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WATER DEFICIT CONDITION INFLUENCES THE MORPHO-PHYSIOLOGY, DRY MATTER PARTITIONING AND YIELD ATTRIBUTES OF AFRICAN RICE CULTIVARS (cv. NERICA)

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ABSTRACT

Hasan MM, Naznin S, Salam MA, Hossain AKMZ (2021) Water deficit condition influences the morpho-physiology, dry matter partitioning and yield attributes of african rice cultivars (cv. NERICA). *Int. J. Sustain. Crop Prod.* 16(4), 1-8.

Drought is one of the notable environmental stresses that severely limit the growth and productivity of rice by hampering the physiological processes and reducing dry matter production. The involvement of drought-tolerant rice cultivars would compensate for the greater amount of yield loss. In this study, the performance of two African rice cultivars (NERICA1 and NERICA10) and one Bangladeshi cultivar (BRRI dhan28) were evaluated under various moisture levels (100%, 80%, 60% and 40% FC). The gradual decrease in water content reduced the growth, dry matter and yield traits among the cultivars. The individual effect of cultivars and moisture levels significantly affected the root and shoot length, stem dry matter, transpiration rate and 1000-grain weight whereas, the combined effect of cultivars and drought stresses showed a significant effect on root dry weight, panicle dry weight, total dry weight, photosynthesis rate, effective tiller no., panicle no., no. of filled grain and grain yield. The drought-tolerant NERICA cultivars showed better performance in almost all studied traits than the Bangladeshi rice variety. Our results conclude that the drought-tolerant NERICA cultivars could offer valuable genetic tools for further improvement of rice productivity in drought-prone regions of Bangladesh during this time of erratic climate change.

Key words: *drought, dry matter, filled grain, photosynthesis, NERICA*

INTRODUCTION

Rice (*Oryza sativa* L.) is a potential member of the Poaceae family and it is the principal food crop in Bangladesh as well as for most of the people in the world. Bangladesh is an over-populated country and each year a huge number of people are added to its population. To meet the consequent increasing demand, food production must be increased either by increasing arable land or by increasing per hectare yield (Hossain and Teixeira da Silva, 2013a). However, the increase of the arable lands in our densely populated country is quite difficult. Rather rice production can be increased by increasing per hectare yield. Bangladesh is one of the most vulnerable countries to climate change. It is anticipated that the adverse effects of climate changes occurred in Bangladesh including drought, particularly in the northern area of Bangladesh (Hossain and Teixeira da Silva, 2013b). Among the major constraints to rice cultivation, water shortage significantly decreases the dry matter partitioning and reduces grain yield (Moonmoon and Islam, 2017; Moonmoon *et al.* 2020). The effect of water stress varies with variety, degree and duration of stress and the growth of the plant (Adejare and Unebesse, 2008). Drought affects more than half of the rice production area worldwide (Bouman *et al.* 2005). Water deficit condition develops low relative water content which leads to a decrease in the leaf growth rate and leaf area development, inhibits dry matter accumulation and accelerates leaf senescence, decrease photosynthesis, increase the frequency of zygotic abortion, and ultimately decrease grain number, size and yield (Sikuku *et al*. 2010). Water deficit during the vegetative stage (maximum tillering) may have relatively little effect on grain yield perhaps owing to the compensatory growth or changed partitioning of dry matter stress is relieved (Moonmoon and Islam, 2017). Drought stress during each growth stage of rice causes spikelet sterility that leads to unfilled grains (Kamoshita *et al.* 2004; Shahryari *et al.* 2008). Usually, drought reduces the grain filling period and induces early senescence by redirecting the remobilization of assimilates from the straw to the grains (Plaut *et al.* 2004). The most critical stage of drought ranges from panicle initiation to flowering. Yield reduction related to water deficit after anthesis occurs due to equally reduced panicle numbers and increased sterility (Zeigler *et al.* 1994). African rice scientists were embarked on a breeding program that ended up to a new plant type namely, New Rice for Africa (NERICA), developed for upland and lowland ecologies, well adapted to rice major constraints of rice including drought tolerance. Research activities should come forward, with prior aiming to sustain food security; with crop varieties, those are tolerant to water limitation conditions to some extent. In this case, the NERICA rainfed rice could be a potential source to identify the drought-tolerant rice cultivars (Heyer *et al*. 1976). The NERICA cultivars are developed for high drought-prone areas, which can endure occasional and periodic water stresses. The present research work was carried out to evaluate the tolerance capacity of the NERICA as cultivars compared with Bangladeshi ones with respect to some morpho-physiological, dry matter production and yield attributes under water shortage conditions.

