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Evaluation of Drought Tolerance of Malaysian Rice Genotypes through Morphological Study, Grain Yield and Drought Tolerance Indices

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ABSTRACT

Drought tolerant rice genotypes are required to lessen yield losses and boost overall production. The study aimed at examining drought tolerance level of 15 rice genotypes during reproductive stage released by MARDI. Drought was applied at early reproductive stage and continued until harvesting, while for control continuous water supply was maintained since the beginning. Drought significantly reduced the morphological growth and development. All genotypes showed a significant difference in the mean grain yield under drought stress when compared with control, indicating that the performance under water stress was considerably different. The mean grain yield ranged from 686.46 to 906.25 g/m^2 under well-watered condition, whereas 0.00 to 96.88 g/m^2 under stressed condition. MR211 represented maximum yield in both the conditions, while MR219 and MR220 had no yield under drought stress. The hierarchical clustering grouped all the genotypes into different clusters based on their similarity. MR307, MR303 and MR284 were similar in performances for most of the studied traits thus grouped in same cluster could be considered as drought-tolerant. Three genotypes (MR211, MR253 and MR263) revealed good performances for grain yield and morphological traits were grouped together in cluster II. MARDI WANGI88, MR219, MR220, MR269, MARDI WARNA98, MR157, MR167, MR185 and MR297 were incorporated in cluster I and could be concluded as drought susceptible genotypes. In conclusion, the study implied that the variances among genotypes for the studied traits were sufficient to assess drought tolerance in rice.

Key words: Rice, drought, reproductive stage, morphological study, grain yield

INTRODUCTION

Rice (*Oryza sativa* L.), is the staple food for over half the world's population (Yadav *et al.*, 2023). Around 30 million people in Malaysia feed on rice (Zhang *et al.*, 2023). Eight significant paddy granary sites in Peninsular Malaysia account for 85.5% of total paddy production in the country (Ahmed *et al.*, 2021) and can be considered as the country's "rice bowl" and source of food security (Rusli *et al.*, 2023). Rice is subjected to numerous abiotic and biotic stresses, including drought, flood, salinity, alkalinity, insect-pests, and diseases. Abiotic stresses affect crop growth and development throughout their life spans in natural climates (Hussain *et al.*, 2019). These variables have significant impact on rice output and productivity, resulting in substantial losses (Yadav *et al.*, 2023).

Drought is the toughest constraint among the abiotic stresses affecting rice, which influences nearly one-third of the total rice cultivation area in Asia and causes significant economic losses (Kashyap and Yadav, 2020). Drought, the principal cause of agricultural yield loss, causes global food shortages (Bhandari *et al.*, 2023). Semi-aquatic rice needs a lot of water for proper growth, development and physiological activities (Nadarajah and Kumar, 2019), whereas drought threatens global food security by affecting half of the rice-growing land (Dar *et al.*, 2020). Drought stress can cause yield loss up to 100%,

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depending on the growth stage of rice. Yield loss must be minimized to support rice producers from developing country and ensure food sustainability to cater for the growing human population (Oladosu *et al.*, 2019).Therefore, an increase in rice production is critically needed to maintain food security and alleviate poverty.

In tropical countries like Malaysia, high temperatures and change in precipitation make rice production challenging (Boon *et al.*, 2021). A previous study by Herman *et al.* (2015) stated that the El Niño phenomenon has disrupted agricultural activities, which has led to a 20% decrease in overall rice production in Malaysia. Precipitation fell off throughout this time, resulting in longer and intense dry seasons (Bong and Richard, 2020). El Niño returned in 2016, causing hydrological shortages in Malaysia and a fall in the water level in seven dams by less than half (Tan *et al.*, 2019). Currently, farmers in Malaysia are cultivating high yielding rice genotypes, among them most are drought-sensitive. Consequently, this impacts severely on the socio-economic condition of the rice industry especially farmers and the country had to rely on other countries to meet local demand. Again, research on the development of drought-tolerant rice genotypes just began a few years ago (Mohd Ikmal *et al.*, 2021). Malaysian Agricultural Research and Development Institute (MARDI) has been working since 1964, has so far released 52 rice genotypes (Sunian *et al.*, 2022) with their main focus on developing genotypes with high grain yield and resistance to diseases. Therefore, the screening of MARDI rice genotypes for drought tolerance can be an effective way to select superior genotypes. Thus, rice farmers can be introduced to and suggested to rice genotypes that showing higher drought tolerance even in water limiting conditions. According to prior studies, the reproductive stage of rice is the most sensitive to water deficiency (Kumar *et al.*, 2021). Hence, 15 MARDI rice genotypes were selected for the study to evaluate drought tolerance level through morphological study and grain yield.

