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Assessment of Bangladeshi Rice Landraces for Drought Tolerance Under Controlled Environment

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ABSTRACT

Drought is one of the major challenging abiotic stresses for rice production in Bangladesh. This study investigated 48 rice landraces obtained from different Eco-zones of Bangladesh for their drought tolerance characteristics. Significant variation was observed in morpho-physiological traits such as length of root and shoot, dry weight of root and shoot, leaf stomatal resistance and stomata number. Stomatal conductance, root length, root dry weight showed significant correlation with visual drought score. A cluster analysis based on morpho-physiological characteristics identified six cluster groups and most of the promising drought tolerance landraces were found in cluster VI. Five landraces - Dhapa, Dud Kalam, Dular, Hogla Pata and Keora showed key desired characteristics for dry weight, stomatal conductance, evapotranspiration, water use efficiency and root parameters for drought tolerance. These landraces could be potential sources in breeding programme for the development of drought tolerant rice varieties.

Key words: Drought tolerance, landraces, morph-physiological traits, rice (*Oryza sativa* L.)

INTRODUCTION

Rice (*Oryza sativa* L.) is a major staple food for most of the people living in Asia and developing countries like Bangladesh. Due to its phylogenetic origin as a semi-aquatic plant (Das and Uchimiya, 2002), rice is highly dependent on a sufficient amount of water for its cultivation. As a result of increasing temperature and decreasing precipitation, drought has been one of the most significant constraints for crop productivity and, eventually, for global food security. Global warming and unpredictable rainfall patterns in recent years have led to excessive drought spells causing huge yield losses and excessive scarcity in food production in many parts of the world (Vikram *et al.*, 2012). Amongst the abiotic factors that have created plant evolution, drought is considered as the most imperative and a major limitation for rice production in rainfed ecosystems (Nelson *et al.*, 2014; Pandey and Shukla, 2015). Drought is a time span with low average precipitation/poor rain or higher evaporation rates causing a downfall in crop growth and yield (Rollins *et al.*, 2013). About 20-25 million hectare of the world's potential cultivable rice land suffers from an inadequate supply of water and/or in drought conditions (Atlin *et al.*, 2009). The severity and timing of water stress varied from season to season and year to year (Pantuwan *et al.*, 2002). Its effect is often amalgamated with other abiotic and/or biotic stresses (Clover *et al.*, 2001). It is estimated that about half of the world's rice is cultivated in rainfed and upland areas where unfavourable conditions limit crop production (Bennett, 2001; Pantuwan *et al.*, 2002).

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The drought intensity and severity are very complex and it is dependent on different factors like frequency of rainfall, evaporation and soil moisture (Hao *et al.*, 2018; Oladosu *et al.*, 2019). In Asia alone, about 34 million ha of rainfed lowland and 8 million ha of upland rice exposed to drought stress (Singh *et al.*, 2016). Breeding for drought tolerance of rice plants have previously been attempted by a number of researchers, but progress has been slow because of complexity of the trait and lack of suitable donors with a high level of drought tolerance. Screening of thousands of genetic materials has been performed earlier for drought resistance in different corners of the world; however, only a few drought - tolerant varieties are yet recognized (Singh *et al.*, 2016; Kumar *et al.*, 2016). The main reasons for the minimal success were non-availability of truly drought-tolerant genotypes and lack of suitable screening methods (Pandey and Shukla, 2015).

The scientists from International Rice Research Institute (IRRI), Philippines have screened nearly 1000 rice accessions originated from 47 countries for drought tolerance and identified 65 accessions having drought-tolerance (Torres *et al.*, 2013). The identified tolerant rice varieties are either *aus* or *indica* type and the highest number of drought-tolerant accessions are *aus* ecotype (19) originated from Bangladesh, followed by India (7), whereas highest number of drought-tolerant *indica* accessions were originated from India (16) followed by Bangladesh (3) and Sri Lanka (3) (Torres *et al.*, 2013; Panda *et al.*, 2021). It is reported that the responses of rice plants to drought stress are believed to be complex that involves numerous physiological, biochemical and molecular changes (Upadhyaya and Panda, 2019; Gupta *et al.*, 2020; Melandri *et al.*, 2020).

The range of water stress is wide and can affect the crop at any stage of growth of rice plants.

As mentioned above that IRRI made some progress for the development of drought tolerant rice but the progress in developing drought tolerance rice varieties has been limited due to the influence of the environment and genetic interactions with them (Fukai and Cooper, 1995). Plant breeders have tried to interpret how environmental conditions influence genotypes, and how genotypes respond to different environments. Unfortunately, the influence of the environment over genotypes and yield models provides a little understanding of the biological significance of water stress (Turner *et al.*, 2001). It was reported that broader leaves play a role in better performance of indica rice under drought stress (Farooq *et al.*, 2010). Several leaf traits have been used for the screening of drought tolerant variety *i.e.* higher flag leaf area, leaf area index, leaf relative water content, leaf pigments content, stomata number etc. (Farooq *et al.*, 2009; Khalequzzaman, 2009, Mishra and Panda, 2017; Hussain *et al.*, 2018). Root characteristics of the plants are considered as the vital attributes for enhancing production under drought stress. Crop function under water stress is determined by the constitution and formation of rice root system (Panda *et al.*, 2021). In case of rice, the genotypes having profound root system, coarse roots, capacity of producing many branches and high root: shoot ratio is important characteristics for drought tolerance (Khalequzzaman, 2009; Kim *et al.*, 2020). It was reported that the morpho-physiological characteristics of rice roots play a major role in determining shoot growth and overall grain yield under drought stress (Kim *et al.*, 2020).

Several authors (Chakravorty *et al.*, 2013; Ray *et al.*, 2013, Hussain *et al.*, 2018; Panda *et al.*, 2021; Sabouri *et al.*, 2022) have investigated phenotypic diversity of rice landraces for adaptation to local conditions to different abiotic stresses. Different morpho-physiological parameters interact variously in relation to genotype in drought conditions. This paper aims to investigate rice landraces from different Eco-zones of Bangladesh with the goal of identifying drought tolerant rice accessions for rainfed and upland habitats. The obtained results may provide useful information for drought tolerance of Bangladeshi rice landraces for drought breeding programmes.

