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Effects of Water Deficit and Spraying of Dessicant on Yield, Yield Components and Water Use Efficiency of Wheat Genotypes

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Abstract: To evaluate yield, yield components and water use efficiency of bread wheat in water stress conditions and spraying of dessicant, a field experiment was carried out in 2006-2007 and 2007-2008. Main plots were assigned to two levels of water stress treatments; D_1: optimum irrigation and D_2: cessation of watering from anthesis to maturity stages. Sub plots were assigned to eight bread wheat genotypes; and assimilates limitations with two levels: P_1: no source limitation and P_2: inhibition of current photosynthesis were in sub-sub plots. Grain yield, biological yield, harvest index, the number of grains per spike, thousand grain weight and water use efficiency were significantly influenced by irrigation treatments and source limitation. Grain Yield (GY) significantly decreased by 35 and 68% under water deficiency and postanthesis photosynthetic inhibition, respectively; compared with control. Water use efficiency was higher for well-watered compared with postanthesis drought stress conditions. WUE_{grain} decrease due to water deficit was attributed to grain yield reduction. Under water stress, current photosynthetic inhibition reduced grain yield by 62%, but under well-watered condition; it significantly decreased grain yield by 71%, that indicate the source is limititing factor under different irrigation regimes. Considering that C-81-10, 9103 and 9116 genotypes showed the highest grain yield, potential for reserves and remobilizations of assimilates under different irrigation conditions; thus, these genotypes could be introduced as promising in breeding programs for arid and semi-arid regions.

Key words: Yield, WUE, cessation of watering, potassium iodid, wheat (*Triticum aestivum* L.)

INTRODUCTION

Crop production in arid and semi-arid areas is most limited by insecure water supply. In these areas, improvement of crop drought tolerance has been recognized as one of the most important factors to increase and stabilize production. In most parts of Iran, limited precipitation is confined mainly to cold and winter seasons and can not be directly used by plants (Ghamarnia and Gowing, 2005); therefore, shortage of water resources has become the major limiting factor for wheat production (Nasseri and Fallahi, 2007). Water use efficiency is critical in determining the production and water use for winter wheat (*Triticum aestivum* L.) in Razavi Khorasan Province Plains, where winter wheat is a major crop and rainfall is scarce and variable. As water stress is the main environmental factor limiting yield, Passioura (1996) proposed a parallel way of considering grain yield in a water-limited situation:

$$GY = W \times WUE_{biomass} \times HI$$

where, W is the water absorbed and further transpired by the crop plus direct evaporation from the soil; HI is the harvest index; and $WUE_{biomass}$ is the ability of the crop to produce biomass per unit of water evapotranspired.

Yield and yield components of wheat are influenced by several factors such as water stress (Emam *et al*., 2007; Ghodsi *et al*., 1998) and cultivar (Tayyar and Gul, 2008). Under severe drought-stressed Mediterranean environments, the number of spikes per square meter becomes the most relevant component of durum wheat yield formation (Garcia del Moral *et al*., 2005), while the contribution of grain weight to final yield increases as drought stress diminishes (Moragues *et al*., 2006). It has been reported that increases in the number of grains per unite area have resulted from increases in the number of plants per unite area, the number of spikes per plant and the number of grains per spike, with relative contributions of 20, 29 and 51%, respectively (Royo *et al*., 2007). In wheat, grain number is established at around the time of anthesis. It has been suggested that the strong competition between the spike growth and vegetative

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sinks during 20-30 days before anthesis could affect floret survival and, then, grain number in wheat (Miralles *et al*., 1998). At the initial grain filling stage, source reduction may cause to an increase of net Photosynthetic Rate (PN) by 10% and decreased the allocation of dry matter to the sheath and stem and promoted the reserve photosynthates to be reallocated to grain (Yin *et al*., 1998). Removal of the flag leaf caused reduction of grains per spike, grain weight and grain yield by 9.94, 7.65 and 16.88%, respectively (Alam *et al*., 2008). Drought stress from anthesis to maturity, especially if accompanied by high temperatures, hastens leaf senescence, reduces the duration and rate of grain filling and hence reduces mean kernel weight but increases remobilization of assimilates from the vegetative tissues to the grains (Ehdaie and Waines, 1996; Royo *et al*., 2000; Plaut *et al*., 2004). Praba *et al*. (2009) demonstrated that water stress significantly reduced the plant height at maturity, number of grains per spike, spike weight and grain yield per spike. Ehdaie *et al*. (2006) concluded that balanced partitioning of stem length into upper and lower internodes should improve accumulation and mobilization of stem reserves in wheat. Wheat grown under drought stress may depend more on stem reserves of Water Soluble Carbohydrates (WSC) for grain filling, because current assimilates of flag leaves alone cannot support canopy respiration and grain growth due to water deficit during grain filling (Rawson *et al*., 1983). The remobilization of preanthesis-stored carbohydrate reserves in wheat culm before flowering is promoted by water deficit, which can improve yield in cases where senescence is unfavorably delayed by heavy use of nitrogen (Yang *et al*., 2000, 2001). The objective of this study was to determine whether postanthesis drought stress and current photosynthesis inhibition (chemical desiccation) affect yield and WUE during the late growing season of different winter wheat genotypes.