MATERIALS AND METHODS

Fifteen rice genotypes used in the study were: MARDI WANGI88, MARDI WARNA98, MR157, MR167, MR185, MR211, MR219, MR220, MR253, MR263, MR269, MR284, MR297, MR303 and MR307. Firstly, the seeds of all genotypes were surface sterilized using 70% ethanol for 30 seconds. The ethanol was washed off the seeds with distilled water. Later, the seeds were stirred in 40% sodium hypochlorite solution for 20 min and rinsed for four to five times with sterile distilled water. Seeds were germinated by uniformly dispersing 10 seeds in a glass jar for each replica lined with a layer of Whatman filter paper (90 mm size). The glass jars were kept in a growth room at 25±20°C temperature, 50-70% relative humidity and 12 h light/12 h dark photoperiod for 10 days.

A pot experiment was conducted in a rainout shelter in CRD. Ten days old seedlings were transferred to pots. Each of the 15 genotypes was grown in three replicates under two treatments: control (well-watered) and drought, where water stress was applied at the early reproductive stage and continued until maturity. For control, a consistent water supply was maintained during the whole experiment. A basal application of N:P:K (150:60:50) kg/ha was applied during the experiment (Kamarudin *et al.*, 2020). During this period, the moisture content in the soil surface ranged between 15 and 25%, causing a mild to moderate drought (Huang *et al.*, 2019), measured with LCD digital moisture meter (5-inch probe portable soil hygrometer).

The plant growth was measured on the basis of plant height (PH), flag leaf length (FLL), flag leaf width (FLW), number of tiller (NOT), number of panicle (NOP), panicle length (PL), total fresh (FW) and dry weight (DW) of the above-ground part. FLL was measured from the ligule to the tip of the blade, while FLW at the widest part of the leaf. After harvesting, FW and DW of above plant parts were measured. The above ground parts of each plant were dried at 80 °C to a consistent weight in order to measure DW (Kamarudin *et al.*, 2020).

After harvesting, filled grains from primary and secondary panicles were collected and weighed. In the study, each genotype was transplanted and grown in three plants per pot (Area = 0.0314 m^2), where three seedlings of each genotype constituted each replica. Hence, the mean GY (g) of three replications was converted into g/m^2. Based on a mathematical correlation between grain yield during drought and control environments, a total of 10 drought tolerance indices (DTI) were proposed (Adhikari *et al.*, 2019). These were stress tolerance index (STI), mean productivity index (MPI), tolerance index (TOL), stress susceptibility index (SSI), drought tolerance efficiency (DTE), geometric mean productivity (GMP), harmonic mean (HM), yield stability index (YSI), yield reduction (YR) and yield index (YI). Yd and Yc represented the mean yield of a genotype evaluated under drought and control (well-watered) conditions, respectively. *Y*d and *Y*c represented the mean yield of all genotypes evaluated under drought and control (well-watered) conditions, respectively.

$$STI = (Yc \times Yd)/(\mathit{Y}c)^2$$
$$MPI = (Yc + Yd)/2$$
$$TOL = Yc - Yd$$
$$SSI = [1 - (Yd / Yc)] / [1 - (\mathit{Y}d / \mathit{Y}c)]$$
$$DTE (\%) = (Yd / Yc) \times 100$$
$$GMP = \sqrt{(Yd \times Yc)}$$
$$HM = 2(Yc * Yd)/(Yc + Yd)$$
$$YSI = Yd/Yc$$
$$YR = 1 - (Yd/Yc)$$
$$YI = Yd/\mathit{Y}d$$

