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Effect of Drought Stress on Morphological and Physiological Traits at Panicle Initiation Stage in Six Rice Genotypes (*Oryza sativa* L.)

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ABSTRACT

Drought is one of the most prevalent forms of abiotic environmental stress that reduce crop productivity. A pot experiment was performed in two Aman seasons under drought (40% field capacity, FC) and control (100% field capacity, FC) irrigations to study drought tolerance mechanism(s) based on morphological and physiological traits in six aromatic rice genotypes. Twelve treatments (6 genotypes × 2 irrigations) were arranged in Complete Randomized Design and experiment was carried out at Bangladesh Institute of Nuclear Agriculture, Bangladesh Agricultural University, Mymensingh. In the experiment, drought was imposed at panicle initiation stage where morphological and physiological data were recorded. Important morphological (stem and root dry weight) and physiological (photosynthesis and chlorophyl content) attributes were significantly (P>0.05) decreased at 40% FC in both the years. Compared to control, relative reduction at 40% FC in above parameters, genotypes were classified into tolerant (Binadhan-13 and NERICA mutant) and sensitive (RM-100-16, Ukunimodhu, Kalizira, and BRRI dhan34) categories. Tolerant genotypes had smaller reduction in shoot and root dry mater (av. 7.73 and 5.56 %, respectively) than sensitive ones (av. 19.32 and 21.80%, respectively). Low reduction percentages of the traits under drought stress to that of the control discriminated Binadhan-13 and NERICA mutant genotypes consistently as drought tolerant.

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Introduction

Plant water deficits affect every aspects of plant growth and the worldwide losses in crop yields from water stress probably exceed the losses from all other causes combined Hsiao (1976). The magnitude of drought in Bangladesh is more frequent because of climate change NDMC (2006). It is a recurrent phenomenon in some parts of the country, but the northwestern region is mostly drought prone because of high rainfall variability. This region is also relatively dry, receiving much lower rainfall compared to the rest of the country Paul (1998). Therefore, drought occurs in this region in a regular basis. In Bangladesh, about 70% of the country's cultivable land is under rice cultivation. Aman rice is rain fed cultivated during June–December. It passes through vegetative stage during August to September when rainfall is usually sufficient. The crop suffers from moisture stress when the rainfall usually ceases by the first week of October in Bangladesh. By this time it passes through reproductive stages. The total rainfall in these two months is very irregular and often inadequate which fails to meet the evapotranspirational demand of Aman rice consequently develops water stress and affects translocation of assimilates and grain development in rice Zubaer et al., (2007); Rahman et al., (2002). Drought stress seriously affects plant growth and development. It results in various physiological changes including reduced photosynthetic active radiation (PAR), photosynthetic rate, transpiration rate, stomatal conductance and growth before plant senescence Chaves and Oliveira (2004); Chaves et al., (2009). These physiological parameters and yield components could be used as selection criteria for improving drought stress in different crops Ashraf (2010). With all those factors above in mind, this study was conducted to investigate morpho-physiological traits at panicle initiation stage under drought imposed; and to assessed dry matter partitioning under drought imposed at panicle initiation stage in six aromatic rice genotypes.

