Turkish Journal of Agriculture - Food Science and Technology, 13(s3): 3849-3863, 2025
DOI: https://doi.org/10.24925/turjaf.v13is3.3849-3863.8047

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Screening of Rice Genotypes for Drought-prone Rainfed Environments

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ARTICLE INFO

Research Article

Received : 01.07.2025
Accepted : 20.08.2025

Keywords:
Drought-tolerance
Leaf Rolling
Spikelet Sterility
Dendogram Clustering
Harvest Index

ABSTRACT

This study was undertaken to investigate the responses of rice genotypes in water stress prone rainfed environments and to select drought-tolerant rice genotypes. Thirty rice genotypes were evaluated in the drought-prone rainfed high Barind tract at Godagari, Rajshahi, Bangladesh (24.27 N latitude, 88.21 E longitude, 40 masl) during two wet seasons (WS), from July to December. In both WSs, 25-day-old seedlings were transplanted on August 16 at a spacing of 25 x 15 cm, with three seedlings per hill, using a randomized block design with three replications. To comprehend the drought stress and assess the performance of the genotypes, estimates of precipitation, temperature, drought severity, ground water depth, soil moisture content, soil water potential, phenology, leaf rolling and desiccation, spikelet sterility, dendogram clustering, rooting behaviors, yield, and yield component data were estimated. Yield, yield components, leaf rolling, spikelet sterility, and root properties exhibited considerable variation (p = 0.001) among the rice cultivars. The grain yield and harvest index of the evaluated rice genotypes varied from 1.28 to 4.51 t ha^{-1} and 0.25 to 0.47, respectively, contingent upon the degree of drought. Across genotypes, 61% of root biomass was found in the upper 0-10 cm soil layer, with a significant decline in the subsequent layers (27%, 9%, and 3% in the 10-20, 20-30, and 30-40 cm layers, respectively). Four rice genotypes (IR74371-70-1-1, IR83377-B-B-93-3, IRRI123, and IR83381-B-B-6-1) were identified as drought-tolerant based on their overall performance under drought-stress, while BR7873-5*(NIL)-51-HR6 was selected as drought-escaping. The genotypes IR74371-70-1-1 and BR7873-5*(NIL)-51-HR6 were released as the drought-tolerant variety BRRI dhan56 and the drought-escaping variety BRRI dhan57, respectively. Consequently, the genotypic variance in our germplasm selection revealed significant potential to generate drought-tolerant varieties through breeding aimed at enhancing rainfed lowland rice.

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Introduction

Rice production under water deficit environments is a severe problem in rice-growing area of the world where water sources and irrigation facilities are limited. Rainfall distribution is more important than total rainfall on productivity of rice affected by drought-stress (Hijmans and Serraj, 2008). Farmer's rice production and their economy significantly reduced due to damage of rice crop affected by water deficit (Pandey et al., 2007). Farooq et al. (2009) found that crop loss is more under drought than any other stresses based on drought duration and its severity. Rajshahi region (northwestern part of Bangladesh) is drought-prone area with low and unpredictable rainfalls, and limited irrigation facilities (Saleh et al., 2000; Saleh and Bhuiyan, 1995). Drought recurrently occurred in this region due to unpredictable rainfall and its uneven distribution. Rice yield losses caused by water stress are usually higher than the damage owing to flood and submergence. Drought is happened about two to three years interval recurrently at reproductive stage of wet season rice that called terminal drought (Islam, 2007). In general, drought may be occurred at seedling stage, tillering and at any growth stage of rice crop in wet season. Moreover, rice can experience with intermittent drought-stress during the season due to irregular rainfall patterns (Kamoshita et al., 2008). These conditions are typical for about 0.16 M ha land of Rajshahi region which are rainfed and mostly drought-prone (Saleh et al., 2000). The major portion of this region is part of the Barind tract. It comprised with gallery type land having series of elevated blocks of undulating terraces. The Barind has two terrace levels from which, one at 40 masl and another at 20 to 23 masl and it has higher elevation compared to the surrounding floodplain (Riches, 2008). Mean annual rainfall of Rajshahi region ranged from 1000 to 1200 mm while average rainfall of the country is about 2300 mm, ranging from 1000 to 5000 mm (Karmakar et al., 2012; Saleh et al., 2000). The weather of this region is getting extreme over the years due to the effect of climate change. Only 800 mm of rain fell on Rajshahi in 2009, according to Karmakar et al. (2010). Annual average rainfall of the Rajshahi region showed a decreasing trend over the last 50 years and it is declining by 3.1 mm per year (Ferdous and Baten, 2011). Considering these changes happening, comprehensive research on field screening of rice genotypes were undertaken in the drought-prone rainfed environment of northwest Bangladesh.

The wet season (Aman) rice production in Bangladesh is dependent on monsoon rainfall. Farmers frequently encounter postponed transplanting of wet season rice due to late rainfall, as they primarily rely on precipitation. Rice yield was reduced when crop faced water-stress at reproductive stage in October. Lower rice yield is also noticed as the crop suffered from water-stress due to late beginning of the rainy season. Delayed rainfall resulting drought-stress sometimes destroys the rice crop (Mahmood et al., 2003) which is a recurrent phenomenon and an important limitation to rainfed rice environments of Asia. However, rice yield is more affected by drought from panicle initiation to the grain filling stage. These stages occur late in the season when the probability of drought is higher than early in the season. Thus, rice productivity significantly reduced by the cumulative effect of late season drought stress compared to early-season drought-stress (Pandey and Bhandari, 2008). Drought-tolerance genotypes are considered to be the first essential footstep to enhance the productivity of rainfed rice. Consequently, research efforts were directed for many years to develop early-maturing short duration and or drought-tolerant rice varieties.

Another important element in drought tolerance are root systems. Rice root systems vary significantly among genotypes and soil conditions in drought prone rainfed environments (Henry et al., 2012). Root characteristics are strongly associated with drought-resistance under rainfed conditions (Sharma et al., 1994). The root system of rice cultivars is strongly determined by genetics; however, it is also affected by the soil moisture situation and crop management practices (Mambani et al., 1990; Sharma et al., 1987; Cruz et al., 1986). Rice root length and its density have significant effect on rice under water-stress. Environments, genotypes, management practices and soil depth have effect on root length and root length density (RLD) of rainfed rice (Tuong et al., 2002; Samson et al., 2002).

Rice genotypes selection for grain yield from drought stress field is found more effective shown by the International Rice Research Institute (IRRI) (Bernier et al., 2007; Venuprasad et al., 2007). IRRI and its National Agricultural Research and Extension System (NARES) partners selected some auspicious rice genotypes that can produce 1.0 to 1.5 t ha^{-1} higher yield than current mega varieties in drought prone environments (Mackill et al., 1996). However, many of these promising rice genotypes have not yet been tested in drought-prone rainfed environments of Bangladesh. But in order to identify the most promising and adaptable genotypes, screening and fine-tuning are required in the target environment. Therefore, a drought screening trial needed to be pursued in the drought-prone rainfed northwest Bangladesh. The main purposes of this study were to identify the performance of rice genotypes in drought-prone rainfed condition, and to determine rice genotypes for drought-tolerance based on root index and overall performance.

Materials and Methods

Experimental Land

The trials were performed at a farmer's field located in Edulpur, Godagari, Rajshahi, Bangladesh (24°27′ N latitude, 88°21′ E longitude, 43 meters above sea level) during the wet seasons of 2009 and 2010. A drought prone rainfed topmost field in the Barind tract was selected for the experiment. The experimental site belongs to the Agro-ecological Zone (AEZ) 26, having silt loam to silty clay soils with a grey color (BARC, 2018). The topsoil at the experimental site had a soil pH of 5.8, a texture of 17% clay - 68% silt - 15% sand, soil organic carbon of 0.70%, total soil N of 0.078%, a C/N ratio of 9.0, available P_{Olsen} of 10.0 mg kg^{-1}, exchangeable Kexch. of 0.21 me/100 g and a cation exchange capacity (CEC) of 6.8 cmol kg^{-1}.

Background of the Tested Rice Genotypes

Thirty rice genotypes including four check varieties were tested for drought tolerance in the drought-prone rainfed conditions (Table 1). Seeds of these rice genotypes were obtained from the International Rice Research Institute (IRRI), the Bangladesh Rice Research Institute (BRRI), the Bangladesh Institute of Nuclear Agriculture (BINA) and farmers. IRRI and NARES partners identified several promising breeding lines that can produce from 1.0 to 1.5 t ha^{-1} higher yield than current mega varieties in water deficit environments (Mackill et al., 1996). Some of the breeding lines were developed following crosses between two drought-tolerant breeding lines with the aim to accumulate positive alleles for drought tolerance from the two parents. Another set of genotypes were developed through crossing between drought-tolerant breeding lines with high-yielding popular drought-susceptible lines, with the aim to develop drought-tolerant breeding lines with high yield potential and good grain quality. All crosses were advanced through cyclic selection under reproductive stage drought stress from F2 to F6 generations based on drought tolerance, high yield, insect and disease tolerance, and good grain quality traits (amylose content, chalkiness etc.). The F6 generation was transplanted under reproductive stage drought and selection was carried out in the nurseries. High-yielding lines under drought stress were bulked and forwarded to the observational yield trial (OYT). In the OYT, selection for high yield was repeated at reproductive stage (Panicle initiation to maturity stage) drought-stress and the better genotypes were forwarded to the advanced yield trials (AYT).

