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Rapid Screening of Traditional Rice Cultivars against Drought Using Tolerance Indices of Seedlings

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To screen the traditional cultivars of rice based on the tolerance indices of seedling characteristics.
Study Design: The experimental plan used was Complete Randomized Design with 59 treatments (genotypes) and two replications.
Place of Study: P.G. Laboratory, Department of Seed Science and Technology, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar district, West Bengal, India.

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Methodology: Seedling was raised in glass in two sets- PEG-mediated drought and normal conditions.

Results: All the seedling characters showed highly significant differences among the varieties, different culture conditions as well as interaction between varieties and environment. Most of the cultivars exhibited reduction in number of primary roots per plant, root length, root fresh weight, root dry weight, shoot length, shoot fresh weight and shoot dry weight. Finally the cultivars were grouped under three categories- tolerant, semi-tolerant and susceptible based on mean tolerance index (MTI). The cultivars having ≥ 90.00, MTI Kashiya binni, Jhagri kartik and Garu Chakua were considered as tolerant. Among those three cultivars, Kashiya binni was found to be highly tolerant to drought as its MTI was ≥ 100.00 (114.96). Subsequently 22 cultivars were classified as semi-tolerant. In conclusion, the tolerance indices of seedling traits and subsequently the MTI can be used for rapid screening of rice genotypes for water stress.

Keywords: Oryza sativa L.; mean tolerance index; PEG-mediated drought; rice genotypes; water stress.

1. INTRODUCTION

Rice is a staple food for more than half of the world's population and is grown in more than 100 countries with 90% of the total global production from Asia [1]. Nearly 75% of the global rice production comes from irrigated ecosystem that covers around 55 % of the total cropped rice area. Rain-fed upland and rain-fed lowland contributed only 21% of the total production from 34% of the cropped area. Frequent occurrence of abiotic stresses like drought and submergence are considered as the key factor for low productivity of rice in rain-fed environments. In such areas drought is the single largest factor for yield reduction in rice. It has been predicted that the water deficit would increase in future years and the intensity and frequency of drought would aggravate. The intensity, duration, and frequency of water stress in relation to various phenological phases differ in the diverse rice ecosystems.

Root development has long been recognized as an important factor in determining the adaptability of a given plant species to varying water conditions. Root characteristics that are responsible for the adaptability to drought stress are root length, root thickness, and root: shoot ratio etc. [2]. The selection for desirable root characteristics has been a major objective in breeding for drought tolerant varieties of rice plant [3]. The deep roots of rice plant help to explore different levels of soil moisture and root thickness may be important in water uptake and translocation as resistance to water flow may be less in thick roots. In addition, thick roots are able to penetrate deeper soil layers. The varieties with high root to shoot ratios were more drought resistant [4]. Selection and breeding for desirable root traits associated with drought tolerance have been practiced in rice [5]. Keeping these considerations in view, an attempt was made in the present study with the objectives of screening traditional rice cultivars with desirable seedling traits indices for drought tolerance.

2. MATERIALS AND METHODS

2.1 Materials

In this endeavour 59 traditional-long duration cultivars of rice were considered. The experiment explored the variation in drought response of different rice genotypes at the seedling stage and determined a suitable selection index for screening protocols.

2.2 Methods

The glass culture experiment was laid out in a randomized complete block design with two replications in each treatment. The control was irrigated in alternate days. Where stress was imposed buy irrigating with polyethylene glycol (PEG-6000) solutions [6,7,8]. The PEG-6000 solution were prepared by dissolving 80 g PEG-6000 in distilled water and made up the volume up to 1.0 litre. The glasses were filled up with soil mixture (soil and vermi-compost at the ratio of 2:1). Seeds were soaked for 24 hours, subsequently, water was drained off and seeds were allowed to germinate. After 2 or 3 days, four sprouted/germinated seeds were placed into the glass and irrigated to keep the soil moistened. The seedlings in the glass were allowed to grow for 15 days (Fig. 1A). Thereafter, soils from individual glasses were washed off in tap water and plant samples were collected for observation. Observations and data were recorded on 15 days old seedlings on eight biometrical traits, such as, number of roots, root and shoot length (cm), root: shoot ratio, root and shoot fresh weight (g) and root and shoot dry weight (g) in each treatment in each replication.

2.3 Observations

Six normal seedlings were randomly selected from each treatment and length of shoots was measured from collar region to the tip of top most leaf and length of root was measured from the collar region to tip of the longest root. Both the root and shoot length were expressed in centimetre. Roots of the plant was cut from the stem, dried moisture free in a hot air oven at 80°C for 48 hours (till attaining constant weight), weighed and recorded in gram.

2.4 Statistical Analysis

The experimental plan used was Complete Randomized Design with 59 treatments (genotypes) replicated twice. Statistical analysis of data was conducted with absolute values. The data were analyzed using Ag Res Statistical Software, (c) 1994 Pascal Intl Software Solutions, Version 3.01 to find out the variability of the experimental treatments.

2.5 Tolerance Index

Tolerance index (TI) was calculated using following formula.

$$\text{Tolerance index (TI)} = \frac{\text{Performance under drought condition}}{\text{Performance under normal condition}} \times 100$$

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Fifty nine traditional cultivars of rice were screened for drought tolerance under glass culture condition at seedling stage. All the seedling characters, namely number of primary roots per seedling, root length, shoot length, root : shoot ratio, root fresh weight, shoot fresh weight, root dry weight and shoot dry weight showed highly significant differences among the varieties, different culture conditions (environments- control and PEG mediated drought condition) as well as interaction between varieties and environment (Tables 1 & 2). These values indicated that each genotype showed the different responses on drought conditions as the result of tolerance levels of individual cultivar. Debbarma and Roy [9] also observed high variability among these populations of rice for grain yield and lodging tolerance.

Variations in root characteristics have not been fully elucidated with reference to their genetic background in traditional cultivars of rice. Understanding the variations of root characteristics in collection of traditional cultivars of rice will be essential for genetic improvement of their root systems. In particular, to facilitate the selection of materials for breeding or genetic analysis, it is important to know whether the different traditional cultivars of rice differ in their root characteristics. Performances of the traditional cultivars based on seedling characters under PEG-fortified stressed environment are being discussed subsequently.

