

Leaf Water Status, Seed Yield and Water-Use Efficiency of Wheat Cultivars under Induced Drought Conditions

Sripati Sikder^{1,2,*}, Yunzhou Qiao¹, Dong Baodi¹, Changhai Shi¹ and Mengyu Liu^{1,*}

¹Laboratory of Crop Water Physiology and Ecology, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286, Huaizhong Road, Shijiazhuang-050021, China

²Department of Crop Physiology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh

*Corresponding author Email: srisikder@gmail.com; mengyuliu@sjziam.ac.cn

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Abstract

Water shortages are an important factor limiting grain production in many parts of the world. In pot experiment six spring wheat cultivars viz., BARIGOM-23, BARIGOM-24, BARIGOM-25, BARIGOM-26, BARIGOM-27, and BARIGOM-28 were grown under well watered and drought conditions to evaluate their genetic variations by relative leaf water content (RWC), growth and water use efficiencies (WUE) under well watered and drought conditions. Significant variations were found in RWC, seed yield and yield components, HI and water-use efficiencies among wheat cultivars under well watered and drought conditions. Drought adversely affected RWC, seed yield and yield components compared to well watered condition. All the cultivars significantly improved their performances under well watered condition. Overall wheat cultivars BARIGOM-23 seemed to be superior in most of the characters. Cultivars BARIGOM-26 and BARIGOM-27 also showed good performances, whereas BARIGOM-24 was the inferior to most of the characters. A clear significant positive linear relationship was found between WUE and seed yield, and HI at well watered and drought conditions. This also indicated that genetic improvement in HI and seed yield were associated with WUE. To select or develop drought tolerant high yielding varieties emphasis should be given on these characters especially grain yield, HI and water-use efficiencies at different water levels.

Keywords: Wheat, drought, RWC, seed yield, HI, water-use efficiency

Introduction

Drought constitutes one of the important environmental constraints limiting wheat productivity world wide. It limits global productivity more severely than that caused by any other environmental stresses. This problem will be further increased due to climate change. Due to raise in temperature soil losses its moisture holding capacity and changes in precipitation patterns, drought is

becoming increasingly common in many parts of the world (IPCC, 2007). So, drought stress is a global phenomenon that has significant economic and ecological impacts in agriculture.

Wheat (*Triticum aestivum* L.) is an important cereal crop of the world. At least one third of the total population of the world live on wheat grains. It provides more nourishment for the nations of the world than any other food crops. It is produced

under diverse environmental conditions ranging from well irrigated to water stress situations and wheat yield are reduced 50-90% of their irrigated potential by drought on at least 60 Mha in developing world (Skomand et al., 2001). Drought severely limits wheat productivity in many different environments around the world. Some estimation indicates that 50% of the approximately 230 M ha sown to wheat annually in the world is regularly affected by drought (Pfeiffer et al., 2005).

Wheat is the main cereal crop grown in the arid and semiarid regions of North China Plain, which supplies more than 71% of the wheat production in China (Dong et al., 2011). It is cultivated during driest season of the year. However, in the wheat growing season (from mid-October to mid-June of the following year), the mean precipitation is about 120 mm, while the evapotranspiration of wheat can reach 400-500 mm. So, irrigation is required to achieving high grain yields of wheat in the North China Plain. The lack of adequate water sources also leads to the extensive use of ground water for irrigation in most parts of North China Plain, which has caused the water level fall, which in turn has created many additional environmental problems (Li et al., 2008). So, it is important to improve drought tolerance, grain yield and water use efficiency for wheat production not only in the North China Plain but also all over the wheat growing region of the world.

The best option for yield improvement and yield stability of wheat under drought condition is to develop drought tolerant wheat varieties. However, some of the highest yielding genotypes under supplementary irrigation condition can also be among highest yielding under rainfed condition. Therefore, evaluation under rainfed condition appears to be necessary to preserve genotypes possessing alleles for drought tolerance. Yield potential (yield under irrigated condition) and traits (yield under rainfed condition) can be combined in one single genotype.

Water-use efficiency is a key physiological parameter indicating the ability of crops to conserve water in a water-scarce region because this combines

drought resistance and high potential yield (Richards, 2006; Fang et al., 2010; Zhang et al., 2007). Water use efficiency has been identified as one of key parameters for selection of crop plant genotypes in arid and semiarid areas to reduce the reliance on irrigation water (Condon et al., 2004). Though WUE alone cannot be a target parameter for plant breeder, it should be considered in addition to crop yield.