MATERIALS AND METHODS

Experimental site and soil condition

A pot experiment was carried out at the glass house of Bangladesh Institute of Nuclear Agriculture (BINA), BAU campus, Mymensingh, during the period from 25 January to 15 May 2012. Geographically it is located at $24^{0}75'$ N latitude and $90^{0}50'$ E longitudes at the elevation of 18 m above sea level. The soil of the experiment was collected from BINA farm, Mymensingh. The collected soil belongs under the agro-ecological zone of the Old Brahmaputra Floodplain (AEZ-9).

Design and treatments

The experiment consisted of two factorial treatments, which were arranged in a RCB design and replicated thrice. The first factor was three rice cultivars namely NERICA1, NERICA10 and BRRI dhan28. The variety BRRI dhan28 was considered as a check. The seed of NERICA and control varieties were collected from BINA. Various soil moisture status in terms of Field Capacity (FC) like 100% FC (control) 80% FC, 60% FC and 40% FC was the another factor. The field capacity moisture content was determined by the method developed by Karim *et al*. (1988). Soil moisture status was monitored by using soil moisture meter at a regular interval before the active tillering stage till the final harvest. The data were used for determining irrigation water requirements.

Drought imposition

Drought treatment was imposed at the active tillering stage, based on soil moisture status in each treatment, and it was continued up to the flowering stage. Irrigation water was applied to bring the soil moisture at the higher range of each treatment (40%, 60%, 80%, and 100% FC). Among these 40 and 60% FC were enumerated as severe drought stress because of their soil moisture percentage (12.51-9.38 and 18.76-15.64, respectively) were about the permanent wilting point. Irrigation was given when the soil moisture came down to the lower levels (30%, 50%, 70%, and 90% FC) of those treatments, respectively. Irrigation requirement was calculated as follows: $IR= \{(M_{FC} - M_{BI}) \div 100\} \times A \times D$; where, R= irrigation requirement (cm), M_{FC}= Soil moisture (%) at field capacity, M_{BI}= Soil moisture (%) before irrigation, A= Soil bulk density in g/cm^3, D= Rooting depth (cm). The various ranges of field capacity (40%-30%, 60%-50%, 80%-70%, and 100%-90%) were adjusted through maintaining different soil moisture (% by weight) as 12.51-9.38, 18.76-15.64, 25.02-21.90, 31.28-28.15, respectively.

Data collection

The length of root and shoot was measured from the junction point to the tip of the longest root and tip of the topmost flag leaf at harvest, respectively. At the harvesting stage, one hill from each pot was harvested. Then the plant parts were separated into roots, stems, leaves, panicles and oven-dried at 60^{0}C for 72 hours followed by weight recording. The stem part includes the leaf sheath and the associated culm. Photosynthetic and transpiration rates of each hill were measured by Portable Photosynthetic System (Licor-6200) at 10 days after flowering. The tillers which had at least one grain in the panicle was considered reproductive tillers. The presence of any amount of starch in the spikelet was considered as filled grain and the total number of grains present on each hill was counted. One thousand clean sun-dried grains were counted from the grain stock obtained from the sample plants and weighed by using an electronic balance. The grains of each hill were separated and then sun-dried and weighed at 12% moisture level to determine the grain yield (g).

Statistical analysis

All the statistical analyses were done using R-4.0.2 for win (http://CRAN.R-project.org/) (accessed on 16 August 2021) in Rstudio-1.3.1093 (https://rstudio.com/) (accessed on 16 August 2021). Data obtained were subjected to 2-factor (cultivars × moisture levels treatment) analysis of variance (ANOVA) in the general linear model using the package lme4 (Bates *et al*. 2015) and the mean differences were compared by Tukey's HSD test using the library agricolae (Steel *et al*. 1997). Differences at $p < 0.05$ were considered significant.

RESULTS AND DISCUSSION

Effect of drought on morphological attributes

The individual effect of various moisture levels was statistically significant for root length, while the single effect of cultivars and drought stresses had a significant influence on shoot length (Table 1). The control condition produced the largest root length (36.44 cm) and the lowest was obtained at 80% FC (30.00 cm). Among the cultivars, the African rice varieties showed better shoot length than the control variety. Drought stress significantly reduced the shoot length but the difference was insignificant up to 80% FC.