Previous studies reported that the drought tolerance of the genotypes was inconsistent over the indices, as different indices identified different genotypes as tolerant. Hence, a ranking method was employed where mean rank (RM), standard deviation of ranks (SDR) and rank sum (RS) were calculated considering all indices to screen the most desirable drought-tolerant genotypes (Dhivyapriya *et al.*, 2016). The following relationship formula was used to calculate RS and to screen drought tolerant genotypes:

Rank sum (RS)=Rank mean (RM) + Standard deviation of rank (SDR)

A DSAASTAT version (1.101) was used to perform analysis of variance (ANOVA). Duncan's multiple range test (DMRT) ($P \leq 0.05$) was used to compare the means where ANOVA showed significant difference. Pearson's correlation was used in SPSS window version 26 (IBM Corp., Armonk, New York, USA) to determine the inter-correlations among the DTI. Cluster analysis using Euclidian distance (Ward method) grouped similar data into same clusters and enabled to find out the inter-relationship between genotypes.

RESULTS AND DISCUSSION

The impact of drought stress on various morphological changes substantially differed among genotypes (Yadav *et al.*, 2023), which underscored the importance of screening rice germplasm for drought tolerance. In the current study PH, FLL, FLW, NOT and NOP were found to be decreased under drought stress (Table 1).

According to Kumar *et al.* (2021), drought frequently restricted plant height, root system, leaf area, and number of tillers in rice. Flag leaf had a great impact in panicle development and grain yield because it provided the most important source of photosynthetic energy during reproduction and grain filling (Yamashita *et al.*, 2022). Hence, the genotype revealed a maximal decrease in FLL, and FLW as expected to produce lower grain. The current study showed MR219 having minimal FLL (25.37 cm) and MARDI WARNA98 showing minimal value for FLW (1.23 cm) during drought stress. As the intensity of the stress increased, most of the morpho-physiological traits tended to decrease (Swapna and Shylaraj, 2017).

Biomass production is essential for improving yield because it is related to food and biofuel production. In the current study, MR297 represented the minimal fresh weight (48.27 g), while MARDI WARNA98 had the minimal dry weight (22.16 g) among the genotypes. PL, both the FW and DW and GY also revealed to be decreased as a result of the stress (Table 2). A previous study by Turin *et al.* (2021) suggested that the underground parts of the rice plants were less affected than the above-ground parts. Consequently, these properties were extremely vital and revealed some potential genotypes with superior root traits that may be recommended for breeding as drought-resistance genotypes.

The reproductive stage of rice is highly sensitive to water shortage, which causes a major reduction in GY (Bhandari *et al.*, 2020). Several experiments have been employed to standardize uniform screening procedures, considering GY as selection criteria for reproductive stage drought. The most widely applied criteria for evaluating drought tolerance in rice is GY (Turin *et al.*, 2021). Increased percentage of spikelet sterility may

Table 1. Morphological traits of 15 rice genotypes evaluated under well-watered (control) and drought conditions