It is well known that the harvest index (HI) and biomass are the two main factors for determining grain yield (White and Wilson, 2006). Many studies have shown that improvement in yield was more strongly associated with a genetic gain in biomass than in yield (Shearman et al., 2005) but others have demonstrated that the HI, not the biomass, was the determining factor in grain yield (Sayre et al., 1997). Brancourt-Hulmel et al. (2003) found that variations of cultivars released in different years were associated with increases in HI but not biomass. During drought, plants from higher-yield cultivars generally showed relatively high WUE at yield level (Xue et al., 2006). Therefore, the objectives of the present study were: (1) to observe leaf water status, growth, seed yield and water-use efficiency at seed yield and biomass levels of wheat cultivars under well watered and drought conditions, (2) to evaluate the relationship of between different parameters respecting the water-use efficiency and yield potential of wheat cultivars and (3) to find out the better cultivar(s) considering their performances under drought condition.

Materials and Methods

Experiments

A pot experiment was conducted in open condition during February to June, 2014 at the Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang (38° 2' 31" N Latitude and 114° 30' 51" E Longitude), Hebei, China. Six spring wheat cultivars viz., BARIGOM-23, BARIGOM-24, BARIGOM-25, BARIGOM-26, BARIGOM-27, and BARIGOM-28 were used as seed materials. Seeds of six genotypes were germinated in small plastic pot (11.5 cm

diameter and 10 cm height) filled with compost. After two weeks seedlings were transferred (two seedlings per pot) to bigger plastic pots (23 cm diameter and 18 cm height) filled with a combined medium of compost and soil (weight ratio = 3:1). Soil moisture content of all 36 pots were kept at field capacity until 40 days after sowing (DAS) to allow a good plant development. At 30 DAS Hogland nutrient solution were applied into every pot with water. After 40 DAS two water regimes: well watered (WW, 65% of field capacity) and water drought conditions (DR, 35% of field capacity) were applied by regulating irrigation water. No precipitation was allowed during drought imposing period of experimental pots due to taking plastic covering before raining. A factorial experiment was performing using completely randomised design with two factors (water regimes and wheat cultivars) and three replications.

Measurements

Relative water content (RWC): RWC of flag leaf was determined at anthesis stage according to the following formula (Kocheva et al., 2014):

$$\text{RWC (\%)} = [(\text{FW} - \text{DW}) / (\text{TW} - \text{DW})] \times 100$$

Where, FW represents fresh weight, DW is dry weight obtained after drying the leaves at 70 °C for 72 h and TW is the turgid weight after soaking the leaves in distilled water for 24 h.

Biomass, seed yield and yield components measurements: At the harvest maturity, plants were harvested manually and then plant height (cm) and spike number per plant were recorded. The fresh biomass was oven dried for 72 h at 70°C and then weighed the plants and different parts with a digital balance. Total biomass (g), root biomass (g) shoot biomass / above ground biomass (g), root/shoot ratio, spike weight per plant, seed number per plant, seed number per spike, seed weight per spike (g), 100-seed weight (g) and seed yield per plant (g) were recorded. Harvest index (HI) was calculated by the ratio of seed yield to above ground biomass.

Calculation of Evapotranspiration (ET) and water use efficiency (WUE)

ET was calculated using the soil water balance equation for the whole drought imposing period as follows:

$$\text{ET} = \text{P} + \text{I} - \text{D} + \text{CR} - \text{R} + \text{SWD} \quad (1)$$

Where, P is the precipitation (mm), I is irrigation (mm), D is the drainage from the root zone (mm), CR is the capillary rise to the root zone (mm), R is the run off, and SWD (mm) is the soil water depletion and was measured by initial substrate soil water content minus final substrate soil water content. Eq (1) was simplified by zeroing P, D, CR and R. As a results Eq. (1) becomes: $\text{ET} = \text{I} + \text{SWD}$.

Finally, water use efficiencies were WUE_{sy} and WUE_{bm} were calculated as ratios of seed yield to ET (m³) and above ground biomass to ET (m³), respectively (Qiao, 2010).

Statistical Analysis

Data were statistically evaluated by analysis of variance (ANOVA) with program CropStat (Version 7.2.3). Mean values compared using least significance differences (LSD), for a probability of P = 0.05. Relationships between WUE_{sy} and HI, Seed yield and WUE_{bm} were evaluated using a simple regression analysis for both the well watered and drought conditions.