MATERIALS AND METHODS

The investigation was conducted during the 2006-2007 and 2007-2008 growing seasons at Torogh Agricultural and Natural Resources Research Station of Mashhad (36°13´ N latitude, 59°40´ E longitudes, elevation 985 m), Iran. This region has a semi-arid (214 mm rainfall yearly) and cold climate. The experimental field was cleared, ploughed, harrowed and divided into plots. The soil texture at the experimental site was silt loam with approximately 0.98% organic matter, pH 8.1, Ec 1.64 dS m^{-1}. The 0-30 cm soil layers contained, respectively 0.14% total nitrogen, 30 ppm available phosphorous and 370 ppm available K. The experimental design was a split plot fitted to randomized complete block with three replications. Main plots were assigned to two levels of water stress treatments; D_1: optimum irrigation and D_2: cessation of watering from anthesis to maturity stages. Sub plots were assigned to eight bread wheat genotypes: 9103 (G_1), 9116 (G_2), 9203 (G_3), 9205 (G_4), 9207 (G_5), 9212 (G_6), C-81-10 (G_7) and Cross Shahi (G_8) and photosynthetic conditions with two levels: P_1: no source limitation and P_2: inhibition of current photosynthesis after anthesis were in sub-sub plots.

Seeds were sown in sub plots of 7 by 1.2 m on 6 rows with 20 cm apart, on the basis of 500 seeds per m^2. Before sowing, phosphorous (P_2O_5) and potassium (K_2O) were applied at a rate of 90 and 50 kg ha^{-1}, respectively. Weeds were manually controlled. Nitrogen fertilizer (urea; 46% N) was applied at a rate of 350 kg ha^{-1} and split into three applications (presowing, tillering and booting). Water was applied through a centrally controlled system and the required amount was calculated on the basis of differences between moisture content before irrigation and at Field Capacity (FC).

$$F_n = (\theta_2 - \theta_1) \times r \times D$$

where, F_n is the net irrigation depth (mm), θ_2 and θ_1 soil moisture content at FC and before each irrigation respectively, r soil bulk density and D, rooting depth (mm).

In order to prevention of precipitation influence, a Mobile Rain Shelter (MRS) was constructed in postanthesis drought stress treatments. For inhibiting plant current photosynthesis was applied potassium iodide, at 0.4% active ingredient, at 12-14 days after anthesis; as a spray to the canopy, including the ears, when kernel growth entered its linear phase (Nicolas and Turner, 1993; Blum, 1998). The effect of potassium iodide was seen 3 days after treatment which mainly destroy chlorophyll. During the study and after crop harvesting, some traits such as plant height, number of spikes per square meter, number kernels per spike, thousand kernel weight, biological and grain yield were measured. Combined analyses of variance for grain yield and its related characters were performed after verifying the homogeneity of trial variance errors using Bartlett's test. Year and block was considered random factors and the other effects fixed. Statistical analysis of experimental data were performed by MSTATC software package and the means were separated following ANOVA by Duncan's multiple range test at the 0.05 level of probability (Alizadeh and Tarinejad, 2001). Correlation coefficients among all characters were computed from the mean values, over years and blocks, for each moisture-photosynthesis regime combination.

RESULTS AND DISCUSSION

Climatic conditions (Table 1) were more favorable for high grain yields during 2007-2008 than 2006-2007. The 2007-2008 growing season was predominated by cool conditions that increased duration of developmental stages.