Genotypes	PH (cm)		FLL (cm)		FLW (cm)		NOT		NOP	
	WW	DS	WW	DS	WW	DS	WW	DS	WW	DS
MARDI WANGI88	102.20±0.70b-f	98.83±3.22c-g	28.97±1.07 d-g	25.23±1.43g	1.53±0.03c-f	1.40±0.10d-h	13.00±0.58a-e	11.33±0.88de	12.33±0.88a-e	11.33±0.88cde
MARDI WARNA98	111.17±5.34ab	100.80 ±5.02b-f	32.50±1.26cde	30.67±2.33d-g	1.37±0.03e-h	1.23±0.03h	16.00±0.58abc	12.67±0.33a-e	15.67±0.33abc	11.33±0.67cde
MR157	96.07±1.21d-h	93.17±4.60f-i	33.70±0.96cd	28.17±1.74d-g	1.53±0.03c-f	1.37±0.03e-h	15.67±1.86a-d	14.33±0.88a-e	15.67±1.86abc	13.00±2.08a-e
MR167	104.90±0.67bcd	99.50±0.76c-g	30.17 ±1.59d-g	28.50±1.04d-g	1.37±0.07e-h	1.27±0.07gh	13.67±0.88a-e	12.67±2.19a-e	13.67±0.88a-e	12.67±2.19a-e
MR185	101.57±2.81b-f	95.83±2.35d-h	32.50±2.02cde	29.20±1.56d-g	1.50±0.10c-g	1.40±0.10d-h	14.00±0.58a-e	13.33±0.33a-e	13.33±0.33a-e	12.33±0.88a-e
MR211	93.37±0.81e-i	89.96±0.62ghi	28.63±1.32d-g	27.53±1.07d-g	1.63±0.15bcd	1.30±0.06fgh	17.00±2.65a	14.67±0.67a-e	16.00 ±2.65ab	13.00±1.00a-e
MR219	104.53 ±0.53bcd	97.93±3.74c-h	29.67±2.33d-g	25.37±1.03fg	1.60±0.06b-e	1.30±0.06fgh	13.00±1.15a-e	12.33±0.88b-e	12.67±1.20a-e	12.00±0.58a-e
MR220	98.20±2.86c-g	90.17±0.60ghi	28.53±1.01d-g	26.17±1.88efg	1.63±0.07bcd	1.30±0.06fgh	12.33±0.33b-e	12.33±0.88b-e	12.33±0.33a-e	11.67±0.67b-e
MR253	88.97±4.20ghi	84.83±3.09i	31.37±3.95d-g	29.37±1.14d-g	1.63±0.07bcd	1.37±0.03e-h	16.33±2.40ab	15.67±1.45a-d	16.33±2.40a	15.33±1.20abc
MR263	87.60±1.45hi	83.93±1.03i	28.83±2.29d-g	26.37±1.50efg	1.80±0.12ab	1.40±0.06d-h	11.67±0.67cde	11.67±0.67cde	11.33±0.88cde	10.67±0.33de
MR269	102.33±0.93b-f	92.47±1.78f-i	28.50±1.26d-g	26.17±1.48efg	1.63±0.03bcd	1.40±0.06d-h	13.33±0.33a-e	13.00±1.00a-e	13.33±0.33a-e	11.67±1.20b-e
MR284	107.03±1.52bc	103.83 ±1.92b-e	29.80±2.11d-g	27.83±1.79d-g	1.67±0.03bc	1.50±0.12c-g	12.00±1.53b-e	11.00±1.15e	11.33±1.20cde	10.00±1.00e
MR297	101.03±2.55b-f	90.07±1.26ghi	39.80±2.66ab	37.63±2.12bc	1.70±0.10bc	1.63±0.07bcd	15.67±3.18a-d	14.00±0.58a-e	15.00±2.65a-d	13.67±0.88a-e
MR303	119.00±6.51a	110.33±4.37ab	31.67±1.86def	28.77±1.49d-g	1.60±0.06b-e	1.50±0.06c-g	12.33±1.45b-e	12.00±1.15b-e	12.33±1.45a-e	10.33±0.88e
MR307	120.10±4.61a	110.67±5.92ab	44.80±3.15a	39.30±1.29ab	1.97±0.03a	1.40±0.10d-h	13.00±0.58a-e	12.67±0.67a-e	12.00±0.58a-e	11.33±0.33cde

There was no significant difference between the means±SE in the same column with same letter at ($P \leq 0.05$). PH–Plant height, FLL–Flag leaf length, FLW–Flag leaf width, NOT–Number of tillers, NOP–Number of panicles, WW–Well-watered and DS–Drought stress.

be associated with decreased GY, which is common during reproductive stage drought (Muthuramu and Ragavan, 2020). Drought impairs major reproductive processes, including anther dehiscence, pollen viability and pollen germination, causing spikelet sterility and yield loss. GY in rice is largely dependent on panicle architecture, particularly panicle size and number of spikelets. Spikelet infertility may be attributed to ROS-induced abortion of pollen grains, faulty pollen germination and fertilization failure (Ahmad *et al.*, 2022).

