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Yield stability of selected rice breeding lines and donors across conditions of mild to moderately severe drought stress

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ABSTRACT

Although mild to moderately severe drought stress may have less of an effect on rice grain yield than severe drought stress during reproductive stage, its prevalence across rice farmers' fields at the global level may be more economically significant. In this study, field experiments were conducted on selected genotypes with known tolerance to severe reproductive-stage drought in order to identify those that would produce high and stable grain yield across seasons and soil moisture conditions varying from well-watered to mild and moderately severe drought stress. Mild stress generally occurred during wet seasons and moderate stress happened during dry seasons. The drought stress was mild enough such that the time to flowering was similar under drought stress and well-watered conditions in either season. However, significant grain yield reductions were incurred even at mild drought levels. Using an AMMI1 biplot analysis, IR83142-B-7-B-B, Binuhangin, IR77298-14-1-2-13, IR70215-70-CPA-3-4-1-3 and IR77298-14-1-2 were identified as the genotypes with the highest and most stable grain yields in both well-watered and mild to moderately severe drought stress environments. In a characterization of traits conferring drought tolerance among the highest yielding genotypes under mild to moderate drought stress, genotypes Binuhangin and IR70215-70-CPA-3-4-1-3 stood out for multiple physiological traits under drought. However, no direct correlations among genotypes between stomatal conductance, normalized difference vegetation index (NDVI) or root dry weight with grain or total dry matter yield were observed under any soil moisture level. These results reflect the complex interaction of drought response traits contributing to grain yield. The genotypic variation and physiological responses observed in this study point to the potential of developing varieties targeted to mild and moderate drought stress using yield as the selection criterion.

1. Introduction

Many different types of drought stress can affect rice crops, which can be characterized by soil moisture levels, the growth stages at which drought occurs, and the duration of the stress (Fukai and Cooper, 1995). Reduction in grain yield is particularly more serious if drought occurs during reproductive development (Hsiao and Namuco, 1980; Saini and Westgate, 2000; Pantuwan et al., 2002a), and severe yield losses can result even from a mild drought stress during the reproductive stage (O'Toole 1982; Venuprasad et al., 2009; Verulkar et al., 2010). Thus, research studies have usually targeted drought stress at the reproductive stage. However, drought stress at any crop stage could reduce the grain yield to certain levels. Although the frequencies at which different types of drought stress occur in rice farmers' fields on a global level have not been quantified, some general estimates based on average rainfall during the crop season indicate the importance of mild to moderate drought stress, particularly in Southeast Asia (Tsubo et al., 2006; Inthavong et al., 2011).

Mild to moderate drought stress usually occurs in rainfed and partially-irrigated fields when there is a lull in rainfall during the crop season. Studies on mild to moderate drought stress occurring at any stage or intermittently during the crop duration can be important for applicability, as this type of stress commonly occurs under actual farmers' field conditions (Xangsayasane et al., 2014). Results from mild to moderate stress studies could be less prone to the high degree of variation that is typical of severe drought stress studies. Kumar et al. (2009) classified drought stress levels based on the relative yield reduction in which very severe, severe, moderate and mild stress is when the yield under drought stress is reduced by more than 85%, 60–85%, 40–60%, and less than 40% of the yield under non-stress conditions, respectively.

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It is important to identify and develop genotypes that could produce high yields at a range of soil moisture conditions that actually occur in farmers' rice fields. This study was conducted to evaluate the long-term performance of rice genotypes with the objective of identifying and selecting those with high and stable yields under well-watered and mild to moderate drought conditions across seasons of varying weather conditions. A subset of 10 genotypes was subsequently evaluated for physiological responses related to yield under the mild to moderate drought stress treatments.

2. Materials and methods

2.1. Screening for agronomic performance and yield stability

Experiments were conducted under well-watered (WW) and drought (DRT) conditions at IRRI Los Baños, Laguna, Philippines (14°30′N, 121°15′E). The soil belongs to the Maahas series which is classified as silty clay loam. Sixty genotypes (Table 1) were studied that had shown potential yield under drought in Genebank selection experiments (Torres et al., 2013) or had been used as parental donors in several IRRI research projects and breeding programs such as the Stress-Tolerant Rice for Africa and Southeast Asia (STRASA), International Network for Genetic Evaluation of Rice (INGER), IRRI Mini Genebank collections, and studies on QTL Lines and other Breeding Lines. The genotypes were grown during the wet season (WS) and dry season (DS) from 2008 DS – 2013 DS, for a total of 11 seasons with two environments (WW and DRT) per season. The entries that had comparatively low yields under drought stress during the first seven seasons of the experiment were replaced with new promising genotypes taken from some of the sources mentioned above. The genotypes and the durations when they were used in the experiments are listed in Table 1. Only the genotypes that were used until 2013 DS were included in the final statistical analysis.

