Shaabanzadeh A *et al*. (2025)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 53, Issue 2, Article number 13137
DOI:10.15835/nbha53213137
Research Article

Yield, yield components, and assimilate remobilization of wheat genotypes under water deficit

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Abstract

To evaluate yield, yield components and remobilization of assimilates of wheat genotypes under normal irrigated and water deficit conditions, an experiment was conducted in a randomized complete block design with three replications in two growing seasons. The results showed that the highest yields and values for yield components were obtained under irrigation. Water deficit after the spike emergence stage significantly reduced yield components and grain yield. Among the studied traits, the highest spike weight, straw weight, total weight, number of spikes, number of grains and grain yield were observed in genotype 5. The highest 1000-grain weights under irrigated (50.42 g) and water deficit (45.93 g) conditions were observed in genotype 10. Harvest index was lower under water deficit than in irrigated conditions in all genotypes with the highest values of harvest index recorded for genotype 1. Evaluation of traits associated with remobilization showed that under irrigated conditions, the highest amount of remobilization was observed in genotype 2 and the lowest amount of remobilization was found in genotype 3. Under water deficit, genotypes 3 and 9 had the highest, and lowest amount of assimilate remobilization, respectively. The average remobilization under irrigated and water deficit conditions was 53.3% and 60.6%, respectively. The contribution of current photosynthesis was 46.7% under irrigated and 39.4% under water deficit conditions. Also, under water deficit, grain yield was significantly, positively correlated with the amount of reallocation of dry matter, the relative contribution of dry matter reallocation, remobilization efficiency and the contribution of current photosynthesis.

Keywords: grain yield; photosynthesis; remobilization; wheat; water deficit

Introduction

Wheat (*Triticum aestivum* L.) is the most widely consumed food in the world. Its production is threatened by climate change (Jia *et al*., 2017), and environmental stresses such as salinity (of soil and water) and drought stress. Water deficit is one of the main impediments to agricultural and horticultural crop

Received: 28 Mar 2023. Received in revised form: 20 Apr 2024. Accepted: 26 Nov 2024. Published online: 12 Jun 2025.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

production in many parts of the world, predominantly in arid and semi-arid regions (King, 1997; Jia *et al.*, 2017). Water availability is critical for plant growth, development, and seed formation (Helaly *et al.*, 2017). In wheat, water deficit reduces the number of spikes per unit area, the number of spikelets per spike, the number of seeds per spikelet, the 1000-seed weight, biological yield, grain yield and harvest index (Allahverdiyev *et al.*, 2018). Water deficit also reduces the dry weight of leaves and stems and the rate of grain filling (Selim *et al.*, 2019).

Several non-traditional techniques (deep rooting, osmotic regulation, etc.) have been adopted to increase the plant's drought tolerance potential and the response of plants varies depending on plant species and cultivar (Hussain *et al.*, 2018; Ul-Allah *et al.*, 2018). Due to the significant interaction between genotype and environment, identifying genotypes with good performance under both irrigated conditions and water deficit seems complicated (Del Moral *et al.*, 2003). Researchers have developed various methods such as selection based on the potential performance of genotypes, stability criteria, the combination of yield and trait correlations with yield, and use of yield of genotypes under both stress and stress-free conditions to evaluate genotypes under drought (Gavuzzi *et al.*, 1997). Evaluation of genotype performance in both stress and non-stress conditions leads to the selection of high-yielding genotypes. Water deficit at spike emergence and pollination stages reduces the number of grains per spike, grain weight and grain protein. This phenomenon indicates that wheat is sensitive to water deficit in the spike emergence and pollination stages (Grzesiak *et al.*, 2019).

Studies performed in irrigated and water deficit environments show that the susceptibility of wheat cultivars to water deficit is variable with a clear effect of the severity of the water deficit (Qaseem *et al.*, 2019; Pour-Aboughadareh *et al.*, 2020; Khayatnezhad and Gholamin, 2020). The effect of drought and heat stress and the combination of these two stresses on eight wheat genotypes showed that grain yield under combined drought and heat stress conditions, as well as under only heat or drought stress conditions decreased by 56.5, 53.1, and 44.7%, respectively. The combination of drought and heat stress conditions reduces the metabolism and displacement of storage materials, affecting the growth of leaves and seeds. Different genotypes had different yield and stress tolerance (Qaseem *et al.*, 2019).