Table 1. Effect of (A) variety, (B) moisture levels, and (C) interaction on the growth and dry matter attributes of rice

	Variety	Moisture Levels (% FC)	Root length (cm)	Shoot length (cm)	Root DW (g) hill^{-1}	Stem DW (g) hill^{-1}	Leaf DW (g) hill^{-1}	Panicle DW (g) hill^{-1}	Total DW (g) hill^{-1}
A	BRRI dhan28	-	30.50	79.58 C	5.57	14.67 a	4.15 a	11.29 b	35.68 b
	NERICA1	-	34.25	88.33 B	11.26	12.84 b	5.06 ab	14.00 a	43.16 a
	NERICA10	-	33.58	91.92 A	12.61	11.96 c	3.87 b	12.82 ab	41.26 a
	Sig. level	-	NS	**	NS	*	**	*	**
B	-	100	36.44 A'	90.89 A'	10.04	14.19 a	4.84	15.88 a	44.95 a
	-	80	30.00 B'	88.00 A'	10.40	13.09 b	4.11	15.34 a	42.94 b
	-	60	33.56 AB'	83.89 B'	9.66	12.30 c	4.16	12.05 b	38.17 c
	-	40	31.11 B'	83.67 B'	9.16	11.03 d	4.32	7.53 c	32.04 d
	Sig. level	-	*	**	NS	**	NS	**	**
C	BRRI dhan28	100	29.33	84.33	7.11 c	14.17	5.50	16.83 a	43.66 b
		80	30.67	79.67	5.47 cd	13.59	3.42	14.13 a	36.63 d
		60	31.33	77.67	4.83 d	11.54	3.77	7.56 b	27.76 f
		40	30.67	76.67	4.87 d	10.36	3.91	6.64 b	25.82 f
	NERICA1	100	38.00	93.00	11.00 b	18.06	6.20	17.63 a	52.87 a
		80	36.33	91.33	10.73 b	16.35	5.84	15.19 a	48.14 ab
		60	33.33	84.67	12.32 b	12.01	5.37	14.39 a	44.19 b
		40	32.33	84.33	11.00 b	12.95	5.04	8.78 b	37.73 d
	NERICA10	100	42.00	95.33	12.00 b	14.35	4.42	16.19 a	46.91 ab
		80	39.00	93.00	15.00 a	13.34	3.68	15.69 a	47.75 ab
		60	33.00	89.33	11.83 b	11.36	3.35	14.20 a	40.79 c
		40	30.33	87.00	11.60 b	9.79	3.02	7.18 b	31.53 e
	Sig. level	-	NS	NS	*	NS	NS	*	*

Various uppercase letters, prime-marked uppercase letters and lowercase letters on the columns within the groups are significantly different by DMRT ($p \leq 0.05$). * and ** indicate significance at $p \leq 0.05$ and $p \leq 0.01$, respectively. NS = not significant.

Water deficit generally caused a reduction in root length. Under the water shortage conditions, the growth-promoting hormones, responsible for cell elongation, are negatively affected. This results in a reduction in cell turgor, cell volume and ultimately cell growth. In our study, the NERICA cultivars were able to maintain root growth at water limitation conditions. This feature has apparent contribution towards higher drought tolerance where deeper and extensive root systems contributed positively to water uptake (Menge *et al.* 2019). Moreover, the rice genotypes having deep, coarse roots with a high ability of branching and penetration and higher root to shoot ratio are reported as component traits of drought avoidance (Samson *et al*. 2002; Wang and Yamauchi, 2006; Gowda *et al*. 2011).

Moisture stress effects on dry matter production

The different magnitude of significance levels was observed in the case of dry matter partitioning in rice cultivars grown under water limitation conditions (Table 1). Among the observed traits, the individual and combined effect of cultivars and moisture levels significantly affected the panicle dry weight and total dry weight hill^{-1}. A significant effect was noticed for the root dry weight under combined conditions (Table 1). The NERICA cultivars maintained greater root dry weight than the check variety under all the moisture regimes status and surprisingly the maximum dry weight of root was recorded in the case of NERICA10 under little shortage of water (80%). Decreased root dry weight with the advancement of the drought was the common feature in this pot experiment and a similar conclusion was also reported by Davatgar *et al.* (2009). The single effect of cultivars and moisture levels was significant for stem dry weight (Table 1). The check variety gained the maximum stem dry weight than the NERICA cultivars while the control state of moisture produced the maximum stem dry weight and it was reduced in the subsequent water shortage stages. The single effect of cultivars was statistically significant in the case of leaf dry weight (Table 1). The NERICA1 produced the maximum dry weight of leaf which was similar to that of check variety. The African rice cultivars produced the greatest panicle dry weight than that of control. The water limitation condition significantly reduced the panicle dry weight, however; the reduction was inconsistent up to 80% FC. Interestingly, the NERICA cultivars maintained the greatest amount of panicle dry weight under a severe shortage of water conditions than that of check variety. The NERICA cultivars produced the maximum amount of total dry weight under little shortage of water (80% FC) than the control variety grown under 100% FC.