Materials and Methods

The pot experiment was conducted in vivo with six rice genotypes *viz*. Binadhan-13, BRRI dhan34, Ukunimadhu, RM-100-16, Kalizira and NERICA mutant. The pot was 25 cm deep with 27 cm diameter at the top, filled with top soils (13 kg soil), placed under polythene sheet at the pot yard of Crop Physiology Division, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh. Seed was sowed on 25th June in each year. One plant was transplanted per pot. The fertilizer doses ha^{-1} were 160, 65, 120 and 90 kg Urea, TSP, MP and Gypsum respectively (Fertilizer Recommendation Guide, BARC- 2012). All soils pots were fertilized with urea, TSP, MP and gypsum @ 3.08, 0.70, 1.12 and 0.707 g pot^{-1}, respectively. All TSP, MP, Gypsum and one-third of the urea were applied as basal dose. The remaining two-thirds of the urea were applied in two equal splits in each pot at 25 and 45 days after transplanting (DAT).The experiment was set in a two factorial Completely Randomized Design (CRD) with three replications in two Aman seasons (2013 and 2014) as Bangladesh face more drought in Aman season. The experiment were done in two consecutive years for more data accuracy. The first factor was rice genotypes and the second factor was irrigations: control (100% FC) and drought (40% FC) stresses treatments. Drought (40 % FC) was imposed at 50 days after transplanting when plants had attained panicle initiation stage. Harvests were made after seven days of stress imposition (57 DAT) for dry matter production and partitioning. Plant height, number of green leaves, number of total tillers, root dry weight, stem dry weight, leaf dry weight, and shoot dry matter was calculated. Root-Shoot ratio was calculated by shoot dry matter divided by root dry matter. Rates of photosynthesis, transpiration, stomatal conductance and inter cellular CO_2 concentrations were measured using Portable Photosynthetic System (Model: Li-6400XT). Chlorophyll content of flag leaves were measured using portable chlorophyll meter (Model: Konica Minolta SPAD 502). The percent reduction of each parameter under drought stress compared to control was calculated for each genotype using formula: Relative increase or decrease (%) = (Data for control treatment – Data for drought treatment)/ (Data for control treatment) × 100. Mathematically, (-)ve value indicate an increase and (+)ve one decrease. The collected data were analyzed statistically following Completely Randomized Design by MSTAT-C computer package programme developed by Russel (1986). The treatment means were adjudged by Duncan's Multiple Range Test (DMRT).

Results

Combined effect of drought and genotype on plant height, tillers hill^{-1}, green leaves hill^{-1} , leaf, stems, root and shoot dry weight, root-shoot ratio, chlorophyll content, photosynthetic rate, stomatal conductance (g_s), Intercellular CO_2 concentration (Ci), and transpiration (E) at panicle initiation stage under drought stress was significant ($P \leq 0.05$) (Table 1, 2 and 3).

Table 1. Combined effect of genotype and drought (40 % FC) with control (100 % FC) irrigation on morphological characters in six aromatic rice genotypes in both seasons

Genotype	Irrigation	Plant height (cm)	Tillers hill^{-1} (No.)	Green leaves hill^{-1} (No.)
Season-1				
Binadhan-13	100% FC	104.0 bc^{+}	35.67 a	130.3 abc
	40% FC	102.7 c (1.25)$^{++}$	33.67 ab (5.61)	121.7 b-e (6.60)
Kalizira	100% FC	107.3 abc	38.67 a	126.3 a-d
	40% FC	104.3 bc (2.79)	31.33 ab (19.98)	97.67 fg (22.67)
RM 100-16	100% FC	116.0 a	35.00 a	144.3 a
	40% FC	103.0 c (11.20)	34.33 ab (1.91)	111.0 c-f (23.08)
Ukunimodhu	100% FC	107.0 abc	37.33 a	141.3 ab
	40% FC	106.7 abc (0.28)	31.00 ab (16.95)	105.3 d-f (25.48)
BRRI dhan-34	100% FC	115.3 a	34.33 ab	126.3 a-d
	40% FC	114.0 ab (1.12)	26.00 bc (24.26)	98.00 fg (22.41)
NERICA mutant	100% FC	100.0 c	22.33 c	103.7 ef
	40% FC	99.33 c (0.67)	20.00 c (10.43)	80.67 g (28.55)
Season-2				
Binadhan-13	100% FC	102.7 a	23.00 b	88.33 a
	40% FC	97.00 ab (5.55)	22.33 b (2.91)	87.67 a (0.75)
Kalizira	100% FC	103.0 a	31.00 a	97.00 a
	40% FC	97.00 ab (5.83)	25.67 ab (17.19)	94.33 a (2.75)
RM 100-16	100% FC	98.00 ab	31.67 a	95.33 a
	40% FC	83.00 c (15.31)	22.67 b (28.41)	79.33 a (16.78)
Ukunimodhu	100% FC	101.7 a	20.67 b	81.33 a
	40% FC	92.00 b (9.54)	20.33 b (1.64)	76.67 a (5.72)
BRRI dhan-34	100% FC	99.33 ab	22.00 b	89.00 a
	40% FC	95.00 ab (4.36)	20.00 b (9.09)	80.33 a (9.74)
NERICA mutant	100% FC	95.67 ab	25.33 ab	89.00 a
	40% FC	92.00 b (3.84)	23.33 b (7.89)	74.67 a (16.10)

+: Data were separately analyzed for the year 2013 and 2014. In a year in each column, figures having common letter(s) do not differ significantly at $P \leq 0.05$ as per DMRT; ++: Figures within parenthesis indicate % decrease at 40 % FC compared to control.