Table 1. Rice genotypes tested in the experiments

SN	Rice genotype	Parentage (Male parent/Female parent)
1	IR83376-B-B-71-1	IR71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
2	IR83381-B-B-137-1	IR72022-46-2-3-3-2 (DT)/IR77080-B-34-1-1 (DT)
3	IR83373-B-B-25-3	IR71700-247-1-1-2 (DT)/IR72875-94-3-3-2 (DT)
4	IR83376-B-B-130-2	IR71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
5	IR83381-B-B-6-1	IR 72022-46-2-3-3-2 (DT)/IR 77080-B-34-1-1 (DT)
6	IR83372-B-B-33-2	IR 71700-247-1-1-2 (DT)/IR 57514-PMI 5-B-1-2 (DT)
7	IR83381-B-B-55-4	IR72022-46-2-3-3-2 (DT)/IR77080-B-34-1-1 (DT)
8	IR83373-B-B-81-2	IR71700-247-1-1-2 (DT)/IR 72875-94-3-3-2 (DT)
9	IR83383-B-B-141-2	IR72022-46-2-3-3-2 (DT)/IR57514-PMI 5-B-1-2 (DT)
10	IR83376-B-B-150-1	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
11	IR83376-B-B-110-2	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
12	IR83376-B-B-24-2	IR 71700-247-1-1-2 (DT)/IR77080-B-34-1-1 (DT)
13	IR83383-B-B-129-4	IR 72022-46-2-3-3-2 (DT)/IR 57514-PMI 5-B-1-2 (DT)
14	IR74371-70-1-1	IR 55419-4*2 (DT)/WAY RAREM (DS)
15	IR83387-B-B-27-4	IR 72022-46-2-3-3-2 (DT)/SAMBHA MAHSURI (DS)
16	IR83614-427-B	IR 78875-131-B-1-2 (DT)/IR 64 (DS)
17	IR83388-B-B-108-3	IR 72022-46-2-3-3-2 (DT)/SWARNA (DS)
18	IR83377-B-B-93-3	IR 71700-247-1-1-2 (DT)/SAMBHA MAHSURI (DS)
19	IR83388-B-B-8-3	IR 72022-46-2-3-3-2 (DT)/SWARNA (DS)
20	IR83387-B-B-134-2	IR 72022-46-2-3-3-2 (DT)/SAMBHA MAHSURI (DS)
21	IRRI123	IR 47761-27-1-3-6 (DT)/IRRI 108 (DS)
22	IR83377-B-B-48-3	IR 71700-247-1-1-2 (DT)/SAMBHA MAHSURI (DS)
23	IR78937-B-3-B-B-1	IR 47701-6-B-1 (DS)/IR 55435-05 (DT)
24	BR7870-5*(Nils)-8-HR4	BR10 (DS)/5*CR146-7027-224 (DT)
25	BR7873-5*(NIL)-51-HR6	BR11 (DS)/5*CR146-7027-224 (DT)
26	NERICA4	WAB 56-104 (DT)/CG 14 (DS)
27	IR64 (Check)	IR 5657-33-2-1 (DT)/IR 2061-465-1-5-5 (DS)
28	Binadhan-7 (Check)	TNDB100/ Kienguyen
29	BRRI dhan49 (Check)	BR4962-12-4-1/IR33380-7-2-1-3
30	Guti Swarna (Local check)	Popular variety of northwest Bangladesh

NB: SN-Serial number, DT-Drought tolerant and DS-Drought susceptible

In the AYT, selected lines were again tested with drought imposition at the reproductive stage. Selected drought-tolerant genotypes from IRRI Philippines were then brought to Bangladesh for field screening in drought-prone rainfed environments. Since there was no existing drought-tolerant rice variety, four promising rice varieties were used as checks in the screening experiments.

Experimental Protocol and Management Practices

Seedlings were raised in a seedbed according to the traditional farm practice. Seeds of the rice genotypes were soaked in water for 24 h and incubated until radicle emerged. Sprouted seeds were broadcasted at 80 g m^{-2} on 22 July of the two successive wet seasons 2009 and 2010. Fertilizers containing N, P, K and S at 46, 20, 30 and 18 kg ha^{-1}, respectively, were applied in the seedbed during final land preparation (BRRI, 2019). Urea (N @ 46 kg ha^{-1}) was top dressed at 10 days after seeding (DAS). Wetland soil preparation with puddling was done according to the common practice. Initially, the land was ploughed once with a country plow, followed by two power tiller passes and laddering. After 7 days, the land was finally prepared by one pass with power tiller followed by laddering to level the land. The levee around the plot was newly made. The fertilizers utilized included urea, triple super phosphate (TSP), muriate of potash (MOP), gypsum, and zinc sulphate, applied at rates of 82 kg ha^{-1} for nitrogen, 15 kg ha^{-1} for phosphorus, 38 kg ha^{-1} for potassium, 10.6 kg ha^{-1} for sulphur, and 2.7 kg ha^{-1} for zinc. The whole quantities of TSP, MOP, gypsum, zinc sulphate, and one-third of the urea were applied at the base during the final land preparation. The remaining urea was applied in two equal increments at 20 days after transplanting (DAT) and 40 DAT, aligned with rainfall or moist soil conditions, as the experiment was conducted under rainfed circumstances. The experiment was structured using a randomized block design with three replications. Twenty-five-day old seedlings were transplanted at a spacing of 25 x 15 cm (BRRI, 2019), with three seedlings per hill, on August 16th in both years. Transplanting of rice seedlings purposely delayed from optimum planting (July) to address terminal drought at reproductive stage. Unit plot size was 2.5 m x 4 m. Based on the drought characteristics of the experimental site; transplanting was purposively delayed compared with the normal transplanting time (July) of Aman rice (wet season) to increase the potential exposure to drought stress (Torres et al., 2012). The levee around the experimental plots was opened at 28 DAT to ensure severe drought stress at reproductive stage of the crop. Uniform and typical management practices were followed to control weed and pest in the plots.

Sampling and Data Collection

Recommended procedures were followed to collect data for yield and yield components, agronomic parameters, and drought-stress measurements (Gomez, 1972; Gomez and Gomez, 1984; IRRI, 2002; IRRI, 1994). Yield and yield component data were collected at maturity.

Tillers and panicles hill^{-1}; total spikelets, sterile spikelets and grains hill^{-1}, and 1000-grain weight were counted from 2 x 2 hill sampling units from three places (12 hills plot^{-1}) sampled on a diagonal in each plot (Gomez, 1972). Grain and straw yields were determined from six m^2 harvested areas at maturity from center of each plot. Grains and straws were sun-dried after harvest and threshing. The weight and moisture content of the grain and straw samples were assessed. Grain yield was standardized to 14% moisture content, whereas straw yield was standardized to 3% moisture content, and expressed in t ha^{-1}.

Climate Monitoring and Drought Stress Characterization

Meteorological data (daily rainfall, air temperature, evaporation and sun shine hour) were collected from the mini-weather station at Edulpur, Godagari, Rajshahi, Bangladesh set up by BRRI Rajshahi and very close (25 m) to the experimental plots.

Rainfall Status

The experimental site at Edulpur, Godagari, Rajshahi received the lowest seasonal rainfall (744 mm) since a decade in the year 2009. Of the total, 210 mm occurred in August, which also had 17 rainless days (Figure 1). In September, rainfall was 181 mm but 80% of that occurred in the 1st half of the month and 21 days were rainless. There were 27 rainless days in October and only 15.8 mm rainfall was observed (Figure 1). Consequently, the crop of the 2009 wet season (WS) experienced severe drought stress during the reproductive phase. In contrast, 897 mm rain occurred at the experimental site in the 2010 WS of which 115, 160, 192, 133 and 2.4 mm rain occurred in July, August, September, October and November, respectively (Figure 2). Rainfall from July to October 2010 was well distributed (Figure 2). Therefore, especially the short and medium duration genotypes did not face drought stress in the 2010 WS. However, the long duration genotypes flowering after the 3rd week of October experienced medium drought stress.

Temperature Status

Monthly mean temperatures from July to November of 2009 were comparatively higher than in 2010. Temperature fluctuation of both years followed similar trends, but the day-night temperature difference in October to November 2009 was higher than in 2010. Monthly mean maximum and minimum temperatures at the site from July to November were 32.1 and 20.5 °C in 2009 WS, and 29.4 and 25.2 °C in 2010WS. Average value of daily sunshine duration was 6.14 and 5.65 h in the 2009 WS and 2010 WS, respectively.

Drought Measuring Protocol

Drought stress was assessed indirectly by measuring soil moisture content, soil water potential, drought amount quantification and leaf rolling score, spikelet sterility percentage, phenotypic acceptability and root characteristics. The methods are outlined below.

Ground water depth measurement

Ground/perched water table was monitored daily with Polyvinyl chloride (PVC) pipe/ piezometers of 1 m length and 0.05 m diameter. The lower 0.8 m end of the pipe, which was below ground, was perforated with 4 mm holes. Three PVC pipes were placed in the experimental plots and the water level was regularly recorded in relation to the upper end of the pipe. Water table depth in the experimental field fell sharply from 13th September onward in the 2009 WS (Figure 3). It reached 0.8 m below ground on the 25th September and stayed there until the end of the 2009 season. In the 2010 WS, the perched water table started to fall from the 27th September but fell slowly. This confirmed that the 2009 WS experienced a severe drought while the 2010 WS was only a moderately drought for the crop.