The study found that GY decreased significantly in all genotypes as a result of drought stress (Table 2). All genotypes showed a significant difference in the mean GY between the well-watered and stress conditions, indicating that the performance under water stress was considerably different. The mean GY ranged from 686.46 to 906.25 g/m^2 under well-watered condition, whereas 0.00 to 96.88 g/m^2 under stressed condition. The genotype MR211 represented maximum yield in both the conditions, while MR219 and MR220 had no GY under drought stress.

There are lists of DTIs, that are based on either drought susceptibility or drought resistance of genotypes (Adhikari *et al.*, 2019). These indices have been employed as useful indicators to select drought tolerant genotypes performing well in stressful environments. The current study applied 10 popular and effectively used indices on the basis of grain yield (Table 3). The study found the maximal TOL value in MR219 (853.13), followed by MR220 (813.54), while MR185 represented the minimal TOL value (630.21). In the present investigation, MR211 showed minimal SSI (0.94), whereas MR219 and MR220 revealed maximal SSI (1.06). Lower values of SSI and TOL denote lower differences in yield between non-stress and stress environments. Genotypes with SSI values less than 1 might be considered drought resistant (Kamarudin *et al.*, 2020) as they exhibited smaller yield reductions under water stress environment compared with well-watered conditions. The current finding identified six genotypes, with an SSI less than 1: MR211, MR263, MR185, MR253, MR307 and MR303, which thus could be regarded as drought tolerant.

STI, one of the most widely used and effective indices, can be utilized to select genotypes with

Table 2. Morphological traits and grain yield of 15 rice genotypes evaluated under well-watered (control) and drought conditions

Genotypes	Plant FW (g)		Plant DW (g)		Panicle L (cm)		Grain Y (g/m^2)	
	WW	DS	WW	DS	WW	DS	WW	DS
MARDI WANGI88	78.23±3.43b-e	62.00±1.53g-j	33.06±0.58cde	27.57±2.15e-k	21.50±0.40d-i	21.44±0.53e-i	833.33±10.88b	32.29±18.95gh
MARDI WARNA98	69.02±2.10d-i	60.71±3.83g-j	27.20±1.60f-k	22.16±0.55k	21.83±0.71c-i	20.20±0.47i	800.00±12.50bc	22.92±11.46gh
MR157	65.85±7.24e-i	54.58±3.32ij	29.40±1.70d-j	24.46±1.74ijk	22.42±0.96b-g	20.90±0.21f-i	833.33±28.94b	38.54±3.76gh
MR167	71.55±3.71c-h	58.11±3.98hij	30.13±0.59c-h	24.17±2.51jk	22.43±0.35b-g	20.83±0.60ghi	729.17±12.67de	42.71±5.80gh
MR185	80.07±2.51b-e	55.85±2.35ij	31.26±1.12c-g	27.59±1.36e-k	22.37±0.75b-g	21.23±0.50e-i	686.46±30.85e	56.25±5.41fgh
MR211	73.61±2.94c-g	56.09±2.44g-j	32.53±1.32c-f	28.03±1.55e-j	23.33±0.44bcd	22.50±0.75b-g	906.25±19.85a	96.88±4.77f
MR219	73.60±2.81c-g	60.55±3.86g-j	28.02±2.29e-j	25.53±1.05h-k	24.00±0.58b	22.93±0.07b-e	853.13±17.40b	0.00±0.00h
MR220	73.12±1.97c-g	63.15±3.07f-i	32.07±1.56c-f	24.03±1.16jk	22.73±0.23b-f	21.90±0.15c-i	813.54±30.74b	0.00±0.00h
MR253	74.37±2.21c-g	56.00±7.03ij	30.87±2.77c-h	27.73±1.19e-k	22.67±1.45b-g	20.50±0.29hi	748.96±24.89d	60.42±30.26f
MR263	73.95±2.19c-g	55.28±5.89ij	30.53±1.01c-h	27.87±0.70e-j	22.73±0.37b-f	23.00±0.12b-e	708.33±13.66de	69.79±8.90fg
MR269	82.01±5.14a-d	61.99±6.29g-j	32.33±0.88c-f	27.51±1.25f-k	23.53±0.62bc	21.63±0.32d-i	748.96±17.34d	41.67±5.21gh
MR284	84.65±1.68abc	73.16±5.95c-g	35.00±2.08bc	27.60±0.87e-k	22.50±0.29b-g	22.60±0.50b-g	835.42±12.01b	39.58±19.87gh
MR297	65.99±4.12e-i	48.27±3.21j	29.79±2.71c-i	24.43±2.76ijk	23.05±0.53b-e	22.30±0.35b-h	759.38±12.63cd	29.17±14.69gh
MR303	88.40±7.12ab	62.44±7.03g-j	33.55±1.80bcd	26.43±0.43g-k	23.36±0.33bcd	23.10±0.21b-e	806.25±20.09bc	59.38±4.77fg
MR307	94.43±3.82a	77.29±3.75b-f	47.37±0.58a	38.33±1.76b	26.21±0.41a	23.00±0.51b-e	826.04±12.67b	62.50±5.41fg