MATERIALS AND METHODS

A total of 48 rice accessions obtained from the Bangladesh Rice Research Institute (BRRI) genebank, which comprised of different agro-ecozones of Bangladesh, were used in the experiment. These accessions were chosen based on provenance information considered as the most suitable for drought tolerance experiments (Table 1).

Table 1. List of the rice landraces with accession number and provenance climates used in the study.

Accession	BRRI accession number	Growing season*	Collection district	Collection region***	Rainfall pattern[a]
Dharial	0018	Aus/Upland	DA-14**	-	Moderate rainfall
Dular	0022	Aus/Upland	DA-22	-	Moderate rainfall
HashiKalmi	0030	Aus/Upland	DA-23	-	Moderate rainfall
Kataktara	0039	Aus/Upland	DA-2	-	Moderate rainfall
Marichbati	0047	Aus/Upland	DA	-	Moderate rainfall
Panbira-1	0050	Aus/Upland	DA-12	-	Moderate rainfall
Hijolee	0571	Aus/Upland	Rangpur	Rangpur	Low/moderate rainfall
Aus Baku	1318	Aus/Upland	Kustia	Meherpur	Low/moderate rainfall
Hasha	1534	Aus/Upland	Dinajpur	JhikorGacha	Low/moderate rainfall
ManikMondal	1692	Aus/Upland	Faridpur	-	Moderate rainfall
HumaGambir	1738	Aus/Upland	Khulna	-	Moderate rainfall
Hanumanjata	1739	Aus/Upland	Khulna	-	Moderate rainfall
Boalia	2068	Aus/Upland	Kishoregonj	Hossainpur	Moderate/heavy rainfall
Ausa Bogi	2075	Aus/Upland	Kishoregonj	Kendua	Moderate/heavy rainfall
Agali	2082	Aus/Upland	Netrokona	Netrokona	Heavy rainfall
Bogi	2083	Aus/Upland	Netrokona	Netrokona	Heavy rainfall
Kumari Aus	2100	Aus/Upland	Jamalpur	Dewangonj	Heavy rainfall
Gopal Bhog	2109	Aus/Upland	Narsingdi	Narsingdi	Moderate rainfall
Sada Aus	2135	Aus/Upland	Pabna	Pabna	Low rainfall
Hazi Faram	2150	Aus/Upland	Rajshahi	Charghat	Low rainfall
Bina Muri-1	2181	Aus/Upland	Bogra	-	Moderate rainfall
Bina Muri-2	2184	Aus/Upland	Bogra	-	Moderate rainfall
Bakee	2358	Aus/Upland	Jamalpur	-	Moderate/heavy rainfall
Boila Bokri	3194	Aus/Upland	Munshigonj	Lauhajong	Moderate rainfall
Aus Nagra	3455	Aus/Upland	Jessore	Navaron	Low/Moderate rainfall
Aug Meghi	3456	Aus/Upland	Jessore	Navaron	Low/moderate rainfall
Bok Tulsi	3461	Aus/Upland	Shatkhira	Sadar	Moderate rainfall
Aus Kushi	3501	Aus/Upland	Shatkhira	Tala	Moderate rainfall
Bali Guri	3502	Aus/Upland	Mymensingh	Haluaghat	Heavy rainfall
Binna Toa	4197	Aus/Upland	Noakhali	Sonagazi	Heavy rainfall
Hogla Pata	3871	T. Aman	Barishal	-	Moderate rainfall
Kada Moni	0573	Aus/Upland	Rangpur	-	Low/moderate rainfall
Kala Mona	0984	T. Aman	Comilla	Baliaghata	Moderate rainfall
Kumra Gair	3878	T. Aman	Barishal	-	Moderate rainfall
Kacha Mota	3879	T. Aman	Barishal	-	Moderate rainfall
Kartik Sail	3662	T. Aman	Sherpur	Sherpur	Heavy rainfall
Kola Mocha	4141	B. Aman	Jhenidah	Jhenidah	Low/moderate rainfall
Lakhai	1800	Boro	Kishoregonj	Tarail	Moderate/heavy rainfall
Nuncha	0942	Aus/Upland	Khulna	Fakirhat	Moderate rainfall
Nona Balam	3203	T. Aman	Barishal	-	Moderate rainfall
Panbira-2	4150	T. Aman	Khulna	Fultola	Moderate rainfall
Tilock Kachari	0758	B. Aman	Chittagong	Boalkhali	Heavy rainfall
Aswina	0927	B. Aman	Sylhet	-	Heavy Rainfall
Dud Kalam	0278	T. Aman	Rangpur	Sundarganj	Low/moderate rainfall
Keora	0731	B. Aman	Comilla	-	Moderate rainfall
Hogla	4178	B/T. Aman	Jessore	-	Moderate rainfall
Kumari	0203	B//T. Aman	-	-	-
Dhapa	0320	T. Aman	Rangpur	Hatibandha	Low rainfall

[a] Low Rainfall <1600mm, Moderate Rainfall 1600-2500 mm, Heavy Rainfall >2500mm

- Data not available, * Rice growing ecosystem, Aus = Summer rice, T.Aman = autumn/rainfed lowland rice, Boro = winter/irrigated rice (Oka, 1991) **DA means Dhaka Agricultural station collection number ***Administrative unit

The accessions were screened in a glasshouse at the University of Southampton, England in 1999. The growing conditions were maintained with an average air temperature of 31°C, solar radiation of 18 MJ/m^2/day and relative humidity of 85% (Fig. 1).