Reduction in biomass production is a common feature of drought stress (Farooq *et al*. 2010). Many studies indicate a significant decrease in fresh and dry weights of shoots (Centritto *et al*. 2009; Mostajeran and Rahimi-

Eichi, 2009) and roots (Ji *et al*. 2012) under drought. Water stimulates and regulates the photosynthetic enzymes and growth-promoting hormones. The water shortage condition affects the height and leaf area of the plant that leads to inferior dry matter (Emmam *et al.* 2010; Usman *et al*. 2013). The greater total biomass accumulated by NERICA cultivars is associated with a higher root length that allows the crops to penetrate deep into the soil and absorb water at lower levels. This feature might also be correlated with a lower transpiration rate in African varieties. Stomatal conductance is considered an indirect method of root water uptake under soil water deficit (Tran *et al.* 2014). The NERICA mutants exhibited higher stomatal conductance with a larger root system and these features allowed them not only to uptake more water but also boost up dry matter production than susceptible genotypes (Menge *et al.* 2019).

Effect of drought on physiological attributes

Water deficit affects rice physiology by hampering plant net photosynthesis (Centritto *et al*. 2009; Yang *et al*. 2014) and transpiration rate (Cabuslay *et al*. 2002). The individual effect of moisture levels and the combined effect of cultivars and moisture levels significantly affected the photosynthetic rate of rice (Figure 1a). Water limitation greatly affected the photosynthesis of rice but the decrement was insignificant with a minimum shortage of water (80% FC). The significant effect of water stress on photosynthesis was also concluded by Yang *et al.* (2003). The African varieties maintained a higher rate of photosynthesis under little shortage of water conditions (80% FC) than the check variety grown under control conditions (100% FC). However, the performance of NERICA cultivars was inferior under extreme water limitation conditions (60% and 40% FC) than that of check cultivar.

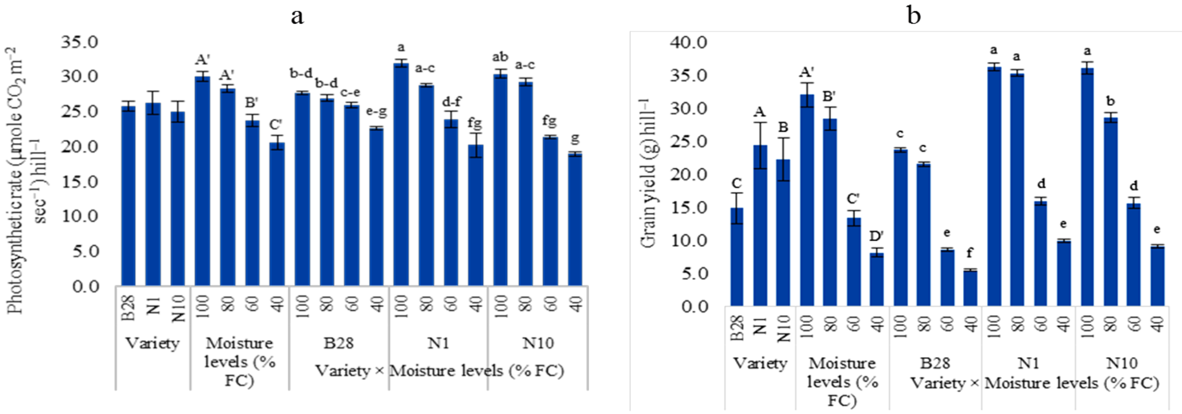

Figure 1. Effect of variety, moisture levels and interaction on the (a) photosynthetic rate and (b) grain yield of rice. Vertical bars indicate the ±SE value for the mean (n=3). Various uppercase letters, prime-marked uppercase letters and lowercase letters on the columns within the groups are significantly different at $p \leq 0.05$ by DMRT. (B28 = BRRI dhan28, N1 = NERICA1, N10 = NERICA10).

