EFFECT OF HIGH TEMPERATURE ON PHOTOSYNTHESIS, STOMATAL CONDUCTANCE, TRANSPIRATION AND YIELD OF BORO RICE VARIETIES UNDER DIFFERENT SOIL MOISTURE REGIMES

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Abstract

Climate is changing and air temperature is rising due to increasing concentration of CO_2 and other atmospheric greenhouse gases. The flowering stage of rice is important for high temperatures. An experiment was carried out at Bangladesh Institute of Nuclear Agriculture, Mymensingh, Bangladesh during December 2020 to May 2021 with three Boro rice varieties to find out proper soil moisture level at flowering stage to reduce high temperature effect. Binadhan-8, Binadhan-10 and Binadhan-14 were grown in pots each of 8 kg soil in ambient temperature. During flowering stage the plants were kept in plant growth chamber at 38 ^{0}C for 24 hrs under different soil moisture levels (standing water of 2 inches, 100% FC and 80% FC) in pot soil. Then all the plants were allowed to complete the maturity under sufficient soil moisture at ambient temperature. The experiment was conducted in RCBD with three replications. The results revealed that under high temperature photosynthesis, transpiration rate and yield significantly decreased but leaf temperature (^{o}C) and water use efficiency increased at 80% FC. Transpiration maintained leaf temperature of 33.17-34.87°C during air temperature of 3°C. Binadhan-8 and Binadhan-10 maintained lower leaf temperature and Binadhan-14 had better water use efficiency at 80% FC. Higher yield was found in 100% FC and standing water of 2 inches compared to 80% FC. So, maintaining 100% FC or standing water of 2 inches at flowering stage of Boro rice varieties can reduce high temperature effect.

Key words: High temperature, photosynthesis, stomatal conductance, transpiration, yield.

Introduction

Changing climate rises air temperature due to increasing concentration of CO_2 and other atmospheric greenhouse gases. The rise in atmospheric temperature causes detrimental effects on growth, yield, and quality of the crop varieties by affecting their phenology, physiology, and yield components (Rawson, 1992; Kumar, 2020). The economic yield of a plant depends mainly on leaf photosynthesis. Stomata can function as valves to control the balance of water loss and carbon gain in plants (Huang *et al*., 2021). The climate changes that are currently occurring make it necessary to understand the effects of temperature on photosynthesis. Models based on large-scale observations indicate that, in the absence of agronomic adaptation, the decrease in crop yields can reach 17% for each 1°C increase in the temperature of the growing season (Yamori *et al*., 2014). Climate model predicts 33%

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rice yield decrease in 2100 (Karim *et al*., 2012). Boro rice is transplanted in January-February and usually faces high temperature (36-39 °C) at its reproductive stage in April-May (Islam 2021a). Flowering stage of rice is very important for high temperature (Islam, 2011 and Islam, 2013). High temperature may cause drying of pollen and stigma and ceasing pollen tube development unsuitable for fertilization. As a result, unfilled grains are produced. Rice grain dry weight increased from fertilization to 18-24 days and water stress decreased the rate of accumulation and finally produced decreased grain weight (Islam and Gretzmacher, 2001; Islam 2010; Hafiz *et al*., 2015; Moonmoon *et al*., 2020a). The yield of rice is an integrated result of various processes including canopy photosynthesis, conversion of assimilates to biomass, and partitioning of assimilates to grains (Jeng *et al*., 2006). Drought stress affects plant growth and development, and ultimately reduces grain yield of rice (Islam *et al*., 1994b; Islam *et al*., 2005a; Zohora *et al*. 2016; Moonmoon *et al*., 2017; Moonmoon *et al*., 2020b). Response of rice yield to drought varies with growth stage being most sensitive at booting followed by flowering and or grain filling stage (Islam *et al*., 1994a). The early reproductive growth period, encompassing tetrad-formation stage of miosis (i.e., about 10-15 d prior to heading), was found to be the most sensitive and critical to water deficit resulting in up to 59% grain sterility that caused similar magnitude of yield reduction (Singh *et al*., 2010). As the grain formation progressed further, the early period of grain-filling was found to be more vulnerable to water stress than the late-milk stages (Singh *et al*., 2010). For stress condition, reproductive stages are critical than vegetative stages and booting to early grain filling stages are more critical (Moonmoon and Islam, 2017; Islam *et al*., 2005b; Rahman *et al*., 2002). So, the experiment was conducted to find out proper soil moisture level at flowering stage of Boro rice varieties to reduce high temperature effect.