Table 2. Combined effect of genotype and drought (40% FC) with control (100% FC) irrigations on dry weight of plants parts in six aromatic rice genotypes in both seasons

Genotype	Irrigation	Leaf dry wt hill^{-1} (g)	Stem dry wt hill^{-1} (g)	Root dry wt hill^{-1} (g)	Root: shoot ration
Season-1					
Binadhan-13	100% FC	12.41 b-e +	21.43 bc	21.36 abc	0.64 abc
	40% FC	11.90 b-e (4.11)++	21.21 bc (1.03)	20.75 bc (2.86)	0.66 a-c (-3.12)
Kalizira	100% FC	14.28 abc	22.80 bc	21.76 abc	0.62 abc
	40% FC	9.86 e (30.95)	20.34 bc (10.79)	15.39 c (29.27)	0.60 a-c (3.22)
RM 100-16	100% FC	14.67 ab	30.79 a	21.22 abc	0.67 ab
	40% FC	9.59 e (34.62)	19.89 c (35.40)	17.48 c (17.62)	0.58 a-c (13.43)
Ukunimodhu	100% FC	14.26 abc	19.99 c	28.15 a	0.81 a
	40% FC	11.65 b-e (18.30)	15.86 c (20.66)	16.43 c (41.63)	0.57 a-c (29.62)
BRRI dhan-34	100% FC	15.88 a	18.04 c	24.90 ab	0.70 ab
	40% FC	11.02 c-e (30.60)	17.57 c (2.61)	21.80 a-c (12.44)	0.78 a (-11.42)
NERICA mutant	100% FC	13.41 a-d	27.27 ab	17.00 c	0.39 c
	40% FC	12.74 b-e (4.97)	26.34 ab (3.41)	16.43 c (3.35)	0.43 bc (-10.25)
Season-2					
Binadhan-13	100% FC	11.62 a	11.79 bc	14.02 b cd	0.73 b
	40% FC	11.58 a-c (0.34)	10.50 bc (10.94)	13.11 cd (6.49)	0.78 ab (-6.84)
Kalizira	100% FC	9.21 a-d	11.96 bc	17.12 bc	0.99 a
	40% FC	7.78 d (15.53)	10.26 bc (14.21)	14.52 b-d (15.19)	0.71 b (28.28)
RM 100-16	100% FC	9.29 a-d	17.08 a	17.52 bc	0.82 ab
	40% FC	8.06 cd (13.24)	13.31 b (22.07)	15.04 b-d (14.16)	0.69 b (15.85)
Ukunimodhu	100% FC	11.05 ab	17.08 a	15.92 bcd	0.63 b
	40% FC	9.90 a-d (10.41)	12.72 bc (25.52)	11.87 d (25.44)	0.42 c (33.33)
BRRI dhan-34	100% FC	8.40 bcd	11.60 bc	23.52 a	0.83 ab
	40% FC	7.66 d (8.81)	9.82 c (15.34)	19.13 b (18.66)	0.79 ab (4.82)
NERICA mutant	100% FC	9.73 a-d	11.65 bc	16.45 bc	0.83 ab
	40% FC	9.64 a-d (0.92)	10.17 bc (12.70)	14.88 b-d (9.54)	0.85 ab (-2.40)

+: Data were separately analyzed for the year 2013 and 2014. In a year in each column, figures having common letter(s) do not differ significantly at $P \leq 0.05$ as per DMRT; ++: Figures within parenthesis indicate % decrease and (-) indicate % increase at 40% FC compared to control.

Relative reduction in percentage (figures in the parenthesis) of this variable under drought as compared to control is shown (Table 1, 2 and 3). In season-1, five genotypes had lower reduction (average of 1.22 %) in plant height than in the genotype RM-100-16 (11.20%) (Table 1).