Results and Discussion

Results

Relative water content (RWC)

Relative water content of flag leaf of six wheat cultivars were significantly affected by water levels (P < 0.01). Drought adversely reduced the RWC of all six cultivars compared to well watered condition (Figure 1). Cultivar BARIGOM-23 showed the highest RWC followed by BARIGOM-28 at well watered condition, whereas BARIGOM-24 had the lowest RWC at drought condition.

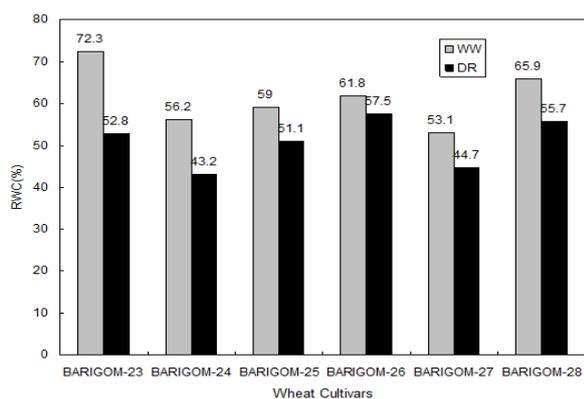


Figure 1 Relative water content (RWC %) of leaf of six wheat cultivars under well watered (WW) and drought (DR) conditions (LSD value is 7.10 at 0.01 probability level)

Plant height (cm)

Plant height of six wheat cultivars under well watered and drought conditions are shown in Table 1. Results showed that drought significantly reduced plant height of all six cultivars compared to well water condition ($P < 0.01$). Under well watered condition cultivar BARGOM-23 had the highest plant height followed by BARGOM-27. Whereas, BARGOM-26 attained the lowest plant height followed by BARGOM-28. At drought condition again cultivar BARGOM-23 attained the highest plant height followed by BARGOM-27, whereas BARGOM-26 had the lowest plant height followed by BARGOM-24.

Total biomass (g)

Results showed that interaction effect of water levels and wheat cultivars on total biomass was significant ($P < 0.01$). Drought reduced the total biomass of all cultivars at different magnitudes. Under well watered condition cultivars BARGOM-27 had the highest total biomass followed by BARIGOM-23, whereas BARIGOM-24 had lowest total biomass. Therefore, at drought condition cultivar BARIGOM-23 attained the highest total biomass and BARIGOM-24 had the lowest biomass.

Root biomass (g)

Results showed that drought significantly reduced the root biomass of all wheat cultivars ($P < 0.01$). At well watered condition all the cultivars showed higher root biomass compared to drought condition. In this condition cultivar BARIGOM-27

had the highest root biomass, whereas BARIGOM-28 attained the lowest root biomass. But at drought condition BARGOM-23 showed the highest root biomass and cultivar BARIGOM-25 had the lowest value in root biomass followed by BARIGOM-24.

Shoot biomass (g)

The combined effect of water levels and wheat cultivars on shoot biomass of different wheat cultivars was significant ($P < 0.01$). Results showed that there were significant variations of shoot biomass of different cultivars under two levels of water (Table 1). At well watered condition, cultivar BARIGOM-26 had the highest shoot biomass followed by BARIGOM-23. whereas, BARIGOM-24 attained the lowest shoot biomass. At drought condition again the BARIGOM-24 attained the lowest shoot biomass and BARIGOM-23 had the highest shoot biomass.

Root/Shoot ratio

Results showed that the interaction effect of water level and wheat cultivars on root/shoot ratio was not significant. But there were considerable variations in this parameter among different wheat cultivars under two water levels and drought reduced root/shoot ratio of all the six wheat cultivars compared to well watered condition.

Spike number per plant

Spike number per plant of six wheat cultivars at well watered and drought conditions are presented in Table 2. It is significantly affected by the interaction of two water levels and six wheat cultivars ($P < 0.05$). Under well watered condition all wheat cultivars attained higher spike number per plant compared to respective spike number at drought condition. In this well watered condition cultivar BARIGOM-23 attained highest spike number of plant followed by BARIGOM-27 and BARIGOM-26. Whereas, the lowest spike number was found in BARIGOM-24. Therefore, at drought condition again the cultivar BARIGOM-23 attained the highest number of spike and BARIGOM-24 showed the lowest number of spike per plant. However, cultivar BARIGOM-27 attained the same number of spike per plant both at well watered and drought conditions.