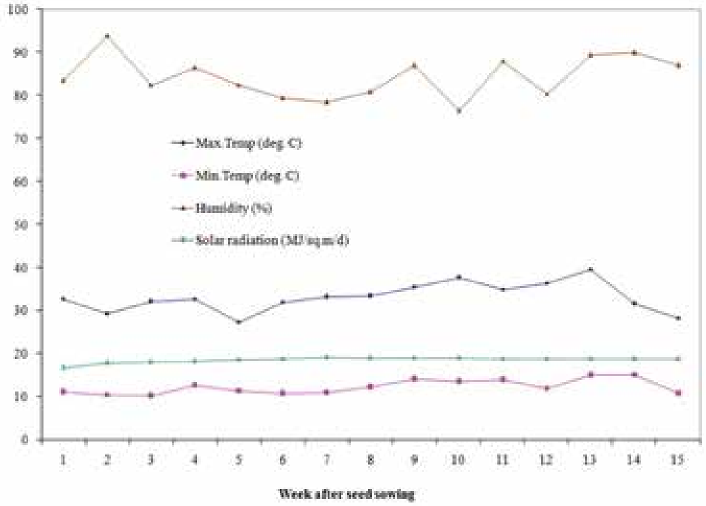

Fig. 1. The weather data in the glasshouse during the drought tolerance trial.

The experiment used a randomized complete block (RCB) design with four replications. Eight seeds of each accession were dibbled to 2 cm depth in pots. Each pot was 15 cm in diameter with a surface area of 177 cm^2, filled with 885 cm^3 of soil (John Innes compost number 2). The number of days required to seedling emergence was recorded. At seedling emergence, the pots were irrigated twice a week (200 cm^3/pot) until the seedling establishment. The seedlings were then thinned out to five seedlings per pot. After 45 days of seeding, irrigation was reduced to once a week until water stress was imposed. At the vegetative stage (before panicle primordial initiation), water stress was imposed after 45 days of emergence and visual score was made for the degree of drought intensity. The drought intensity was scored after 15 days of imposed stress using the methods described by O'Toole and Maguling (1981) and Standard Evaluation System of the International Rice Research Institute (IRRI, 1996). The drought severity scale was used from 0 to 9, where score of 0 signifies a score of higher drought tolerance (healthy leaves, no visible leaf rolling or necrosis) and score of 9 signifies high drought susceptibility (plants apparently dead). After measuring the visual drought score, pots were re-watered once a week.

The abaxial stomatal conductance (cm s^{-1}) of the youngest fully expanded leaf of five plants per treatment was measured using a diffusive resistance automatic porometer (Delta-T device, Mark II, Cambridge, England) just prior to the stress period (37 days after emergence) and at the stress period (52 days after emergence). The average stomata density (per mm^2) of five plants was measured using a stereomicroscope. Plant canopy heights were measured from the ground base to the end of the tallest leaf. Leaf area (cm^2) was calculated by using a Leica-Q-winimage processing and analysis system (Lecia-imaging system Ltd., Cambridge, England). After harvesting, plants were oven dried (constant weight at 80°C) and the weight of the shoots and roots of five hills per replication was measured. The ratios of root-to-shoot length (root/shoot length) and their dry weight (root/shoot dry weight) were calculated. Tiller numbers per hill from randomly selected five hills per replication were counted. Each pot was weighed once a week in order to determine water loss. Evapotranspiration (ET) was calculated weekly using a water balance equation: $ET = \{I + (S_1 - S_2)\}$/surface area of pot (mm/week); where I= irrigation, (S_1 and S_2) = the initial and final weight of pot, respectively. Water use efficiency (WUE) (g/kg) was then calculated as the ratio of dry matter or crop yield to ET (Kramer, 1980).

Analysis of variance and covariance, coefficient of variation (CV), simple linear regression and Pearson's bi-variate correlation were used to determine the inter-relationships between the drought-related parameters studied. A cluster analysis was then conducted using an agglomerative hierarchical clustering method (HCA), and a rescaled distance similarity measure was used to identify potential drought tolerant accessions. Principal component analysis (PCA) was carried out on the data matrix. The principal component scores with eigenvalues, which were greater than or equivalent to 1.0, were used as new variables for cluster analysis. All analyses were carried out using spreadsheets and SPSS version 10.

RESULTS

Table 2 presents descriptive statistics of the morpho-physiological traits of the accessions used in the experiment.

Table 2. Descriptive statistics and F values of different morpho-physiological characteristics based on two-way ANOVA in the tested 48 rice landraces.

Characteristic	Minimum	Maximum	Mean ±SE	CV (%)	F Value
Drought score	0.50	7.50	2.87±0.10	31.71	5.86**
Days to emergence	10.00	16.50	12.94±0.12	12.83	1.16^{NS}
Tiller number per hill	3.30	34.00	7.33±0.26	37.62	3.98**
Plant Canopy height (cm)	49.70	97.50	71.57±0.59	6.89	7.48**
Root length (cm)	15.50	40.44	25.81±0.66	14.62	4.11**
Root-shoot length ratio	0.21	0.63	0.36±0.01	15.88	4.94**
Stomatal conductance (cm/s) prior to stress	0.13	0.54	0.33±0.01	27.53	1.88**
Stomatal conductance (cm/s) at stress	0.05	0.11	0.08±0.00	80.50	1.05^{NS}
Stomata number	83	198	131±1.80	19.01	2.91**
Leaf length (cm)	32.50	60.10	45.09±0.38	7.30	6.18**
Leaf width (cm)	0.77	1.60	1.42±0.02	7.69	16.96**
Leaf area (cm^2)	13.47	38.50	22.53±0.48	12.58	9.37**
Root dry weight per hill (g)	0.40	2.80	1.22±0.03	21.16	4.42**
Shoot dry weight per hill (g)	3.20	33.90	6.54±0.11	17.76	3.31**
Total dry mass per hill (g)	3.60	36.30	7.76±0.11	15.66	3.09**
Root-shoot dry weight ratio	0.02	0.40	0.19±0.01	22.35	5.49**
Evapotranspiration (mm/day)	2.66	3.55	3.07±0.01	4.04	1.63*
Water use efficiency (g/kg)	3.41	12.54	6.93±0.10	14.48	2.88**

SE= Standard error of mean, CV= coefficient of variation ** Significant at the 1% level, *Significant at the 5% level, NS = Not significant at the 5% level, F value= Fisher significant test value.