In season-2, in contrast, four genotypes had lower reduction (average of 4.89%) compared to genotypes RM-100-16 and Ukunimodhu. In season-1, relative reduction in tillers hill^{-1} under drought compared to control was lesser in the genotypes Binadhan-13, NERICA mutant and RM- 100-16 (average of 5.98%) than in all remainders. In season-2, in contrast, it was smaller in genotypes Binadhan-13, NERICA mutant and Ukunimodhu (average of 4.15%) than in the rest (Table 1). In season-1, relative reduction in leaves hill^{-1} under drought as compared to control, was lesser in Binadhan-13 (6.60%) than all remainder genotypes. In season-2, genotypes Binadhan-13 and Kalizira also did show lesser relative reduction (average of 1.75%) than others. It indicated that two genotypes (Binadhan-13 and NERICA mutant) had lower reduction in both the years and could be greater drought tolerant. In season-1, relative reduction of LDW was extremely low in Binadhan-13 and NERICA mutant (average of 4.54%) than all the (Table 2). In season-2, similar result was found. In season-1, relative reduction of SDW was much lower in genotypes Binadhan-13, BRRI dhan-34 and NERICA mutant (average of 2.35%) than the rest (Table 2). In season-2, however, relative reduction of SDW was much lesser in genotypes Binadhan-13 and NERICA mutant (average of 11.82%) than the rest. Under control condition, RDW (g hill^{-1}) varied from 17.00 to 28.15 in season-1 and 14.02 to 23.52 in season-2. Contrarily, under drought, it ranged from 15.39 to 21.80 in season-1 and 11.87 to 19.13 in season-2 (Table 2). This result indicated that root DM yield was reduced in all genotypes except Ukunimodhu in season-1 and BRRI dhan34 in season-2 due to drought. Magnitude of RDW reduction, at 40% FC compared to control, varied greatly between genotype and season. In season-1, relative reduction in RDW was much lower in genotypes Binadhan-13 and NERICA mutant (average of 3.11%) compared to other four genotypes. In season-2, once again, Binadhan-13 and NERICA mutant had very low relative reduction (average of 8.02%) compared to the rest (Table 2). Under control condition, R-S ratios varied from 0.39 to 0.81 in Season-1 and 0.63 to 0.99 in season-2. Contrarily, under drought, it ranged from 0.43 to 0.78 in season-1 and 0.42 to 0.85 in season-2 (Table 2). Result indicated that R-S was reduced in all genotypes except Binadhan-13, BRRI dhan34 and NERICA mutant in season-1 and Binadhan-13 and NERICA in season-2 due to drought. In season-1, relative reduction in R-S ratio once again appeared lower in Binadhan-13 and NERICA mutant (average of -6.69%) than all other four genotypes. In season-2, it was also smaller in Binadhan-13 and NERICA mutant (average of -4.62%) compared to the rest (Table 2). From the data of the two years, results indicated that the genotypes Binadhan-13 and NERICA mutant had smaller relative reduction in DM of leaf, stem and shoot and it suggests theirs greater degree of drought tolerance. Relative reduction in chlorophyll content under drought was lower in genotypes NERICA mutant, Binadhan-13 and Kalizira (average of 3.17%) than rest of the in season-1.

Table 3. Combined effect of genotype and drought (40 % FC) with control (100% FC) irrigations on chlorophyll content, photosynthetic rate, stomatal conductance (g_s), inter cellular CO_2 conc. (Ci) and transpiration (€) of plants parts in six rice genotypes in both seasons