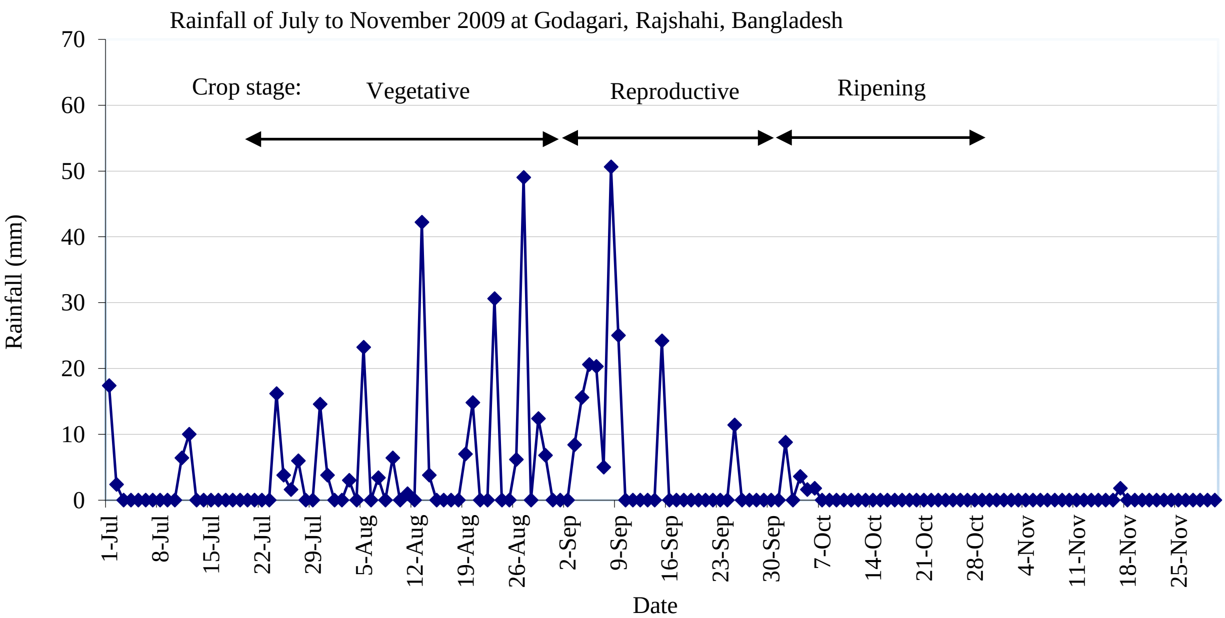

Figure 1. Crop stage and rainfall distribution at the experimental site during July-November 2009 (Source: Mini weather station of BRRI Rajshahi at Godagari, Rajshahi, Bangladesh).

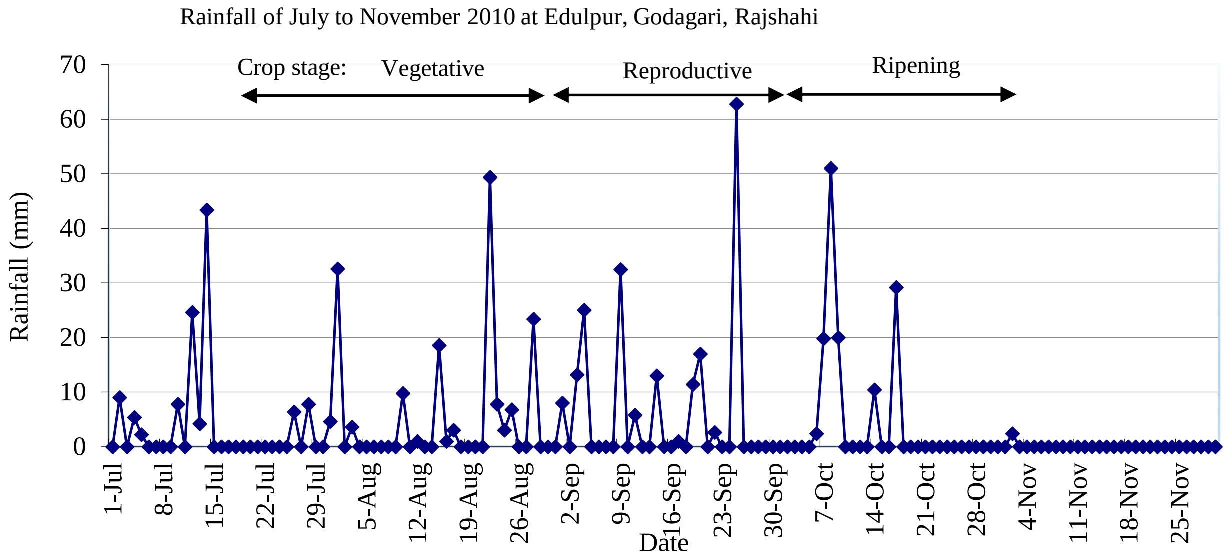

Figure 2. Crop stage and rainfall distribution at the experimental site during July-November 2010 (Source: Mini weather station of BRRI Rajshahi at Godagari, Rajshahi, Bangladesh).

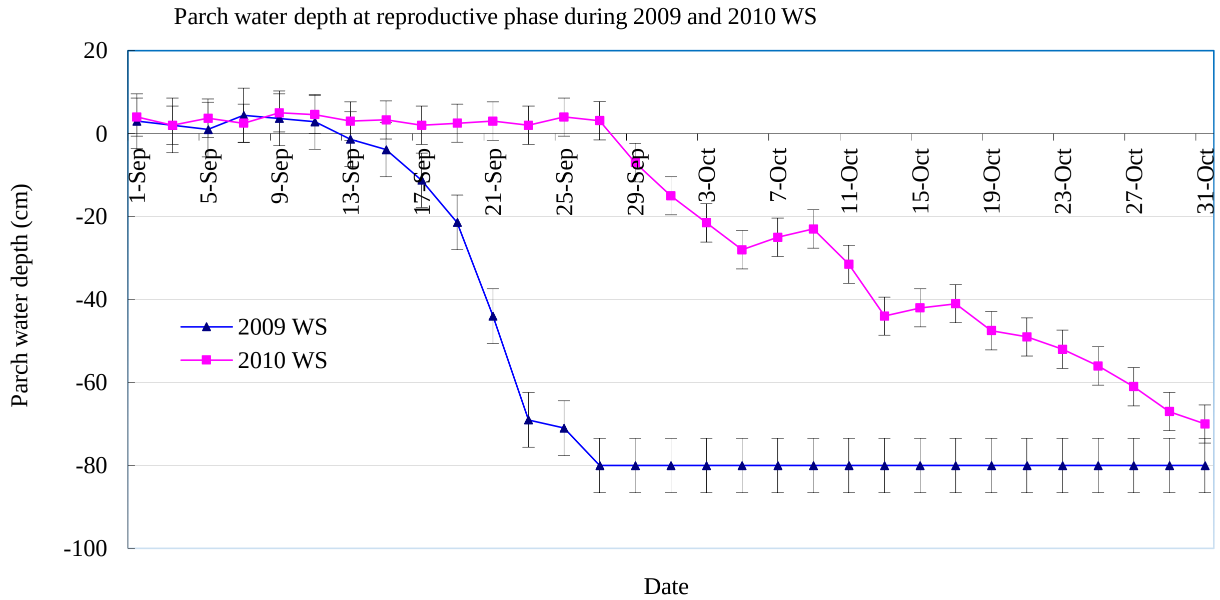

Figure 3. Parch water depth at the experimental field during 2009WS and 2010WS at Godagari, Rajshahi, Bangladesh

Soil moisture content measurement

The levee surrounding the plots was cut at 28 DAT, so that the soil dried faster during rainless days. Cracks developed in the soil of the plots quickly and became deeper during the season. Three soil samples from 0-0.2 m depth of each replication were taken by auger twice weekly from 30 DAT until the ripening stage. After recording the initial weight, the soil samples were wrapped in aluminum foil and oven dry weight was determined after drying at 70 $^{\circ}$C temperature for 72 h. Initial and oven dry weight of the soil samples were used to calculate soil moisture content as a measure of soil water status in the field. Soil moisture content was calculated using the following formula:

$$\text{Soil moisture content (\%)} = \frac{\text{W1-W2}}{\text{W1}} \times 1 - W \qquad (1)$$

Where, W1= Initial weight of the sample and W2= Oven dried weight of the sample

Soil moisture status of the experimental plots during the seasons is shown in Figure 4. In general, soil moisture during the 2009 WS was much lower than in the 2010 WS. It decreased up to 8% at the last week of October during 2009 WS while it was 20% in 2010 WS.

Soil water tension measurement using Tensiometer

Soil tensiometers were used to measure soil water tension that typically measures 0-100 kPa (kilopascals). Soil water potential measured with tensiometers after draining the plots at 28 DAT in both seasons is shown in Figure 5. The soil water potential declined generally, however, it was fluctuated up and down in both early seasons due to alternating periods of rainless and rainy days (Figure 5). Fluctuating soil moisture potentials continued longer in the 2010 WS. A steady decline started from 7th October 2009 but only the 17th October in 2010.