3.2 Number of Primary Roots per Plant

Breeders are positioned to breed plants with root traits that improve productivity under water stress. Total number of primary roots per plant at crown region were considered and recorded in this venture (Table 3). The TI of number of roots per seedling ranged from 25.00 to 118.75 (Table 5). Lal Dhyapa, Jhapaka, Sial Bhomra and Sadamala showed long root under normal condition, however, root growth of all those cultivars had been highly restricted under PEG-mediated water stress condition leading to very low TI (Table 5) suggesting their susceptibility in respect of root length.

Kashiyabinni and Dudheswar Mota Jaswa have exhibited TI≥ 90.00 for number of roots per seedling under PEG-mediateddrought situation (Table 5). A number of studies have reported QTL linked to traits associated with increasing the foraging capacity of root systems including number ofroot per plant [10,11]. Roots are one of the most important organs. Roots help plant to be anchored in soil and to absorb water and nutrients from the soil. The present research was conducted to explore the role of rice roots in drought tolerance capacity by investigating the number of primary roots rice cultivars under PEG-mediated drought condition. Kashiyabinni and Dudheswar Mota Jaswa exhibited TI in respect of number of primary roots per seedling ≥ 90.00, so these two cultivars may be considered as tolerant to drought.

3.3 Root Length (cm)

Root systems form one of the important components of drought resistance. Among the root morphological traits, root length, root thickness and number of primary roots are found to be associated with drought resistance [12]. Root length varied from 8.10 to 17.60 cm under non-stress condition (Table 3). Many researchers also reported variations among rice genotypes in respect of root length [13,14]. Cultivated rice lines vary greatly in root system architecture [15]. Lal Dhyapa showed longest root followed by Kharadhan, Sitalkuchi and Sial Bhomra, however root tolerant index (RTI) of those cultivars ≤90.00 suggesting their susceptibility to PEG-mediated drought at seedling stage (Table 5).

Simply deep rooted cultivars may not show drought tolerance. Thus, study of root tolerance ability under drought condition is very essential to draw some inference on drought tolerance. Highest RTI was observed in Jhagrikartik followed by Jashyopa, Khasa, Malshira, Seshphal (Fig. 1F), Tulsimukul, Kalokhasa, Garu Chakua, Mohanbhog, Kataribhog, Kashiyabinni, Jhapaka, Ladu (Fig. 1D), Baigon Machua (Fig. 1E), Konkonijoha, Bitti, Fudugey, Badshabhog, Tulaipanji, Gobindabhog, Boichi, Tarapakri, Beto (Fig. 1B) and Radhatilak (Table 5). All those cultivars exhibited high RTI (≥ 90.00). Rout et al. [16] suggested in their review article that the rice genotypes having RTI value more than 90.00 may be classified as tolerant for Al-toxicity. RTI also used by Roy and Bhadra [17] for classification of rice genotypes against Al-toxicity. High RTI will facilitate in proficient harvesting the available water from the soil leading to minimum expression of drought symptoms. Deep rooting may help plants to avoid drought-induced stress by extracting water from deep soil layers [18]. To improve drought avoidance in rice, therefore, introducing the deep-rooting characteristic into shallow-rooting cultivars is considered one of the most promising breeding strategies [18]. Deep and thick root traits contribute to better growth and higher yield under drought stress [19]. Rice is particularly susceptible to drought-induced stress owing to its shallow rooting relative to other cereal crops [20].

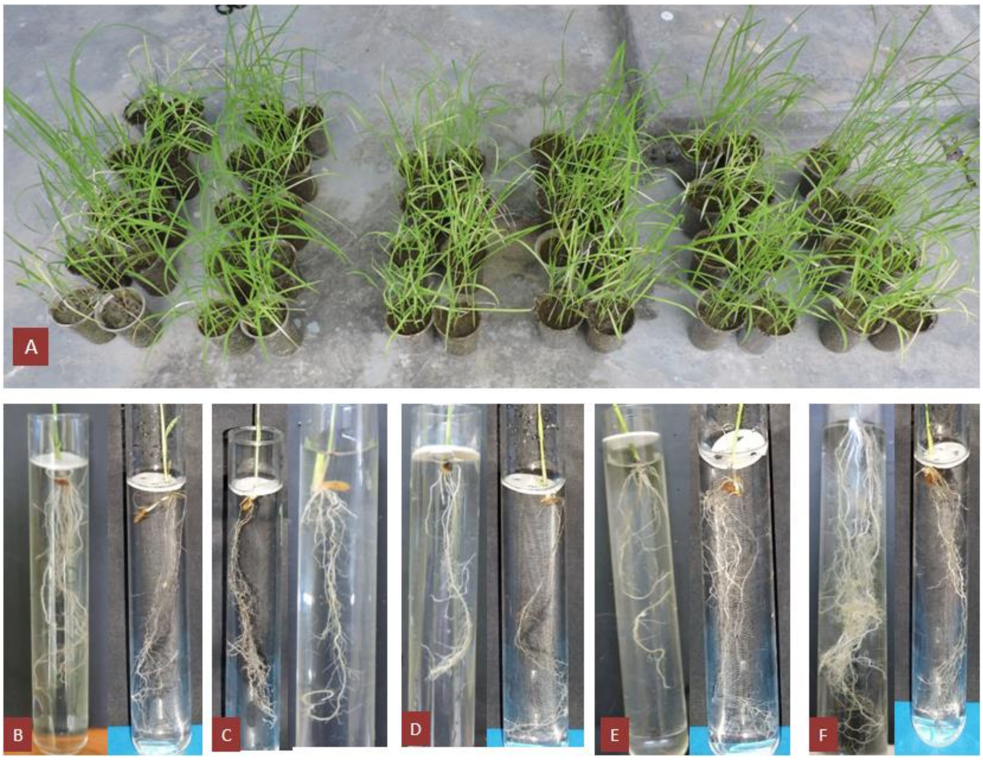

Fig. 1. Screening under glass (sand) culture for drought tolerance. A) View of screening under glass culture; B) Root character of cultivar Beto; C) Root character of cultivar Kagey; D) Root character of cultivar Ladu; E) Root character of cultivar Baigon Mucha; F) Root character of cultivar Seshaphal