There was no significant difference between the means±SE in the same column with same letter at ($P \leq 0.05$), FW–Fresh weight; DW–Dry weight, Panicle L–Panicle length, Grain Y–Grain yield; WW–Well-watered and DS–Drought stress.

better yield in both the stress and non-stress situations. A higher value of STI implied enhanced tolerance to drought (Adhikari *et al.*, 2019; Kamarudin *et al.*, 2020). Several researchers also reported that genotypes having the highest STI value were drought-tolerant (Pour-Aboughadareh *et al.*, 2019). Among the genotypes, MR211 (0.14) revealed the maximal STI. MR263, MR303 and MR307 scored the same (0.08) value for STI. The greater the value of DTE, GMP and MPI lesser the yield reduction under stress conditions and the higher the drought tolerance (Bhandari *et al.*, 2020). Drought tolerant genotypes were expected to have high YI and YSI; thus, genotypes with high values of these two could be considered stable genotypes under both the conditions (Gitore *et al.*, 2021). Six genotypes reported in the present investigation with a YI value greater than 1 were MR211 (2.23), MR263 (1.61), MR307 (1.44), MR253 (1.39), MR 303 (1.37) and MR185 (1.29). Again, the YSI observed in the genotypes were MR211 (0.11), MR263 (0.10), MR185 (0.08), MR 253 (0.08) MR307 (0.08), and MR303 (0.07), respectively. The estimations of drought tolerance indicators (Table 3) showed that screening drought-tolerant genotypes using a single criterion seemed inconsistent because different indices identified different genotypes as drought-tolerant.

Therefore, it becomes contradictory to select drought-tolerant genotype based on a single criterion. More experiments have reported that the selection of stable genotypes should be based on a combination of indices. Therefore, the ranking method was studied to have an overall judgement considering all indices. The ranking method was used effectively to select drought-tolerant rice genotypes. Tolerant genotypes had relatively low rank sum (RS) and standard deviation of ranks (SDR) when all indices were taken into account (Gitore *et al.*, 2021). In the study, the genotype MR211 was most tolerant, and MR219 and MR220 were most susceptible considering the RS value. Table 4 shows the rank of DTI, rank mean, standard deviation of ranks and rank sum. MR211 had rank 1 for both the maximum grain yield under control (Yc) and drought (Yd). Under control condition, MR185 revealed minimal yield and thus ranked 15 for Yc. Similarly, MR219 and MR220 had no yield under water stress and had a rank value

