive environmental variance on these characters. The linear component of GxE was significant only for 1000-grain weight, grain yield, and harvest index, suggesting that the genotypes differ in their linear response to environment. Genotypes were stable for the rest of the characters studied. The mean square for pooled deviation was significant for plant height, number of tillers/plant, spikelet length, grain yield, and straw yield, indicating that the performance of genotypes was entirely unpredictable in nature. The results were consistent with the findings of Narayanaswamy and Dushyanta Kumar (2003).

Table 9. Stability ANOVA (summary) of 10 rice genotypes grown under aerobic conditions.

Source of variation	df	Plant height (cm)	Tillers/plant (no.)	Productive tillers/ plant (no.)	Spikelet length (cm)	Grains/ spikelet (no.)	1000-grain weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index
Rep within env.	6	10.14	0.87	1.10	0.23	58.84	0.58	84552	160802	0.00
Varieties	9	60.84	3.32	6.81**	5.53*	319.81**	52.66**	720090**	513934	0.00*
Env.+ (Var.* Env.)	20	137.89	3.03	2.23	12.93**	118.04**	2.72**	502839**	449950	0.00**
Environments	2	930.81**	11.70*	10.27**	115.42**	1011.02**	12.73**	4206896**	751442	0.02**
Var.* Env.	18	49.78	2.07	1.34	1.54	18.82	1.61*	91277	416451	0.00*
Environments (lin.)	1	1861.63**	23.39*	20.54**	230.84**	2022.05**	25.46***	8413792**	1502885*	0.04**
Var.* Env. (lin.)	9	28.89	1.36	1.58	1.61	9.22	2.67**	137883*	546729	0.00**
Pooled deviation	10	63.61**	2.51*	0.98	1.32*	25.57	0.49	40204*	257556**	0.00
Pooled error	54	8.49	1.06	0.70	0.54	26.30	0.34	19136	63940	0.00
Total	29	113.97	3.12	3.65	10.63	180.66	18.22	570262	469807	0.00

Table 10. Stability parameters for harvest index and 1000-grain weight of 10 rice genotypes grown under aerobic conditions.

Genotype	Harvest index			1000-grain weight (g)		
	m Mean	b_i	S^2d_i	m Mean	b_i	S^2d_i
JGL-11727	0.45	0.07	0.000	20.00	0.34	0.37
JGL-1798	0.41	1.78**	0.001	12.26	0.09	-0.34
JGL-3844	0.39	2.96**	0.000	14.43	0.76	-0.12
JGL-384	0.39	0.82*	0.000	12.89	0.86	1.41
BPT-5204	0.36	0.22	0.000	12.06	-0.11	0.37
Tellahamsa	0.37	0.04	0.001	21.34	1.58**	0.50
RNR M-7	0.44	0.96	0.000	12.97	0.55	-0.22
MTU-1010	0.43	0.85*	0.000	21.47	3.26**	-0.22
MTU-1001	0.42	1.15**	0.000	21.32	2.03**	-0.18
JGL-3828	0.41	1.15**	0.000	13.77	0.64	-0.28
Population Mean	0.41	0.39		16.25	0.439	

Reichardt *et al*. (2001) and Witt *et al*. (2001) presented evidence confirming the greater effect of environment and cultural practices on rice yield. Location has strongly determined yield and yield quality in rice cultivars (Anhar and Leilani 2001). Ceccarelli (1987) reported that relatively low temperature and low irradiance reduced yield of barley significantly, indicating the important role of environment. Under these conditions, he reported quite large G x E interactions. Several workers have shown the importance of G x E interaction on the consequent yield of various cereal crops (Oosterom *et al.,* 1993). Harsanti *et al.* (2003) noticed the occurrence of G x E interaction in rice genotypes and found that 2 of his mutant lines were stable under a wide range of environments.

Of the 10 genotypes tested, JGL-11727 had significantly out yielded all the other varieties in terms of grain yield (3477 kg/ha). As shown in Table 10, this genotype was found to be widely adaptable with average stability and high 1000-grain weight (20 g). MTU-1010 (21.46 g), Tellahamsa (21.34 g), and MTU-1001 (21.32 g) were found adaptable to favorable environment with less than average stability for 1000-grain weight. High harvest index, coupled with average stable performance, was seen in JGL-11727 and RNR M-7. Two genotypes, MTU-1010 and MTU-1001, were adaptable to favorable environments with less than average stability in terms of harvest index.

CONCLUSIONS

Of all the varieties tested in the field experiment under aerobic conditions on Alfisols, JGL-11727 exhibited the highest agronomic performance and stability parameters. High heritability and genetic advance estimates of grain yield and 1000-grain weight are higher and more reliable in predicting improvement of these characters. Correlation studies indicate that improvement of characters such as number of tillers/plant, productive tillers/plant and grains/spikelet, and spikelet length will enhance grain yield. Divergence studies suggest that hybridization between clusters II and IV will result in maximum hybrid vigor and the highest number of useful segregants. The next best clusters for hybridization are found to be II and III, followed by III and IV.

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