Genotype	Irrigation	Cholorophyll (Spad value)	Pn ($\mu molCO_2m^{-2}s^{-1}$)	g_s ($molH_2Om^{-2}s^{-1}$)	Ci ($\mu molmol^{-1}$)	E ($mol\ H_2Om^{-2}s^{-1}$)
Season-1						
Binadhan-13	100% FC	42.70a+	38.70ab	0.41a+	793.0a	5.80a
	40% FC	39.70a(6.81)++	37.30a-c(3.62)	0.34bc(17.07)++	542.3abc(31.61)	5.62a(3.10)
Kalizira	100% FC	41.13a	39.93a	0.40ab	754.7ab	4.59a
	40% FC	40.43a(1.70)	33.57a-d(15.93)	0.34bc(15)	563.7abc(25.30)	4.45a(3.05)
RM 100-16	100% FC	42.60a	35.33a-d	0.34bc	749.0ab	5.66a
	40% FC	38.97a(8.74)	32.10b-e(9.14)	0.31c(8.82)	700.0abc(6.54)	4.67a(17.49)
Ukunimodhu	100% FC	40.73a	29.03cde	0.31c	699.0abc	4.98a
	40% FC	37.87a(7.02)	28.73de(3.82)	0.31c(0)	654.3abc(6.39)	4.66a(6.42)
BRRI dhan-34	100% FC	42.57a	33.20a-d	0.32c	774.0a	4.96a
	40% FC	38.97a(8.46)	28.43de(14.36)	0.31c(3.13)	511.3bc(33.94)	4.86a(2.01)
NERICA mutant	100% FC	40.50a	29.87de	0.34bc	559.7abc	4.24a
	40% FC	40.10a(0.99)	24.63e(15.16)	0.30c(11.76)	477.3c(14.72)	4.14a(2.35)
Season-2						
Binadhan-13	100% FC	38.57a	38.03a	0.37a	801.7ab	5.06a
	40% FC	37.52b-d(2.72)	37.32a(1.87)	0.35abc(5.40)	764.4bc(4.65)	4.43bc(11.92)
Kalizira	100% FC	37.59ab	35.47ab	0.35abc	875.7a	5.05a
	40% FC	34.12d(9.23)	33.94b(4.31)	0.33bc(5.71)	718.9bcd(17.91)	4.11c(18.61)
RM 100-16	100% FC	37.11abc	36.47ab	0.36ab	794.1ab	5.03a
	40% FC	35.38b-d(4.66)	33.86b(7.25)	0.32bc(11.11)	686.6cd(13.54)	3.91c(22.72)
Ukunimodhu	100% FC	38.34a	35.68ab	0.38a	777.8bc	4.90ab
	40% FC	36.43a-d(4.98)	33.14b(7.11)	0.32bc(15.78)	688.9cd(11.42)	4.03c(17.75)
BRRI dhan-34	100% FC	37.93ab	36.49ab	0.37a	706.2bcd	4.77ab
	40% FC	34.89cd(8.01)	34.51b(5.42)	0.32bc(13.51)	627.3de(11.17)	3.97c(16.77)
NERICA mutant	100% FC	38.19a	38.03a	0.38a	783.1abc	4.77ab
	40% FC	37.57ab(1.62)	35.42ab(6.86)	0.35abc(7.89)	743.1bc(5.11)	3.99c(16.35)

+: Data were separately analyzed for the year 2013 and 2014. In a year in each column, figures having common letter(s) do not differ significantly at $P \leq 0.05$ as per DMRT; ++: Figures within parenthesis indicate % decrease at 40 % FC compared to control.

In season-2, on the other hand, genotypes NERICA mutant and Binadhan-13 had lesser relative reduction (average of 2.17%) than the rest (Table 3). These results indicated that chlorophyll content varied between the seasons and genotypes, and importantly genotypes NERICA mutant and Binadhan-13 had significantly lower chlorophyll content in both seasons. Relative reduction in photosynthetic rate under drought was lower in genotypes Binadhan-13 and Ukunimodhu (average of 3.72%) than the rest in season-1. In season-2, only genotype Binadhan-13 had the lower relative reduction (1.87%) than all others (Table 3). Results suggest that the genotype Binadhan-13 showed lower reduction in photosynthetic rate in both the years thereby confer greater degree of drought tolerance. Relative drought reduction compared to control on stomatal conductance was lower in genotypes Ukunimodhu and BRRI dhan-34 (average of 1.57%) than the rest in season-1 while genotypes Binadhan-13, Kalizira and NERICA mutant had the lower relative reduction (average of 6.33%) than the rest in season-2 (Table 3). These results suggest that stomatal conductance varies across genotypes and seasons. Binadhan-13 and NERICA mutant genotypes had lower conductance thereby can save water for continued plant function under drought condition. Relative reduction in Ci under drought was lower in genotypes RM-100-16 and Ukunimodhu (average of 6.47%) in season-1 compared to all others, while in season-2, it was smaller in Binadhan-13 and NERICA mutant (average of 4.88%) compared to the rest (Table 3). In season-1, relative reduction in E under drought was lesser in four genotypes (average of 2.63%) compared to others. In season-2, it was smaller in Binadhan-13, BRRI dhan34 and NERICA mutant (average of 15.01%) compared to the rest (Table 3). In general, however, genotypes Binadhan-13 and NERICA mutant showed insignificant lower reduction in the important physiological functions like gs, Ci and E.This suggests their tolerance to drought has confirmatory physiological standing.