Differences are observed in the parameters of mean, standard error and CV indicating the existence of diversity in the germplasm. Statistical distribution presented in Box and Whisker plot (Fig. 2) which showed the distribution of the population and dot sign in the middle of the boxplot indicate the mean performance of the traits.

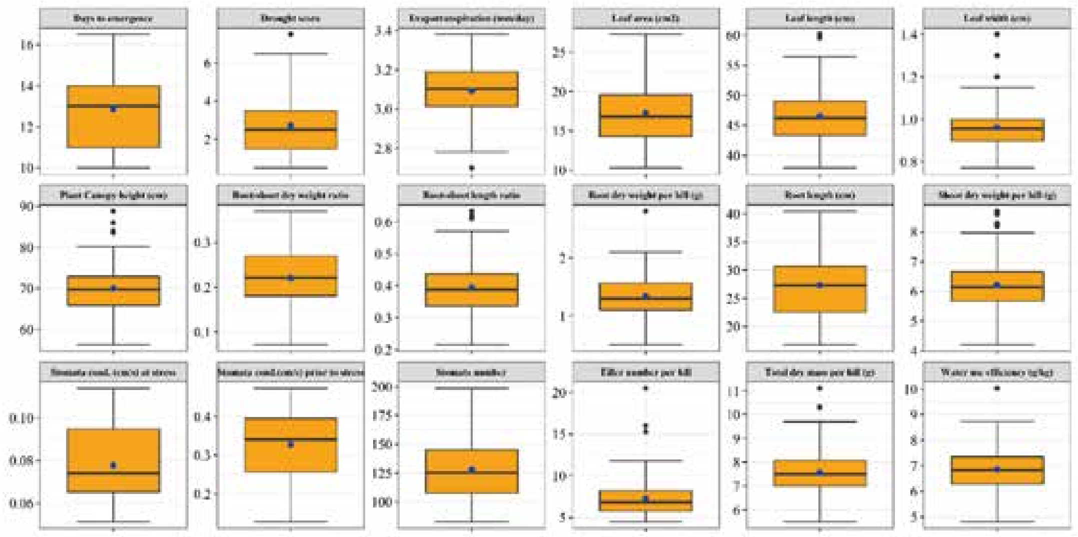

Fig. 2. Box and Whisker plot for different parameters of morpho-physiological traits of the tested 48 rice landraces.

Table 3 presents correlation between the studied parameters. Drought score showed significant negative correlation with root length (r = -0.43**), dry weight of root (r = -0.26**) and root-shoot length ratio (r = -0.33**). This indicates that larger root length and higher dry weight of roots are associated with drought tolerance of the accessions studied in this experiment.

A negative correlation also exists between drought score and stomata conductance prior to imposition of stress (r =- 0.27**) but it became significantly positive under stress conditions (r = 0.27**), whereas no relationships to stomata number. Thus, the accessions with desirable leaf characteristics, such as higher stomatal conductance when unstressed but lower conductance when stressed are potential drought tolerant traits.

It is apparent that the accessions with higher water use efficiency at lower evapotranspiration have useful characteristics for the selection of drought tolerant traits. The results revealed that the landraces Dhapa, Boalia, Dular, Hashi Kalmi, Hogla Pata etc had higher water use efficiency at lower ET (Fig. 3).

Table 3. Simple Pearson's correlation coefficient among the drought related parameters in the assessment of 48 rice landraces.

	Drought Score	St. cond. prior (cm/s) to stress	St. conduct (cm/s) at stress	Stomata number (per mm^2)	Leaf length (cm)	Leaf width (cm)	Leaf area (cm^2)	Shoot length (cm)	Root length (cm)	Root-shoot length ratio	Shoot dry weight (g)	Root dry weight (g)	Root-shoot dry weight ratio	Total drymass (g)	ET (mm/day)	WUE (g/kg)	Tiller number/ plant	Days to emergence
D. Score	1	-0.27**	0.27**	0.11 ^{NS}	-0.14 ^{NS}	-0.02 ^{NS}	-0.014 ^{NS}	-0.13 ^{NS}	-0.43**	-0.33**	0.06 ^{NS}	-0.26**	-0.28**	-0.01 ^{NS}	-0.14*	-0.01 ^{NS}	-0.09 ^{NS}	-0.25**
St. conductance prior to stress		1	-0.23**	0.32**	-0.02 ^{NS}	-0.001 ^{NS}	0.01 ^{NS}	-0.03 ^{NS}	0.25**	0.25**	-0.11 ^{NS}	0.29**	0.32**	-0.04 ^{NS}	0.24**	-0.02 ^{NS}	0.09 ^{NS}	0.04 ^{NS}
St. cond. At stress			1	0.11 ^{NS}	0.11 ^{NS}	0.09 ^{NS}	0.18*	0.07 ^{NS}	-0.26**	-0.26**	0.23**	-0.24**	-0.36**	0.16*	-0.002 ^{NS}	0.15 ^{NS}	0.02 ^{NS}	-0.03 ^{NS}
St. number				1	0.002 ^{NS}	0.06 ^{NS}	0.42**	0.02 ^{NS}	-0.25**	-0.23**	-0.02 ^{NS}	-0.04 ^{NS}	-0.02 ^{NS}	-0.03 ^{NS}	0.20**	-0.03 ^{NS}	0.04 ^{NS}	-0.10 ^{NS}
Leaf length					1	0.14 ^{NS}	0.36**	0.55**	0.07 ^{NS}	-0.21**	0.14 ^{NS}	0.04 ^{NS}	-0.07 ^{NS}	0.14 ^{NS}	0.05 ^{NS}	0.16*	-0.06 ^{NS}	0.07 ^{NS}
Leaf width						1	0.51**	0.48**	-0.14 ^{NS}	-0.36**	0.15*	-0.23**	-0.25**	0.08 ^{NS}	0.09 ^{NS}	0.08 ^{NS}	-0.12 ^{NS}	0.07 ^{NS}
Leaf area (cm^2)							1	0.45**	-0.17**	-0.38**	0.45**	-0.09 ^{NS}	-0.33**	0.41**	0.24**	0.41**	0.08 ^{NS}	0.01 ^{NS}
Shoot length (cm)								1	0.07 ^{NS}	-0.45**	0.23**	-0.02 ^{NS}	-0.14 ^{NS}	0.21**	0.17*	0.22**	-0.06 ^{NS}	0.13
Root length (cm)									1	0.85**	-0.07 ^{NS}	0.44**	0.47**	0.04 ^{NS}	0.02 ^{NS}	0.06 ^{NS}	0.14*	0.25**
R/Shoot length ratio										1	-0.15*	0.41**	0.47**	-0.05 ^{NS}	-0.04 ^{NS}	-0.04 ^{NS}	0.18*	0.18*
Shoot dry weight (g)											1	0.14*	-0.45**	0.97**	0.38**	0.94**	0.38**	0.26**
Root dry weight (g)												1	0.78**	0.37**	0.06 ^{NS}	0.39**	0.19*	0.10 ^{NS}
R/shoot dry weight ratio													1	-0.25**	-0.19**	-0.20**	-0.06 ^{NS}	-0.05 ^{NS}
Total dry weight (g)														1	0.37**	0.97**	0.41**	0.27**
ET (mm/day)															1	0.24**	0.23**	0.16*
WUE (g/kg)																1	0.38**	0.25**
Tiller number																	1	0.30**
Days to emergence																		1