Table 1. Analysis of variance (ANOVA) of seedling characters of 59 rice genotypes

Sources of variation	**d.f.**	**Mean sum of squares**			
		Number of primary roots/seedling	**Root length**	**Shoot length**	**Root: Shoot ratio**
Total	235	15.591	5.145	38.463	0.013
Replication	1	0.928	9.130	12.214	0.005
Treatment	117	29.401**	8.760**	72.100**	0.021**
Error	117	1.906	1.496	5.050	0.005
Variety (V)	58	13.248**	9.181**	65.846**	0.021**
Environment (E)	1	2220.225**	197.731**	1481.457**	0.079**
V × E	58	7.781**	5.081**	54.055**	0.020**
Error	117	1.906	1.496	5.050	0.005
Sources of variation	d.f.	Root fresh weight	Shoot fresh weight	Root dry weight	Shoot dry weight
Total	235	0.00225	0.0055	0.000035	0.000111
Replication	1	0.00005	0.0008	0.000002	0.000011
Treatment	117	0.00449**	0.0107**	0.000070**	0.000217**
Error	117	0.00004	0.0004	0.000002	0.000006
Variety (V)	58	0.00368**	0.0086**	0.000042**	0.000181**
Environment (E)	1	0.20103**	0.5365**	0.004028**	0.008616**
V × E	58	0.00191**	0.0038**	0.000029**	0.000107**
Error	117	0.00004	0.0004	0.000002	0.000006

*** denote significance P = 0.01*

Table 2. Standard deviation and Critical difference of different seedling characters

S. Ed./C.D.	V	E	V × E	S. Ed./C.D.	V	E	V × E
No. of primary roots per plant				**Shoot dry weight**			
S. Ed.	0.97631	0.17975	1.38071	S. Ed.	0.00168	0.00031	0.00237
C.D. at P=0.05	1.93355	0.35600	2.73446	C.D. at P=0.05	0.00332	0.00061	0.00470
C.D. at P=0.01	2.55650	0.47069	3.61544	C.D. at P=0.01	0.00439	0.00081	0.00621
Root length				**Root : Shoot dry weight ratio**			
S. Ed.	0.86496	0.15925	1.22324	S. Ed.	0.01457	0.00268	0.02060
C.D. at P=0.05	1.71302	0.31539	2.42258	C.D. at P=0.05	0.02885	0.00531	0.04080
C.D. at P=0.01	2.26492	0.41701	3.20308	C.D. at P=0.01	0.03815	0.00702	0.05395
Shoot Length				**Shoot fresh weight**			
S. Ed.	1.58903	0.29256	0.07076	S. Ed.	0.01457	0.00268	0.02060
C.D. at P=0.05	3.14703	0.57942	0.14013	C.D. at P=0.05	0.02885	0.00531	0.04080
C.D. at P=0.01	4.16093	0.76609	0.18528	C.D. at P=0.01	0.03815	0.00702	0.05395
Root: shoot length ratio				**Root: shoot length ratio**			
S. Ed.	0.05003	0.00921	0.07076	S. Ed.	0.00168	0.00031	0.00237
C.D. at P=0.05	0.09909	0.01824	0.14013	C.D. at P=0.05	0.00332	0.00061	0.00470
C.D. at P=0.01	0.13101	0.02412	0.18528	C.D. at P=0.01	0.00439	0.00081	0.00621

S. Ed.: Standard deviation; C.D.: Critical difference, V: Variety; E: Environment.

Table 3. Mean performance of 59 traditional cultivars of rice under normal and stress conditions in glass culture to study seedling characteristics- number of primary roots per plant, root length, shoot length and root: shoot ratio

Genotypes	No. of primary roots per plant		Root length (cm)		Shoot Length (cm)		Root: shoot length ratio	
	N	S	N	S	N	S	N	S
Beto	13.00	10.25	12.75	11.53	27.21	24.33	0.47	0.59
Binni	12.25	7.75	15.10	12.70	29.54	32.37	0.51	0.42
Bitti	5.75	3.25	10.08	9.68	18.95	22.68	0.53	0.39
Boichi	6.50	2.75	10.18	9.33	15.50	15.90	0.66	0.59
Bonnidhan	11.00	4.25	14.88	9.40	30.73	28.36	0.48	0.39
Dhyapa	9.75	7.65	11.35	8.63	22.18	22.82	0.52	0.39
Dudhekalam	11.25	5.75	13.40	10.43	27.75	25.08	0.49	0.45
Dudheswar Mota Jaswa	8.00	7.75	10.18	8.23	21.38	20.39	0.48	0.41
Jashyopa	8.75	3.00	9.43	12.35	25.03	23.54	0.38	0.56
Jhagrikartik	9.00	4.17	8.10	12.07	19.48	20.79	0.42	0.57
Kalakali	13.25	4.00	12.33	9.88	19.98	24.39	0.62	0.32
Kalodhyapa	8.25	3.25	13.70	9.48	25.73	21.89	0.53	0.50
Kalshipa	14.00	5.00	12.80	10.75	32.20	28.13	0.40	0.42
Kashiyabinni	8.00	9.50	13.60	13.65	17.60	19.20	0.77	0.56
Kauka	9.75	4.25	11.58	10.20	21.15	19.75	0.55	0.51
Kharadhan	14.25	8.25	16.83	13.00	31.85	27.95	0.54	0.55
Ladu	13.50	4.75	13.65	13.48	34.03	28.39	0.40	0.61
Lal Dhyapa	16.75	6.25	17.60	13.58	32.63	28.34	0.54	0.60
Malshira	8.25	3.75	11.25	13.43	18.55	22.20	0.62	0.50
Panikuthi Shyamlal	12.00	3.50	15.75	11.63	34.10	24.40	0.46	0.84
Phoolpakri	11.75	3.75	14.75	12.98	36.08	30.06	0.41	0.55
Sadamala	15.50	5.25	15.38	12.40	34.68	26.94	0.44	0.63
Satia	15.25	12.25	14.78	12.00	41.30	33.25	0.51	0.82
Seshphal	9.25	4.75	8.85	10.30	18.30	15.93	0.48	0.77
Sial Bhomra	16.25	6.00	16.18	10.90	29.95	24.40	0.54	0.56
Sitalkuchi	12.50	8.75	16.45	12.80	36.33	31.74	0.45	0.51
Tarapakri	14.25	5.00	13.43	12.23	26.00	25.90	0.52	0.47
Thuri	10.25	8.25	11.93	10.23	33.55	28.38	0.36	0.41
Tulsimukul	9.50	4.25	9.10	10.45	17.08	17.71	0.53	0.54
Badshabhog	11.25	4.83	10.93	10.30	23.03	18.25	0.47	0.67
Baigon Machua	10.50	4.17	10.88	10.55	19.85	17.26	0.56	0.71
Bora	14.00	6.75	13.78	11.45	30.13	22.76	0.46	0.73

