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Use of Genotype x Environment Interactions and Drought Susceptibility Index for Identification of Drought Tolerant Genotypes at Vegetative Stage in Upland Rice

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ABSTRACT: In order to study the magnitude and consistency of yield response to drought and to identify genotypes that confer drought resistance, a series of experiments with 12 selected genotypes in advanced yield trial lower than 100 days (AYTLT 100) on the basis of observational yield trial (OYT) performance were conducted under vegetative stage drought stress and irrigated conditions at CRRI, Cuttack for three years. Significant genotype x environment interactions were observed for days to maturity, plant height, harvest index and grain yield and having homogenous error variance in environments for these characters. Among the linear and non linear components, G x E interactions were predominant for most of the characters, suggesting variation in the performance of different genotypes grown over environments could be predicted. Based on the stability parameters, the genotypes Vandana and CB 0-13-1 were found to be stable. To some extent, genotype IR 76569-259-1-1-3, RR 383-2 and Kakro may satisfy stability parameters but being low yielder, it remains questionable. Genotypic variation in drought susceptibility index (DSI) was consistent among the most of the experiments and mean DSI ranged from 0.57 to 0.91. Simultaneously, Lalsar, RR 440-167-2-13, CR 143-2-2 and IR 76569-259-1-1-3 estimated lowest DSI for yield and all component characters. Grain yield reduction due to drought ranged from 64 to 82%. The results indicated that selection for yield and yield components under stress is reliable but selection under non stress is inefficient in estimation of the yield performance of genotypes under stress condition, particularly in severe drought condition. The top genotypes under stress *viz.* Lalsar and CR 143-2-2 were accepted drought tolerant genotypes which may be used as the genetic sources in breeding programme. Vandana may be suggested as the best tolerant genotype for cultivation under vegetative stage drought stress.

Key words: Upland rice, drought, stability, coefficient of determination, DSI

Introduction

Drought stress at either vegetative or reproductive stages of plant growth is the major constraint to rice production and yield stability in the rain-fed upland regions. Most of the farmers in India usually grow local varieties under diverse agro-climatic conditions. Even though these varieties are well adapted to the local conditions, they are poor yielders. Therefore, stable genotypes which perform better under stress as well as under favorable condition are desirable in target environment for sustainable rice production. Short duration varieties with tolerance to drought suit drought prone upland ecology. Several studies conducted across number of Asian countries have shown that the genotype-by-environment (G x E) interactions for grain yield of rice grown in the rainfed areas were relatively large (Wade *et al.*, 1999 and Ouk *et al.*, 2007). A major objective of these studies was to investigate environmental and genetic constraints to the improvement of broad and specific adaptation of rainfed rice for a range of target environments (Cooper *et al.*, 1999).

The effects of genotype and environment on phenotype may not be always independent. The phenotypic response to change in environment is not same for all genotypes; the consequences of variation in phenotype depend upon the environment. Since G x E interaction has marking effect on genotypes, these interactions are of considerable importance to plant breeders in identifying the genotypes suitable for favourable location/environment and assumes importance for potential expression of characters under interest. Plant breeders rely on stability parameters to assess the performance of their crosses or advanced genotypes across environments. The most popular method for determining stability across environments has been the joint regression approach proposed by Yates and Cochran (1938), which was further developed by Finlay and Wilkinson (1963), and Eberhart and Russell (1966). Hence, present study was carried out utilizing 12 genotypes over the years and diverse water regimes to assess the stability of seed yield contributing traits in rice.