Discussion

Among morphological traits studied, Binadhan-13 and NERICA mutant genotypes had smaller reduction in plant height, tillers hill^{-1} and green leaves hill^{-1} than all the rest of the genotypes. This result agreed with the report of Akram et al. (2013) and Pantuwan et al., (2002) who also had observed smaller reduction in morphological traits in resistant rice genotypes under drought. DM partitioning into shoot and root growth due to drought existed and such variations in morphological and growth characters in rice were also observed by many researchers Lafitte et al., (2007); Zubayer et al., (2007); Farooq, et al., (2009). Drought causes a substantial reduction in root and shoot dry matter yield Henry et al., (2011); Farooq, et al., (2009). Our current result of leaf dry weight agrees to the report of Kumar and Sharma (2009) who stated that drought tolerant rice genotypes had smaller reduction in leaf growth compared to sensitive ones. Smaller DM reduction in root growth under drought stress compared to control was also reported by Bing-Song et al. (2006). This author stated that drought tolerant genotypes showed smaller reduction in root growth compared to sensitive ones. Root to shoot (R-S) ration is an important index of drought tolerance Xu et al., (2015). Besides the lesser relative reduction in root dry weight, a notable observation was the increase in R-S ration in the tolerant genotypes under drought stress in this study. The R-S ration is often observed to increase under adverse conditions such as drought Cui et al., (2008); Liu et al., (2004). Drought tolerant genotypes showed not only smaller reduction in morphological traits but also in physiological parameters. Differential decrease in physiological response of upland rice varieties was also observed by Botwright et al., (2008), Kamoshita et al., (2004) and Basu et al., (2008). Transpiration rate was adversely affected by drought stress in the present study. Such reduction in transpiration rate could be due to disturbances in biochemical, physiological and adverse effect on enzyme under drought Akram et al., (2013). Rate of transpiration has been suggested as an indicator for water deficit tolerance Suriyan et al., (2010); Cabuslay et al., (2002). The decrease in chlorophyll content is a commonly observed phenomenon under drought stress (Bijanzadeh and Emam, (2010). Like transpiration and chlorophyll reduction under drought photosynthetic rate was also significantly reduced. Drought stress reduces the photosynthetic rate by stress-induced stomatal or nonstomatal limitations Rahnama et al., (2010); Saibo et al., (2009). In summary, drought stress not only limits Ci, E, chlorophyll content but also photosynthetic rate. Based on the lower relative reduction of all above physiological variables, Binadhan-13 and NERICA mutant genotypes demonstrated better tolerance to drought.

Summary and Conclusion

Two genotypes (BINAdhan-13 and NERICA) showed lower reduction under drought stress compared to control in morphological parameters compared to all remainders. Likewise, apart from significant interaction between genotypes and irrigation treatments, relative reduction of dry matter growth in leaf, stem, root and shoot, and root-shoot ration also showed smaller in the same two genotypes, respectively; compared to all others. Finally, key physiological features like photosynthesis, transpiration, stomatal conductance and intercellular CO_2 concentration investigated, which also showed significant tolerant genotypes and all of these key physiological features interactions. Moreover, their relative reduction under drought stress as compared to respective control showed lower in general in Binadhan-13 and NERICA mutant genotypes. Thus suggest their tolerance level to drought in key physiological features apart from morphological traits and water relation standings.

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