D= Drought, St = Stomata, Cond= conductance, *Significant at $P<0.05$ and ** Significant at $P<0.01$, ^{NS}Not Significant at $P = 0.05$ & 0.01, N=192.

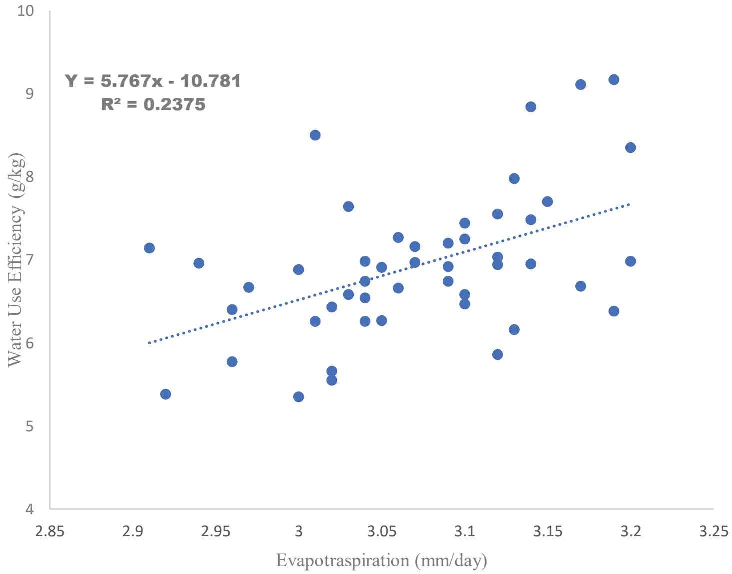

Fig. 3. Scatter diagram showing distribution of the tested 48 rice landraces based on evapotranspiration and water use efficiency.

Dry mass production was found to be related to ET and water use efficiency. The accessions- Dhapa, Dular, Boalia, Hashi Kalmi and Kala Mona had higher dry matter production with lower ET (Fig. 4, and Fig. 5). This is possibly due to their water use efficient characteristics. The above mechanism is considered useful for drought avoidance because the plants were able to reduce water loss by closing stomata.

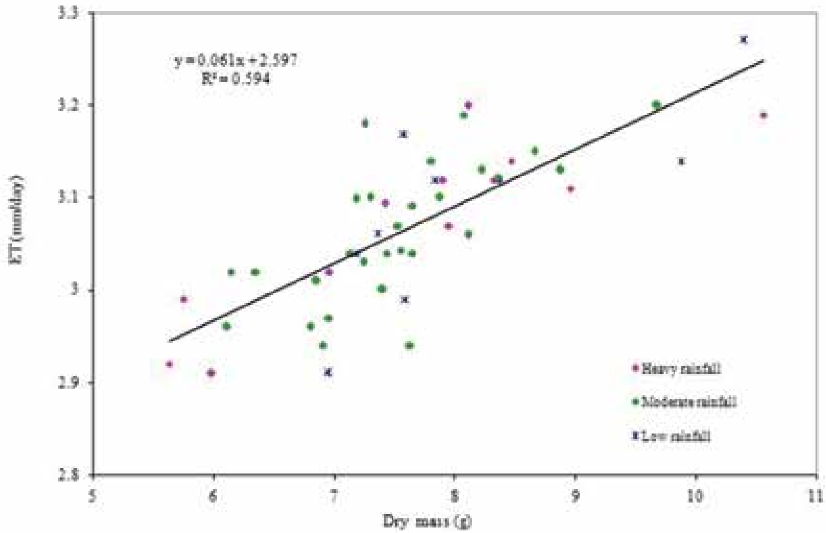

Fig. 4. Scatter diagram on the basis of ET (mm/day) and dry mass (g) showing distribution of the tested 48 rice landraces.