Grain yield formation in cereals is a complex physiological, and biochemical process primarily related to the accumulation and remobilization of photosynthetic materials. Under drought stress conditions, the assimilates produced in the leaves do not meet the assimilate requirements for grain filling, and the assimilates needed to fill the growing grains are partly supplied by other assimilate-producing sources, including the remobilization of stored carbohydrates from the stem nodes and the photosynthesis of spikes (Azhand *et al.*, 2015). The ability of wheat genotypes to remobilize carbohydrates varies (Ovenden *et al.*, 2017). Liu *et al.* (2020) reported that the accumulation and remobilization of soluble carbohydrates differ widely among different genotypes in interaction with growth stage, water conditions, and stem intermediates, and drought stress significantly increased the remobilization of stored soluble carbohydrates during grain filling. Allahverdiyev *et al.* (2018) also reported that drought stress enhanced dry matter remobilization.

Knowledge of the effect of water deficit on yield and yield components, recognition of possible mechanisms in creating resistance or tolerance to drought, as well as accurate estimation of variation in tolerance to stress among genotypes, can be necessary to improve the efficiency of breeding programs in various environments. In addition, due to the coincidence of the final stages of physiological growth of wheat with water deficit, it is necessary to identify and use wheat cultivars with tolerance to terminal water stress. Therefore, the present study was conducted to find genotypes of wheat that have good yields under water deficit conditions.

Materials and Methods

Location, experimental treatments, and project implementation method

To evaluate the yield, yield components and assimilate remobilization of wheat genotypes under water deficit, field experiments were carried out at the agricultural and natural resources research station Miandoab, Iran (46°90′ E, 36° 58′ N, 1314 m elevation) during two growing seasons of 2018/2019 and 2019/2020. The experimental trials were set up according to the randomized complete block design with three replications. The soil of the experiment site had a silt-loam texture (Table 1). Climate data are listed in Table 2. The experimental materials included 10 genotypes of wheat (Table 3), which were investigated under irrigated conditions and when stressed during spike emergence. Each plot had six planting lines with a length of 3 m and a row distance of 20 cm (plot dimension 3.0 × 1.2 m).

Table 1. Soil physicochemical characteristics of the experimental site

Soil texture	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Carbonate calcium (%)**	**Saturation humidity (%)**	**pH**
Silt-loam	22	60	18	11.5	38	7.3
EC (dS/m)	Total nitrogen (%)	Organic carbon (%)	Zn (mg/kg)	Fe (mg/kg)	K (mg/kg)	P (mg/kg)
0.84	0.12	0.72	0.71	6.28	390	12

Table 2. Climate data of Miandoab station during 2018-2019 and 2019-2020 cropping seasons

Months of the year	**Precipitation (mm)**		**Evaporation (mm)**		**Average of maximum temperature (°C)**		**Average of minimum temperature (°C)**		**Average of mean temperature (°C)**		**Average of relative humidity (%)**	
	2018-19	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**	**2018-19**	**2019-20**
January	25.8	34.5	0	0	6.8	6.0	-2.6	-3.2	2.1	1.4	69	**74**
February	64.5	35.5	0	0	9.6	4.2	-1.3	-4.2	4.2	0.0	68	**69**
March	28.2	32.6	0	0	11.1	13.7	0.2	1.7	5.6	7.7	64	**68**
April	25.4	88.0	77.0	69.3	21.4	15.3	4.1	4.9	10.9	10.1	57	**64**
May	28.5	48.5	156.5	194.1	29.6	21.8	7.4	6.9	15.5	14.4	50	**55**
June	0.4	4.3	246.8	303.2	33.4	30.9	12.8	13.6	21.8	22.2	43	**42**
July	1.0	0	307.1	333.9	33.4	33.8	17.2	16.8	26.3	25.3	42	**37**
August	0	0	308.3	340.8	34.2	35.1	16.0	17.1	26.3	26.1	41	**41**
September	3.5	0	201.5	255.5	32.0	31.3	12.8	12.5	21.6	21.9	51	**48**
October	2.4	5.2	126.8	160.6	25.2	27.2	8.3	7.9	16.7	17.5	56	**50**
November	31.6	1.7	61.0	34.6	15.1	16.6	3.7	0.1	9.4	8.3	67	**60**
December	90.7	21.8	13.3	0	10.1	10.1	2.2	-0.2	6.2	5.0	76	**72**