Grain Yield (GY) significantly decreased by 35% and 68% under water deficiency and postanthesis photosynthetic inhibition, respectively; compared with control (Table 2, 3). Average grain yields from optimum and water stress conditions were 4577 and 2976 kg ha^{-1}, respectively; Whereas in normal and source limited conditions, the yields were 5722 and 1830 kg ha^{-1}, respectively (Table 3). Grain yield decrease due to water deficit was attributed to reduction in number of kernels per spike (NK/S) and 1000 kernel weight (TKW) (Table 3). This results were also confirmed elsewhere (Hamam, 2008). Palta *et al*. (1994) reported that under water stress, the grain yield and recurrent photosynthesis decreased by 24 and 57%, respectively. Grain yield decline due to postanthesis current photosynthesis inhibition was related to less NK/S and TKW (Table 3). On average, drought stress significantly ($p<0.01$) reduced grain yield by 26%, kernel weight by 13% and number of kernels per spike by 9% in 2007. In 2008, the three traits also were significantly ($p<0.01$) reduced under droughted field conditions by 41, 22 and 10%, respectively. The grain yields obtained in 2008 were higher, because the cool winter in 2007-2008 growing season increased tillering and consequently the final number of spikes and grain yield. Genotypes significantly produced different final yields (Table 1). Ebadi *et al*. (2007) reported with increase in water deficit severity, the amount of dry matter remobilization from various organs of plant to grain was increased. On average, C-81-10, 9116 and 9103 genotypes produced 4177, 4098 and 4105 kg ha^{-1}, respectively and were significantly superior to 9203, 9205, 9207, 9212 and Cross Shahi (Table 3). The higher grain yield of C-81-10, 9116 and 9103 genotypes was due to higher harvest index, TKW and NK/S. There was a genotypic variance in drought tolerance among cultivars and cultivars with high grain yield under well-watered conditions, usually tolerated better water stress conditions and produced satisfactory yield. Our results are in agreement with previously reported conclusions (Fisher, 1979; Hamam, 2008). The highest grain yield was obtained from

Table 1: Average monthly temperature and precipitation during growing season

	Temperature months (°C)			Precipitation (mm)		
Months	2006-2007	2007-2008	Normal*	2006-2007	2007-2008	Normal
October	20.08	s13.63	13.91	1.8	0.0	5.6
November	10.52	11.55	10.83	17.5	17.5	19.8
December	3.35	3.64	2.23	44.3	26.5	30.5
January	3.20	-6.85	1.54	14.1	25.0	24.4
February	6.22	0.94	2.36	42.9	22.2	33.7
March	7.99	15.03	10.93	117.3	4.1	47.3
April	17.19	17.26	15.34	10.7	21.6	25.8
May	21.02	23.19	20.45	23.9	22.6	22.8
June	25.34	25.96	24.87	7.3	0.0	4.3
Mean or total	12.77	11.59	11.38	279.8	139.5	214.2

*Normal refers to the long-term (30 years) average

Table 2: Analysis of variance (Mean squares) for the effects of water stress and photosynthetic conditions on the grain yield, biological yield, harvest index, number of spikes per square meter, number of kernels per spike, thousand kernel weight, WUE$_g$, WUE$_b$, plant height and grain filling period of winter wheat genotypes (*Triticum aestivum* L.)