Table 1 Plant height (cm), total biomass (g), root biomass, shoot biomass (g) and root-shoot ration (R:S) of six wheat cultivars under well watered (WW) and drought (DR) conditions

Cultivar	Water Level	Plant height (cm)	Total biomass (g)	Root biomass (g)	Shoot biomass (g)	Root/ Shoot Ratio
BARIGOM-23	WW	75.666	18.740	1.346	17.393	0.077
	DR	71.000	17.060	1.066	15.993	0.067
BARIGOM-24	WW	69.766	16.306	1.513	14.793	0.106
	DR	65.333	11.390	0.820	10.570	0.077
BARIGOM-25	WW	73.333	18.396	1.193	17.203	0.069
	DR	70.666	13.163	0.773	12.390	0.063
BARIGOM-26	WW	65.000	18.690	1.160	17.530	0.062
	DR	62.333	12.886	1.050	11.836	0.089
BARIGOM-27	WW	75.133	18.780	1.640	17.140	0.096
	DR	68.333	14.820	1.020	13.800	0.074
BARIGOM-28	WW	65.333	16.590	1.133	15.456	0.073
	DR	63.666	13.940	0.986	12.953	0.076
Level of significance		**	**	**	**	NS
LSD		3.933	1.695	0.328	1.749	0.093
SE (\pm)		1.333	0.574	0.111	0.593	0.028

Note: * Significant at the .05 probability level; ** Significant at the .01 probability level; NS Not significant at the .05 probability level

Seed number per plant

Seed number per plant is considered as the key determinant of seed yield in wheat. As it clear from the data on seed number per plant in Table 2 that seed number was significantly affected by the interaction of water levels and wheat cultivars ($P < 0.05$). Drought reduced seed number per plant of all

cultivars compared to well watered condition. Cultivar BARIGOM-23 attained the highest number of seed per plant both in drought and well watered conditions followed by BARIGOM-26 and BARIGOM-27. Whereas, cultivars BARIGOM-24 had the lowest number of seed per plant both in well watered and drought conditions.

Spike weight per plant (g)

Spike weight per plant of six wheat cultivars at well watered and drought conditions is presented in Table 2. Results showed that the combined effect of water levels and wheat cultivars

on spike weight per plant was significant ($P < 0.05$). All the cultivars showed reduced spike weight per plant at drought condition compared to well watered condition. Cultivar BARIGOM-23 attained the highest number of spike weight per plant both in well watered and drought conditions followed by BARIGOM-26 and BARIGOM-27. Whereas, cultivar BARIGOM-24 had the lowest spike weight per plant at both the well watered and drought conditions.

100-seed weight (g)

Data on 100-seed weight in Table 3 revealed that it was significantly affected by two water levels and six wheat cultivars at ($P < 0.05$). Drought reduced 100-seed weight of all the cultivars compared to well watered condition. Wheat cultivar BARIGOM-23 attained the highest 100-seed weight at both the well watered and drought conditions followed by BARIGOM-25, whereas BARIGOM-28 the lowest 100-seed weight both in well watered and drought conditions.

Table 2 Spike number per plant, Seed number per plant and Spike weight per plant (g) of six wheat cultivars under well watered (WW) and drought (DR) conditions

Cultivar	Water level	Spike number plant ⁻¹	Seed number plant ⁻¹	Spike wt. (g) plant ⁻¹
BARIGOM-23	WW	6.000	182.333	10.506
	DR	5.666	171.000	8.726
BARIGOM-24	WW	4.666	120.000	8.090
	DR	4.000	105.000	5.383
BARIGOM-25	WW	5.000	152.333	9.683
	DR	4.666	130.000	7.140
BARIGOM-26	WW	5.333	177.667	10.036
	DR	4.666	134.333	6.396
BARIGOM-27	WW	5.333	169.667	9.573
	DR	5.333	156.333	7.876
BARIGOM-28	WW	5.000	163.667	9.146
	DR	4.333	149.000	7.180
Level of significance		*	*	*
LSD		1.149	17.153	1.211
SE (±)		0.389	5.814	0.411

Note: * Significant at the .05 probability level; ** Significant at the .01 probability level; NS Not significant at the .05 probability level

Seed yield per plant (g)

Results on seed yield per plant in Table 3 showed that it was significantly varied with different wheat cultivars under well watered and drought conditions ($P < 0.05$). Seed yield of six cultivars were improved when they were treated with well watered conditions. All the cultivars showed reduced seed yield under drought condition. Wheat cultivar BARIGOM-23 attained the highest seed yield per plant both in the well watered and drought conditions followed by BARIGOM-26 and BARIGOM-27. Whereas, cultivar BARIGOM-24 showed the lowest seed yield per plant at both the well watered and drought conditions.