Genotypes	No. of primary roots per plant		Root length (cm)		Shoot Length (cm)		Root: shoot length ratio	
	N	S	N	S	N	S	N	S
Dubari Komal	12.00	5.00	13.48	10.50	23.60	18.93	0.57	0.67
Dudheswar	13.00	9.00	13.73	11.43	22.68	23.64	0.60	0.44
Fudugey	13.25	4.50	13.03	12.28	32.90	28.28	0.40	0.48
Garu Chakua	9.50	8.00	12.15	12.85	23.60	27.90	0.51	0.39
Ghee Bora	9.25	4.00	10.28	8.95	21.80	21.45	0.47	0.40
Gobindabhog	9.75	3.17	12.13	11.18	28.85	21.46	0.42	0.75
Hatidat Komal	13.75	5.50	15.33	10.72	33.33	26.51	0.46	0.68
Jhapaka	16.25	6.50	12.53	12.53	37.18	30.66	0.34	0.49
Kabra	13.25	4.00	14.00	10.64	26.03	22.16	0.54	0.59
Kagey	13.00	7.50	14.60	7.73	31.35	25.18	0.47	0.45
Kalojeera	12.50	7.25	12.68	10.15	29.33	25.89	0.43	0.45
Kalojoha	12.00	3.00	12.55	9.33	24.23	21.26	0.53	0.47
Kalokhasa	10.25	3.25	10.08	11.05	24.90	22.85	0.41	0.53
Kalo Nunia	8.25	6.00	11.00	8.83	20.73	20.24	0.53	0.43
Kaltury	13.00	9.25	15.63	11.55	30.25	30.08	0.52	0.43
Kataribhog	13.50	4.00	12.53	12.83	24.90	23.55	0.51	0.58
Khasa	11.00	4.75	10.08	12.23	19.38	19.16	0.52	0.61
Konkonijoha	8.75	4.25	10.55	10.15	17.03	16.91	0.62	0.60
Lagidhan	13.00	5.58	13.68	8.51	32.95	23.45	0.41	0.58
Mohanbhog	12.00	6.50	12.55	13.13	21.05	19.98	0.60	0.67
Muni	11.75	4.50	10.93	8.70	24.43	30.06	0.45	0.26
Radhatilak	13.25	4.75	13.65	12.30	29.55	25.05	0.46	0.59
Radunipagal	10.50	7.75	11.45	8.88	17.60	18.13	0.65	0.49
Rampha	13.75	4.00	15.68	10.05	32.68	26.71	0.49	0.50
Silathia Bora	14.00	4.25	13.95	8.63	34.08	27.91	0.41	0.40
Tulaipanji	12.25	4.75	11.23	10.40	30.35	27.25	0.37	0.47
Tulsibhog	13.00	3.25	12.20	9.08	25.98	21.91	0.47	0.47
Range	5.75-16.75	2.75-12.25	8.10-17.60	7.73-13.65	15.50-41.30	15.90-33.25	0.34-0.77	0.26-0.84
Mean	11.68	5.54	12.75	10.92	26.65	24.06	0.49	0.53

N: Non-stressed environment; S: Drought stressed environment.

Table 4. Mean performance of 59 traditional cultivars of rice under normal and stress conditions in glass culture to study seedling characteristics- root fresh weight, root dry weight, shoot fresh weight, shoot dry weight and root: shoot dry weight ratio