Table 3. Pedigree of wheat cultivars and genotypes

Genotype number	**Pedigree**
1	Mihan
2	Haydari
3	Zarrineh
4	Ghk"s"/Bow"s"//90Zhong87/3/Shiroodi/4/55.174/P101//Maya/3/Snb
5	Ghk"s"/Bow"s"//90Zhong87/3/Shiroodi/4/55.174/P101//Maya/3/Snb
6	Vorona//Milan/Sha7/3/MV17/4/Pehlivan
7	Tam113
8	Unknown/Zolotava/6/Jup/4/Cllf/3/II1453/Odin//Ci134431/Sel6425/Wa00477*2/5/Croc-1/Ae.Squarro1 (213)//Pgo
9	Charger//CMH80A.768/3*Cno79
10	MV35-13

According to soil tests, the land needed pre-planting fertilizers including ammonium phosphate (150 kg/ha), potassium sulfate (150 kg/ha) and urea (70 kg/ha) mixed with the soil. The planting operation was done on November 15 of the experimental year with a sowing density of 450 seeds per m^2, and the first irrigation was done immediately after the seeds were planted to make the seeds germinate and seedlings established. In the tillering stage, 40 grams of 46 % urea fertilizer was used in each plot as a top dressing. Broadleaf weeds were controlled using 2, 4-D herbicide in the tillering stage.

Assessing yield, yield components, and harvest index

At the end of the growing season, to assess yield components and grain yield, plants from 1 m^2 in the central rows of each plot were pulled out, and the spike weight, straw weight, total plant weight, number of spikes, number of grain, and 1000-grain weight, and grain yield in the samples were recorded. The harvest index was determined according to the following equation:

$$HI = GY / BY \times 100$$

HI is the harvest index, GY is the grain yield, and BY is the (total) biomass yield.

Assessing dry matter re-allocation, the contribution of remobilization, and remobilization efficiency

The amount of translocated dry matter (DMT), the contribution of remobilization to grain yield, and the remobilization efficiency were calculated using the following equations.

$$DMT = DMA - (DMM - GY)$$

$$CR\% = DMT/GY \times 100$$

$$RE\% = DMT/DMA \times 100$$

Where, DMT is the amount of dry matter translocated to the grains; DMA is the dry weight at anther emergence; DMM is the dry matter weight at physiological maturity; GY is grain yield; CR% is the relative contribution of remobilization to grain yield, and RE% is the remobilization efficiency.

Assessing current photosynthesis and its contribution to grain yield

The contribution of current photosynthesis and the relative contribution of current photosynthesis were calculated using the following equations:

$$\text{Contribution of current photosynthesis} = GY - DMT$$

$$\text{Relative contribution of current photosynthesis} = 100 - CR\%$$

Statistical analysis

SAS software was used to analyze the variance of the data. Also, the protected LSD test ($P<0.05$) was used for mean comparisons. To evaluate the correlation between grain yield and remobilization of photosynthetic materials, the correlation coefficients were calculated using the Pearson method.

Results

Yield, yield components and harvest index

The analysis of variance showed that the effects of year on straw weight, total weight, 1000-grain weight, and harvest index were significant (Table 4). The interactions between year and stress level were significant for all studied crop traits, which shows the impact of environmental conditions on these traits (Table 4). Also, the effects of stress level and genotype on yield and yield components were significant ($p\leq0.01$). Still, the interaction between stress level and genotype was significant only for 1000-grain weight and harvest index ($p\leq0.01$) (Table 4). Mean comparisons showed that the highest yield and highest values for yield components were obtained under irrigated conditions, while water deficit after the spiking emergence stage led to a substantial reduction in yield components and grain yield (Table 5). The highest spike weight, straw weight, total weight, number of spikes, number of grains, and grain yield were observed for genotype 5 (Table 5). The 1000-grain weight amount in some wheat genotypes increased under water stress after the spike emergence stage, and some genotypes decreased. The highest 1000-grain weight values for genotype 10 under water deficit and irrigated conditions were 50.42 g and 45.93 g respectively, which were significantly higher than the values of the other genotypes (Figure 1 A).

Harvest index was lower under water deficit than under irrigated conditions for all genotypes, and the highest values of harvest index under irrigated conditions and water deficit were observed for genotype 1 (Figure 1 B).