Table 3. DTI of rice genotypes based on grain yield

Genotypes	Yc	Yd	STI	MPI	TOL	SSI	DTE%	GMP	HM	YSI	YI	YR
MARDI WANGI88	833.33	32.29	0.04	865.63	801.04	1.02	3.88	164.04	62.17	0.04	0.74	0.96
MARDI WARNA98	800.00	22.92	0.03	822.92	777.08	1.03	2.86	135.40	44.56	0.03	0.53	0.97
MR157	833.33	38.54	0.05	871.88	794.79	1.01	4.63	179.22	73.68	0.05	0.89	0.95
MR167	729.17	42.71	0.05	771.88	686.46	1.00	5.86	176.47	80.69	0.06	0.98	0.94
MR185	686.46	56.25	0.06	742.71	630.21	0.97	8.19	196.50	103.98	0.08	1.29	0.92
MR211	906.25	96.88	0.14	1003.13	809.38	0.94	10.69	296.30	175.04	0.11	2.23	0.89
MR219	853.13	0.00	0.00	853.13	853.13	1.06	0.00	0.00	0.00	0.00	0.00	1.00
MR220	813.54	0.00	0.00	813.54	813.54	1.06	0.00	0.00	0.00	0.00	0.00	1.00
MR253	748.96	60.42	0.07	809.38	688.54	0.97	8.07	212.72	111.81	0.08	1.39	0.92
MR263	708.33	69.79	0.08	778.13	638.54	0.95	9.85	222.34	127.06	0.10	1.61	0.90
MR269	748.96	41.67	0.05	790.63	707.29	1.00	5.56	176.65	78.94	0.06	0.96	0.94
MR284	835.42	39.58	0.05	875.00	795.83	1.01	4.74	181.85	75.59	0.05	0.91	0.95
MR297	759.38	29.17	0.04	788.54	730.21	1.02	3.84	148.82	56.18	0.04	0.67	0.96
MR303	806.25	59.38	0.08	865.63	746.88	0.98	7.36	218.79	110.60	0.07	1.37	0.93
MR307	826.04	62.50	0.08	888.54	763.54	0.98	7.57	227.22	116.21	0.08	1.44	0.92

Yc–Yield in control, Yd–Yield in drought, STI–Stress tolerance index, MPI–Mean productivity index, TOL–Tolerance index, SSI–Stress susceptibility index, DTE–Drought tolerance efficiency, GMP–Geometric mean productivity, HM–Harmonic mean, YSI–Yield stability index, YI–Yield index and YR–Yield reduction.

of 14 for Yd. The ranking of STI, MPI, DTE, GMP, HM, YSI, and YI has been done following the same order. The genotype MR211 was ranked as 1 in STI, MPI, DTE, GMP, HM, YSI and YI, implying that MR211 had maximal value for these indices. On the other hand, the ranking of SSI, TOL and YR has been done in reverse order. The genotype MR185 was ranked 1 for TOL, whereas MR211 was ranked 1 for SSI and YR, indicating that the genotypes had a minimal value for these indices.

Finally, drought tolerant genotypes were identified using the rank sum (RS) of the mean rank and the standard deviation of rank. The genotypes were arranged on the basis of rank (R) as MR211>MR307>MR303>MR253>MR263 >MR269>MR284>MR185>MR157>MR167>MARDI WANGI88>MR297>MARDI WARNA98>MR220> MR219 according to their tolerance (Table 4). The cluster analysis grouped similar data into the same clusters thereby allowed conferring the relationship between genotypes (Mohi-Ud-din *et al.*, 2021). Clustering grouped the genotypes into different clusters based on all of the studied traits (Fig. 1). The dendrogram grouped 15 genotypes into three different

Table 4. Rank (R) of drought tolerant indices, rank mean (RM), standard deviation of ranks (SDR) and rank sum (RS) of all indices