Genotypes	Root fresh weight (g)		Root dry weight (g)		Shoot fresh weight (g)		Shoot dry weight (g)		Root: Shoot dry weight ratio	
	N	S	N	S	N	S	N	S	N	S
Beto	11.13	8.40	11.13	8.40	158.25	121.65	24.75	18.00	0.45	0.49
Binni	17.63	6.00	17.63	6.00	178.88	119.50	34.88	22.00	0.51	0.24
Bitti	7.38	4.50	7.38	4.50	65.63	35.25	11.25	10.75	0.67	0.45
Boichi	8.75	3.00	8.75	3.00	102.75	41.25	17.25	9.25	0.51	0.32
Bonnidhan	13.88	2.25	13.88	2.25	249.88	83.50	29.25	14.75	0.48	0.15
Dhyapa	10.13	8.35	10.13	8.35	144.38	104.25	16.00	11.25	0.63	0.67
Dudhekalam	12.63	2.70	12.63	2.70	179.25	70.50	26.00	11.00	0.49	0.27
Dudheswar Mota Jaswa	9.75	2.50	9.75	2.50	117.75	43.75	14.38	7.75	0.68	0.36
Jashyopa	10.13	3.50	10.13	3.50	165.38	73.25	24.00	12.50	0.42	0.27
Jhagrikartik	7.50	5.67	7.50	5.67	90.75	86.50	13.38	22.50	0.57	0.23
Kalakali	12.75	2.75	12.75	2.75	164.38	69.50	21.50	11.75	0.59	0.23
Kalodhyapa	7.50	2.25	7.50	2.25	152.75	65.50	25.25	11.25	0.31	0.18
Kalshipa	18.38	3.75	18.38	3.75	251.88	102.00	39.63	18.25	0.46	0.21
Kashiyabinni	9.75	7.50	9.75	7.50	107.88	152.50	13.38	25.50	0.73	0.47
Kauka	9.38	1.50	9.38	1.50	125.13	50.75	16.50	6.50	0.56	0.21
Kharadhan	16.38	10.00	16.38	10.00	343.50	141.25	51.75	21.25	0.32	0.49
Ladu	22.00	6.00	22.00	6.00	275.00	103.25	42.38	18.00	0.52	0.32
Laldhyapa	22.38	5.50	22.38	5.50	334.75	106.50	51.25	15.25	0.44	0.33
Malshira	7.50	4.75	7.50	4.75	121.00	98.75	16.63	19.50	0.45	0.28
Panikuthi Shyamlal	27.88	3.50	27.88	3.50	249.38	96.50	35.63	19.50	0.80	0.17
Phoolpakri	13.75	5.25	13.75	5.25	243.25	85.25	35.88	15.75	0.38	0.35
Sadamala	19.63	3.00	19.63	3.00	285.63	73.25	39.00	9.75	0.50	0.46
Satia	20.25	15.50	20.25	15.50	330.00	239.00	49.50	32.75	0.41	0.54
Seshphal	8.13	3.75	8.13	3.75	135.75	54.25	16.88	10.25	0.48	0.36
SialBhomra	24.13	6.00	24.13	6.00	275.25	88.00	45.75	15.50	0.53	0.40
Sitalkuchi	21.75	6.50	21.75	6.50	314.50	112.50	45.75	18.00	0.48	0.41
Tarapakri	11.25	5.50	11.25	5.50	180.88	89.00	25.13	15.50	0.45	0.34
Thuri	14.88	4.00	14.88	4.00	197.50	119.25	31.50	19.75	0.47	0.21
Tulsimukul	4.38	4.25	4.38	4.25	125.75	61.75	12.13	9.75	0.36	0.43
Badshabhog	11.25	4.17	11.25	4.17	127.25	75.00	21.25	17.50	0.53	0.25
Baigon Machua	7.63	2.67	7.63	2.67	110.63	47.00	16.00	7.50	0.48	0.36

Genotypes	Root fresh weight (g)		Root dry weight (g)		Shoot fresh weight (g)		Shoot dry weight (g)		Root: Shoot dry weight ratio	
	N	S	N	S	N	S	N	S	N	S
Bora	15.75	3.50	15.75	3.50	235.63	82.50	41.25	15.50	0.38	0.22
Dubari Komal	13.50	8.50	13.50	8.50	200.63	88.50	26.00	19.00	0.52	0.43
Dudheswar	13.38	5.75	13.38	5.75	181.50	138.25	25.63	23.75	0.52	0.26
Fudugey	17.25	5.25	17.25	5.25	250.00	87.00	31.50	15.50	0.56	0.40
Garu Chakua	11.13	9.00	11.13	9.00	171.13	163.50	23.13	29.00	0.48	0.30
Ghee Bora	11.50	4.50	11.50	4.50	127.88	71.00	22.25	12.50	0.52	0.35
Gobindabhog	8.25	3.83	8.25	3.83	125.75	68.00	19.63	13.50	0.42	0.29
Hatidat Komal	20.00	5.83	20.00	5.83	251.75	90.83	41.75	15.67	0.48	0.31
Jhapaka	17.63	4.75	17.63	4.75	257.50	125.50	38.63	20.00	0.46	0.24
Kabra	11.63	3.92	11.63	3.92	186.38	70.25	25.50	12.33	0.46	0.34
Kagey	16.38	5.25	16.38	5.25	236.25	103.75	29.38	17.50	0.56	0.29
Kalojeera	13.50	3.50	13.50	3.50	175.88	73.00	32.88	14.50	0.41	0.24
Kalojoha	12.00	3.00	12.00	3.00	146.13	56.00	25.38	11.00	0.47	0.30
Kalokhasa	10.25	3.75	10.25	3.75	140.38	71.75	19.63	14.25	0.53	0.27
Kalo Nunia	6.75	4.75	6.75	4.75	102.25	68.75	16.13	12.75	0.42	0.40
Kaltury	20.13	15.50	20.13	15.50	251.50	177.15	32.50	24.00	0.62	0.67
Kataribhog	13.00	4.50	13.00	4.50	151.88	90.00	26.13	18.50	0.50	0.24
Khasa	5.50	4.75	5.50	4.75	98.00	74.50	17.38	15.50	0.33	0.33
Konkonijoha	5.63	5.50	5.63	5.50	100.00	56.00	15.50	11.75	0.37	0.48
Lagidhan	16.88	2.25	16.88	2.25	240.88	54.08	39.38	7.83	0.43	0.28
Mohanbhog	10.63	6.75	10.63	6.75	123.25	67.25	21.63	13.00	0.49	0.56
Muni	11.25	4.75	11.25	4.75	147.88	75.50	20.25	15.00	0.56	0.32
Radhatilak	12.88	4.00	12.88	4.00	190.75	76.50	27.75	15.75	0.47	0.26
Radunipagal	8.50	6.20	8.50	6.20	119.38	90.25	16.88	12.50	0.50	0.50
Rampha	16.63	4.75	16.63	4.75	116.75	83.50	33.00	16.00	0.50	0.28
Silathia Bora	25.75	3.25	25.75	3.25	318.13	68.25	45.88	12.25	0.56	0.26
Tulaipanji	10.50	4.50	10.50	4.50	147.75	73.00	27.13	13.75	0.39	0.29
Tulsibhog	12.38	3.75	12.38	3.75	156.38	69.25	25.50	14.25	0.49	0.31
Range	4.37 -27.87	1.50- 15.50	4.37 -27.87	1.50- 15.50	65.63 -343.50	35.25- 239.00	11.25- 51.75	6.50- 32.75	0.31- 0.80	0.15- 0.67
Mean	13.360	5.093	13.360	5.093	184.0064	88.54181	27.64	15.51	0.49	0.34

N: Non-stressed environment; S: Drought stressed environment.