The photosynthetic efficiency of NERICAs also revealed that they possess drought tolerance ability. Except for the interaction effect, the individual effect of cultivars and moisture levels significantly affected the transpiration rate of rice (Table 2). The rate of transpiration was greater in NERICA1 which was statistically similar to the control variety while NERICA10 showed a lower rate. The response of cultivars to transpiration rate under water stress conditions was also reported by Cabuslay *et al.* (2002) and Sikuku *et al.* (2012) in rice. The decrement in water content continuously reduced the transpiration rate and it was the maximum under control condition followed by 80% FC.

Table 2. Effect of (A) variety, (B) moisture levels, and (C) interaction on the physiological and yield attributes of rice

	Variety	Moisture Levels (% FC)	Transpiration rate (mole water m^{-2} sec^{-1}) $hill^{-1}$	Effective tiller no. $hill^{-1}$	Panicle no. $hill^{-1}$	Filled grain no. $hill^{-1}$	1000-grain weight (g)
A	BRRI dhan28	-	5.30 A	10.58 B	10.42 B	784.42 C	16.87 B
	NERICA1	-	5.60 A	12.75 A	12.92 A	1045.67 A	24.03 A
	NERICA10	-	4.75 B	11.83 AB	11.92 AB	948.92 B	23.31 A
	Sig. level	-	*	**	**	**	**
B	-	100	6.65 A'	14.00 A'	14.00 A'	1399.78 A'	22.90 A
	-	80	5.69 B'	14.00 A'	13.78 A'	1286.33 B'	22.90 A'
	-	60	4.72 C'	10.67 B'	10.67 B'	668.67 C'	20.49 AB'
	-	40	3.81 D'	8.22 C'	8.56 C'	350.56 D'	19.3 B'
	Sig. level	-	***	**	**	**	**
C	BRRI dhan28	100	7.07	12.67 cd	12.67 b-e	1379.33 ab	17.30
		80	5.41	12.67 cd	12.00 c-e	1293.33 b	18.83
		60	4.49	10.67 de	10.67 e-g	285.00 fg	14.83
		40	4.24	6.33 g	6.33 h	180.00 g	12.50
	NERICA1	100	7.13	15.00 ab	15.00 ab	1460.00 a	24.97
		80	6.31	13.33 bc	13.33 b-d	1426.67 ab	24.90
		60	5.47	12.33 cd	12.33 c-e	838.33 d	21.10
		40	3.49	10.33 e	11.00 d-f	457.67 e	18.13
	NERICA10	100	5.74	14.33 a-c	14.33 a-c	1360.00 ab	26.43
		80	5.34	16.00 a	16.00 a	1139.00 c	24.97
		60	4.21	9.00 ef	9.00 fg	882.67 d	22.53
		40	3.69	8.00 fg	8.33 gh	414.00 ef	19.30
	Sig. level	-	NS	**	**	**	NS

Various uppercase letters, prime-marked uppercase letters and lowercase letters on the columns within the groups are significantly different by DMRT ($p \leq 0.05$). * and ** indicate significance at $p \leq 0.05$ and $p \leq 0.01$, respectively. NS = not significant.

During drought conditions, the photosynthesis of flag leaf is limited which affects reproductive development. The reduced photosynthesis is associated with stress-induced stomatal and nonstomatal limitations (Saibo *et al*. 2009; Rahnama *et al*. 2010). Limited CO_2 diffusion due to early closure of stomata, reduced activity of photosynthetic enzymes and decreased photochemical efficiency of PSII are the major components affecting photosynthesis under drought stress. Under severe drought conditions, photosynthesis is declined due to a reduction in Rubisco activity (Bota *et al*. 2004; Zhou *et al*. 2007). The water and nutrient absorption of plants is promoted by transpiration. The African cultivars showed a higher transpiration rate. This adaptive feature to drought stress reveals that the NERICA cultivars might possess genes responsible for water deficit tolerance. During water shortage, a crop plant facilitates the dissipation of excess heat by maintaining proper transpiration. This prevents photoinhibition of tolerant cultivars by enhancing the efficiency of the photosynthetic system and lowering the production of toxic active oxygen species (Akram *et al.* 2013; Li *et al.* 2014).