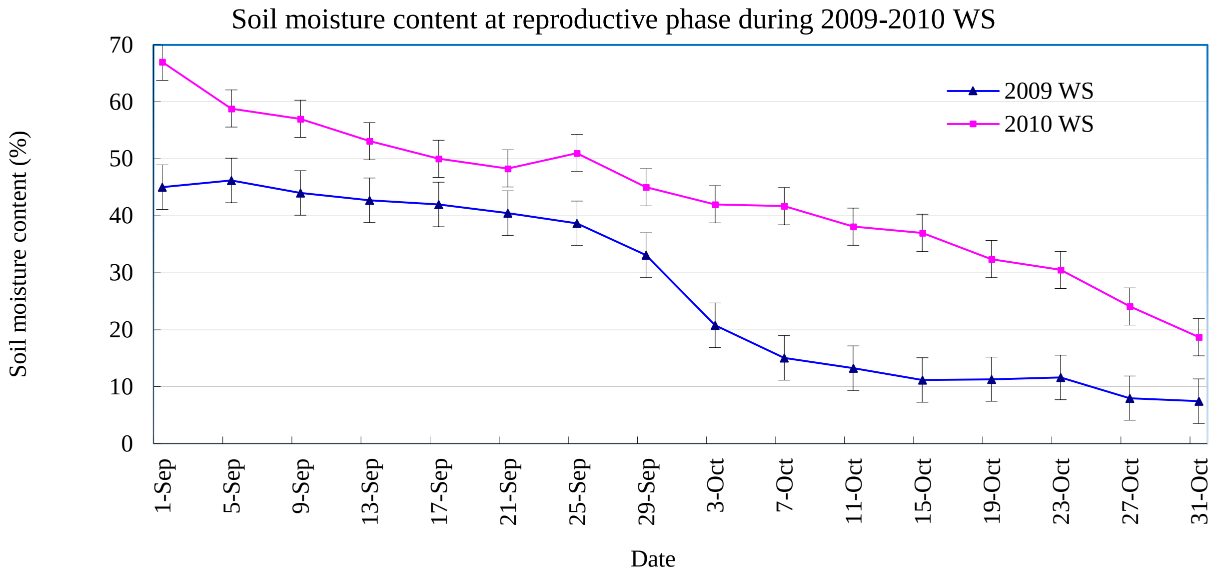

Figure 4. Soil moisture content at the experimental fields during 2009 and 2010 WS at Godagari, Rajshahi, Bangladesh.

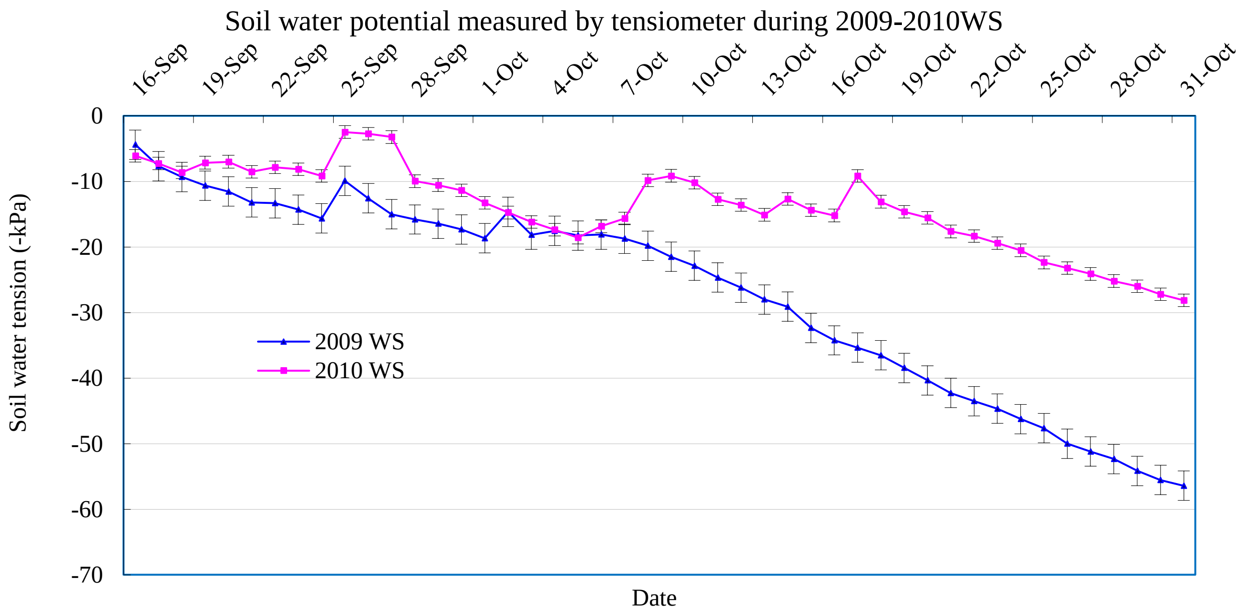

Figure 5. Soil water potential at the experimental fields during 2009WS and 2010WS at Godagari, Rajshahi, Bangladesh.

Drought severity quantification

Drought Severity was determined using a Drought Simulation Model (Islam et al., 2007) and expressed in water deficit compared to a simulated normal watered crop. Drought severity was measured as the water deficit in the soil being equal to the unfulfilled demand of a simulated normal crop and drought duration is duration when crop suffered due to water-stress. Drought severity was the collective amount of drought for that duration. Drought amount and duration were quantified in three crop stages like vegetative (08 August to 15 September), reproductive (16 September to 15 October) and ripening stage (16 October to 15 November based on the seeding and transplanting date of the crop in 2009 and 2010 WS, The model assumes two water storage types; the first one is called surface water storage (SWS) and the second one is soil moisture storage (SMS). SWS consists of standing water in the field above the soil surface and SMS describes soil moisture in the root zone soil. The Evapotranspiration (ET) demand of crop is met from the first storage (SWS) on the dry days if there is water. When the first storage is exhausted then ET demand is met from the second storage (SMS). If the SMS is unable to satisfy ET demand in the continued dry period, the crop experiences drought stress. The amount of drought is considered to be equal to ET demand that remains unfulfilled due to inadequate moisture in the soil.

Leaf-rolling

Drought sensitivity of the germplasm tested was measured through scoring of leaf rolling during the vegetative and reproductive stage of the crop following the protocol developed by IRRI, using a score between 0 (leaves healthy; no rolling) and 9 (leaves tightly rolled) (IRRI, 2002).

Spikelet fertility and sterility

Drought-stress was also measured indirectly through the level of spikelet sterility, using a score between 1 (less than 20% sterility) and 9 (more than 90%) (IRRI, 2002).

Root Biomass

Roots were collected from the depth of 0-10, 10-20, 20-30 and 30-40 cm during harvest, by soil core sampler (10 cm diameter auger) from the center of a hill and 5 cm apart from the center of hills with average tiller number (Karmakar et al., 2004). The soil core sampler was placed on the soil surface and hammered in to 40 cm depth (Uddin et al., 2009). Five root specimens were collected from each plot. Following sampling, soil cores were segmented into layers of 0-10, 10-20, 20-30, and 30-40 cm using a knife. Each layer was maintained on an iron net with a 2 mm hole. The roots were rinsed and separated from the soil using water. Each sample was laid out after to washing, , and root length was quantified using a Comair Root Length Scanner (Hawker De Havill and Victoria Ltd., Australia). Root length of the samples were scanned and then, root samples were dehydrated in an oven at 70 °C for 48 hours, (Henry et al., 2012; Uddin et al., 2009; Karmakar et al., 2004). A well-precision milligram balance was used to measure the dry weight of root biomass.

Statistical Analysis

Data recorded in the experiments were statistically analyzed following procedures described by Gomez and Gomez (1984). Analysis of variance (ANOVA) was conducted using statistical software CropStat 7.2, cluster constructed by JMP 7.0.2 based on phenotypic characteristics and diversity analyses were done by GenStat 5.3. The least significant difference (LSD) test was used to compare means differences of the data.

Results

Drought Severity and Drought Duration Quantification

The genotype screening experiment was conducted under rainfed environments and the bund was cut at 28 days after transplanting (DAT). Consequently, the crop was fully dependent on rainfall. The crop of the wet season 2009 received rains up to the vegetative stage while the crop of 2010 received rainwater up to the reproductive stage. Therefore, drought severity and drought duration were higher in the 2009 WS than in the 2010 WS. Drought severity at vegetative, reproductive and ripening stage in 2009 was 2, 93 and 152 mm water deficit, respectively, while it was 9, 22 and 76 mm water deficit in 2010 WS (Figure 6). Accordingly, the total water deficit (247 mm) was remarkably higher during in 2009 WS than 2010 WS (107 mm). The drought duration followed the trend of drought amount. Drought duration at vegetative, reproductive and ripening stage was 1, 22 and 20 days in 2009 but it was 3, 8 and 14 days in 2010 WS. Therefore, the crop of the 2009 WS faced 43 days drought stress whereas the stress duration was only 25 days in 2010 WS. Consequently, the crop of the 2009 WS experienced a severe drought-stress while it faced moderate drought-stress in the 2010 WS.