SOV	df	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	No. of spikes (m^{-2})	No. of kernels spike^{-1}	Thousand kernel weight (g)	WUE$_g$ (kg/ha/mm)	WUE$_b$ (kg/ha/mm)	Plant height (cm)	Grain filling period (day)
Year	1	37172080**	146784828.8**	93.116**	563387.5**	58.179^{ns}	25.121*	1.257**	5.561**	1185.047**	1463.021**
R (Y)	4	114575.8	371247.2	1.975	1268.140	40.495	2.546	0.005	0.014	19.479	4.521
D	1	122996827.7**	220109794.9**	1774.326**	1134.422^{ns}	484.728**	1081.813**	1.145**	0. 165^{ns}	24.797^{ns}	1598.521**
Y×D	1	16505869.9**	31025556.1**	80.718**	142.313^{ns}	1.430^{ns}	68.438**	0.389**	0.545^{ns}	30.880^{ns}	3.521^{ns}
RD (Y)	4	54005.7	1107549.8	10.360	3212.503	35.399	4.875	0.002	0.046	10.417	2.083
G	7	4674665.4*	1517147.1*	205.943*	7114.437^{ns}	277.554**	15.260*	0.200*	0.063*	3919.886**	11.973**
Y×G	7	748806.5^{ns}	298470.4^{ns}	31.057*	4205.313^{ns}	116.579**	12.199^{ns}	0.032^{ns}	0.014^{ns}	70.714**	16.259**
D×G	7	431343.5^{ns}	196525.6^{ns}	15.033^{ns}	1031.032^{ns}	25.040*	12.542^{ns}	0.016^{ns}	0.006^{ns}	29.797^{ns}	4.354^{ns}
Y×D×G	7	286565.9*	793611.9^{ns}	6.068^{ns}	874.452^{ns}	2.738^{ns}	8.062^{ns}	0.013*	0.035^{ns}	5.714^{ns}	3.378^{ns}
Errore	56	107535.3	548937.1	5.348	3666.503	20.182	3.967	0.005	0.024	14.668	3.165
P	1	727045060.6**	525293860.6**	24471.076**	6511.182^{ns}	7721.994**	14838.047**	25.344**	9.883**	7.922^{ns}	67.688**
Y×P	1	37159760.9^{ns}	29812404.4^{ns}	433.712^{ns}	157.868^{ns}	523.281^{ns}	47.810^{ns}	1.257^{ns}	0.739^{ns}	141.797**	11.021^{ns}
D×P	1	69681535.9^{ns}	72288706.9^{ns}	741.394^{ns}	2385.014^{ns}	61.212^{ns}	282.634^{ns}	0.542^{ns}	0.034^{ns}	7.130^{ns}	22.688^{ns}
Y×D×P	1	12442505.9**	28300033.2**	24.133^{ns}	2138.001^{ns}	16.234^{ns}	229.403**	0.266**	0.668**	3.797^{ns}	13.021^{ns}
G×P	7	1058746.3^{ns}	1181165.9^{ns}	26.841^{ns}	717.023^{ns}	40.944^{ns}	11.796^{ns}	0.042^{ns}	0.050^{ns}	2.350^{ns}	1.092^{ns}
Y×G×P	7	521092.7^{ns}	437325.9^{ns}	31.053^{ns}	1061.197^{ns}	52.567^{ns}	6.533^{ns}	0.026^{ns}	0.020^{ns}	1.678^{ns}	0.783^{ns}
D×G×P	7	363078.5^{ns}	169604.3^{ns}	19.900^{ns}	726.945^{ns}	8.045^{ns}	10.347^{ns}	0.017^{ns}	0.009^{ns}	3.487^{ns}	1.092^{ns}
Y×D×G×P	7	220471.7^{ns}	311152.5^{ns}	9.198^{ns}	582.990^{ns}	16.605^{ns}	10.058**	0.011*	0.014^{ns}	2.511^{ns}	0.307^{ns}
Error	64	108660.0	255484.5^{ns}	5.059	2098.955	14.186	4.267	0.004	0.011	6.026	1.370
CV (%)		8.32	4.02	8.03	9.15	11.66	8.31	8.62	3.98	2.46	3.38

Y, R, D, G and P: Year, Replication, Drought stress, Genotype and Photosynthetic conditions, respectively. **,* and ^{ns}indicate significant at the 0.01, 0.05 probability levels and lack of significant at the 0.05 probability level, respectively

Table 3: Mean comparison of some agronomic traits of wheat genotypes (*Triticum aestivum* L.) as affected by postanthesis photosynthetic conditions

Components	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	No. of spikes m^{-2}	No. of kernels spike^{-1}	Thoushand kernel weight (g)	WUE$_g$ (kg/ha/mm)	WUE$_b$ (kg/ha/mm)	Plant height (cm)	Grain filling periode (day)
D_1	4577a	13650a	31.07a	503.1a	33.9a	27.24a	0.841a	2.598a	100.02a	37.50a
D_2	2976b	11509b	24.99b	498.2a	30.7b	22.49b	0.687b	2.656a	99.30a	31.73b
G_1	4105a	12791a	29.67a	505.6a	34.8ab	24.73ab	0.830a	2.670a	96.58c	35.58a
G_2	4098a	12807a	29.87a	518.2a	33.1b	24.63ab	0.829a	2.671a	98.00c	33.92ab
G_3	3811ab	12343b	28.74ab	469.9b	37.4a	24.19b	0.769ab	2.578a	80.75d	33.63b
G_4	3509b	12381ab	26.71b	487.4a	31.3b	24.70ab	0.715b	2.589a	107.21b	34.46ab
G_5	3818ab	12487a	28.60ab	508.0a	31.7b	24.77ab	0.772ab	2.606a	97.37c	34.25ab
G_6	3869ab	12463a	28.99ab	520.5a	30.7b	25.71a	0.786ab	2.603a	99.79bc	34.50ab
G_7	4177a	13005a	30.31a	488.9ab	33.7ab	26.33a	0.848a	2.716a	92.29c	35.29a
G_8	2823c	12362ab	21.30c	506.6a	25.8c	23.85c	0.565c	2.584a	125.29a	35.29a
P_1	5722a	14234a	39.31a	506.5a	38.7a	33.65a	1.127a	2.584a	99.46a	35.21a
P_2	1830b	10926b	16.74b	494.8a	25.9b	16.07b	0.401b	2.400a	99.87a	34.02b

