Development of Upland Rice Varieties for Drought Tolerance through Drought Susceptibility Index and Stability Parameters

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Breeding for upland rice having high yield potential coupled with drought tolerance should be the strategy for a successful breeding programme. Twenty seven genotypes were evaluated for drought susceptibility index (DSI) and stability under three water regimes. Genotype, environment and their interactions influenced significantly the phenotypes for all characteristics of genotypes. CBT 3-06 and Anjali were identified as stable genotypes by Eberhart & Russell model. The use of DSI is likely to be most beneficial in selecting parents for development of drought resistant populations, particularly when yield potential vary greatly among the tested genotypes. Lalsar, RR 348-6, CR 143-2-2, Kalinga III, Brown Gora and CB 0-13-1 were recorded lowest DSI (DSI<1/=1) for seed yield over the conditions. This contrast CR 143-2-2 Brown Gora and CB 0-13-1 recorded good score for EVV, tip drying, leaf rolling and drought score and suggested for inclusion into hybridization to obtain improved recombinants for water stress environments. Based on the various parameters, the genotypes Kalinga III CB 0-13-1 may be exploited for commercial cultivation under different water regimes after some adjustment to stabilize the yield.

Key Words: Drought Tolerance, DSI and Stability, Selection Parameters, Upland rice

Introduction

Rice in Asia is cultivated by many farm families and closely linked with the social harmony, prosperity, national food security and political stability of many countries (Hossain and Fischer, 1995). Demand for rice is expected to grow faster than the production in most countries (Swaminathan, 1998). Nearly 100 million people now depend on upland rice as their daily staple food. Upland rice is usually grown in systems where little or no fertilizer is applied, and is direct-seeded into unpuddled, unsaturated soil (Atlin *et al*., 2004). Most traditional upland rice varieties are low-yielding and prone to lodging, but are adapted to non-flooded soils (Atlin *et al*., 2006). Upland rice encompasses 12 per cent of global rice production area and is generally the lowest yielding ecosystem (Khush, 1997). Climate related natural disasters are the principal sources of risk and uncertainty in rice farming. Drought is one of the major constraints to low and unstable rice production in Asia. At least 23 million ha area of rice in Asia is drought prone and India accounts for the largest share (59%) of total drought-prone rice area in Asia (Pandey *et al*., 2007).

Irrigation is not a viable option to alleviate drought problems in rainfed rice growing ecosystem. Drought mitigation through improved drought resistant rice varieties and complementary management practices, represent an important exit pathway from poverty (Serraj and Atlin, 2008). Recently, improved upland rice varieties with higher harvest index, improved input responsiveness and consequently higher yield potential have been developed at IRRI, in Brazil and several Asian countries. Such "aerobic rice" varieties, combine aerobic adaptations of traditional upland varieties with input-responsiveness, lodging tolerance and yield potential of irrigated varieties (Atlin *et al*., 2006). Thus, the present study was taken up to identify drought tolerant cultivars combined with high yield potential for drought prone upland.

Materials and Methods

Field screening experiments for large number of entries (216 from Observational Yield Trial under IIDBN programme) were conducted to identify drought tolerant genotypes at Central Rice Research Institute, Cuttack. On the basis of performance, 27 promising genotypes selected from different centers including CRRI, Cuttack and International Rice Research Institute, Philippines, were grown under field condition along with three check varieties *viz*., Anjali, Kalinga III and Vandana selected on the basis of performance under drought prone upland condition.

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The experiment was laid out in Alpha Lattice Design with three replications under three water regimes: (a) irrigated control (E_1) (b) moderate stress (E_2) and (c) severe stress (E_3) conditions at vegetative stage during dry season in the year 2008. These three water regimes were always apart from each other to avoid water interference. Plants were grown under adequate soil moisture for 30 days after germination under both the conditions. The irrigation was withdrawn for 30 days and beyond, till the susceptible check shows permanent wilting in the severe stress field, subsequently the plot was re-watered for recovery. Soil moisture content (SMC) during stress period was monitored through periodical soil sampling at 0-15, 15-30 cm soil depth after suspension water. The experimental field under irrigated condition was designed to maintain assured soil moisture by keeping 5 cm standing water. Peizometers were installed in all the treatments to monitor the ground water table. Each plot was 5 m long and 3 m wide, row to row distance was 20 cm and plant to plant distance was 15 cm each plot. Rice varieties under all the conditions were dry direct seeded at 2-3 cm soil depth by hand plough with the seed rate of 60 kg ha^{-1} to maintain 3-4 seeds $hill^{-1}$. This method gave uniform seedling emergence for all the plots in 6-8 days. Recommended package of agronomic practices were followed.