Effect of drought on yield attributes and yield

Significant interaction effect between cultivars and moisture levels was noticed in the case of all yield attributes except the 1000-grain weight (Table 2). The number of panicle bearing tillers was reduced as the water shortage increased. However, the African cultivars maintained a greater amount of effective tillers under the water limitations stages and more interestingly the NERICA10 produced the maximum effective tillers under little shortage of water (80% FC) which again confirmed the drought tolerance potentiality of African rice cultivars. The total number of panicles in a hill showed a very similar response to the effective tiller number. In this case, the NERICA1 produced the maximum number of panicles under the control condition which was statistically similar to that of the little water limitation stage (80% FC). The African cultivars produced heavier grains than that of local check variety which resulted in the greater amount of 1000-grain weight. The unavailability of the required amount of water significantly declined the 1000-grain weight, however; the decrement was inconsistent up to the severe water shortage condition (60% FC). The interaction effect of cultivars and drought stresses was significant for the grain yield of rice (Figure 1b). Grain yield reduced gradually with the shortage of water status. However, the African cultivars showed a greater amount of grain yield than that of check variety. While comparing the performance of African cultivars, it was noticed that the NERICA1 performed better than NERICA10 under little shortage of water (80% FC).

Drought stress adversely affects the meiosis, early microscopic stage of pollen development and anthesis. These are all associated with a reduced number of grains (Ji *et al*. 2010) and lower grain yield (Cattivelli *et al*. 2008).

The reduced crop growth due to water limitation during flowering might be strongly associated with the reduced number of filled grains per panicle in a hill. Shortage of water at or before panicle initiation is responsible for the reduction in the most potential spikelet number which ultimately reduces the percentage of filled grain. The cell growth is severely hampered due to loss in turgor pressure developed by water limitation conditions (Taiz and Zeiger, 2006). Drought affects both cell elongation as well as expansion (Shao *et al.* 2008) and inhibits cell enlargement more than cell division (Jaleel *et al*. 2009). The yield of a crop depends not only on the accumulation of dry matter and but also on its partitioning (Baruah *et al.* 2006).

Limitation in the supply of assimilates to the developing grain (source limitation) and/or the limited capacity of the reproductive organ to accept the photosynthates (sink limitation) may reduce the grain yield of rice. The NERICA varieties possessed improved physiological traits as well as a better capacity to partition the assimilates that helps it to maintain a greater amount of grain yield during drought. The reductions in total grain number per panicle and 1000-grain weight are the principal causes of to decline of the grain yield under drought conditions. The seed yield of rice decreased with increased drought level and this result goes in line with the previous works of Manneh and Ndjiondjop (2006); Zubaer *et al.* (2007); Bakul *et al.* (2009); Sikuku *et al.* (2010) and Sikuku *et al.* (2012).

CONCLUSION

Moisture stress significantly affects the growth features and yield attributes of rice. Genetically drought-tolerant NERICA cultivars are quite capable to compensate morpho-physiological aspects, dry matter production and yield under moisture stress than Bangladeshi cultivars. Therefore, NERICA cultivars would be introduced in the further breeding program to develop new drought-tolerant rice.

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REFERENCES

Adejare FB, Unebesse CE (2008) Water stress induces cultivar department changes in stomatal complex, yield and osmotic adjustments in *Glyche Max* L. *Int. J. Agric. Res.* 3, 287-295.

Akram HM, Ali A, Sattar A, Rehman HSU, Bibi A (2013) Impact of water deficit stress on various physiological and agronomic traits of three basmati rice (*Oryza sativ*a L.) cultivars. *J. Anim. Plant Sci.* 23(5), 1415-1423.

Bakul MRA, Akter MS, Islam MN, Chowdhury MMAA, Amin MHA (2009) Water stress effect on morphological characters and yield attributes in some mutants T-Aman rice lines. *Bangladesh Res. Pub. J*. 3(2), 934-944.

Baruah KK, Rajkhowa SC, Das K (2006) Physiological analysis of growth, yield development and grain quality of some deep water rice cultivars. *Agron. Crop Sci*. 192, 228-232.

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting Linear Mixed-Effects Models Using lme4. *J. Stat. Soft*. 67, 1–48.

Bota J, Medrano H, Flexas J (2004) Is photosynthesis limited by decreased Rubisco activity and RuBP content under progressive water stress? *New Phytol*. 162(3), 671–681.