D_1: Optimum irrigation, D_2: Cessation of watering from anthesis to maturity stages. G_1, G_2, G_3, G_4, G_5, G_6, G_7 and G_8 indicate eight bread wheat genotypes: 9103, 9116, 9203, 9205, 9207, 9212, C-81-10 and Cross Shahi, respectively. P_1: No source limitation, P_2: Inhibition of current photosynthesis (12-14 days after anthesis). *Means of the same category fallowed by different letters are significantly different at the 0.05 probability level

well-watered conditions and no assimilate limitation, whereas the least grain yield was acquired from water stress and photosynthetic inhibition. Under water stress conditions, average grain yield of genotypes reduced 39.4% in no source limitation and 19.5% in source limited conditions compared with well-watered conditions. Water stress×genotype×photosynthesis interaction was not significant on the grain yield, but 9103 genotype produced maximum yield under D_1P_1 (7870 kg ha^{-1}) and D_2P_1 (4900 kg ha^{-1}) treatments. Also, C-81-10 and 9116 genotypes produced maximum grain yield under D_1P_2 (2836 kg ha^{-1}) and D_2P_2 (1887 kg ha^{-}) treatments, respectively whereas Cross Shahi cultivar produced minimum grain yield in the whole moisture and photosynthetic conditions. In this study, non sufficient assimilates because of water stress during grain filling period, caused to a significant decrease in number of grains per spike and grain weight (Table 2). Significant and positive correlation of grain yield with 1000 grain weight ($r = 0.88$; $p<0.01$) and number of grains per spike ($r = 0.78$; $p<0.01$) showed that less allocation of dry matter to kernel demand under water stress and lower harvest index is mostly due to decrease in number of grains per spike and 1000 grain weight, but Nicolas and Turner (1993) demonstrated that the correlation across diverse genetic materials between the rate of reduction in kernel weight by current photosynthesis restriction and the rate of reduction by drought stress was found to be significant ($r = 0.81$; $p<0.01$) and reasonably high.

Biological yield (BY) significantly decreased by 15.7% under waterholding (11509 kg ha^{-1}) compared with well-watered (13650 kg ha^{-1}). The higher BY of D_1 treatment was mainly related to more GY and higher plant height. Biological yield significantly decreased by 23.2% under P_2 (10926 kg ha^{-1}) compared with P_1 (14234 kg ha^{-1}) treatment. The less BY of P_1 treatment was due to more YG and longer spike length. On average, 9203 and 9116 genotypes produced the least (12343 kg ha^{-1}) and the most (12807 kg ha^{-1}) biological yield, respectively. The increase of above ground dry matter was due to higher leaf area index, crop growth rate and radiation absorbtion.

Postanthesis drought stress and current photosynthetic inhibition caused a significant reduction ($p<0.01$) in Harvest Index (HI) by 19 and 57.4% under water deficiency (24.99%) and control (16.74%), respectively (Table 3). The results of mean comparison of water stress×photosynthesis interaction showed that the most and the least of HI were obtained from D_1P_1 and D_2P_2 treatments. The results of mean comparison of genotype×photosynthesis interaction showed that 9103, 9212 and 9116 genotypes produced the most harvest index. Also, 9116 and 9212 genotypes produced the most grain and biological yields. On the other hand, C-81-10 and Cross Shahi genotypes had the highest and the lowest HI under P_2 treatment. In generally, in present research, genotypes with high grain and also biological yields, produced high HI.