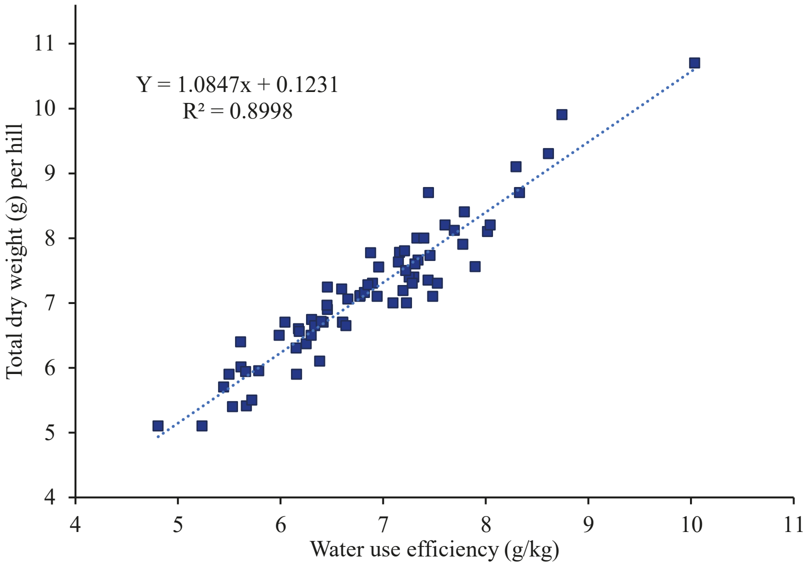

Fig. 5. Relationship between total dry weight (g) per hill and water use efficiency in the tested 48 rice landraces.

Dry matter results revealed that the accessions Dhapa (7.59 g), Kada Moni (7.18 g), Dular (7.63 g), Kala Mona (8.22 g), Dud Kalam (7.83 g), Keora (7.23 g) and Dud Mona (7.23 g) had increased dry matter production together with efficient water use characteristics (Table 4). Hence, these accessions could be selected for drought tolerance traits.

Table 4. Selected drought tolerant landraces with key characteristics related to drought tolerance.

Accessions	Drought score	Root length (cm)	Shoot length (cm)	Root dry mass (g) per pot	Shoot dry mass (g) per pot	ET (mm/day)	Total Dry weight (g)	WUE (g/kg)
Dud Kalam	1.56±0.7	33.58±2.8	63.32±2.6	7.52±1.0	31.62±1.9	3.12±0.1	7.83±0.3	6.94±0.2
Aug Meghi	1.63±0.6	30.87±3.3	78.43±1.5	7.13±1.1	30.50±2.9	3.07±0.1	7.52±0.5	6.97±0.5
Keora	1.75±0.5	29.97±1.9	65.89±3.6	7.28±1.0	28.89±4.1	3.03±0.1	7.23±0.7	6.58±0.7
Manik Mondol	1.75±0.5	30.25±1.9	74.55±3.2	6.16±0.5	28.38±2.5	3.05±0.1	6.91±0.5	6.27±0.5
Huma Gambir	1.75±1.0	30.42±1.7	76.93±9.3	6.74±0.5	31.00±3.5	3.04±0.1	7.55±0.7	6.98±1.0
Agali	1.75±0.5	29.08±4.4	79.95±6.4	6.20±0.3	30.91±5.2	3.09±0.2	7.42±1.0	6.74±0.7
Dhapa	1.75±0.2	34.12±2.3	68.76±2.5	8.06±0.6	29.90±1.5	2.91±0.2	7.59±0.4	7.14±0.1
Kala Mona	1.88±0.8	34.10±2.8	84.48±3.9	8.70±0.7	32.38±2.3	3.03±0.1	8.22±0.7	7.64±0.5
Bina Muri-2	1.75±0.5	27.78±4.9	60.90±3.1	5.44±0.8	25.25±1.2	3.02±0.1	6.14±0.3	5.67±0.2
Kada Moni	1.90±0.5	32.90±1.9	71.75±4.3	8.25±0.9	27.62±3.6	3.04±0.1	7.18±0.8	6.54±0.8
Bina Muri-1	2.00±06	26.55±5.1	61.25±5.4	5.64±1.0	24.88±1.9	2.96±0.1	6.11±0.5	5.77±0.3
Hogla Pata	2.00±0.4	27.55±2.6	69.20±2.5	6.00±0.4	28.00±2.6	2.96±0.2	6.80±0.5	6.40±0.3
Tilock Kachari	2.25±0.5	31.22±3.9	61.90±3.5	8.45±1.4	31.27±3.3	3.07±0.1	7.95±0.7	7.17±0.8
Dular	2.75±1.0	30.33±3.4	71.25±5.3	8.25±1.0	29.90±8.9	2.94±0.2	7.63±1.9	6.96±1.3
Hashi Kalmi	2.75±1.3	29.35±2.8	70.18±3.1	7.38±1.5	28.31±4.6	2.97±0.1	7.14±0.9	6.67±0.5

Principal component analysis (PCA) revealed six principal components, which indicates 85.1% of the variability of the parameters measured in this experiment Fig. 6 and Fig. 7 presents the bi-plot of the first two PCA's.

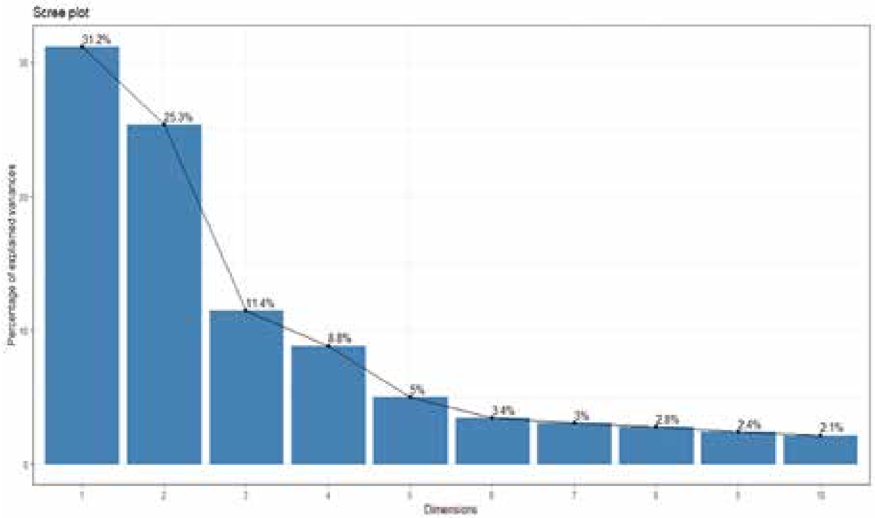

Fig. 6. Scree plot of PCA of the tested 48 rice landraces explained variance for different principal components.