Harvest Index (HI)

Harvest index is the ratio of seed yield to above ground biomass. As a useful index of assessing the phytomass converted into useful economic yield, the HI was significantly influenced by the combined effect of water levels wheat cultivars ($P < 0.05$). The range of harvest index was 0.358 – 0.410. Drought reduced the HI for BARIGOM-23 but it increased for BARIGOM-24

and BARIGOM-25 compared to well watered condition. The changes of HI between well watered and drought conditions for BARIGOM-26, BARIGOM-27 and BARIGOM-28 were very minimum. Therefore, cultivars BARIGOM-23 and BARIGOM-24 had the highest and lowest HI at well watered condition, respectively.

Water-use efficiency at seed yield level (WUE_{sy})

Results on water-use efficiency at seed yield level in Table 3 showed that WUE_{sy} of different wheat cultivars varied significantly with two water levels ($P < 0.05$). For the cultivars BARIGOM-23, BARIGOM-24, BARIGOM-27 and BARIGOM-28, drought slightly increased the WUE_{sy} but in BARIGOM-26, drought slightly decreased the WUE_{sy}. Whereas, in BARIGOM-25 the WUE_{sy} was near about similar between well watered and drought conditions. Overall, cultivar BARIGOM-23 maintained the highest WUE_{sy} and BARIGOM-24 showed the lowest WUE_{sy} both in well watered and drought conditions.

Water-use efficiency at biomass level (WUE_{bm})

The data on water-use efficiency on biomass level (WUE_{bm}) in Table 3 indicated that the interaction effect of water levels and wheat cultivars on WUE_{bm} was significant ($P < 0.01$). Drought increased WUE_{bm} for the cultivars BARIGOM-23, BARIGOM-27 and BARIGOM-28 but drought decreased WUE_{bm} for other three cultivars viz. BARIGOM-24, BARIGOM-25 and BARIGOM-26. However, the highest WUE_{bm} was found in cultivars BARIGOM-23 and lowest WUE_{bm} was in BARIGOM-24 at drought condition.

Regression analysis

Harvest index and water-use efficiency at seed yield level were also significantly varied among wheat cultivars under well watered and drought conditions. A linear relationship between HI and WUE_{sy} were found (Figure 2). The relationship between HI and WUE_{sy} were positive at well watered condition ($p < 0.05$) but not at drought. This also suggests that genetic improvement in HI were associated with WUE_{sy}. The relationship between water-use efficiency at biomass level (WUE_{bm}) and seed yield per plant were evaluated. There was significant positive linear relationship between WUE_{bm} and seed yield under well watered ($P < 0.05$) and drought ($P < 0.01$) conditions. (Figure 3).

Table 3 Hundred seed weight (g), Seed yield per plant, Harvest index (HI) and Water use efficiency (WUE) of six wheat cultivars under well watered (WW) and drought (DR) conditions

Cultivar	Water Level	100-seed wt. (g)	Seed yield (g) plant ⁻¹	Harvest index (HI)	WUE _{sy}	WUE _{bm}
BARIGOM-23	WW	4.198	7.146	0.410	1.440	3.504
	DR	4.096	6.043	0.378	1.587	4.200
BARIGOM-24	WW	3.915	5.036	0.341	1.015	2.981
	DR	3.536	4.303	0.407	1.130	2.776
BARIGOM-25	WW	4.145	6.320	0.367	1.273	3.466
	DR	3.742	4.863	0.393	1.277	3.254
BARIGOM-26	WW	3.739	6.640	0.358	1.338	3.734
	DR	3.355	4.513	0.358	1.185	3.108
BARIGOM-27	WW	3.800	6.443	0.376	1.298	3.453
	DR	3.346	5.216	0.378	1.370	3.624
BARIGOM-28	WW	3.732	6.113	0.395	1.231	3.114
	DR	3.482	5.190	0.399	1.363	3.402
Level of significance		*	*	*	*	**
LSD		0.196	0.7300	0.035	0.158	0.387
SE (±)		0.067	0.247	0.012	0.054	0.131