Table 4. Analysis of variance of grain yield and yield components of wheat genotypes under different levels of water deficit

SOV	DF	Mean of squares							
		Spike weight	Straw weight	Total plant weight	Number of spikes	Number of grains	1000-grain weight	Grain yield	Harvest index
Year	1	79589.13^{ns}	603668.21**	112380.62**	2270.7^{ns}	3832043^{ns}	9244.28**	31019.61^{ns}	**453.2****
Repetition (year)	4	820.64	99.03	1443.84	3276.1	1451610	7.99	4617.34	**3.6**
Stress	1	712746.44**	104951.03**	1362348.3**	139946.7**	345210625**	560.9**	510299.55**	**96.21****
Year × Stress	1	2869567.88**	835117.62**	6806250.79**	236030.7**	10033620267**	232.52**	1771591.5**	**168.54****
Genotype	9	41971.43*	20106.8**	10437.2*	9696.03**	19630278**	2040.28**	19161.65*	**70.54****
Year × Genotype	9	9500.31^{ns}	4535.05^{ns}	21183.02^{ns}	4209.36^{ns}	5296688^{ns}	267.22**	5740.001^{ns}	**4.57***
Genotype × Stress	9	11454.06^{ns}	8308.57^{ns}	28919.46^{ns}	4476.03^{ns}	3552147^{ns}	149.6**	4356.02^{ns}	**6.28****
Year × Stress × Genotype	9	23450.19^{ns}	9167.29^{ns}	21183.22^{ns}	5177.36^{ns}	8821961^{ns}	294.22**	13272.05^{ns}	**9.21****
Error	76	17512.46	5655.82	41754.29	3245.58	6133899	32.68	9448.33	**2.24**
CV	-	21.59	17.16	19.44	18.71	22.22	3.3	21.16	**3.49**

**, *, ns: significantly different at the 1% and 5% probability and non-significant, respectively.

SOV = Sources of variation; DF = degrees of freedom; CV = coefficient of variation (%)

Table 5. Comparison of the mean effects of water deficit treatments and genotype on some studied properties of wheat

Treatment	Treatment/ Genotype	Spike weight (g/m^2)	Straw weight (g/m^2)	Total plant weight (g/m^2)	Number of spikes per m^2	Number of grains per m^2	Grain yield (g/m^2)
Stress	Control	690^{a}	468^{a}	1157^{a}	339^{a}	12334^{a}	**525^{a}**
	Stress	536^{b}	405^{b}	944^{b}	270^{b}	8942^{b}	**394^{b}**
Genotype	1	625^{bc}	371^{d}	996^{bc}	251^{d}	10700^{bc}	**469^{abc}**
	2	644^{ab}	456^{abc}	1100^{ab}	318^{ab}	10742^{bc}	**476^{abc}**
	3	553^{bc}	427^{bcd}	980^{bc}	315^{ab}	10121^{bcd}	**418^{c}**
	4	637^{ab}	467^{ab}	1103^{ab}	285^{bcd}	11876^{ab}	**473^{abc}**
	5	834^{a}	516^{a}	1252^{a}	334^{a}	13188^{a}	**537^{a}**
	6	570^{bc}	412^{bcd}	981^{bc}	335^{a}	11197^{abc}	**456^{bc}**
	7	591^{bc}	420^{bcd}	1011^{bc}	329^{ab}	10477^{bcd}	**438^{bc}**
	8	521^{c}	401^{cd}	922^{c}	268^{bcd}	8489^{d}	**412^{c}**
	9	615^{bc}	465^{ab}	1080^{bc}	306^{abc}	9923^{bcd}	**417^{c}**
	10	639^{ab}	446^{bc}	1084^{bc}	305^{abc}	9671^{cd}	**497^{ab}**

Different letters indicate significant differences among the treatments according to LSD test ($P < 0.05$)