Materials and Methods

Experimental site, design and tested genotypes

Field experiments were conducted under well-watered (E_1) and managed stress (E_2) conditions in leveled fields at CRRI, Cuttack during 2007 to 2009. Drought stress was artificially imposed during the vegetative stage as managed stress environment and experiments under well watered condition where no stress was imposed are referred to as non-stress trials and conducted under an anaerobic soil environment with pounded water. Twenty seven genotypes in advanced yield trial less than 100 days (AYTLT 100 days) were tested for drought tolerance and yield performance. Based on performance under vegetative stage drought stress, twelve genotypes were selected and evaluated over three years during dry season to study the magnitude and consistency of yield response of diverse, rainfed upland rice genotypes and to identify genotypes that confer drought tolerance. The experiments were established by dry seeding in late January and exposing 30 days old seedlings to drought stress for more than 30 days in Alpha Lattice Design with three replications.

Crop management

Rice varieties were directly sown at 2-3 cm soil depth in dry and pulverized soil by hand plough with the seed rate of 60 Kg ha^{-1} to maintain 3-4 seeds per hill at a spacing of 15X10 cm. This method gave uniform seedling emergence for all the plots in 6-8 days. Fertilizer was applied at the rate of 80, 40, and 40 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. One third of nitrogen and entire dose of P_2O_5 and K_2O were given as basal dressing and remaining N was split into two doses applied at maximum tillering and flowering stages. Recommended package of practices was followed to raise the crop.

Observations and evaluation

Ten plants from each plot were randomly chosen for recording observations on their days to flowering (DTF), days to harvest (DTH), panicle number (PN), plant height (PH) and harvest index (HI). Observations on grain yield (GY) were recorded on the plot basis. The effect of drought was assessed as percentage reduction in mean performance of characteristics under managed drought stress condition relatively to the performance of the same trait under well watered condition. The levels of stress were monitored through tensiometers. The trials were re-irrigated only when the tensiometers reading reached to 80 kPa at 20 cm depth. Genotypes were visually scored for drought reaction at 10-12% soil moisture content at 30-cm soil depth and below 90 cm water table depth. Drought Susceptibility Index (DSI) for each trait was calculated on the basis of mean data of severe stress and irrigated condition experiments, following Fischer and Maurer (1978). The data were analyzed by appropriate statistical analysis (Gomez and Gomez, 1984) using CropStat 7.2 (IRRI, 2009) programme. Pooled analysis of variance over three environments was estimated as per the model suggested by Eberhart and Russell (1966) and followed to estimate the three stability parameters *viz*., mean, regression coefficient (bi) and mean squared deviation (S^2di) for each genotype.

Results and Discussion

The pooled analysis of variance revealed that G x E interactions was significant for four characters *viz*. days to harvest, plant height, harvest index and grain yield implying differential response of genotypes under two water regimes during three years for these characters (Table 1). Similar reports were earlier made by Panwar *et al*. (2008) and Ramya and Senthilkumar (2008). The G x E interactions for remaining two characters days to flowering and number of panicles were found to be non-significant. Therefore, further analysis of stability was not carried out for these characters. This is in accordance with previous report on rice by Sreedhar *et al*. (2011). Mean squares due to environment (linear) were found significant for all the characters, indicating differences between environments and their influence on genotypes for expression of these characters. This is in accordance with previous reports on rice by Sawant *et al.* (2005) and Panwar *et al.* (2008). The environment + (G x E) was significant for all the characters indicating distinct nature of environments and G x E interactions in phenotypic expression. The G x E (linear) interaction component showed significance for all the characters studied except days to flowering and number of panicle. This indicated significant differences among the genotypes for linear response to environments (bi) behaviour of the genotypes could be predicted over environments more precisely and G x E interaction was outcome of the linear function of environmental components. Hence, prediction of performance of genotypes based on stability parameters would be feasible and reliable. Gouri Shankar *et al.* (2008) and Parry *et al.* (2008) also noticed significant linear component of G x E and non linear components of G x E interaction for most of the characters studied.