Note: * Significant at the .05 probability level; ** Significant at the .01 probability level; NS Not significant at the .05 probability level

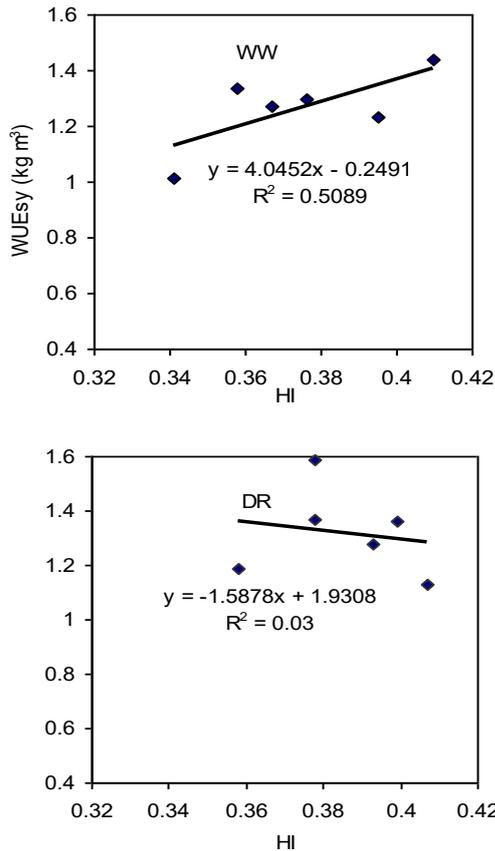


Figure 2 Relationship between harvest index (HI) and water use efficiency at seed yield level (WUE_{sy}) under well watered (WW, P < 0.05) and drought (DR) conditions

Discussion

The main objectives of the present investigation was to evaluate the genetic variations among six wheat cultivars by measuring relative leaf water content, growth, seed yield and water use efficiencies under well watered and drought conditions.

Relative water content (RWC) of leaf is an important biological trait of drought stressed plant as it has great relation to stomatal conductance and also net photosynthesis. In present study droughted leaf of all wheat cultivars showed reduced RWC at different magnitude. In droughted wheat plants reduced RWC was also found by Siddique et al. (1999). The foliar photosynthetic rate of higher

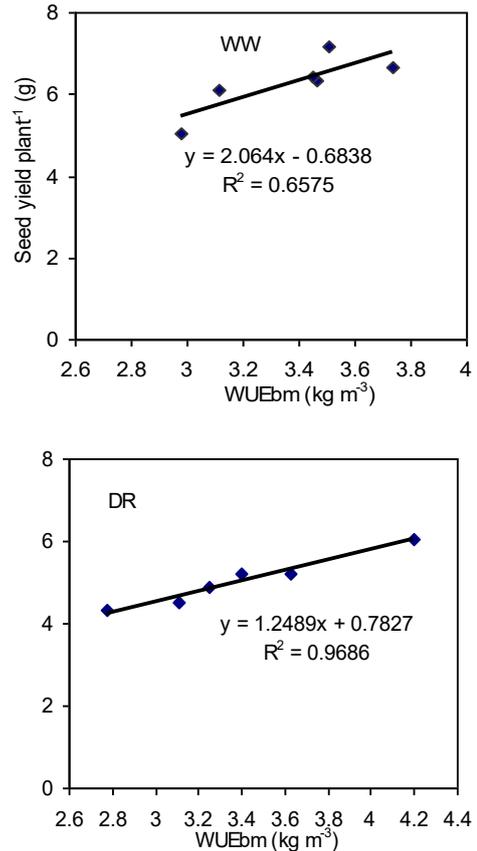


Figure 3 Relationship between Water use efficiency at biomass level (WUE_{bm}) and seed yield per plant under well watered (WW, P < 0.05) and drought (DR, P < 0.01) conditions

plants is known to decrease as leaf water content and leaf water potential decreased (Lawlor and Cronin, 2002). The ultimate driver of wheat yield is photosynthesis. It is a highly complex mechanism but is becoming one of the main targets to improve wheat yield (Parry et al., 2011). In the present study drought significantly reduced both RWC and seed yield compared to well watered condition.