The drought scores and recovery observations were taken as per SES method, on a scale of 1 to 9 (IRRI, 1996). Plant samples above the ground were collected at maturity. Observations were recorded on seed yield (t ha^{-1}), days to 50 per cent flowering, days to maturity and plant height. The effect of stress was assessed as percentage reduction in mean performance of a characteristic under stress condition relative to the performance of the same trait under continuously saturated soil moisture condition. 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 programme (IRRI, 2009). 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

Drought Susceptibility Index (DSI)

The managed water stress protocol resulted in considerable reduction in yield compared to yield under irrigated conditions and trials achieved mean reduction of 30-50% under moderate stress and 65-80% yield reduction compared to control under severe stress. Experiments were conducted during dry season, rain fall was nil during stress period, so experiment expose to desired level of stress. 66% genotypes (including checks) recorded high yield potential (>4.5) but dramatically reduced the yield under both water stress condition. Comparison across the stress conditions indicated that the genotypes Lalsar and CR 143-2-2 emerged as tolerant genotypes for grain yield under both the conditions. Results indicted the severity of stress.

The use of the 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. The Lalsar, RR 348-6, CR 143-2-2, Kalinga III, Brown Gora and CB 0-13-1 recorded lowest DSI (DSI≤1) for seed yield over the conditions, thereby indicating that the genotypes were tolerant to vegetative drought stress conditions. Further, more tolerant genotypes especially CR 143-2-2, Brown Gora and CB 0-13-1 also showed good score for early vegetative vigour in all the conditions, leaf rolling and tip drying in both stress condition and drought score in severe stress condition (Table 1). Early vigour in upland rice is associated with improved ability to tolerate weed competition, which is a major constraint in direct seeded rice crops (Namuco *et al*., 2009). Weed competitiveness was negatively but weakly correlated with yield potential, and positively, with crop duration (Dingkuhn *et al*., 1999). Specific leaf area and tillering ability, which are major determinants of vegetative vigour, and crop duration, which affects the ability to recover from early competition, are useful traits in the selection of weed competitive rice, particularly in breeding programme. Much larger gains should be expected from use of genotypes with below average DSI in future breeding for drought tolerant rice.

Table 1. Estimates of Drought Susceptible Index (DSI) for seed yield (t ha^{-1}) and Early Vegetative Vigour (EVV), Drought score, Leaf Rolling (LR) and Tip Drying (TD) of genotypes under different environments

S. No	Genotypes	Seed Yield (t ha-1)		E1	E2			E3			
		DSI (E2)	DSI (E3)	EVV	EVV	LR	TD	EVV	D Score	LR	TD
1	ASD 17	1.00	1.03	2	1	3	2	1	3	2	1
2	Ashoka 228	1.09	1.04	2	1	3	3	1	6	4	3
3	Birsa Gora	1.02	0.89	2	2	3	2	2	2	1	1
4	Brown Gora	0.93	1.00	2	2	1	2	2	3	1	1
5	CB 0-13-1	0.94	1.00	1	1	2	2	1	3	1	1
6	CBT 3-05	1.02	1.00	1	2	3	3	2	3	2	2
7	CBT 3-06	0.91	1.01	1	3	3	2	2	3	2	2
8	CR 143-2-2	0.68	0.96	1	3	1	1	3	2	1	1
9	IR 76569-259-1-1-3	1.09	1.01	2	2	3	2	2	3	2	1
10	Kakro	1.02	1.00	1	2	3	2	1	3	2	1
11	Lalsar	0.30	0.85	1	3	2	2	2	3	2	1
12	N 22	1.03	1.04	1	2	3	3	1	3	2	1
13	RR 222-1	1.10	1.03	2	3	4	3	1	6	4	3
14	RR 267-9	1.05	0.98	1	3	3	2	2	4	2	2
15	RR 345-2	1.12	1.00	2	3	3	2	2	4	3	2
16	RR 348-6	0.62	1.00	1	3	2	1	2	4	3	2
17	RR363-3	1.03	0.94	2	2	3	2	1	3	1	1
18	RR366-5	1.04	0.97	2	2	4	3	2	3	2	2
19	RR 372-2	1.06	1.03	2	1	4	2	2	4	3	2
20	RR 383-2	1.04	1.00	2	2	2	1	2	2	1	1
21	RR433-2	1.08	1.05	2	2	3	2	2	6	4	3
22	RR 440-167-2-13	1.05	0.90	2	2	4	2	2	3	2	1
23	Sathi 34-36	1.06	1.01	1	2	4	2	1	4	2	2
24	Thara	0.89	1.01	2	1	3	3	3	3	2	1
25	Anjali (Check)	1.05	1.03	1	3	3	2	2	6	4	2
26	Kalinga III (Check)	0.91	0.97	2	2	4	3	2	3	2	2