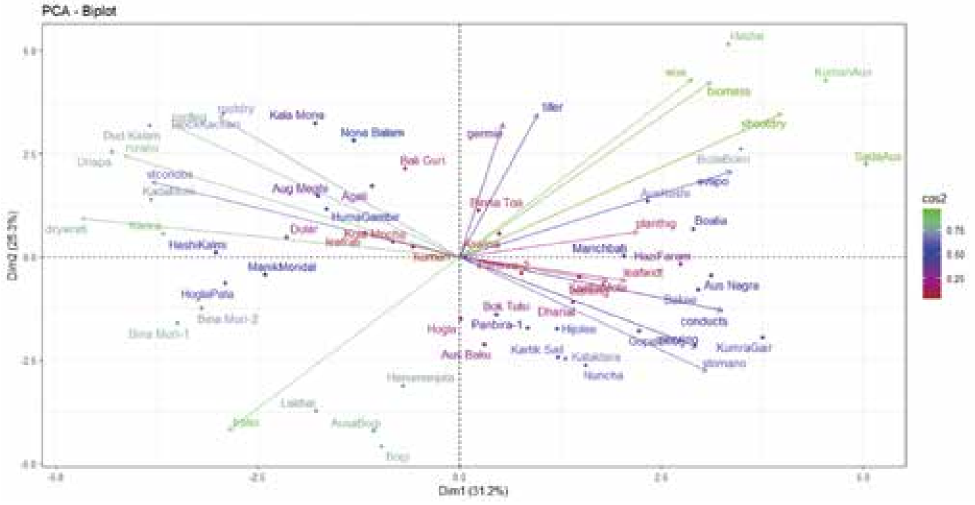

Fig.7. PCA of biplot for the tested 48 rice landraces based on morpho-physiological traits.

The hierarchical cluster analysis (HCA) was carried out to classify and identify accessions based on the variability extracted by principal components. The landraces with similar characteristics for drought tolerance were clustered into six groups (Fig. 8). Considering the studied results and findings, it is clear that the accessions with drought tolerance characteristics were grouped into cluster VI and identified drought tolerant landraces were Tilock Kachari, Dhapa, Hogla Pata, Keora, Dular, Hashi Kalmi and Dud Kalam (Table 5). In addition, this implies a probable genetic similarity among these accessions in terms of morpho-physiological characteristics and these are the potential candidate accessions for drought tolerance. Further evaluation is needed to confirm their drought tolerance.

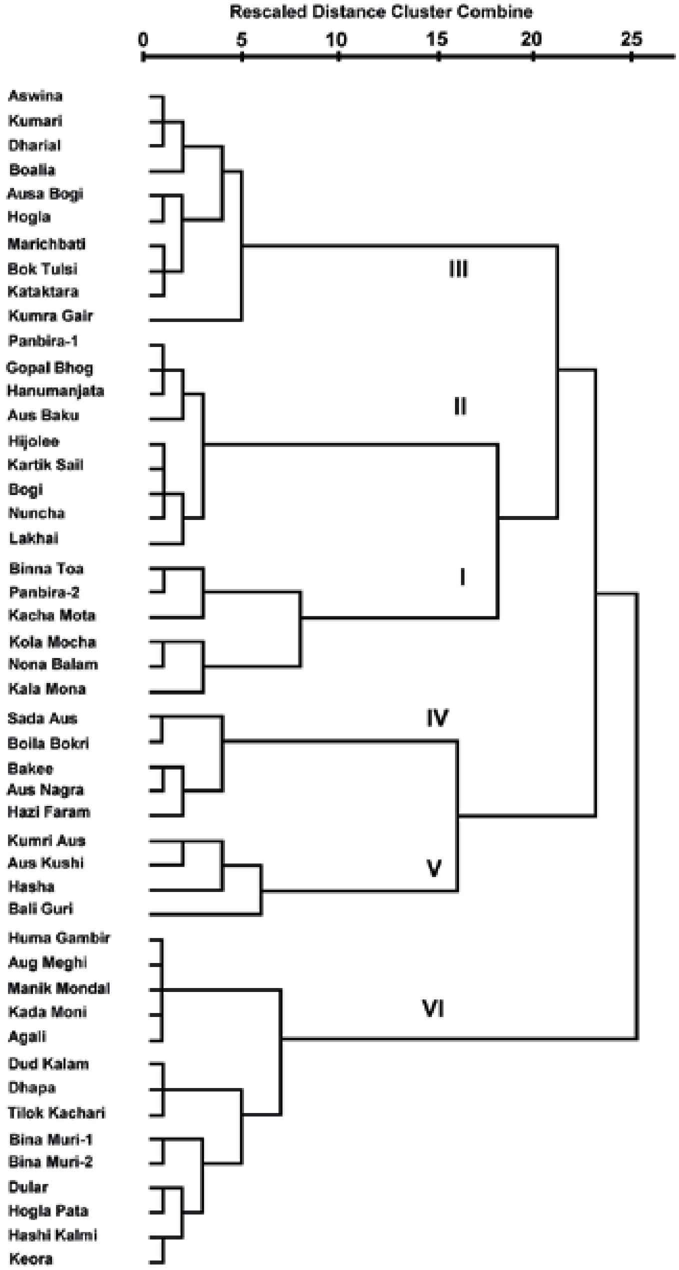

Fig. 8. Hierarchical clustering method (HCA) dendrogram showing different clusters of rice landraces based on morpho-physiological characteristics in the tested 48 rice landraces.

Table 5. Distribution of the tested 48 rice landraces revealed by cluster analyses based on morpho-physiological characteristics.