Genotype Clustering Through Dendogram Regarding Leaf Rolling and Drying, Spikelet Sterility; And Phenotypic Acceptability

A dendrogram was created utilizing a distance matrix derived from phenotypic acceptability, leaf-rolling, leaf-drying, and spikelet fertility metrics. This dendrogram established the relationships among the 30 examined rice genotypes, categorizing them into three clusters (Figure 7). The distribution pattern revealed that cluster I included the most tested entries (22), followed by cluster II (2) and cluster III (6) (Table 2). Among the clusters, genotypes in cluster-III had the highest score having lowest values of phenotypic acceptability, leaf rolling, and spikelet sterility scores, indicating that these genotypes possess more drought tolerance compared to other clusters. In contrast, the mega varieties BRRI dhan49 and Guti Swarna were placed in cluster II which showed more susceptibility to drought stress. Cluster-I showed intermediate drought tolerance, having values of the parameter's phenotypic acceptability, leaf-rolling, leaf-drying and spikelet fertility in between cluster II and III. Cluster mean of 30 rice genotypes was the highest (8.167) in phenotypic acceptability at the reproductive stage ranging from 1.267 to 8.167 (Table 3). Variations in cluster means were observed for nearly all the examined characteristics. The inter- and intra-cluster distances differed among the clusters (Table 3). The inter-cluster distance was greatest (10.936) between clusters II and III, followed by clusters I and III (7.245), while the lowest distance was observed between clusters I and II (5.952). Intra-cluster distances were derived from the distance matrix of the evaluated 30 rice genotypes. Genotypes in cluster I showed the highest intra cluster distance (0.745), followed by cluster III (0.615) and cluster II (0.382). Table 4 presented the relative contribution towards divergence. Among characteristics for drought tolerance, the value of phenotypic acceptability at vegetative, leaf-rolling at vegetative and reproductive stage of the genotypes showed positive divergence in vector I (Table 4). It indicated that these characters contributed more towards divergence among the genotypes. In contrast, the values of phenotypic acceptability at vegetative stage and spikelet sterility were negative in vector I and contributed less toward divergence. All the parameters scored at reproductive stage showed positive values in vector-II while it was negative in case of scored recorded at vegetative stage (Table 4). The double positive values generally contributed higher in divergence. In the present study, three characters such as phenotypic acceptability, leaf-rolling at reproductive stage showed double positive value in both the vectors indicated that those characters contributed most towards divergence. In contrast, single character phenotypic acceptability at vegetative showed double negative values in both vectors. Spikelet sterility showed positive values in vector-II and negative values in Vector-I, indicating that it also contributed remarkably to the divergence.

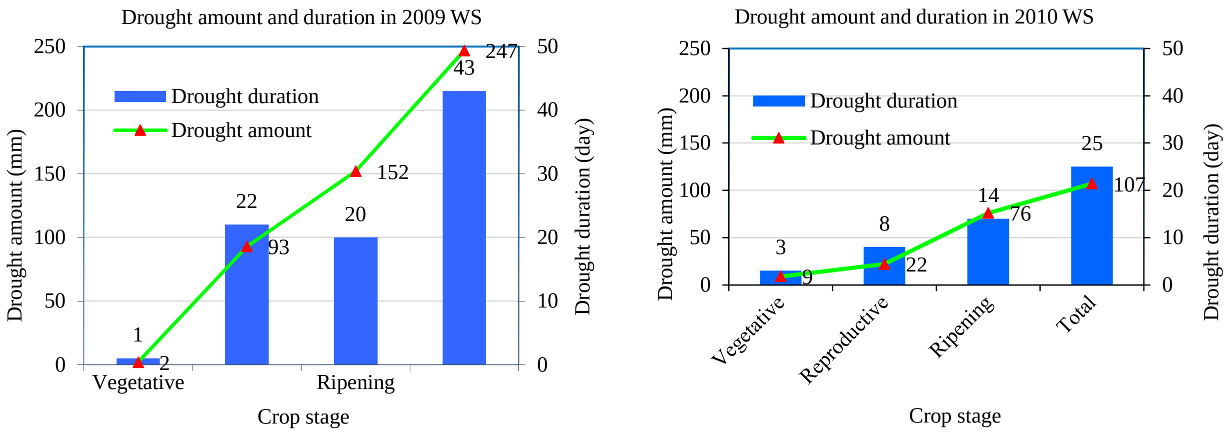

Figure 6. Drought amount and drought duration in the experimental field during 2009 and 2010 WS at Godagari, Rajshahi, Bangladesh.

Table 2. Intra-cluster (Diagonal) and inter-cluster (D^2) divergence values of 30 rice genotypes.

Clusters	Cluster I	Cluster II	Cluster III
Cluster I	0.745		
Cluster II	5.952	0.382	
Cluster III	7.245	10.936	0.615

NB: Bold figures denote intra cluster distance

Table 3. Cluster means of the characteristics of 30 rice genotypes

Characteristics	Cluster mean		
	I	II	III
Phenotypic acceptability at vegetative stage	3.887	6.189	2.333
Phenotypic acceptability at reproductive stage	6.133	8.167	2.550
Leaf rolling at vegetative stage	1.778	1.953	0.200
Leaf rolling at reproductive stage	3.900	4.044	1.267
Leaf drying at vegetative stage	1.533	1.589	0.267
Leaf drying at reproductive stage	3.444	3.993	1.433
Spikelet fertility	4.511	4.560	3.667

Table 4. Characters contribution towards divergence among the 30 rice genotypes

Characteristics	Vector I	Vector II
Phenotypic acceptability at vegetative stage	-0.0511	-0.7070
Phenotypic acceptability at reproductive stage	0.2904	0.1821
Leaf rolling at vegetative stage	0.5026	-0.9340
Leaf rolling at reproductive stage	0.1956	0.2377
Leaf drying at vegetative stage	0.6383	-1.7975
Leaf drying at reproductive stage	1.2135	0.9422
Spikelet fertility	-0.2526	0.3186

Genotypic Variation on Yield, Yield Attributes and Agronomic Parameters Under

Drought-stress

Significant genotypic difference existed among the rice cultivars for yield, yield components and ancillary parameters in both the 2009 and 2010 WS (Table 5). Across the genotypes, IR83377-B-B-93-3 attained the highest grain yield (3.65 t ha^{-1}) followed by IRRI 123 (3.53 t ha^{-1}) and IR74371-70-1-1 (3.52 t ha^{-1}) in 2009-WS under severe drought-stress. Quite the reverse, locally popular mega variety Guti Swarna produced the lowest grain yield (1.30 t ha^{-1}) followed by BRRI dhan49 (1.36 t ha^{-1}). The genotype NERICA-4 gave 2.10 and 2.71 t ha^{-1} grain yield during 2009 and 2010 WS, respectively. In general, yield of the tested genotypes was lower in 2009 WS than 2010 WS as the crop of 2009 WS confronted more water deficient stress at panicle initiation to maturity stages compared to 2010 WS (Figure 6). Grain yield of the rice genotypes ranged from 1.28 to 3.65 t ha^{-1} in 2009 WS while it was 2.44 to 4.51 t ha^{-1} in 2010 WS. Similarly, percentage of grain yield reduction in 2009 over 2010 ranged from 14 to 57% (Table 5). Grain yield reduction was the highest (57%) in the Guti Swarna while the lowest (14%) was in IR74371-70-1-1 followed by IR83377-B-B-93-3 (19%) and IRRI 123 (20%) in 2009 WS over 2010 WS. In general, harvest index was lower than the optimum level of high yielding varieties, and it was also lower in 2009 WS than 2010 WS. Across the genotypes and years, most of the genotypes contained lower harvest indices in 2009WS with an average of 0.37 ranging from 0.25 to 0.45, while it was 0.41 ranging from 0.33 to 0.47 during 2010 WS.

Table 5. Phenology, yield and yield components of the rice genotypes under drought-prone rainfed environment at Godagari, Rajshahi Bangladesh during 2009 and 2010 WS.

Genotype	Grain yield ($t\ ha^{-1}$)		Yield reduction (%) in 2009 over 2010	Harvest Index		Growth duration (day)		Plant height cm)	
	2009	2010		2009	2010	2009	2010	2009	2010
IR 83376-B-B-71-1	1.68	2.92	43	0.34	0.40	110	112	102	104
IR 83381-B-B-137-1	1.87	3.02	38	0.36	0.41	111	113	103	105
IR 83373-B-B-25-3	1.50	2.57	42	0.31	0.38	109	111	108	109
IR 83376-B-B-130-2	2.20	3.12	29	0.37	0.39	109	110	106	107
IR 83381-B-B-6-1	3.11	4.07	22	0.41	0.43	108	110	104	109
IR 83372-B-B-33-2	1.46	2.58	44	0.33	0.36	107	109	95	97
IR 83381-B-B-55-4	1.35	2.38	43	0.31	0.37	110	113	104	106
IR 83373-B-B-81-2	1.89	3.01	37	0.36	0.41	105	108	95	96
IR 83383-B-B-141-2	2.55	3.78	33	0.41	0.45	108	111	102	104
IR 83376-B-B-150-1	2.35	3.25	26	0.39	0.41	109	110	108	111
IR 83376-B-B-110-2	2.76	3.87	29	0.43	0.46	111	113	103	105
IR 83376-B-B-24-2	1.41	2.44	42	0.30	0.35	109	111	92	93
IR 83383-B-B-129-4	2.91	3.92	26	0.42	0.46	113	115	103	108
IR74371-70-1-1	3.52	4.11	14	0.44	0.47	105	108	106	110
IR 83387-B-B-27-4	2.14	3.07	30	0.36	0.39	111	114	92	97
IR83614-427-B	2.28	3.17	27	0.37	0.40	103	105	87	90
IR 83388-B-B-108-3	2.37	3.41	31	0.39	0.42	109	112	100	104
IR 83377-B-B-93-3	3.65	4.51	19	0.45	0.47	112	115	103	110
IR 83388-B-B-8-3	2.36	3.26	28	0.37	0.40	112	115	103	106
IR 83387-B-B-134-2	2.17	3.08	29	0.35	0.38	113	116	102	107
IRRI 123	3.53	4.40	20	0.44	0.47	116	120	103	109
IR 83377-B-B-48-3	2.21	3.10	29	0.38	0.41	105	108	102	103
IR78937-B-3-B-B-1	2.08	3.27	36	0.36	0.42	112	115	101	104
BR7870-5*(NIL)-8-HR4	2.52	3.61	30	0.38	0.42	112	117	94	100
BR7873-5*(NIL)-51-HR6	3.04	4.01	24	0.42	0.44	102	105	99	102
NERICA 4	2.10	2.71	23	0.36	0.35	115	118	93	98
IR64 (Check)	2.38	3.50	32	0.41	0.44	107	110	88	91
Binadhan-7 (Ck)	2.60	4.16	38	0.40	0.46	112	115	91	97
BRRI dhan49 (Ck)	1.36	2.52	46	0.27	0.33	126	130	96	100
Guti Swarna (L. Ck)	1.30	3.01	57	0.25	0.36	134	136	103	109
$LSD_{0.05}$	0.33	0.24	-	0.03	0.02	1.2	1.5	1.3	1.0
F-test	***	***	-	***	***	***	***	***	***