Materials and Methods

An experiment was conducted with three rice genotypes *viz*. Binadhan-8, Binadhan-10 and Binadhan-14 at pot yard and in plant growth chamber of Bangladesh Institute of Nuclear Agriculture (BINA) during December, 2020 to May, 2021 to assess the effect of high temperature under different soil moisture levels. The soils of the experiment were collected from the field of BINA Farm. The top soil was non-calcareous Dark Grey Floodplain with loamy texture belonging to the AEZ Old Brahmaputra Floodplain. The collected soil was pulverized, inert materials, visible insect pest and plant propagules were removed. Pots are filled with top soils. The soil moisture stresses were calculated based on field capacity (FC). Gravimetric Method determined FC. Each pot contained 8 kg soil. All soils pots were fertilized with urea, TSP, MP and gypsum @ 2.08, 0.32, 0.41 and 0.21g pot^{-1} corresponding 260, 125, 180 and 80 kg ha^{-1} Urea, TSP, MoP and Gypsum, respectively. All TSP, MoP, 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). One seedling was transplanted in a puddled pot. For gap filling there were extra seedlings preserved. All necessary intercultural operations, mainly weeding, and irrigation was done as and when necessary. The experiment was set in a two factorial RCBD with three replications. The first factor was rice genotypes and the second factor was irrigations: standing water of 2 inches, 100% FC, 80% FC and in pot soil. Plants were grown in ambient temperature and during flowering stage those were kept in plant growth chamber at 38^0C for 24 hours under different soil moisture levels (standing water of 2 inches, 100% FC, 80% FC). Then all the plants were allowed to complete the maturity in ambient temperature. Data on photosynthesis, Fv/Fm (maximum quantum efficiency of PSII photochemistry), stomatal conductance, transpiration, leaf temperature and water use efficiency were recorded during stress imposition using Portable Photosynthesis System (Li-6800, LICOR, USA) and yield and yield attributes were recorded at maturity. Data were analyzed statistically and DMRT was used to compare the means.

Results and Discussion

Photosynthesis gradually decreased but Tleaf (^{o}C) increased with decreasing soil moisture levels (Table 1). The results agree with Yang *et al*. (2020) who opined that photosynthesis is highly sensitive to high temperature stress. Higher value of Fv/Fm was found at standing water of 2 inches compared to other soil moisture levels. Stomatal conductance and transpiration rate was decreased only at 80% FC. Stomata can function as valves to control the balance of water loss and carbon gain in plants (Huang *et al*., 2021). Transpiration maintained Tleaf (^{o}C) of 33.17-34.87°C during air temperature of 38°C (Table 2). The results agree with Islam 2021b and Moonmoon *et al*., 2020c. In photosynthesis system, CO_2 enters the leaf where its reduction in the chloroplasts is accompanied by O_2 production (Cornic, 2021). Its entry is almost exclusively through the stomata. For each molecule of CO_2 absorbed, 50 to 300 molecules of water are transpired from the leaves, depending on the plant (Cornic, 2021). This water allows, among other things, the cooling of the leaf. The leaf is a converter of solar energy into chemical energy and, like any energy converter, requires a permanent cooling system. Binadhan-8 showed higher photosynthesis, stomatal conductance, transpiration but lower water use efficiency and Tleaf (^{o}C) (Tables 1 and 2). On the other hand Binadhan-14 had lower photosynthesis, stomatal conductance, transpiration but higher water use efficiency and Tleaf (^{o}C). Binadhan-10 was intermediate in those parameters. The rice varieties did not vary in Fv/Fm.

Number of panicles plant^{-1}, grains panicle^{-1}, 1000-grain weight and yield were decreased only at 80% FC (Table 3). Number of unfilled grains panicle^{-1} gradually increased with the decrease of soil moisture levels. Better yield was found in 100% FC and standing water of 2 inches compared to 80% FC. The results are in conformity with many researchers (Islam 2001; Islam *et al*., 2005c; Islam *et al*., 2012; Hazra *et al*., 2016). Binadhan-8 showed higher number of grains panicle^{-1}, 1000-grain weight and yield. Binadhan-10 had higher number of panicles plant$^{-1,}$ medium unfilled grains panicle^{-1}, 1000-grain weight and yield (Tables 3 and 4). Whereas Binadhan-14 showed higher number of unfilled grains panicle^{-1} and lower number of panicles plant^{-1}, number of grains panicle^{-1}, 1000-grain weight and yield.

Under high temperature most of the gas exchange parameters significantly decreased at 80% FC compared to 100% FC or standing water of 2 inches in pot soil. The rice varieties had sufficient soil moisture at 100% FC or standing water of 2 inches. Under the treatment, physiological parameters like photosynthesis, stomatal conductance and transpiration were affected at 80% FC. Although 80% FC was mild water stress but combined effect of high temperature and 80% FC had negative effect on physiological parameters, yield attributes and yield. So, soil moisture at 100% FC or standing water of 2 inches at flowering stage of the rice varieties can reduce high temperature effect.

Table 1. Effect of soil moisture levels on photosynthetic parameters of rice varieties under high temperature

Treatment	Photosynthesis ($\mu molCO_2m^{-2}s^{-1}$)	Fv/Fm	Stomatal conductance ($mmolH_2Om^{-2}s^{-1}$)	Transpiration ($mmolH_2Om^{-2}s^{-1}$)	Water use efficiency	Tleaf (^oC)
T1	22.30 a	0.90 a	0.64 a	8.21 a	2.72 b	33.48 c
T2	21.56 b	0.78 b	0.63 a	8.11 a	2.66 b	33.79 b
T3	18.27 c	0.75 b	0.43 b	5.53 b	3.34 a	34.03 a
CV (%)	2.81		1.95	2.74	3.66	0.46
Varieties						
V1	21.91 a	0.83 a	0.58 a	7.70 a	2.86 b	33.32 c
V2	20.47 b	0.82 a	0.56 b	7.36 b	2.83 b	33.61 b
V3	19.74 c	0.79 a	0.56 b	6.80 c	3.01 a	34.37 a
CV (%)	2.81	4.74	1.95	2.74	3.66	0.46

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT.
Here, V1: Binadhan-8, V2: Binadhan-10 and V3: Binadhan-14; T1: Standing water of 2 inches, T2: 100% FC and T3: 80% FC.