Bouman BAM, Peng S, Castaneda AR, Visperas RM (2005) Yield and water use of irrigated tropical aerobic rice systems. *Agric. Water Manage*. 74, 87-105.

Cabuslay GS, Ito O, Alejal AA (2002) Physiological evaluation of responses of rice (*Oryza sativa* L.) to water deficit. *Plant Sci*, 163(4), 815–827.

Cattivelli L, Rizza F, Badeck FW, Mazzucotelli E, Mastrangelo AM, Francia E, Marè C, Tondelli A, Stanca AM (2008) Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. *Field Crops Res.* 105, 1–14.

Centritto M, Lauteri M, Monteverdi MC, Serraj R (2009) Leaf gas exchange, carbon isotope discrimination, and grain yield in contrasting rice genotypes subjected to water deficits during the reproductive stage. *J. Exp. Bot*. 60(8), 2325–2339.

Davatgar N, Neishabouria MR, Sepaskhahb AR, Soltani A (2009) Physiological and morphological responses of rice (*Oryza sativa* L.) to varying water stress management strategies. *Int. J. Plant Pro*. 3(4), 19-32.

Emmam Y, Shekoofa A, Salehi F, Jalali AH (2010) Water stress effects on two common bean cultivars with contrasting growth habitats. *Am-Eur. J. Agric. Environ. Sci.* 9(5), 495-499.

Farooq M, Kobayashi N, Ito O, Wahid A, Serraj R (2010) Broader leaves result in better performance of indica rice under drought stress. *J. Plant Physiol.* 167(13), 1066–1075.

Gowda VRP, Henry A, Yamauchi A, Shashidhar HE, Serraj R (2011) Root biology and genetic improvement for drought avoidance in rice. *Field Crops Res*. 122(1), 1–13.

Heyer J, Maitha JK, Senga WM (1976) Agricultural development in Kenya- An economic Assessment. *Oxford University Press,* Nairobi, Kenya. 2-281.

Hossain A, Teixeira da Silva JA (2013a) Wheat and rice, the epicenter of food security in Bangladesh. *Songklanakarin J. Sci. Tech.* 35(3), 261-274.

Hossain A, Teixeira da Silva JA (2013b) Wheat production in Bangladesh: its future in the light of global warming. *AoB Plants*, 5.

Jaleel CA, Manivannan P, Wahid A, Farooq M, Al-Juburi HJ, Somasundaram R, Panneerselvam R (2009) Drought stress in plants: A review on morphological characteristics and pigments composition. *Int. J. Agric. Biol*. 11, 100–105.

Ji KX, Wang YY, Sun WN, Lou QJ, Mei HW, Shen SH, Chen H (2012) Drought-responsive mechanisms in rice genotypes with contrasting drought tolerance during reproductive stage. *J. Plant Physiol*. 169(4), 336–344.

Ji X, Shiran B, Wan J, Lewis DC, Jenkins CL, Condon AG, Richards RA, Dolferus R (2010) Importance of pre-anthesis anther sink strength for maintenance of grain number during reproductive stage water stress in wheat. *Plant Cell Environ.* 3, 926–942.

Kamoshita A, Rodriguez R, Yamauchi A, Wade LJ (2004) Genotypic variation in response of rainfed lowland rice to prolonged drought and re-watering. *Plant Prod. Sci*. 7, 406-420.

Karim Z, Rahman SM, Tdris M, Karim AJMS (1988) Soil bulk density. In: A manual for determination of soil physical parameters. Soil and irrigation division. BARC.

Li J, Nishimura Y, Zhao X, Fukumoto Y (2014) Effects of drought stress on the metabolic properties of active oxygen species, nitrogen and photosynthesis in cucumber 'Jinchun No. 5'seedlings. *Japan Agric. Res. Qua.* 48(2), 175-181.

Manneh B, Ndjiondjop MN (2006) NERICA Compendium. Module 5. Drought screening of upland NERICA cultivars. 62.

Menge DM, Onyango JC, Yamauchi A, Kano-Nakata M, Asanuma S, Thi TT, Inukai Y, Kikuta M, Makihara D (2019) Effect of nitrogen application on the expression of drought-induced root plasticity of upland NERICA rice. *Plant Pro. Sci.* 22(2), 180-191.

Moonmoon S, Fakir MSA, Islam MT (2020) Assimilation of grain on yield and yield attributes of rice (*Oryza sativa* L.) genotypes under drought stress. *Fourr.* 241(3), 85-98.