Analysis of variance for the number of spikes per m^{-2} (NS/M^2) showed that year effect only was significant; although genotype effect was significant at 0.09 level of probability. NS/M^2 was 503.1 and 498.2 under D_1 and D_2 treatments, respectively. According to reports, water stress in tillering, shooting and booting stages decrease NS/M^2 (Slafer *et al*., 1996); but water stress at anthesis and postanthesis stages doesn't influence NS/M^2 (Pandy *et al*., 2001). The results of mean comparison showed that 9212 and 9203 genotypes produced the most (520.5) and the least (489) NS/M^2, respectively.

Number of kernels per spike (NK/S) significantly decreased by 15.7% under water deficit (30.72) compared with well-watered (33.90). Emam *et al.* (2007) demonstrated postanthesis drought stress reduced the grain yield and yield components in all genotypes. Mean of each trait significantly ($p<0.05$) decreased under drought stress conditions, except for spikelet number per spike and spike number per square meter. The highest yield loss was

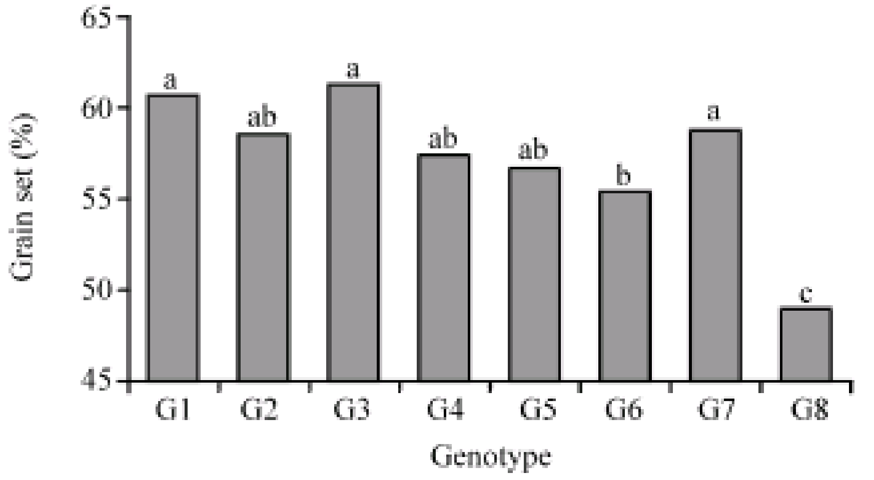

Fig. 1: Grain set (%) of wheat genotypes to postanthesis different water deficit and chemical desiccant treatments. Bars showing the same letter at any stage are not significantly different ($p<0.05$) as determined by ANOVA

caused by the grain number per spike and 1000 grain weight reduction under drought stress conditions. The decline of NK/S at postanthesis drought stress was due to florets infertility (Data not shown). There was positive and significant correlation between grain yield with number grains per spikelet ($r = 0.96$; $p<0.01$) and grain set percentage ($r = 0.97$; $p<0.01$) under different treatments. There was significant difference among genotypes for grain set percentage (Fig. 1). In recent years, increasing of grain yield was mainly been due to increasing of NK/S or NK/M^2 and increasing of grain weight had been less effect (Calderini *et al*., 1999). NK/S significantly decreased by 23.2% under current photosynthesis inhibition (25.97) compared with no source limitation (38.65). The less NK/S of P_2 treatment was due to assimilates reduction and consequently florets infertility. On average, 9203 and Cross Shahi genotypes produced the most and the least NK/S, respectively. More NG/S of 9203 genotype related to less NS/M^2, more number of spikelets per spike and number of kernels per spikelet (Data not shown). Less NK/S of Cross Shahi cultivar was due to fewer number of kernels per spikelet. A universally recognized factor that greatly reduces yield potential is reproductive failure (e.g., floret abortion in wheat) consequent to drought episodes at flowering and the early stages of grain development (Boyer and McLaughlin, 2007). Water stress×genotype interaction on NK/S showed that under well-watered and also waterholding, 9203 and Cross Shahi genotypes produced the most and the least NK/S, respectively. Genotype×photosynthesis interaction on NK/S showed that under P_1 and P_2 treatments, 9203 and Cross Shahi genotypes had the most and the least NK/S, respectively. Machadoo *et al*. (1993) reported water stress at near anthesis significantly decreased grain formation and fertilization and spike dry weight declined by 30 and 8% at anthesis and grain filling stages, respectively. Mean Thousand Kernel Weight (TKW) of wheat genotypes was 27.24 and 22.49 under well-watered (D_1) and waterholding (D_2), respectively. Usually, the increase of grain filling during caused more translocation of photosynthates to grain and consequently increased TKW. Shahryari *et al*. (2008) found in drought condition, correlation of grain yield with 1000 grain weight and total number of tillers per plant was positively significant. TKW significantly decreased by 52.2% under current photosynthesis inhibition (16.07 g) compared with no source limitation (33.65 g). Reduction in final grain weight caused by dessicant spraying was probably due to less grain filling duration. The reduction in grain filling duration could be explained by the decline in the availability of assimilates in the P_2 treatment. TKW related to grain filling rate and duration. The length of grain filling during, the amount and rapidity of stored assimilates translocation and current photosynthesis efficiency affect TKW. The decline of grain filling during, disturbance at current photosynthesis and photosynthates remobilization decrease TKW (Slafer and Savin, 1994). In this study, grain filling occurred when temperatures was increasing and waterholding caused kernel shriveling, reduced test weight and loss in grain yield. Araus *et al*. (2003), Calderini *et al*. (1999) and Blum (1998) reported similar results. Genotype×photosynthesis interaction on TKW showed that 9212 and 9103 genotypes produced the most and the least TKW under P_1 treatment, respectively. On the other hand, under P_2 treatment, C-81-10 and Cross Shahi genotypes obtained the most and the least TKW, respectively. High TKW of C-81-10 genotype was due to more potential in using of stem reserves (Table 4). The average utilization of stem reserves among genotypes was 28.5 and 37.8% under well-watered and postanthesis drought stress, respectively. It is therefore to be expected that estimates of the relative contributions of stem reserves to total grain mass per ear or to grain yield would vary among the different reports, according to the experimental conditions and cultivars used. These contributions were estimated to be anywhere between 6 and 100% (Gent, 1994; Palta *et al*., 1994; Ehdaie *et al*., 2008). Gholami and Asadollahi (2008) reported with increase in water stress intensity, the contribution mobilized dry matter (DMRC) to grain yield increased. The highest DMRC value obtained from high water stress with 25.37%.