Table 5. Tolerance index (TI) in respect of individual seedling characters of cultivars and mean tolerance index (MTI)

Genotype	TI of root number	TI of root length	TI of shoot length	TI of root fresh weight	TI of root dry weight	TI of shoot fresh weight	TI of shoot dry weight	MTI
Beto	78.85	90.43	89.42	125.53	78.15	75.47	76.87	87.82
Binni	63.27	84.11	109.58	82.35	42.45	34.03	66.80	68.94
Bitti	56.52	96.03	119.68	73.58	42.90	60.98	53.71	71.91
Boichi	42.31	91.65	102.58	89.39	44.96	34.29	40.15	63.62
Bonnidhan	38.64	63.17	92.29	81.25	18.30	16.21	33.42	49.04
Dhyapa	78.46	76.04	102.89	75.00	75.45	82.43	72.21	80.35
Dudhekalam	51.11	77.84	90.38	91.84	44.74	21.38	39.33	59.52
Dudheswar Mota Jaswa	96.88	80.84	95.37	85.42	67.02	25.64	37.15	69.76
Jashyopa	34.29	130.97	94.05	147.37	89.85	34.55	44.29	82.20
Jhagri kartik	46.33	149.01	106.72	135.71	82.04	75.60	95.32	98.68
Kalakali	30.19	80.13	122.07	51.61	44.21	21.57	42.28	56.01
Kalodhyapa	39.39	69.20	85.08	94.34	66.18	30.00	42.88	61.01
Kalshipa	35.71	83.98	87.36	105.00	36.86	20.40	40.50	58.54
Kashiyabinni	118.75	100.37	109.09	72.73	185.52	76.92	141.36	114.96
Kauka	43.59	88.08	93.38	92.73	43.98	15.99	40.56	59.76
Kharadhan	57.89	77.24	87.76	101.85	42.04	61.05	41.12	66.99
Ladu	35.19	98.75	83.43	152.50	27.81	27.27	37.55	66.07
Laldhyapa	37.31	77.16	86.85	111.11	38.09	24.58	31.81	58.13
Malshira	45.45	119.38	119.68	80.65	76.19	63.33	81.61	83.76
PanikuthiShyamlal	29.17	73.84	71.55	182.61	22.93	12.55	38.70	61.62
Phoolpakri	31.91	88.00	83.31	134.15	32.77	38.18	35.05	63.34
Sadamala	33.87	80.62	77.68	143.18	19.23	15.28	25.65	56.50
Satia	80.33	81.19	80.51	160.78	74.71	76.54	72.42	89.50
Seshphal	51.35	116.38	87.05	160.42	59.84	46.13	39.96	80.16
SialBhomra	36.92	67.37	81.47	103.70	19.72	24.87	31.97	52.29
Sitalkuchi	70.00	77.81	87.37	113.33	29.22	29.89	35.77	63.34
Tarapakri	35.09	91.06	99.62	90.38	53.16	48.89	49.20	66.77
Thuri	80.49	85.75	84.59	113.89	28.78	26.88	60.38	68.68
Tulsimukul	44.74	114.84	103.69	101.89	48.55	97.03	49.11	79.98
Badshabhog	42.93	94.24	79.24	142.55	35.77	37.07	58.94	70.11
Baigon Machua	39.71	96.97	86.95	126.79	30.14	34.99	42.48	65.43
Bora	48.21	83.09	75.54	158.70	30.78	22.22	35.01	64.79
Dubari Komal	41.67	77.89	80.21	117.54	51.20	62.96	44.11	67.94

Genotype	TI of root number	TI of root length	TI of shoot length	TI of root fresh weight	TI of root dry weight	TI of shoot fresh weight	TI of shoot dry weight	MTI
Dudheswar	69.23	83.25	104.23	73.33	49.81	42.97	76.17	71.28
Fudugey	33.96	94.24	85.96	120.00	22.15	30.43	34.80	60.22
GaruChakua	84.21	105.76	118.22	76.47	108.30	80.86	95.54	95.62
Ghee Bora	43.24	87.06	98.39	85.11	44.14	39.13	55.52	64.66
Gobindabhog	32.51	92.17	74.38	178.57	43.60	46.42	54.08	74.53
HatidatKomal	40.00	69.93	79.54	147.83	29.90	29.15	36.08	61.78
Jhapaka	40.00	100.00	82.46	144.12	24.93	26.94	48.74	66.74
Kabra	30.19	76.00	85.13	109.26	31.86	33.71	37.69	57.69
Kagey	57.69	52.95	80.32	95.74	27.70	32.05	43.92	55.77
Kalojeera	58.00	80.05	88.27	104.65	23.65	25.93	41.51	60.29
Kalojoha	25.00	74.34	87.74	88.68	25.17	25.00	38.32	52.04
Kalokhasa	31.71	109.62	91.77	129.27	32.45	36.59	51.11	68.93
KaloNunia	72.73	80.27	97.64	81.13	85.96	70.37	67.24	79.33
Kaltury	71.15	73.90	99.44	82.69	60.05	77.00	70.44	76.38
Kataribhog	29.63	102.39	94.58	113.73	36.36	34.62	59.26	67.22
Khasa	43.18	121.33	98.86	117.31	82.38	86.36	76.02	89.35
Konkonijoha	48.57	96.21	99.30	96.77	105.11	97.69	56.00	85.66
Lagidhan	42.92	62.21	71.17	141.46	16.15	13.33	22.45	52.81
Mohanbhog	54.17	104.62	94.92	111.67	55.65	63.50	54.56	77.01
Muni	38.30	79.60	123.05	57.78	50.88	42.22	51.05	63.27
Radhatilak	35.85	90.11	84.77	128.26	30.43	31.06	40.10	62.94
Radunipagal	73.81	77.55	103.01	75.38	76.85	72.94	75.60	79.31
Rampha	29.09	64.09	81.73	102.04	26.45	28.56	71.52	57.64
Silathia Bora	30.36	61.86	81.90	97.56	13.13	12.62	21.45	45.55
Tulaipanji	38.78	92.61	89.79	127.03	39.88	42.86	49.41	68.62
Tulsibhog	25.00	74.43	84.33	100.00	31.27	30.29	44.28	55.66