Table 2. Interaction effect of variety and soil moisture level on photosynthetic parameters of rice varieties under high temperature

Variety×Soil moisture	Photosynthesis ($\mu molCO_2m^{-2}s^{-1}$)	Fv/Fm	Stomatal conductance ($mmolH_2Om^{-2}s^{-1}$)	Transpiration ($mmolH_2Om^{-2}s^{-1}$)	Water use efficiency	Tleaf (^oC)
V1T1	23.60 a	0.93 a	0.66 a	8.47 a	2.79 d	33.23 c
V1T2	23.17 a	0.78 c	0.66 a	8.40 ab	2.76 de	33.17 c
V1T3	18.97 d	0.76 c	0.44 de	6.23 e	3.05 c	33.57 b
V2T1	21.57 bc	0.92 ab	0.63 bc	8.23 abc	2.62 de	33.57 b
V2 T2	20.83 bc	0.78 c	0.61 c	8.07 bcd	2.58 e	33.60 b
V2T3	19.00 d	0.76 c	0.44 d	5.77 f	3.30 b	33.67 b
V3T1	21.73 b	0.86 b	0.64 ab	7.93 cd	2.74 de	33.63 b
V3T2	20.67 c	0.77 c	0.63 bc	7.87 d	2.63 de	34.60 a
V3T3	16.83 e	0.74 c	0.42 e	4.60 g	3.67 a	34.87 a
CV (%)	2.81	4.74	1.95	2.74	3.66	0.46

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT.
Here, V1: Binadhan-8, V2: Binadhan-10 and V3: Binadhan-14; T1: Standing water of 2 inches, T2: 100% FC and T3: 80% FC.

Table 3. Effect of soil moisture levels on yield and yield components of rice varieties under high temperature

Treatment	Panicle plant^{-1} (no.)	Grains panicle^{-1} (no.)	Unfilled grains panicle^{-1} (no.)	1000-grain wt. (g)	Yield plant^{-1} (g)
T1	10.56 a	131.33 a	23.67 c	24.14 a	33.42 a
T2	10.56 a	131.11 a	31.89 b	23.88 a	33.00 a
T3	10.00 b	111.89 b	54.33 a	22.61 b	25.32 b
CV (%)	4.50	2.01	6.78	2.20	3.58
Varieties					
V1	10.00 b	131.56 a	37.00 b	24.99 a	32.99 a
V2	10.89 a	118.33 c	50.89 a	23.36 b	30.11 b
V3	10.22 b	124.44 b	22.00 c	22.29 c	28.64 c
CV (%)	4.50	2.01	6.78	2.20	3.58

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT.

Here, V1: Binadhan-8, V2: Binadhan-10 and V3: Binadhan-14; T1: Standing water of 2 inches, T2: 100% FC and T3: 80% FC.

Table 4. Interaction effect of variety and soil moisture level on yield and yield attributes of rice varieties under high temperature

Variety×Soil moisture	Panicle plant^{-1} (no.)	Grains panicle^{-1} (no.)	Unfilled grains panicle^{-1} (no.)	1000-grain wt. (g)	Yield plant^{-1} (g)
V1T1	10.33 ab	138.00 a	16.00 f	25.30 a	36.06 a
V1T2	10.33 ab	135.67 a	20.00 ef	25.17 a	35.27 a
V1T3	9.33 c	121.00 b	75.00 a	24.50 ab	27.64 c
V2T1	11.00 a	121.00 b	44.67 c	23.80 bc	31.68 b
V2T2	11.00 a	122.33 b	52.00 b	23.17 c	31.16 b
V2T3	10.67 ab	111.67 c	56.00 b	23.10 c	27.49 c
V3T1	10.33 ab	135.00 a	10.33 g	23.33 c	32.53 b
V3T2	10.33 ab	135.33 a	23.67 e	23.30 c	32.56 b
V3T3	10.00 bc	103.00 d	32.00 d	20.23 d	20.84 d
CV (%)	4.50	2.01	6.78	2.20	3.58

Values having common letter(s) in a column do not differ significantly at 5% level as per DMRT.

Here, V1: Binadhan-8, V2: Binadhan-10 and V3: Binadhan-14; T1: Standing water of 2 inches, T2: 100% FC and T3: 80% FC.

Conclusion

Under high temperature photosynthesis, transpiration rate and yield of the Boro rice varieties were significantly decreased at 80% FC compared to 100% FC or standing water of 2 inches in pot soil. So, maintaining soil moisture at 100% field capacity or standing water of 2 inches appears to reduce the high-temperature effect of Boro rice varieties at flowering stage.

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