E1: Control, E2: Vegetative Stage Moderate Stress and E3: Vegetative Stage Severe Stress

Analysis of Variance for Stability Analysis

Highly significant variances due to genotype for all the traits indicated the presence of genetic variance in the plant material. Mean squares due to environment 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 Honarnejad *et al*. (2000) and Sedghi-Azar *et al*. (2008). Mean square due to G x E interaction was significant only for seed yield (t ha^{-1}). The G x E interaction mean squares were further partitioned into two components *viz*., G x E (linear) and pooled deviation (non linear) for all the traits. Pooled deviation showed significant differences for all the traits except seed yield (t ha^{-1}) while, G x E (linear) significant for seed yield (t ha^{-1}). Linear and non-linear components of G x E interaction were significant for all the characters, confirming the findings of Panwar *et al*. (2008) and Nayak *et al.* (2003). Simultaneously, "F" value of all the characters under study were found significant for Environment + (G x E) and Environments (Lin.).

Stability Parameters

Mean value (μ), regression coefficient (bi) and deviation from regression (S^2di) are presented in Table 2. Twelve genotypes recorded higher yield over grand mean of 1.99 t ha^{-1}. Only six genotypes i.e. RR 372-2, Kakro, RR 383-2, CBT 3-06, IR 76569-259-1-1-3 and Sathi 34-36 showed bi values close to unity. The significant values of S^2di were observed in two genotypes. The remaining genotypes recorded non significant deviation from regression. Deviation from regression for plant height was found to be non significant in six genotypes. Of 27 genotypes, 16 genotypes registered higher mean over grand mean for plant height while, only five genotypes recorded bi values near unity.

The genotype ASD 17 (2.79 t ha^{-1}), Kalinga III (2.74 t ha^{-1}), CB 0-13-1 (2.67 t ha^{-1}), Ashoka 228 (2.56 t ha^{-1}) are having highest mean yield along with RR 267-9 (2.43 t ha^{-1}), N 22 (2.36 t ha^{-1}), CBT 3-05 (2.30 t ha^{-1}) and RR 222-1 (2.29 t ha^{-1}) but having bi value more than one, indicating that these genotypes are having below average stability of performance and are specifically adapted to favorable environments, however, these are sensitive to environmental changes. Similar results have also been reported by Vidhu *et al.* (2005) and Panwar *et al*. (2008). While, only Thara yielded more than 2 t ha^{-1} but having b value less than 1 do not respond favorable condition hence, it could be regarded as specially adapted to unfavorable environments. It was observed from the present study that majority of the high yielding genotypes have either above average (b>1) or below average (b<1)

Table 2. Genotypic means and stability parameters for different characters in rice