The mean performance coupled with the regression coefficient (bi) and variance of deviation from regression (S^2di) of each genotype represents its stability (Table 2). With these conditions, the genotypes were classified and discussed for their adaptability and stability in respect of yield and component characters studied. CB-0-13-1 for days to maturity; two genotypes *viz.* Brown Gora and RR 383-2 for plant height and two genotypes namely IR 76569-259-1-1-3 and RR 383-2 for harvest index had values near to unit regression. Hence, these genotypes are suitable for over all environmental conditions and they are considered as stable genotypes. The generalization regarding the stability of genotypes is quite difficult. Some of the genotypes used in this study did not exhibit a uniform stability and response

Table 1 : Analysis of variance for different characters over the years in upland rice under irrigated and drought stress

Source of Variation	DF	DTF (Days)	DTH (Days)	PN	PH (cm)	HI	GY (t ha^{-1})
Genotypes	11	212.**	211.91**	641.64**	897.73**	70.95**	0.96**
Environments	5	986.74**	901.42**	252.97**	2901.88**	229.43**	31.07**
Genotype x Environment	55	30.51	33.47*	56.47	103.01**	2661.15**	0.24**
Environment+(G x E)	60	110.20**	105.80**	72.84*	336.27**	8.37**	2.81**
Environment (Linear)	1	4933.68**	4507.08**	1264.88**	14509.40**	13305.75**	155.33**
Genotype x Environment (Linear)	11	59.89	82.02**	85.49	398.77**	34.45**	0.92**
Pooled Deviation	48	21.24**	19.55**	45.11*	26.64	1.69	0.065**
Pooled Error	132	3.99	3.56	26.64	18.61	3.82	0.013

*, **, Significant at 5 % and 1 % probability levels, respectively. EVV: Early vegetative vigour; DTF: Days to 50 per cent flowering;
DTH: Days to harvest; PN: Number of panicles; HI: Harvest index; PH: Plant height and GY: Grain yield

Table 2 : Estimate of different stability parameters for metric traits in upland rice

Genotypes	Days to maturity				Plant height (cm)				Harvest index				Grain yield (t ha^{-1})			
	Mean (μ)	b_i	S^2d_i	r^2	Mean (μ)	b_i	S^2d_i	r^2	Mean (μ)	b_i	S^2d_i	r^2	Mean (μ)	b_i	S^2d_i	r^2
Brown Gora	105.28	0.34*	-0.32	0.64	88.39	1.09*	-17.56	0.99	32.60	1.21	-2.67	0.99	1.62	0.95	0.10**	0.96
CB 0-13-1	111.44	1.15	-3.34	0.98	82.89	1.69*	8.37	0.96	34.18	1.15	0.64	0.98	1.84	1.05	0.01	0.97
CBT 3-06	109.89	0.67	8.18	0.74	91.11	1.71*	-15.44	0.99	29.99	0.85	-2.56	0.99	2.32	1.25*	0.05**	0.48
CR 143-2-2	100.22	0.28*	-5.35	0.86	69.33	0.46	57.83**	0.45	37.88	1.16	2.69	0.98	1.76	0.79	0.16**	0.92
IR 76569-259-1-1-3	113.22	1.24	3.44	0.94	96.17	0.77	-10.66	0.95	33.44	1.00	-3.52	0.99	1.69	1.00	0.01	0.98
Kakro	111.56	1.33*	-2.06	0.97	93.72	1.94*	13.18	0.97	26.68	0.90	-2.97	0.99	1.67	0.96	0.01	0.99
Kalinga III	103.33	0.87	-5.52	0.99	97.06	0.82*	-15.06	0.98	33.16	1.12	-3.44	0.99	2.49	1.45*	0.05**	0.79
Lalsar	91.72	1.91	97.55**	0.78	62.50	0.21*	25.13	0.2	25.71	0.71	-2.31	0.98	1.12	0.49*	0.02*	0.65
RR 383-2	109.94	1.29	-0.48	0.96	106.78	1.15*	-15.31	0.99	28.57	1.03	-3.26	0.99	1.76	1.01	0.01	0.99
RR 440-167-2-13	105.50	1.36	40.84**	0.78	91.17	0.17*	-8.33	0.46	29.82	0.72	-2.02	0.98	1.29	0.64*	0.03*	0.76
Thara	106.00	0.81	24.26**	0.67	95.44	0.83	-9.91	0.95	33.24	1.19	-3.57	0.99	2.06	1.25*	0.02*	0.59
Vandana	105.50	0.75	-1.76	0.92	92.72	1.16	83.03**	0.79	32.47	0.96	-2.71	0.88	2.21	1.01	0.01	0.98
Mean	106.13	88.94	31.48	1.82												
Correlation coefficients																
Stability parameters	Mean (μ)	b_i	S^2d_i	r^2	Mean (μ)	b_i	S^2d_i	r^2	Mean (μ)	b_i	S^2d_i	r^2	Mean (μ)	b_i	S^2d_i	r^2
Mean (μ)	-	-0.54**	0.56**	0.33	-	0.73**	-0.75**	0.79**	-	0.74**	0.54**	-0.11	-	0.64**	0.14	0.49
b_i			-0.21	0.02			0.99**	0.57**			0.42	0.12			0.53**	0.76**
S^2d_i				-0.46				-0.59**				-0.02				-0.72**