WUE_{yield} significantly decreased by 18.31% and 64.42% under D_2 (0.687 kg m^{-3}) and P_2 (0.401 kg m^{-3}) treatments, respectively; compared with D_1 (0.841 kg m^{-3}) and P_1 (1.127 kg m^{-3}) treatments (Table 2 and 3). The amount, timing and frequency of irrigation have strong impacts in $WUE_{biomass}$ and WUE_{yield} (Qiu *et al*., 2008) . In

Table 4: The mean of grain yield (kg ha^{-1}) of bread wheat genotypes under optimum and water stress conditions for utilization of stem reserves

	D_1			D_2		
Components	P_1	P_2	Utilization of stem reserves (%)	P_1	P_2	Utilization of stem reserves (%)
G_1	7870a	1930jk	24.5	4900f	1719l	35.1
G_2	7774a	2207jk	28.4	4522fg	1887kl	41.7
G_3	7390b	2009jk	27.2	4153h	1693lm	40.8
G_4	6340d	1767l	27.9	4310gh	1617lm	37.5
G_5	7171bc	2203jk	30.7	4216h	1684lm	39.9
G_6	7141bc	1961jk	27.5	4881f	1492m	30.6
G_7	7435ab	2836i	38.1	4585fg	1853kl	40.4
G_8	5879e	1312m	22.3	2988i	1114n	37.3
Mean	7125	2028	28.5	4319	1632	37.8

D_1: Optimum irrigation and D_2: Cessation of watering from anthesis to maturity stages. G_1, G_2, G_3, G_4, G_5, G_6, G_7 and G_8 indicate eight bread wheat genotypes: 9103, 9116, 9203, 9205, 9207, 9212, C-81-10 and Cross Shahi, respectively. P_1: No source limitation and P_2: Inhibition of current photosynthesis (12-14 days after anthesis). *Means of the same category fallowed by different letters have significantly difference at the 0.05 probability level