Table 6. Common tolerant genotypes of seven characters based on TI values

Characters	Tolerant cultivars based on TI	Tolerant cultivars based on MTI
Number of primary roots per plant	**Kashiyabinni** and Dudheswar Mot aJaswa	Kashiyabinni, Jhagrikartik and GaruChakua
Root Length	**Jhagrikartik**, Jashyopa, Khasa, Malshira, Seshphal, Tulsimukul, Kalokhasa, **Garu Chakua**, Mohanbhog, Kataribhog, **Kashiyabinni**, Jhapaka, Ladu, Baigon Machua, Konkonijoha, Bitti, Fudugey, Badshabhog, Tulaipanji, Gobindabhog, Boichi, Tarapakri, Beto and Radhatilak	
Shoot Length	Muni, Kalakali, Bitti, Malshira, **Garu Chakua**, Binni, **Kashiyabinni**, **Jhagrikartik**, Dudheswar, Tulsimukul, Radunipagal, Dhyapa, Boichi, Tarapakri, Kaltury, Konkonijoha, Khasa, Ghee Bora, Kalo Nunia, Dudheswar Motajaswa, Mohanbhog, Kataribhog, Jashyopa, Kauka, Bonnidhan, Kalokhasa and Dudhekalam	
Root Fresh Weight	Jashyopa, KaloNunia, Khasa and **Jhagrikartik**	
Root Dry Weight	KonkoniJoha and Tulsimukul	
Shoot Fresh Weight	**Kashiyabinni**, **Garu Chakua** and **Jhagrikartik**	
Shoot Dry Weight	**Kashiyabinni**, **Jhagrikartik**, **Garu Chakua**, Malshira, Bitti and Dudheswar	

3.4 Shoot Length (cm)

Shoot length showed highly significant differences among the varieties, different culture conditions (environments- control and PEG-mediated drought condition) as well as interaction between varieties and environment (Table 1). Ibrahim et al. [21] also observed different responses in different cultivars on shoot length under water stress. Most of the traditional cultivars exhibited reduction in shoot length under PEG-mediated drought condition. This result corroborated with the findings of Mishra et al. [22].

The shoot length varied from 15.50 to 41.30 cm (Table 3). Longest shoot was observed for Satia followed by Jhapaka, Sitalkuchi and Phoolpakri. However, all those cultivars showed TI ≤ 90.00 suggesting their susceptibility to PEG-mediated drought environment at seedling stage (Table 5). However, the cultivars Muni, Kalakali, Bitti, Malshira, Garu Chakua, Binni, Kashiyabinni, Jhagrikartik, Dudheswar, Tulsimukul, Radunipagal, Dhyapa, Boichi, Tarapakri, Kaltury, Konkonijoha, Khasa, Ghee Bora, Kalo Nunia, Dudheswar Mota Jaswa, Mohanbhog, Kataribhog, Jashyopa, Kauka, Bonnidhan, Kalokhasa and Dudhekalam displayed TI ≥90.00 signifying their tolerance ability in respect of shoot length.

3.5 Seedling Root to Shoot Length Ratio

Root to shoot length ratio exhibited highly significant differences among the varieties, different culture conditions (environments-control and PEG mediated drought condition) as well as interaction between varieties and environment (Table 1). Root to shoot ratio under drought stress condition differed from 0.34 to 0.77 (Table 3). For most of the cultivars, PEG-mediated drought stress condition increased the ratios. Findings of Xu et al. [23] indicated that the increase in root to shoot length ratio in response to drought is closely associated with the higher proportion of dry matter.

3.6 Root Fresh Weight (mg)

The cultivars, Kharadhan, Panikuthi Shyamlal, Sia lBhomra, Laldhyapa, Sitalkuchi, Satia, Sadamala, Hatidat Komal, Ladu, Kaltury, Fudugey, Silathia Bora, Jhapaka, Kalojeera, Lagidhan, Bora, Binni, Kalshipa, Rampha, Kagey, Phoolpakri, Radhatilak, Kataribhog and Dudheswar had fresh weigh ≥100.00 mg/seedling (Table 4). However, the fresh weight reduced drastically under the drought situation leading to low TI (Table 5) suggesting susceptibility of those cultivars to PEG mediated drought.

TI of root fresh weight under PEG-mediated drought condition showed significant decrease in all cultivars as compared with normal condition except Khashiyabinni, Garu Chakua and Konkonijoha (Table 5). Root fresh weight of Jashyopa, Kalonunia, Khasa and Jhagrikartik were least affected under drought environment. So, the above mentioned seven cultivars may be treated as tolerant in respect of root fresh weight. These results are consistent with Larkunthod et al. [24] and Ibrahim et al. [21], they observe that all rice cultivars under study showed reduction in root fresh in PEG-mediated drought situation.

3.7 Root Dry Weight (mg)

Selection and breeding for desirable root dry weight associated with drought resistance have been practiced in rice [5]. In most cases, the target of the breeding program is increased yield, and the target at the vegetative stage is dry biomass accumulation. Dry matter production of plants under PEG-mediated drought situation, regardless of cultivar was significantly inhibited when compared with that of plants under normal situation. Lowest reduction in root dry weight (TI ≥ 90.00) was reported for Konkoni Joha and Tulsimukul indicating their tolerance under water stress condition (Table 5). A common adverse effect of drought is the reduction in biomass production [25,26]. Many studies indicate significant decrease in fresh and dry weights of roots [27]. Therefore, the cultivars (Konkoni Joha and Tulsimukul) which showed very low reduction in fresh weight or high TI value of root of seedling under drought condition may be considered as drought tolerant. Reduced fresh shoot and root weights as well as their lengths ultimately reduce the photosynthetic rate of physiology and biochemical processes of rice [28].