Moonmoon S, Islam MT (2017) Effect of drought stress at different growth stages on yield and yield components of six rice (*Oryza sativa* L.) genotypes. *Fund. Appl. Agric.* 2(3), 285-289.

Mostajeran A, Rahimi-Eichi V (2009) Effects of drought stress on growth and yield of rice (*Oryza sativa* L.) cultivars and accumulation of proline and soluble sugars in sheath and blades of their different ages leaves. *Am-Eur. J. Agric. Environ. Sci.* 5(2), 264–272.

Plaut Z, Butow BJ, Blumenthal CS, Wrigley CW (2004) Transport of dry matter into developing wheat kernels and its contribution to grain yield under post-anthesis water deficit and elevated temperature. *Field Crops Res*. 86, 185-198.

Rahnama A, Poustini K, Tavakkol-Afshari R, Tavakoli A (2010) Growth and stomatal responses of bread wheat genotypes in tolerance to salt stress. *Int. J. Bio. Life Sci*. 6, 216-221.

Saibo NJM, Lourenço T, Oliveira MM (2009) Transcription factors and regulation of photosynthetic and related metabolism under environmental stresses. *Annals Bot*. 103, 609-623.

Samson BK, Hasan M, Wade LJ (2002) Penetration of hardpans by rice lines in the rainfed lowlands. *Field Crops Res*. 76(2-3), 175-188.

Shahryari R, Gurbanov E, Gadimov A, Hassanpanah D (2008) Tolerance of fourty two bread wheat genotypes to drought stress after anthesis. *Pak. J. Biol. Sci*. 11, 1330-1335.

Shao HB, Chu L, Jaleel CA, Zhao CX (2008) Water-deficit stress-induced anatomical changes in higher plants. *Comptes rendus biologies*. 331(3), 215-225.

Sikuku PA, Netondo GW, Onyango JC, Musyimi DM (2010) Chlorophyll fluorescence, protein and chlorophyll content of three NERICA rainfed rice varieties under varying irrigation regime. *Agric. Bio. Sci*. 5(2), 19-25.

Sikuku PA, Onyango JC, Netondo GW (2012) Yield components and gas exchange responses of NERICA rice cultivars (*Oryza sativa* L.) to vegetative and reproductive stage water deficit. *Global J. Sci. Frontier Res*. 12(3), 51-61.

Steel RGD, Torrie JH, Dicky DA (1997) Principles and Procedures of Statistics: A Biometrical Approach. 3rd Edition, McGraw Hill, Inc. Book Co., New York. 352-358.

Taiz L, Zeiger E (2006) Plant Physiology. 4th edn. Sunderland, MA: Sinauer Associates.

Tran TT, Kano-Nakata M, Takeda M, Menge D, Mitsuya S, Inukai Y, Yamauchi A (2014) Nitrogen application enhanced the expression of developmental plasticity of root systems triggered by mild drought stress in rice. *Plant Soil*. 378(1), 139-152.

Usman M, Raheem ZF, Ahsan T, Iqbal A, Sarfaraz ZN, Haq Z (2013) Morphological, physiological and biochemical attributes as indicators for drought tolerance in rice (*Oryza sativa* L.). *Eur J Biol Sci*. 5(1), 23–28.

Wang H, Yamauchi A (2006) Growth and function of roots under abiotic stress in soil. *In*: Huang B R. Plant-Environment Interactions. 3rd edn. New York: CRC Press: 271–320.

Yang J, Zhang J, Wang Z, Liu L, Zhu Q (2003) Post anthesis water deficits enhance grain filling in two-line hybrid rice. *Crop Sci*. 43, 2099-2108.

Yang PM, Huang QC, Qin GY, Zhao SP, Zhou JG (2014) Different drought-stress responses in photosynthesis and reactive oxygen metabolism between autotetraploid and diploid rice. *Photosynthetica* 52(2), 193–202.

Zeigler RS, Leong SA, Teng PS (1994) Rice blast disease. IRRI, Manila, Philipines. 7-10.

Zhou Y, Lam HM, Zhang J (2007) Inhibition of photosynthesis and energy dissipation induced by water and high light stresses in rice. *J Expt. Bot*, 58(5), 1207–1217.

Zubaer MA, Chowdhury AKMMB, Islam MZ, Ahmed T, Hasan MA (2007) Effects of water stress on growth and yield attributes of Aman Rice Genotypes. *Int. J. Sustain. Crop Prod*. 2(6), 25-30.