Genotype	Grain yield ($t\ ha^{-1}$)		Yield reduction (%) in 2009 over 2010	Panicles m^{-2} (no.)		Sterility (%)		1000-grain wt. (g)	
	2009	2010		2009	2010	2009	2010	2009	2010
IR 83376-B-B-71-1	1.68	2.92	43	190	206	46	38	22.6	23.5
IR 83381-B-B-137-1	1.87	3.02	38	192	212	45	39	23.1	23.8
IR 83373-B-B-25-3	1.50	2.57	42	187	203	47	40	22.8	23.3
IR 83376-B-B-130-2	2.20	3.12	29	201	226	38	35	22.7	23.2
IR 83381-B-B-6-1	3.11	4.07	22	212	235	29	24	23.3	23.7
IR 83372-B-B-33-2	1.46	2.58	44	188	210	51	41	22.7	23.4
IR 83381-B-B-55-4	1.35	2.38	43	174	190	52	43	22.3	23.2
IR 83373-B-B-81-2	1.89	3.01	37	196	220	45	40	22.6	22.9
IR 83383-B-B-141-2	2.55	3.78	33	213	233	35	30	22.9	23.3
IR 83376-B-B-150-1	2.35	3.25	26	206	222	37	32	23.2	23.5
IR 83376-B-B-110-2	2.76	3.87	29	220	242	34	29	22.7	23.5
IR 83376-B-B-24-2	1.41	2.44	42	167	199	52	42	22.4	22.7
IR 83383-B-B-129-4	2.91	3.92	26	220	233	31	27	23.0	23.3
IR74371-70-1-1	3.52	4.11	14	228	251	26	23	23.2	23.4
IR 83387-B-B-27-4	2.14	3.07	30	213	229	42	37	23.8	24.3
IR83614-427-B	2.28	3.17	27	219	235	41	35	22.5	23.2
IR 83388-B-B-108-3	2.37	3.41	31	217	235	37	31	22.7	23.2
IR 83377-B-B-93-3	3.65	4.51	19	245	261	26	22	23.3	23.6
IR 83388-B-B-8-3	2.36	3.26	28	213	231	43	34	22.6	23.4
IR 83387-B-B-134-2	2.17	3.08	29	197	217	44	35	22.9	23.4
IRRI 123	3.53	4.40	20	245	267	28	24	23.2	23.7
IR 83377-B-B-48-3	2.21	3.10	29	206	222	37	32	23.3	23.5
IR78937-B-3-B-B-1	2.08	3.27	36	204	217	42	33	22.6	22.8
BR7870-5*(NIL)-8-HR4	2.52	3.61	30	226	242	39	29	21.0	21.6
BR7873-5*(NIL)-51-HR6	3.04	4.01	24	252	267	28	25	20.7	21.0
NERICA 4	2.10	2.71	23	201	215	35	33	22.3	22.7
IR64 (Check)	2.38	3.50	32	219	240	37	28	22.2	22.5
Binadhan-7 (Ck)	2.60	4.16	38	249	265	41	26	22.8	23.3
BRRI dhan49 (Ck)	1.36	2.52	46	235	252	61	42	22.0	22.5
Guti Swarna (L. Ck)	1.30	3.01	57	240	258	62	41	22.6	23.0
$LSD_{0.05}$	0.33	0.24	-	9	7	4	3	0.6	0.5
F-test	***	***	-	***	***	***	***	***	***

***P≤0.001 (Strongly significant)

Table 6. Correlation coefficients among the traits of 30 genotypes under rainfed environment

Parameters	Grain yield (t ha^{-1})	Panicles m^{-2} (no.)	Sterility (%)	Grain wt. (g)	Plant ht. (cm)	Biomass (t ha^{-1})	Harvest index
Wet season 2009							
Grain yield	1						
Panicles m^{-2}	0.661**	1					
Sterility (%)	-0.919**	-0.483**	1				
Grain weight	0.226*	-0.062 ns	-0.214ns	1			
Plant ht. (cm)	0.206*	-0.025 ns	-0.151ns	0.310**	1		
Biomass	0.963**	0.707**	-0.831**	0.198ns	0.207ns	1	
Harvest index	0.919**	0.504**	-0.937**	0.231*	0.142ns	0.793**	1
Wet season 2010							
Grain yield	1						
Panicles m^{-2}	0.778**	1					
Sterility (%)	-0.928**	-0.689**	1				
Grain weight	0.175ns	-0.087ns	-0.059ns	1			
Plant ht. (cm)	0.348**	0.160ns	-0.291**	0.312**	1		
Biomass	0.924**	0.840**	-0.854**	0.108ns	0.340**	1	
Harvest index	0.913**	0.572**	-0.851**	0.231*	0.317**	0.691**	1

*Significant at P≤0.05, **Significant at P≤0.01 and ns=not significant.

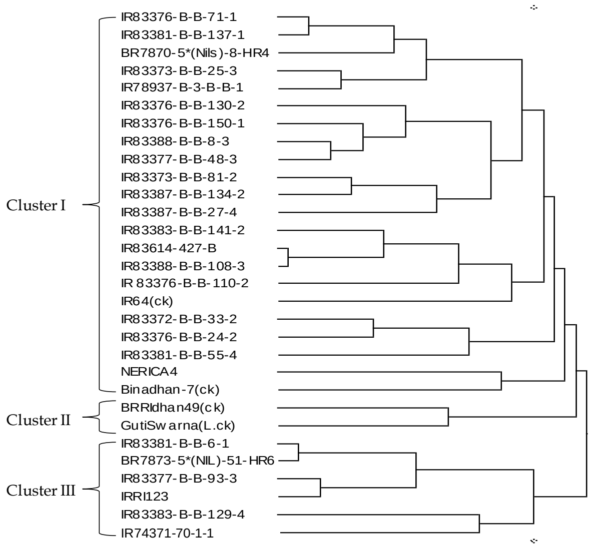

Figure 7. Dendogram of 30 rice genotypes based on phenotypic acceptability, leaf rolling, leaf drying and spikelet fertility under drought-prone rainfed environment.

Harvest index was the highest (0.45) in IR83377-B-B-93-3 followed by IR74371-70-1-1 (0.44) and IRRI (0.44) in 2009 WS. It was the lowest (0.25) in Guti Swarna in 2009 WS while it was the lowest (0.27) in BRRI dhan49 in 2010 WS. Days required to maturity and plant height were remarkably affected by the genotypes (Table 5). Days to maturity ranged from 102 to 134 during 2009 WS while it was 105 to 136 days in 2010 WS (Figure 5). It is might be due to that soil water tension was higher in 2009 WS compared to 2010 WS resulted more drought stress occurred in 2009 WS than 2010 WS. Across the experimental years and genotypes, plant height varied from 87 to 111 cm due to water stress. Panicle production m^{-2} ranged from 167 to 252 in 2009 while it was 190 to 267 during 2010 WS. Moreover, the mega variety BRRI dhan49 and Guti Swarna produced significantly lower panicles m^{-2} than the highest one. The tested genotypes expressed high significant variability regarding spikelet sterility (Table 5). Sterility percentage was the highest (62%) in Guti Swarna during 2009 WS but in 2010 WS the highest percentage of sterility (42%) was found in BRRI dhan49 and IR83376-B-B-24-2. In contrast, IR74371-70-1-1 and IR83377-B-B-93-3 performed better with the lowest sterility 26 and 22%, respectively. Strong significant differences in respect of 1000-grain weight of the genotypes found in both the experimental years. Among the cultivars, IR83387-B-B-27-4 produced grain with highest 1000-grain weight (23.8 and 24.3 g in 2009 and 2010, respectively) at the same time as the genotype BR7873-5*(NIL)-51-HR6 gave constantly the lowest 1000-grain weight of 20.7 and 21.0 g in 2009 and 2010, respectively.

Relationship of Grain Yield and Yield Attributes

Correlation between yield and yield parameters was highly significant in both experimental years (Table 6). Moreover, Figure 8 and 9 show the relationship among grain yield with panicles m^{-2}, spikelet sterility, 1000-grain weight, plant height, biomass and harvest index during 2009 and 2010 WS. The highest R^2 values (0.927 and 0.853 in 2009 and 2010 WS, respectively) were found in the relation of yield and biomass followed by harvest index (Fig 7 and 8). Compound interrelationship among various traits was found between yield and yield components determining one depended variable such as grain yield. Grain yield showed positive association with all the parameters except spikelet sterility. Panicles m^{-2}, biomass and harvest index were strongly corelated with grain yield while plant height and 1000-grain weight low positively related. In contrast, spikelet sterility was highly negatively related with grain yield during both the experimental years.