3.8 Shoot Fresh Weight (mg)

Seedling shoot fresh weight under normal drought condition varied from 65.63 mg to 343.50 mg (Table 4). Kharadhan, Laldhyapa, Satia, Silathia Bora, Sitalkuchi, Sadamala, Sial Bhomra, Ladu, Jhapaka, Kalshipa, Hatidat Komal, Kaltury, Fudugey, Bonnidhan and

Panikuthi Shyamlal exhibited high shoot fresh weight, but all TI of all those cultivars were comparatively low (Table 5) indicating their susceptibility under PEG-mediated drought condition.

Kashiyabinni displayed increase in shoot fresh weight (TI = 141.36) under drought condition. The cultivars which showed high TI ≥90.00 were Kashiyabinni, Garu Chakua and Jhagrikartik. A common adverse effect is the reduction in biomass production [25,26]. Many studies indicate significant decrease in fresh weights of shoots [29]. Therefore, the traditional cultivars which showed very low reduction in fresh weight of shoot of seedling may be considered as drought tolerant.

3.9 Shoot Dry Weight (mg)

Shoot dry weight in PEG-mediated drought situation varied from 11.25 mg to 51.75 mg (Table 4). Highest dry weight (51.75 mg) was observed for Kharadhan trailed by Laldhyapa, Satia, Silathia Bora, Sial Bhomra, Sitalkuchi, Ladu, Hatidat Komal, Bora, Kalshipa, Lagidhan and Sadamala at non-stressed condition. None of these cultivars showed high TI due to low values of shoot dry weight under stressed condition indicating their susceptibility in PEG-mediated drought situation (Table 5).

Four cultivars, namely Kashiyabinni, Jhagrikartik, Garu Chakua and Malshira showed TI more than 100.00 indicating higher shoot dry weight in PEG-mediated drought condition as compared to non-drought condition. Other cultivars which exhibited higher TI for shoot dry weight under drought condition were Bitti and Dudheswar. A common adverse effect is the reduction in biomass production [25,26]. Many studies indicate significant decrease in dry weights of shoots [26]. Therefore, the traditional cultivars which showed increase in dry weight or very low reduction in fresh weight of shoot of seedling under drought condition may be considered as drought tolerant.

3.10 Root to Shoot Dry Weight Ratio

In most of the cases shoot and root dry weight reduced under PEG-mediated drought condition as compared to non-stressed condition. Dien et al. [30] also evidence that drought treatment had reduced dry matter accumulation in shoots and roots, and reduced shoot length and root length. The cultivars Dhyapa, Kaltury, Mohanbhog, Satia, Radunipagal, Beto, Kharadhan, Konkonijoha, Kashiyabinni, Sadamala, Bitti, Tulsimukul, Dubari Komal, Sitalkuchi, Sial Bhomra and Fudugey exhibited high root to shoot dry weight ratio under PEG-mediated drought environment (Table 4) demonstrating their tolerance against drought.

3.11 Mean Tolerance Index

Mean tolerance index (MTI) were calculated from average of tolerance index of seven seedling characters (Table 5), namely number of primary roots per seedling, root length, shoot length, root fresh weight, shoot fresh weight, root dry weight and shoot dry weight. MTI varied from 45.55 to 114.96 and rice varieties were categorized into three groups basis of these values as outline by Wang et al. [31]. MTI values of the studied ranging from ≥ 91.55, 68.55 to 91.55 and 45.55 to 68.55 were considered tolerant, semi-tolerant and sensitive, respectively. Three cultivars, namely Kashiyabinni, Jhagrikartik and Garu Chakua were found to be tolerant (Table 6). Twenty two cultivars, such as Satia, Khasa, Beto, Konkonijoha, Malshira, Jashyopa, Dhyapa, Seshphal, Tulsimukul, Kalo Nunia, Radunipagal, Mohanbhog, Kaltury, Gobindabhog, Bitti, Dudheswar, Badshabhog, Dudheswar Motajaswa, Binni, Kalokhasa, Thuri and Tulaipanji were classified as semi-tolerant. Remaining 34 cultivars were found sensitive to drought at seedling stage.

Root distribution has been quantitatively characterized by using several traits, including number of primary roots, root length, root: shoot length ratio, root fresh weight, root dry weight, root : shoot dry weight ratio etc., and these characteristics differed among cultivars [15]. A number of studies have reported QTL linked to traits associated with increasing the water harvesting capacity of root systems. These include, increased root length [32,33], and root number [10,33].

Root traits have been claimed to be critical for increasing yield under water stress. Due to the reduction in turgor pressure under water stress, cell growth is severely impaired [34]. Drought affects both elongation as well as expansion growth [35], and inhibits cell enlargement more than cell division [36]. Root dry mass and length are good predictor of rice yield under drought [37,38].

Studies on rice roots have identified many root characters that provide drought resistance. Rice genotypes that have deep roots with a high ability of branching and penetration and higher root to shoot ratio are reported as component traits of drought avoidance [18,39]. Constitutive root traits, interacted with drought intensity, have a large effect on extractable soil water during drought [40]. Selection and breeding for desirable root characteristics accompanying with, drought resistance have been practiced in rice [5]. Understanding the root physiology under drought will enable further insight of important traits that might influence crop productivity under water stress and can contribute toward selection and development of drought resistant varieties.

4. CONCLUSION

Early tolerance capability of rice to drought is anticipated to be maintained throughout the productive life. All the seedling traits showed highly significant differences among the varieties, different culture conditions as well as interaction between varieties and environment. Most of the cultivars exhibited reduction in number of primary roots per plant, root length, root fresh weight, root dry weight, shoot length, shoot fresh weight and shoot dry weight. Using the TI of individual traits tolerant cultivars were identified. TI of different traits showed different tolerant cultivars, however, few of them remained common as tolerant under each seedling trait. Finally the cultivars were grouped under three categories- tolerant, semi-tolerant and susceptible based on mean tolerance index (MTI). The cultivars having ≥ 90.00, MTI Kashiyabinni, Jhagrikartik and Garu Chakua were considered as tolerant. Among those three cultivars, Kashiyabinni was found to be highly tolerant to drought as its MTI was ≥ 100.00 (114.96). In conclusion, the tolerance indices of seedling traits and subsequently the MTI can be used for rapid screening of traditional cultivars of rice for water stress.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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