Genotypes	Yc	Yd	STI	MPI	TOL	SSI	DTE	GMP	HM	YSI	YI	YR	RM	SDR	RS	R
MARDI WANGI88	4	11	11	5	12	11	11	11	11	11	11	11	10.00	2.59	12.59	11
MARDI WARNA98	9	13	13	8	9	13	13	13	13	13	13	13	11.92	1.98	13.89	13
MR157	4	10	8	4	10	10	10	8	10	10	10	10	8.67	2.31	10.98	9
MR167	13	7	10	14	3	7	7	10	7	7	7	7	8.25	3.02	11.27	10
MR185	15	6	6	15	1	3	3	6	6	3	6	3	6.08	4.50	10.59	8
MR211	1	1	1	1	13	1	1	1	1	1	1	1	2.00	3.46	5.46	1
MR219	2	14	14	7	15	14	14	14	14	14	14	14	12.50	3.90	16.40	15
MR220	7	14	14	9	14	14	14	14	14	14	14	14	13.00	2.37	15.37	14
MR253	11	4	5	10	4	4	4	5	4	4	4	4	5.25	2.49	7.74	4
MR263	14	2	3	13	2	2	2	3	2	2	2	2	4.08	4.42	8.50	5
MR269	11	8	9	11	5	8	8	9	8	8	8	8	8.42	1.56	9.98	6
MR284	3	9	7	3	11	9	9	7	9	9	9	9	7.83	2.48	10.31	7
MR297	10	12	12	12	6	12	12	12	12	12	12	12	11.33	1.78	13.11	12
MR303	8	5	4	6	7	6	6	4	5	6	5	6	5.67	1.15	6.82	3
MR307	6	3	2	2	8	5	5	2	3	5	3	5	4.08	1.88	5.96	2

Yc–Yield in control, Yd–Yield in drought, STI–Stress tolerance index, MPI–Mean productivity index, TOL–Tolerance index, SSI–Stress susceptibility index, DTE–Drought tolerance efficiency, GMP–Geometric mean productivity, HM–Harmonic mean, YSI–Yield stability index, YI–Yield index, YR–Yield reduction, RM–Rank mean, SDR–Standard deviation of rank, RS–Rank sum and R–Rank.

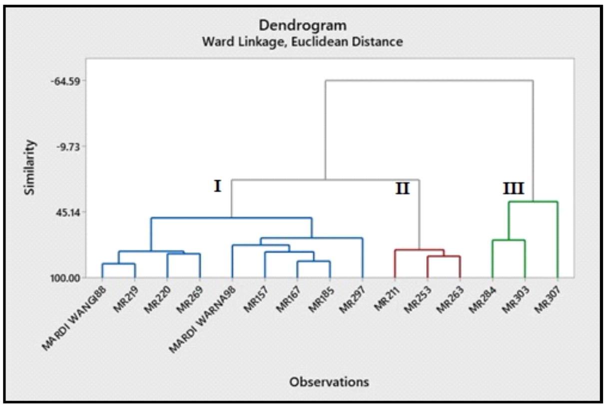

Fig. 1. Dendrogram of 15 rice genotypes based on morphological parameters and grain yield.

clusters. MR307 was found to be the most tolerant genotype based on all the parameters grouped together in cluster III with MR284 and MR303, whereas MR284 and MR303 were closely related to each other. Three genotypes named MR211, MR253 and MR263 were grouped into one cluster (cluster II), thereby sharing similar characteristics were drought tolerant based on grain yield and morphological traits studied. Another nine genotypes were placed in cluster I and considered as drought susceptible. These were MARDI WANGI88, MR219, MR220, MR269, MARDI WARNA98, MR157, MR167, MR185 and MR297. Among the nine drought susceptible genotypes, MARDI WANGI88, MR219, MR220 and MR269 were closely related and another five other genotypes (MARDI WARNA98, MR157, MR167, MR185 and MR297) were close in cluster I.

CONCLUSION

This study demonstrated that drought stress at the reproductive stage negatively affected the morphological performances and yield of all rice genotypes. The study revealed that the morphological traits investigated had greater relevance for the assessment of drought tolerance at the reproductive stage. Further, the results suggested that evaluation based on DTIs could be an efficient tool to identify superior drought tolerant genotypes with higher yield potential and stability. The current study concluded six genotypes named MR307, MR303, MR284, MR211, MR253 and MR263 as drought tolerant. On the other hand, MARDI WANGI88, MARDI WARNA98, MR157, MR167, MR185, MR219, MR220, MR269 and MR297 were categorized as drought susceptible genotypes. In summary, the analysis of variance and genetic parameters showed extensive genetic variability under normal and drought stress conditions. This implied that the variances among genotypes for the studied traits were sufficient to assess drought tolerance. Therefore, knowledge of clustering and DTIs can be employed in breeding and to select superior germplasms by analyzing their greater performance in given conditions.

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