Root Biomass

Root biomass varied significantly across the genotypes in both experimental years. Most of the roots of all the genotypes existed in 0 to 10 cm soil depth and, and the root biomass was much reduced in 10 to 40 cm depth. The maximum mean root dry matter (4.21 g/0.015 cm^3) was observed in the genotype IR74371-70-1-1 which was statistically similar to NERICA-4 (4.19 g/0.015 cm^3), IR83377-B-B-93-3 (4.15 g/0.015 cm^3), IRRI 123 (4.13 g/0.015 cm^3) and IR83381-B-B-6-1 (3.80 g/0.015 cm^3) among the 30 rice genotypes across the two seasons (Figure 10). Root biomass ranged from 2.05 to 4.21 g/0.015 cm^3. Thereby, the five lines IR74371-70-1-1, NERICA 4, IR83377-B-B-93-3, IRRI 123 and IR83381-B-B-6-1 were found to be drought tolerant.

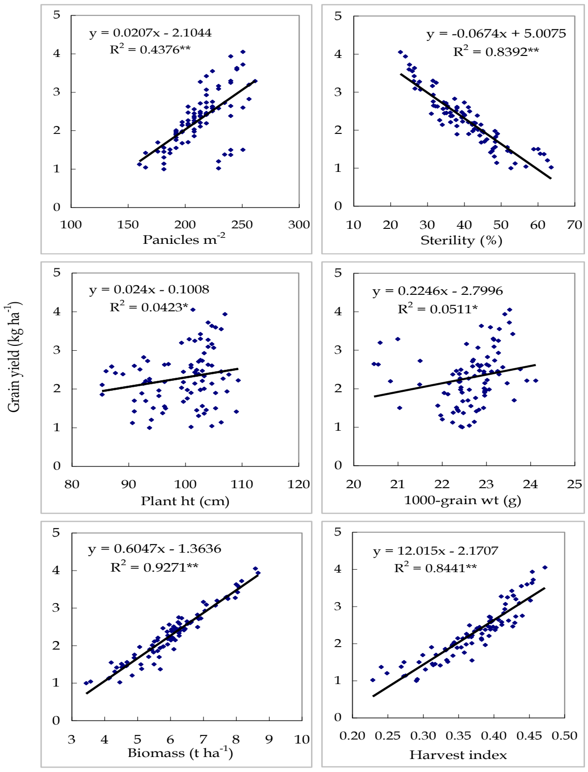

Figure 8. Relationship of grain yield and yield attributes of 30 rice genotypes under drought-prone rainfed environment during 2009 WS.

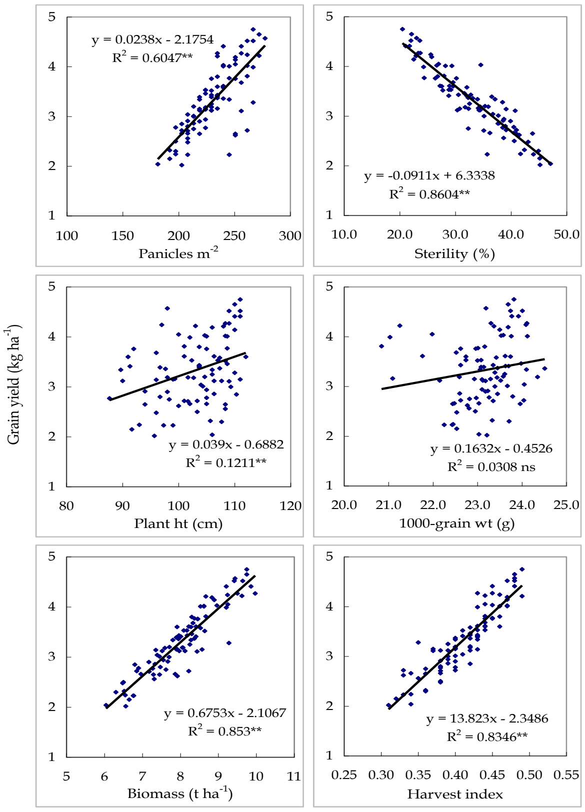

Figure 9. Relationship of grain yield and yield attributes of 30 rice genotypes under drought-prone rainfed environment during 2010 WS.

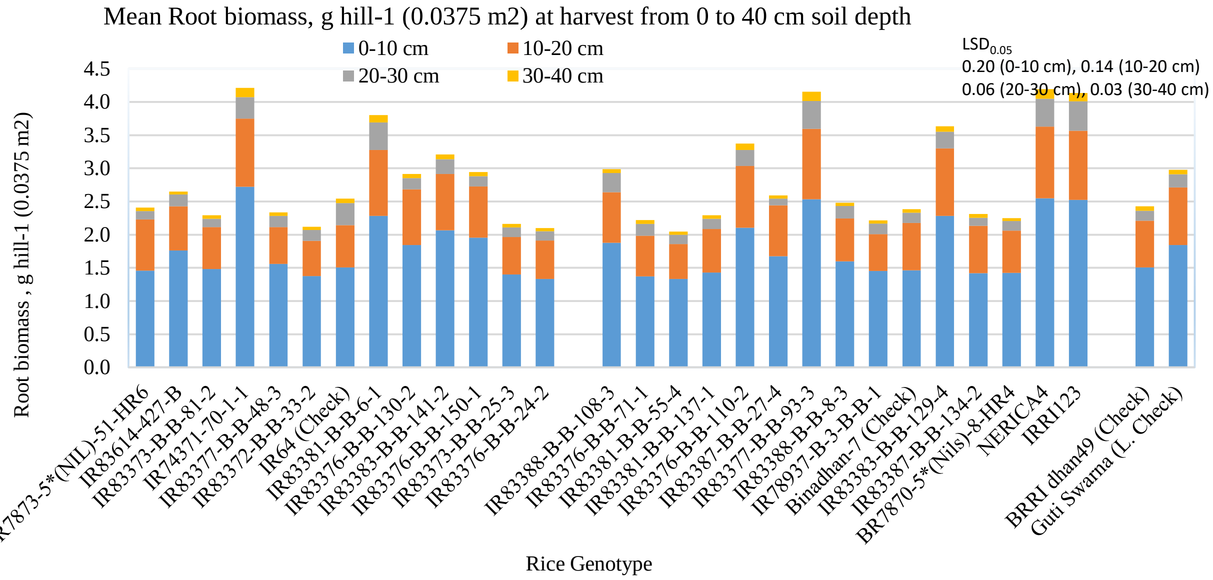

Figure 10. Mean Root biomass, g hill-1 (0.0375 m2) of the rice genotypes in 0 to 40 cm soil depth at harvest under drought-prone rainfed environment during 2009 and 2010 WS.

Discussion

Drought-Stress Quantifying Based on Rainfall, Soil Moisture and Soil Water Potential

Drought-stress occurred in each season of the study in different intensities, where drought severity was higher in 2009 WS compared to 2010 WS (Henry et al., 2011). Rainfall received by the crops of the experiments was considerably lower at the northwest region of Bangladesh (Karmakar et al., 2010). Moreover, the rains were very much unevenly distributed (Figure 1) within the years and seasons (Haefele et al., 2006). Mean annual rainfall of the experimental years (744 and 897 mm in 2009 and 2010, respectively) were much lower than the country average of 2300, mm ranging from 1000 to 5000 mm (Saleh et al., 2000; Karmakar et al., 2012). Meteorological data shows that much less rains occurred in 2009WS while 2010WS was moderately rainy (Figure 1 and 2). Consequently, the crop experienced substantial and intermittent drought stress in 2009 and 2010 WS, respectively. Rainfall distribution, groundwater level (Haefele and Bouman, 2008) and soil moisture content and soil water tension (Henry et al., 2011) during the reproductive phase of crop directed a difficult drought stress for the trials conducted under rainfed conditions. Consequently, there is no doubt that rainfall is a vital factor to determine the yield of rice crop grown under rainfed environments (Wade et al., 1998). Drought amount and duration varied in different crop stages as well as cropping years. At the vegetative stage, the crop did not face drought stress in both years. However, severe drought stress occurred in reproductive and ripening stages causing higher spikelet sterility (Islam and Islam, 2010) in 2009 WS while it was moderate in 2010 WS. Drought amount and duration was significantly higher in 2009 WS than 2010 WS which caused higher grain yield reduction (14 to 57%) in 2009 WS. This result corroborates with Islam and Islam (2010) who found that yield was reduced by 30 to 55% due to drought stress in Bangladesh. Moreover, the crop experienced severe drought stress with 43 drought days amounting to 247 mm water deficit in 2009 WS while it was only 25 days and 107 mm water deficit in 2010 WS. Islam et al. (2007) reported that maximum drought of 40 days and minimum drought of 22 days in northwest Bangladesh.