pattern for different traits. The two attributes appeared to be specific for the individual traits for a given genotype. Eberhart and Russell (1966) suggested that, if the traits associated with high yield show stability, the selection of genotype only for yield could be effective. A non significant deviation from regression (S^2di) and mean performance (xi) or regression coefficient (bi) indicated that the stability parameters might be under the control of different genes located on different chromosomes (Reddy and Choudhary, 1991).

Grain yield (t ha^{-1}) is the most important trait in the development of rice varieties. Identification of genotypes with high grain yield and average stability is of immense value. A perusal of stability parameters for grain yield indicated that both linear and non linear components of G x E interaction were found to be significant in current study. Similar results were reported by Panwar *et al*. (2008) and Sreedhar *et al*. (2011). The deviation from regression for grain yield was significant in the rice mutant Kalinga III showed highest mean value and significant for regression (bi). Linear regression for the average grain yield of a single genotype on the average yield of all genotypes in each environment resulted in regression coefficients (bi values) ranging from 0.49 (Lalsar) to 1.45 (Kalinga III) for grain yield. This large variation in regression coefficients indicates different responses of genotypes to environmental changes. A perusal of stability parameters for grain yield indicated that out of twelve genotypes, the genotype Kalinga III registered highest grain yield and showed significant bi and deviation from regression while, two genotypes *viz.,* CBT 306 and Thara registered significant bi value and deviation from regression with high mean. Genotypes with high mean yield, a regression coefficient equal to the unity (bi=1) and small deviations from regression ($S^2di=0$) are considered stable (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966). The regression coefficient of genotypes CBT 0-13-1 and Vandana with high yield above experimental mean (>1.82) while IR 76569-259-1-1-3 and RR 383-2 (<1.82) for grain yield was non-significant (bi 1.0) and had a small deviation from regression (S^2di), and thus possessed fair stability. Therefore, these genotypes were stable for grain yield in all the environments. Similar findings were reported by Gouri Shankar *et al.* (2008). The Kakro genotype had the regression value below one (bi < 1) and were found to be suited for unfavourable/ poor environments. Similar results were observed by Bhakta and Das (2008) and Panwar *et al.* (2008).

Coefficient of determination (R^2)

The coefficient of determination ranged from 0.48 (CBT 3-06) to 0.99 (RR 383-2) and it indicated that the linear regression accounted for major part of variation (Table 2). High R^2 values showed the regression lines give nearly perfect fit to actual yield of varieties in different environments. Thus the coefficient of determination is considered as a confirmation of variety's linear response to change in growth condition (Bhakta and Das, 2008). According to Akcura *et al*. (2005) the three stability parameters like bi, S^2d and R^2 are equally effective in assessing stability of performance. However, preference can be given on coefficient of determination over deviation from regression (Bhakta and Das, 2008).