In each season, seedlings were raised on seed beds for 18 to 21 days before transplanting into the main experimental field. The experimental layout was generated using IRRIStat v. 5. An alpha lattice design was used with six blocks × 10 plots and 3 replications. The WW and DRT treatments were located in adjacent areas of the field that were separated by a permanent bund and a distance of about 5 m apart. The plots were 3 m long with 3 rows spaced at 25 cm between rows and 20 cm between plants within a row. Complete fertilizer was applied as basal at the rate of 40-40-40 kg NPK ha^{-1} and ammonium sulfate was topdressed during maximum tillering stage at the rate of 50 kg N ha^{-1} in both the WW and DRT treatments. The DRT treatment was initiated at four weeks after transplanting by withdrawing the irrigation supply and opening the drainage outlets.

Re-watering by surface flooding was done when the tensiometer readings were about −65 kPa at 30 cm soil depth. The WW treatment was kept continuously flooded with about 2 cm surface water until about ten days before harvest.

In the drought stress treatment, soil volumetric moisture content and soil matric potential at 30 cm depth were monitored using a Diviner 2000 (Sentek Sensor Technologies, Stepney SA, Australia) and dial-gauged tensiometer (Soilmoisture Equipment Corp., CA, USA), respectively. One Diviner 2000 observational tube and one tensiometer were installed in each replication after draining the DRT treatment plots when the soil dried to near field capacity. Readings from these devices were suspended when the soil was soaked or flooded after re-watering or when there was rainfall and resumed again when the soil was at about field capacity until the next drought episode. In 2012 WS, Diviner 2000 tubes and tensiometers were not installed because the field had been continuously soaked or flooded until maturity due to rainfall. Rainfall data were acquired from the IRRI agro-meteorological station located about 300 m from the experiments. The amount of rainfall that occurred from 50 to 110 DAS, which corresponds to the period from irrigation withdrawal in the DRT treatment to about hard dough stage of the grains, was considered as the effective rainfall for the drought-stressed crop.

The number of days to flowering (DTF) was recorded when at least 50% of the hills in the plot started to flower. Plant height was measured from ground level to the highest part of three random plants per plot at maturity. Above-ground biomass and grain yield at harvest were determined from the central 2 m of 3 rows per plot. Grain yield was normalized to 14% grain moisture content. Total dry matter yield was calculated as the sum of the oven-dry weights of above-ground parts normalized to 3% moisture content.

2.2. Physiological response of selected cultivars to drought

Ten entries that had shown high yield potential under drought in the initial screening experiments and genotype IR77298-5-6-B-11 that had been observed to be susceptible to drought (Swamy et al., 2013) were selected to characterize their physiological response to drought stress. The physiology study was conducted under WW and DRT conditions using a randomized complete block design with four replications in 2013 WS, 2014 DS, and 2014WS. The fields and experimental protocol for the agronomic practices and water treatments used were the same as those used in the preceding screening experiments. Physiological measurements on these 11 genotypes included canopy temperature (MI-210, Apogee Instruments, Logan UT, USA), stomatal conductance (AP4 porometer, Delta-T Devices, Cambridge, UK), and Normalized Difference Vegetation Index (NDVI, Greenseeker Hand-held Sensor, NTech Industries, CA, USA). NDVI is a measure of the density of green vegetation on a land area based on spectral reflectance and calculated as: (near infrared − red reflectance)/(near infrared reflectance + red reflectance). The canopy temperature, NDVI, and stomatal conductance observations were conducted only in the drought treatment at about mid-day during sunny days and when plants exhibited leaf rolling as a symptom of drought stress. Photosynthesis was measured at flowering during the drought period in the DS using a Li-Cor 6400 (Li-Cor Inc., Lincoln, Nebraska USA). Root samples were collected during flowering stage mid-way between 2 hills from 3 locations per plot in the 2014WS using a 4-cm diameter, 60-cm long soil core sampler. The soil core samples were sectioned into 15 cm lengths to determine the root distribution with depth to 60 cm. The grain and total dry matter yields were determined using the procedure described for the screening study.

2.3. Statistical analysis

The yield stability of the genotypes under drought and well-watered treatments across all 11 crop seasons and both treatments was determined with an additive main effects and multiplicative interaction (AMMI 1) biplot analysis using STAR Ver. 2.1 software. The AMMI 1 biplot allowed the identification of genotypes with both high and stable grain yields across varying soil moisture levels and seasonal environmental conditions, based on their proximity to the x-axis (PC1) and their mean grain yield. Genotypic variation in physiological traits was evaluated by ANOVA and LSD using the same STAR software and R v. 3.1.0 (R Foundation for Statistical Computing). Traits were correlated using linear regression in R v. 3.1.0.

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