Genotype Clustering Through Dendogram Regarding Phenotypic Acceptability, Leaf-Rolling, Leaf-Drying and Spikelet Sterility

The dendogram of the rice genotypes showed drought stress severity based on phenotypic acceptability, leaf-rolling and leaf-drying score, and spikelet fertility. The highest genetic variation having in the genotypes maintained distant clusters. Genotypic capriciousness in any crop is a requirement for selection of superior genotypes over the existing cultivars (Murthy et al., 2011). The rice lines and varieties taking lower inter-cluster distance values in cluster I and III could be used as parents for the development of drought-tolerant rice variety. The other cluster (II) had the uppermost inter group average value representing that materials of this group are strongly vulnerable to drought stress. These results suggested that selection of genotype(s) from cluster III have a positive impact whereas selection of genotypes from cluster I and II have a negative impact for drought resistance. It was preferential to make a decision that cluster-I showed the highest intra-cluster diversity indicating more diverse genotypes had in this cluster. Increased inter- and intra-cluster distances indicated greater genetic variability among genotypes both within and within clusters, respectively. Phenotypic acceptability based on leaf-rolling characteristics at the reproductive stage had positive impacts in both the vectors. The characters that showed positive values in both vectors contributed most towards divergence. Spikelet sterility had a negative impact in vector I and a positive impact in vector II towards divergence. Double negative values of phenotypic acceptability at the vegetative stage in vector I and II contributed least to divergence in the studied materials. Generally, positive vector values of parameters like phenotypic acceptability, leaf rolling and spikelet sterility contributed more for divergence while the negative values had a lower contribution.

Genotypic Variation on Yield, Yield Attributes and Agronomic Parameters Under

Drought-stress

The tested genotypes varied significantly in respect of grain yield, yield attributes and agronomic parameters under drought stress (Murthy et al., 2011). It was due to the genotypic variability in response to drought stress (Sakai et al., 2010; Sarvestani et al., 2008). In general, grain yield was lower in the 2009 WS compared to the 2010WS because drought stress was higher in 2009 WS than 2010 WS. Genotypes responded differently under different drought stress conditions and habitually reduced grain yield of rainfed rice (Pantuwan et al., 2002b). Grain yield reduction varied from 14 to 57% due to drought-stress across the cropping years and genotypes. An average of 80% grain yield was reduced for drought-stress at flowering stage compared to non-stress condition (Kumar et al., 2007). Drought-stress at vegetative, flowering and grain filling stages reduced grain yield by 21, 50 and 21%, respectively (Sarvestani et al., 2008). Higher number of panicles m^{-2}, higher grain weight and lower spikelet sterility contributed significantly to attain higher grain yield in 2010 WS compared to 2099 WS. Sakai et al., (2010) found that genotypes performed differently under drought-stress in terms of yield and yield components. Long duration varieties like Guti Swarna and BRRI dhan49 suffered severely from late season drought-stress so that yield of these mega varieties decreased much more due to reduced panicle development and panicle exertion. Sarvestani et al. (2008) also found lower yield in the long duration cultivar Nemat due to late season drought. The low yield obtained in these genotypes was generally caused by a large percentage of sterilized spikelets per panicle due to reproductive phase drought stress (Wopereis et al., 1996). Therefore, the key explanations for yield reduction were late season drought constraining panicle development, and reducing grain filling, grain number and grain weight (Sarvestani et al., 2008; Islam et al., 1994; Bouman and Toung, 2001; Pantuwan et al., 2002a). Across the genotypes and years, the harvest index fluctuated from 0.25 to 0.45 among the genotypes. Similar findings are also reported by Fageria et al., 2010; and Kiniry et al., 2001. Harvest index diverged remarkedly among cultivars fluctuated from 0.36 to 0.52 (Fageria et al., 2010) and from 0.35 to 0.62 (Kiniry et al., 2001) indicating the importance of this variable for yield stimulation. Harvest index generally was lower than the optimum level of high yielding varieties in 2009 (more drought stress existed) but it was comparatively higher in the 2010WS. Extremely low harvest index values related to drought stress was linked to higher sterility, lower spikelet fertility, lower grain filling and lower grain weight, and thereby grain yield (Haefele et al., 2003). Genotypes with comparatively higher yields under drought-stress maintained higher harvest indices. Jearakongman et al. (1995) was reported that cultivars suitable for rainfed conditions having higher harvest index and high yield potential. Spikelet sterility and harvest index are therefore important parameters to quantify drought stress. In contrast, higher values of sterility and lower harvest indices indicated susceptibility to drought (IRRI, 2002; Lafitte et al., 2002).

Days to flowering and maturity of almost all genotypes tested were reduced by 1 to 5 days in the 2009 WS due to drought-stress compared to the 2010 WS with less drought-stress. In general, time required to flowering ranged considerably among the genotypes and experimental years (Henry et al., 2012). Drought-stress started from panicle initiation to maturity of many cultivars. However, some short duration genotypes escaped most of this drought-stress. Rice is extremely sensitive to drought-stress at 12 days before 50% flowering and 7 days after flowering under rainfed environments (Fischer et al., 2012). In our study, drought stress at the reproductive phase was often related to early maturity, indicating that water stress at the reproductive stage forced the plant to mature faster. In contrast, many researchers (Sakai et al., 2008) reported that flowering and maturity of rice delayed when drought stress occurred prior to flowering stage. Differing responses to drought stress were also reported by Atlin et al. (2006) who found that flowering of high yielding rice varieties (O. sativa indica) was delayed by 15 days while it was 5 days earlier for O. sativa japonica varieties in water stressed drought prone environments.

Plant height, panicles m^{-2}, grains panicle^{-1}, grain weight, and fertility were reduced while sterility increased significantly in the severe drought year compared to less drought year. The findings are in line with Pantuwan et al., (2002a) found that unfilled spikelets in drought-stress conditions were 48% compared with 20% in well-watered conditions. Also, the 1000-grain weight was 18% lower under drought stress. This might have partially been due to genetic variability of the genotypes, but was also caused by drought stress (Fageria and Filho, 2007; Peng et al., 2000). Overall performance of rice cultivars grown under water stress defend on spikelets sterility as principal yield component (Garrity and O'Toole, 1994).

Grain yield was significantly allied with all the yield attributes panicles m^{-2}, grains panicle^{-1}, grain weight, spikelet fertility in water-stress; however, spikelet sterility had a negative correlation with yield (Pantuwan et al., 2002a; Murthy et al., 2011; Yadav, 1992). Haider et al. (2012) also found that the grain weight (0.476**), grains per panicle (0.733**), and spikelet fertility (0.709**) had positive and significant associations with grain yield under water deficit. Rice cultivars having shorter growth duration can avoid terminal and also create ample scope to establish rabi crop in time so that those cultivars would be in priority choice for water stress environments to escape terminal drought stress (Haefele et al., 2006). However, short duration varieties generally have a lower yield potential than medium-duration mega-varieties in favorable years (Pantuwan et al., 2002a; Fischer et al., 2012). The rice genotypes providing desirable grain yield under water-stress might be considered as drought-tolerant cultivars (Pantuwan et al., 2002b).

Root Biomass

The tested genotypes varied significantly in respect of root dry matter (Fageria, 2010; Uddin et al., 2009). Most root biomass (61.1%) across genotypes was located in the 0-10 cm soil layer, followed by 10-20 cm (27.1%), 20-30 cm (8.8%) only 3.0% in the 30-40 cm layer. These findings corroborate with reports of Henry et al. (2011), Fageria (2010), and Uddin et al. (2009). Most of the root system (88.2%) was positioned within top 20 cm of the soil. Sharma et al. (1994) also observed 90% of the total root system was located in top soil (0 to 20 cm). Some genotypes having more roots biomass extracted more water from deeper soil than others and acquired more drought-tolerance.

Conclusion

Based on overall performances, the genotypes IR74371-70-1-1, NERICA4, IRRI 123, IR83377-B-B-93-3, and IR83381-B-B-6-1 were selected as drought-tolerant whereas BR7873-5*(NIL)-51-HR6 was drought-escaping. Based on this data and accompanying trials in farmers' fields, the genotypes IR74371-70-1-1 and BR7873-5*(NIL)-51-HR6 were released as drought-tolerant rice varieties "BRRI dhan56" and "BRRI dhan57", respectively, through the national variety release system. The study also indicated that rice cultivars having extensive deep root systems are proficient to extract moisture from deeper soil layers and are more efficient in drought-prone rainfed environments. Moreover, the selected genotypes can be utilized to improve varieties through classical breeding or using biotechnological protocol. And their productivity will be maximized by innovative agronomic management.

Declarations

This study was presented at the IV. International Congress of the Turkish Journal of Agriculture - Food Science and Technology (Niğde, TURJAF 2025)

Ethical Approval Certificate

The experimental procedures of this study were approved by the authority of Bangladesh Rice Research Institute, 1701, Gazipur, Bangladesh.

Author Contribution Statement

B.K.: Conceptualization, methodology, Research work execution, investigation and data collection; writing up original draft

A.H.: Writing up original draft, Review and editing of the manuscript

S.M.H .: Review and editing of the manuscript

M.H.R.M.: Data compilation, curation validation and formal analysis

M.M.H.: Data compilation, curation validation and formal analysis

A.K.: Review and editing of the manuscript

Fund Statement: This research was financially supported by the Stress Tolerant Rice for Poor Farmers in Africa and South Asia (STRASA) project of the International Rice Research Institute (IRRI), and the National Agricultural Technology Project (NATP) of Bangladesh Agricultural Research Council (BARC).

Conflict of Interest

The authors declare no conflict of interest.

Data availability statement

All the data supporting the findings of this study are included in this article.

Acknowledgements

We are grateful to STRASA, IRRI, BARC and BRRI for financial support.

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