For plant height all the six cultivars improved their respective plant height in well watered condition compared to drought stress and there were significant variations in this character among different cultivars under two water levels. Similar results have been published by Sikder et al. (2011). They observed the drought severely reduced the plant height of wheat cultivars. Reddy et al. (2004)

reported that plant growth is adversely affected by environmental stress and drought stress is among the worst scourges of agriculture.

For biomass production in the present research revealed that drought significantly reduced the total biomass, root biomass and shoot/above ground biomass of all the six cultivars compared to well watered condition. In fact biomass is the out put of net photosynthesis. Here net photosynthetic performances of wheat cultivars under well watered and drought conditions were reflected on biomass. Similar results have been published by Van Den Boogaard et al. (1997) in wheat and Gulias et al. (2012) in grasses. Dong et al. (2011) also found improved biomass of wheat cultivars under well irrigated conditions compared to non irrigated drought stress condition. These findings are an agreement of present study.

The yield components viz. spike number per plant, seed number per plant and 100-seed weight may consider to be the key determinant of seed yield of wheat cultivars. In the present study it is clear that these yield components of wheat cultivars were increased significantly with well watered condition, i.e. drought significantly reduced all these yield components. However, the ultimate results of yield components are reflected on seed yield per plant of wheat cultivars. All the cultivars improved their seed yield per plant at well watered condition compared to drought condition. Wheat cultivar BARIGOM-23 showed the highest performance followed by BARIGOM-26 and BARIGOM-27, whereas BARIGOM-24 had the lowest performance in seed yield and yield components under well watered and drought conditions. This result is similar to Sikder et al. (2011) and Siddique et al. (1999). The both of them found water stress reduced spike number per plant, grain number per plant and seed weight compared to well watered non stress condition.

Crop improvement for grain yield can be obtained by two methods. One is by increasing the amount of above ground biomass with a constant harvest index. Other is by increasing HI with a constant above ground biomass. As a useful index of assessing the phytomass converted into useful

economic yield, the HI of present studied wheat cultivars were significantly varied among cultivars under well watered and drought conditions. In maximum cultivars HI did not markedly change between well watered and drought conditions. This result is similar to that observed by Dong et al. (2011). They found HI measurement for wheat cultivars did not markedly change as a result of different water regimes in the same growing seasons.

Water-use efficiency is a key physiological parameter indicating the ability of crops to conserve water in a water scarce region because this combines drought resistance and high yield potential (Richard, 2006; Fang et al., 2010; Zhang et al., 2007). In the present study water use efficiency at seed yield level (WUE_{sy}) and water-use efficiency at biomass level (WUE_{bm}) were significantly varied among six wheat cultivars under well watered and drought conditions. But there were minimum variations between well watered and drought conditions in WUE_{sy} and WUE_{bm}. Nevertheless, in drought condition maximum cultivars showed slightly increased WUE_{sy} and WUE_{bm}. But few cultivars had somewhat decreased WUE_{sy} and WUE_{bm} at drought condition. Cultivar BARIGOM-23 had the highest water-use efficiencies at drought condition. There is agreement with results published by Dong et al. (2011). They found both the increased and also the decreased water-use efficiency of wheat cultivars under drought condition. Result from other studies it was found that there were significant differences in WUE at yield level of different wheat cultivars (Miranzadeh et al., 2011; Zhang, 2006). Selecting wheat cultivars with higher yield could improve WUE_{sy} to some degree (Zhang 2005, 2009). During drought plant from higher cultivars generally showed relatively high WUE_{sy} (Xue et al., 2006). Therefore, a clear significant positive linear relationship was found between HI and WUE_{sy}, and WUE_{bm} and seed yield at well watered and drought conditions. This also indicated that genetic improvement in HI and seed yield were associated with WUE_{sy} and WUE_{bm}, respectively.

It might be concluded that there were significant variations in RWC, seed yield and yield components, HI and water-use efficiencies among

wheat cultivars under well watered and drought conditions. Overall, wheat cultivars BARIGOM-23 seemed too superior to most of the characters compared to others. However, cultivars BARIGOM-26 and BARIGOM-27 also played a good performance, whereas BARIGOM-24 had inferior performance in most of the characters. In future to select or develop drought tolerant high yielding varieties and to saving irrigation water emphasis should be given on these characters especially net photosynthetic capacity, grain yield, HI and water use efficiencies at different water levels.

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