Correlation coefficient

The correlation coefficient among different stability parameters indicated that the mean performance (μ) and regression coefficient (bi) had a significant positive association for plant height, harvest index and grain yield and significant negative association for days to harvest (Table 2). The deviation from regression (S^2di) was significantly correlated with mean performance for all characters except grain yield. Simultaneously, the deviation from regression positively correlated with regression coefficient for plant height and grain yield.

Drought Susceptibility Index (DSI)

The DSI for seed yield and component characteristics was calculated to characterize the relative tolerance of genotypes. Plant height, harvest index and seed yield were reduced under rain-fed conditions. The mean values of DSI for plant height (PH), harvest index (HI) and grain yield (GY) were close to or below one, indicating the relative tolerance of these traits (Table 3). The use of DSI can help to distinguish suitable variety for drought stress from phenology and yield potential. Large DSI values indicate greater drought susceptibility (Chauhan *et al*., 2007). Low DSI mean values (DSI<1) observed for seed yield indicated that this character is relatively resistant to stress. In this study, significant and desirable correlations were obtained between DSI and GY in irrigated (*r*=0.961**, 0.556**, 0.443**) and GY in drought stress (*r*=-0.032, -0.762**, -0.896**). Lalsar, CR 143-2-2, RR 383-2, RR 440-167-2-13, Thara, Vandana recorded consistently low DSI with stable rank and rest of the genotypes although showed low DSI but rank was not consistent. Present results are in agreement with Ouk *et al*. (2006) who reported consistent DSI and concluded that DSI under drought condition would allow breeders to identify resistant line with high drought tolerance. While, Pantuwan *et al*. (2002) reported that DSI can be used to identify resistant genotypes for a particular environment, but such selections will not be superior in other and different drought environments so concluded inconsistency of the estimates in DSI which reflects the nature of the large genotype-by-environment interactions observed for grain yield.

Table 3 : Estimates of drought susceptibility index (DSI) of upland rice genotypes for grain yield and yield contributing characters

Genotypes	Grain yield (t ha^{-1})								Plant height (cm)	Harvest index (%)
	2007	Rank	2008	Rank	2009	Rank	Pooled	Rank	Pooled	
Brown Gora	0.83	7	0.82	4	0.94	4	0.86	7	1.09	1.11
CB 0-13-1	0.84	8	0.80	3	0.95	3	0.86	8	1.67	1.0
CBT 3-06	0.85	9	0.92	12	0.75	12	0.84	5	1.56	0.92
CR 143-2-2	0.80	5	0.83	5	0.33	5	0.68	2	0.65	0.97
IR 76569-259-1-1-3	0.77	3	0.89	9	0.90	9	0.86	9	0.74	0.95
Kakro	0.78	4	0.84	6	0.91	6	0.84	6	1.66	1.03
Kalinga	0.89	12	0.88	8	0.97	8	0.91	11	0.80	1.03
Lalsar	0.66	2	0.66	1	0.35	1	0.57	1	0.34	0.88
RR 383-2	0.82	6	0.85	7	0.93	7	0.87	10	0.98	1.09
RR 440-167-2-13	0.65	1	0.67	2	0.75	2	0.69	3	0.19	0.80
Thara	0.86	10	0.91	11	0.97	11	0.91	12	0.82	1.08
Vandana	0.87	11	0.90	10	0.67	10	0.83	4	1.10	0.94
Mean	0.84		0.83		0.79		0.81		0.97	0.99
Range	0.65-0.89		0.66-0.92		0.35-0.75		0.57-0.91		0.34-1.67	0.88-1.11

Conclusion

High-yielding genotypes with broad adaptation and some genotypes with specific adaptation were identified. It is concluded that Vandana and CB 0-13-1 are promising genotypes satisfying the requirement for stability with high mean values and drought tolerance. Therefore, these cultivars may be cultivated over a wide range of environments.

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