fact, WUE may drop (Nasseri and Fallahi, 2007; Tambussi *et al*., 2007) or increase (Brandyopadhyay and Mallick, 2003) at higher irrigation levels. Irrigation increased the WUE_{yield} without any effect in $WUE_{biomass}$, due to the increase of postanthesis water use, which resulted in a higher harvest index and better grain yield. Reduction in WUE_{yield} caused by water deficit was attributed to grain yield reduction. Anderson (1992) reported severe drought stress in critical development stages (stem elongation, heading and anthesis) decreased WUE. Although, Nasseri and Fallahi (2007) demonstrated in comparative to full irrigation, the WUE_{yield} achieved from cutting off irrigation after stem elongation and flowering were identically increased more than one-half and that increased about one-third after dough stage. $WUE_{biomass}$ significantly reduced by 2.18 and 15.91% under D_1 (2.598 kg m^{-3}) and P_2 (2.400 kg m^{-3}) treatments, respectively; compared with D_2 (2.656 kg m^{-3}) and P_1 (2.854 kg m^{-3}) treatments (Table 2, 3). Under D_1 treatment, 9116 genotype acquired the highest of WUE_{yield} at the first year, but under D_2 treatment, 9212 genotype had the highest of WUE_{yield}. Cross Shahi cultivar obtained the least WUE_{yield} at twe moisture regimes and two years. On average, C-81-10 and Cross Shahi genotypes had the most and the least WUE_{yield} under D_1 and D_2 treatments, respectively. A higher WUE may be related to a lower water use (and virtually, lower growth and grain yield) under drought conditions. In addition, although harvest index may be drought-independent in some cases, drought-dependent HI is often a function of postanthesis water use (Richards *et al*., 2001). Improved WUE_{yield} in modern cultivars was associated with the increase of HI, in addition to a faster development, earlier flowering and improved canopy structure (Siddique *et al*., 1990).

The $WUE_{biomass}$, by contrast, seems to be similar between old and modern cultivars (Richards *et al*., 2001). Because the HI seems to achieve the maximum (at least in wheat; Austin, 1999; Reynolds *et al*., 2000), further increments in WUE_{yield} should implicate the rise of $WUE_{biomass}$. Modern cultivated wheat had been indicated to have a higher WUE compared with their diploid and tetraploid ancestors in glasshouse experiments but they did not find consistent differences between new and old varieties (Richards, 1987). The WUE_{yield} of modern cultivars was higher than that of old varieties' among nine Australian varieties, because modern wheat cultivars with higher harvest index (Siddique *et al*., 1990).

Analysis of variance for plant height showed that year and genotype effects only were significant (Table 2). Plant height was 100.02 and 99.30 cm under D_1 and D_2 treatments, respectively. According to reports, water stress in tillering, shooting and booting stages decrease plant height (Hamam, 2008); but water stress at anthesis and postanthesis stages doesn't influence plant height (Ghodsi *et al*., 1998). The average plant height of 8 genotypes over all treatments during two years ranged from 80.75 cm for 9203 genotype to 125.29 cm for Cross Shahi cultivar with an average of 99.66 cm over all genotypes (Table 3).

The Grain Filling Period (GFP) in 2008 coincided with partly cloudy days and less heat. Therefore, GFP was longer in 2008 (37.37) than in 2007 (33.85). GFP significantly decreased by 15.4% under water deficiency (31.73) compared with well-watered (37.50) (Table 2, 3). GFP decreased by 3.4% under P_2 (34.02) compared with P_1(35.21) treatment (Table 2, 3). In this study, drought stress from anthesis to maturity, hastened leaf senescence, reduced the grain filling duration and hence reduced mean kernel weight but increased remobilization of assimilates from the vegetative tissues to the grains. Our results agree with the conclusions of Ehdaie and Waines (1996), Royo *et al*. (2000) and Plaut *et al*. (2004). The average GFP of 8 genotypes over all treatments during two years ranged from 33.92 days for 9116 genotype to 35.58 days for 9103 genotype with an average of 34.61 days over all genotypes (Table 3). The reduction in grain filling duration caused by dessicant spray was due to decline in the availability of assimilates.

CONCLUSION

Bread wheat breeding programs were conducted to increase sink size but, at the same time, in larger constraints imposed on yield by the source. Reductions in the sink limitation of promising genotypes may have been not only due to the improved number of kernels per unit area, but also to a larger grain weight potential. Under postanthesis drought stress, current photosynthetic inhibition reduced grain yield by 62%, but under well-watered condition; it significantly decreased grain yield by 71%, that indicate the source is limititing factor under different irrigation regimes. The average utilization of stem reserves among genotypes was 28.5 and 37.8% under well-watered and postanthesis drought stress, respectively. Considering that C-81-10, 9103 and 9116 genotypes showed the highest grain yield, potential for reserves and remobilizations of assimilates under different irrigation conditions; thus, these genotypes could be introduced as promising in breeding programs for arid and semi-arid regions.

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