SN		Genotypes			Days to 50 per cent flowering			Days to Maturity			Plant Height (cm)	Seed yield (t ha^{-1})	
		Mean	Bi	S^2d	Mean	Bi	S^2d	Mean	Bi	S^2d	Mean	bi	S^2d
1	ASD 17	72.78	1.38	4.23	103.22	1.62	11.55**	88.17	1.77	-5.54	2.79	1.48	-0.08
2	Ashoka 228	72.78	1.66	11.92*	103.22	1.91	21.91**	82.65	1.66	47.37	2.56	1.49	-0.04
3	Birsa Gora	70.56	0.68	-2.29	100.67	0.80	-1.46	78.93	0.94	-21.77	1.72	0.76	0.01
4	Brown Gora	69.67	0.55	1.04	99.22	0.26	-1.02	83.99	0.95	-18.86	1.46	0.69	-0.07
5	CB 0-13-1	72.22	0.23	18.16**	102.22	0.28	19.08**	80.92	1.70	42.73	2.67	1.27	-0.05
6	CBT 3-05	70.44	0.93	-0.93	100.78	1.11	-0.36	72.36	0.83	86.10*	2.30	1.19	-0.08
7	CBT 3-06	72.89	1.54	6.11	103.56	1.89	17.65**	85.91	1.46	70.07	2.17	1.00	0.01
8	CR 143-2-2	68.00	0.16	5.18	98.67	0.45	2.59	64.56	0.89	-24.51	1.64	0.58	0.20
9	IR 76569-259-1-1-3	73.44	1.91	-2.19	104.33	2.53	-0.45	90.18	0.62	-21.29	1.89	1.03	-0.03
10	Kakro	70.67	1.54	-2.38	100.33	1.13	-1.46	84.38	1.35	24.14	1.96	1.01	-0.08
11	Lalsar	49.89	0.59	-2.59	80.44	0.27	-1.48	63.74	0.15	131.06*	0.94	0.16	0.32*
12	N 22	67.00	1.76	3.67	96.89	1.79	4.90*	88.95	1.29	-14.24	2.36	1.31	-0.09
13	RR 222-1	70.78	0.84	4.61	101.22	0.74	17.81**	79.41	1.02	-0.02	2.29	1.33	-0.02
14	RR 267-9	71.11	1.10	-2.60	100.56	0.72	-1.19	74.19	1.07	-15.92	2.43	1.26	-0.01
15	RR 345-2	69.11	0.73	5.37	99.22	0.72	5.78*	88.76	1.16	-23.18	2.09	1.18	0.08
16	RR 348-6	64.67	0.87	-2.64	95.11	0.94	-1.48	57.18	0.43	-1.22	1.77	0.63	0.50*
17	RR363-3	70.56	0.07	0.43	100.45	0.04	2.34	89.75	0.81	-21.88	1.53	0.73	-0/05
18	RR366-5	70.44	0.98	-2.51	100.56	1.08	-1.47	86.06	0.38	32.25	1.57	0.79	-0.06
19	RR 372-2	54.78	2.12	34.14**	86.00	2.28	43.80**	85.16	0.57	216.74**	1.77	0.98	-0.08
20	RR 383-2	70.67	0.58	-2.20	99.89	0.09	1.59	97.84	1.43	58.61	1.95	1.02	-0.07
21	RR433-2	73.44	1.04	-1.27	104.33	1.32	-1.23	77.19	1.07	51.91	1.96	1.14	-0.07
22	RR 440-167-2-13	67.89	0.14	3.79	98.78	0.38	2.38	83.15	0.29	121.75*	1.45	0.67	0.01
23	Sathi 34-36	76.78	1.61	5.74	107.22	1.62	11.55**	76.26	0.71	99.55*	1.99	1.03	-0.05
24	Thara	66.89	0.61	0.81	96.22	0.22	-1.17	89.81	1.10	18.54	2.05	0.95	0.02
25	Anjali	69.33	0.73	1.81	99.44	0.60	3.04	80.74	1.35	-14.83	2.12	1.00	0.02
26	Kalinga III	65.89	2.16	-1.69	97.22	1..1	1.69	88.83	1.15	92.84*	2.74	1.20	-0.05
27	Vandana	70.33	0.50	3.05	100.45	1.08	0.84	87.48	0.84	18.19	1.66	0.85	-0.09
	Mean	69.00			99.27			81.72			1.99		

responses. Mishra and Mahapatra (1998) suggested to evaluate these genotypes in irrigated as well as drought stress condition and to carry out the regression analysis separately to identify genotypes combining high yield potential with wider array of adaptation to variable environments.

Among the 27 genotypes, only two genotype CBT 3-06 (2.17 t ha^{-1}) and Anjali (2.12 t ha^{-1}) registered bi=1 and showed non significant deviation from regression near to zero. Therefore, these genotypes were stable for yield in all the environments. Genotype RR 372 (1.77 t ha^{-1}), Kakro (1.96 t ha^{-1}) and RR 383-2 (1.95 t ha^{-1}) along with IR 76569-259-1-1-3 (1.89 t ha^{-1}) and Sathi 34-36 (1.99 t ha^{-1}) are having relatively higher mean yield, regression coefficient near unity and about no deviation from regression. Indicating that these genotypes are having average stability and above average yields in most of the environments. Moreover, these genotypes, particularly RR 372, Kakro and RR 383-2 possess b value slightly less then unity for yield, indicating that these should also respond to the more favorable environments (Bhakta and Das 2008). In other words these genotypes are grouped as stable genotypes with general adaptability. These genotypes are not following any consistent stability (values of bi & S^2di) trend for other traits, *i.e.* days to maturity and plant height, under studied. Tall stature during vegetative stage is prerequisite for upland rice to compete the weed. It seems that for stabilizing the yield these genotypes are making some morpho-physiological adjustments leading to below average or above average stability of performance of the genotypes for yield contributing traits other that yield. Moreover, yield is the most preferred and reliable criterion for selection of genotypes under stress condition than secondary trait selections (Serraj and Atlin, 2008), thus can be the sole criterion for identification of suitable genotypes.

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