Cluster groups	Name of the landraces
I	Binna Toa. Panbira-2, Kacha Mota, Kola Mocha, Nona Balam, Kala mona
II	Panbira-1, Gopal Bhog, Hanumanjata, Aus Baku, Hijolee, Katrikshail, Bogi, Nuncha, Lakhai
III	Aswina, Kumari, Dharial, Boalia, AusaBogi, Hogla, Marichbati, Bok Tulsi. Kataktara, Kumar Gair
IV	Sada Aus, Bolia Bokri, Bakee, Aus Nagra, Hazi Faram
V	Kumari Aus, Aus Kushi, Hasha, Bali Guri
VI	Huma Gambir, Aug Meghi, Manik Mondal, Kada Moni, Agali, Dud Kalam, Dhapa, TilokKachari, Bina Muri-1, Bina Muri-2, Dular, Hogla Pata, Hashi Kalmi, Keora

DISCUSSION

As long as climate changes and subsequent substantial decline of grain yield caused by drought stress, the need for drought-tolerance is an essential breeding objective.

The visual drought score is one of the best selection indices for drought tolerance as this correlates with root development systems (Ingram *et al.*, 1990) and leaf water potential (O'Toole and Moya, 1978; Ekanayake *et al.*, 1985). In the present study, visual drought score showed significant correlation with dry root weight and stomatal conductance. The landraces/ accessions that were evaluated in this study showed a wide range of drought scores with physiological traits investigated. Correlations identified that deeper and more extensive root systems result in lower drought score (higher drought tolerance). This may be due to enhanced uptake of soil water. O'Toole (1982) states that rice cu1tivars with large root dry mass and deep roots can be considered to be drought tolerant. Similar results were reported by Chang *et al.*, (1974) in traditional upland rice cultivars. In the present investigation, it was found that the landraces, which had larger root systems and higher root-to-shoot ratios may be able to maintain high leaf water potential. The landraces which showed the above mentioned criteria may be selected for drought tolerance.

Stomata play an important role in regulating water loss. Drought score is related to leaf parameters such as stomatal conductance. The identified landraces might have the capability to maintain high leaf water potential and the ability to control transpiration through the opening and closing of the stomata. Further evidence from the leaf stomatal conductance confirmed this because the landraces/accessions with lower values of drought score had higher values of conductance prior to stress but considerably lower values under stress conditions. It has been reported by several authors (Collinson *et al.*, 1997; Clifford *et al.*, 2000. Azam-Ali and Squire, 2002, Khalequzzaman, 2002) that stomata decrease conductance under water stress conditions. This is in turn increases water use efficiency when water is limited (Clover *et al.* 2001). The present study show that stomatal conductance decreased to 28% under water stress conditions.

It is observed in the study that leaf rolling (one parameter used for drought score) decreases transpiration from leaves by reducing leaf area and along with stomata closure. This may have caused the genetical differences in maintaining high water status during water stress conditions. It has been reported that excessive transpiration is harmful for crop plants because it leads to significant reductions in productivity especially under limited water conditions

(O'Toole and Maguling, 1981). The crop must keep a careful balance between water uptake and loss to avoid excessive water deficit in the tissues otherwise it has to pay a yield penalty. This water balance may be achieved by a combination of reduced branching/tillering, leaf number, decreased leaf expansion and/or leaf rolling (Clifford *et al.*, 2000). In reality, leaf rolling helps to reduce the radiation incident on leaves and consequently reduces leaf temperature and water loss, which leads to increase the avoidance of dehydration.

In the current study evapotranspiration (ET) was related to the drought score and was significantly correlated with leaf area; root-shoot dry weight ratio, shoot and total biomass (Table 3). It appears that dry mass and water use efficiency increased with increased ET, although some landraces had higher dry mass production with low ET (Figs. 3, 4 and 5). This shows that these landraces have some capacity to increase their water use efficiency. This is possibly due to genetic factors as drought has minor effect on water use efficiency (Clover *et al.*, 2001).

It was reported earlier that longer roots, greater root dry weight and higher ratios of root-shoot length to dry weight can play a significant role in drought resistance mechanisms (Ludlow and Muchow, 1990; Thanh *et al.*, 1999; Azam-Ali and Squire, 2002; Khalequzzaman, 2002; Khalequzzaman, 2009). Several landraces of this studied showed that root-to-shoot ratios and leaf stomatal conductance prior to stress conditions reduced under stress conditions, indicating tolerance to drought. Principal component analysis (Figs. 6 and 7) and cluster analysis revealed that most of the possible drought tolerant accessions were confined to one group (Table 5 and Fig. 8) This implies that they were similar in relation to their morpho-physiological characteristics such as root system, root biomass, dry weight of root and shoot, stomata number and conductance.

To solve the water scarcity issue, developing drought-tolerant rice varieties has been a major challenge of rice breeders. Moreover, utilizing best-performing genotypes as donor parents in breeding program could be very effective in improving rice for drought tolerance.

CONCLUSION

In conclusion, the assessment of Bangladeshi rice landraces for drought tolerance under controlled environment has provided valuable insights into the potential of traditional varieties to withstand drought stress. The results of this study suggest that some of these landraces have adaptive traits that enable them to cope with limited water availability, which is a promising indication for their potential use in future breeding programs aimed at improving drought tolerance in rice cultivars. The evaluation of physiological and morphological traits provided a comprehensive understanding of the response of these landraces to drought stress. It was observed that some of the landraces maintained their growth under drought conditions, indicating the existence of natural variability that can be exploited to improve rice cultivars' resilience to water scarcity. The findings of this of this study have significant implications for sustainable agriculture in Bangladesh, where drought stress is a prevalent constraint for rice production. The use of drought-tolerant varieties can help farmers cope with changing climatic conditions and reduce their reliance on irrigation water, ultimately contributing to food security and rural livelihoods. Overall, the assessment of Bangladeshi rice landraces for drought tolerance under controlled environment provides a promising direction for future breeding programmes and highlights the importance of preserving traditional crop diversity as a valuable resource for agricultural sustainability.

AUTHORS' CONTRIBUTION

NH generated the idea and MK developed methodology, gathered data, carried out analysis and wrote the manuscript.

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DECLARATION OF INTERESTS

We wish to confirm that there are no known conflicts of interest associated with this publication.

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