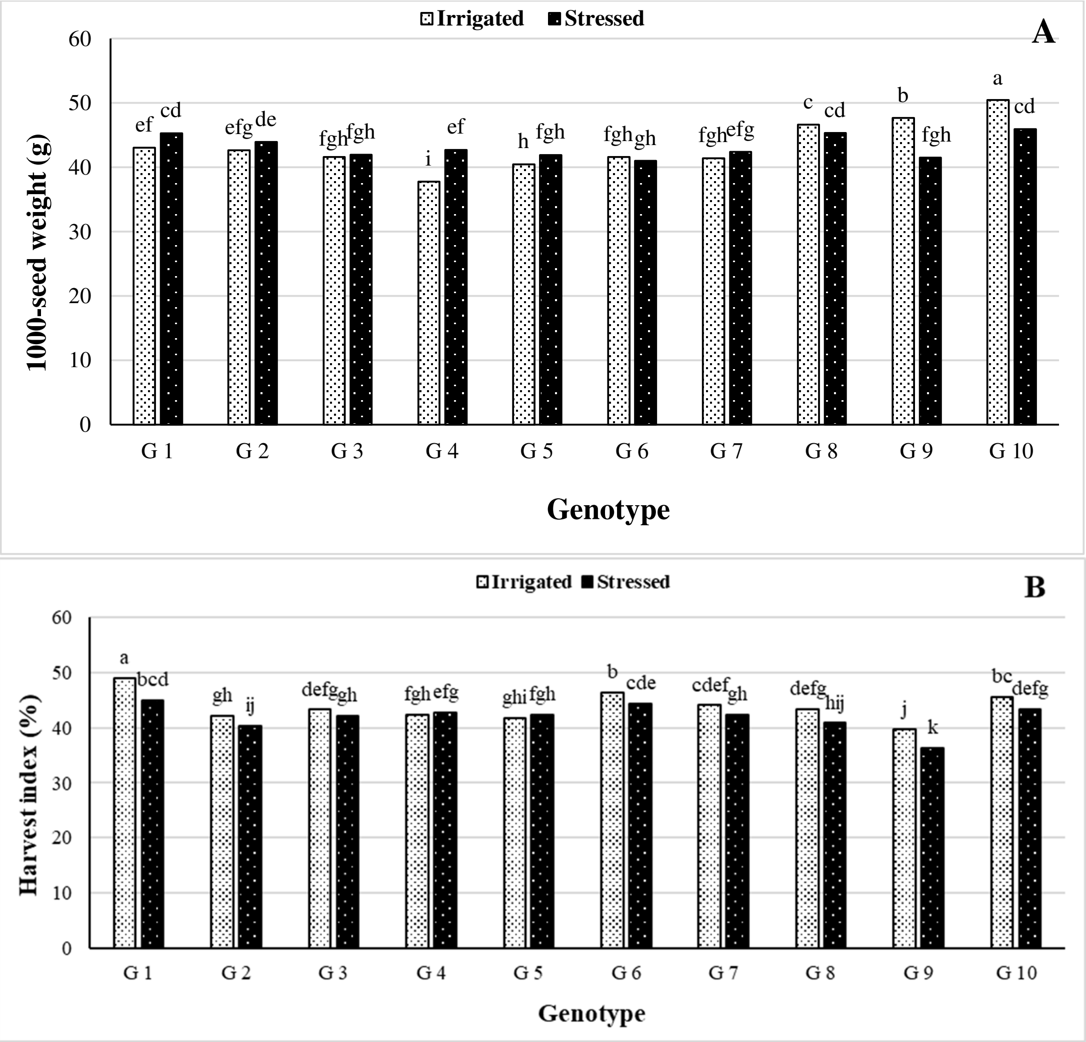

Figure 1. 1000-grain weight (A) and harvest index (B) of wheat genotypes under different levels of water deficit

Different letters indicate significant differences among the genotypes according to the LSD test ($P < 0.05$)

Translocation of dry matter, contribution of remobilization, and remobilization efficiency

The analysis of variance (Table 6) showed that the effects of year, water deficit treatment and genotype, and the interaction effects between water deficit level and genotype for the amount of dry matter translocated, remobilization and remobilization efficiency of photosynthetic materials were significant ($p \leq 0.01$), but the effect of water deficit on translocation of dry matter was not significant. The highest amounts of dry matter translocated under irrigated and water deficit conditions were observed in genotypes 2 and 5, respectively. The lowest amount of dry matter transferred under irrigated and water deficit conditions was observed in genotypes 3 and 9, respectively (Figure 2 A). The average contribution of remobilization in wheat genotypes under water deficit and irrigated conditions was 60.6% and 53.3%, respectively. The highest and lowest contribution of remobilization under water deficit conditions were observed in genotypes 3 and 9, respectively (Figure 2 B). The highest remobilization efficiency of photosynthetic materials under normal and stress conditions was observed in genotypes 2 and 3, respectively, which indicates the high potential of these genotypes to remobilize assimilates stored before pollination towards the grains (Figure 2 C).

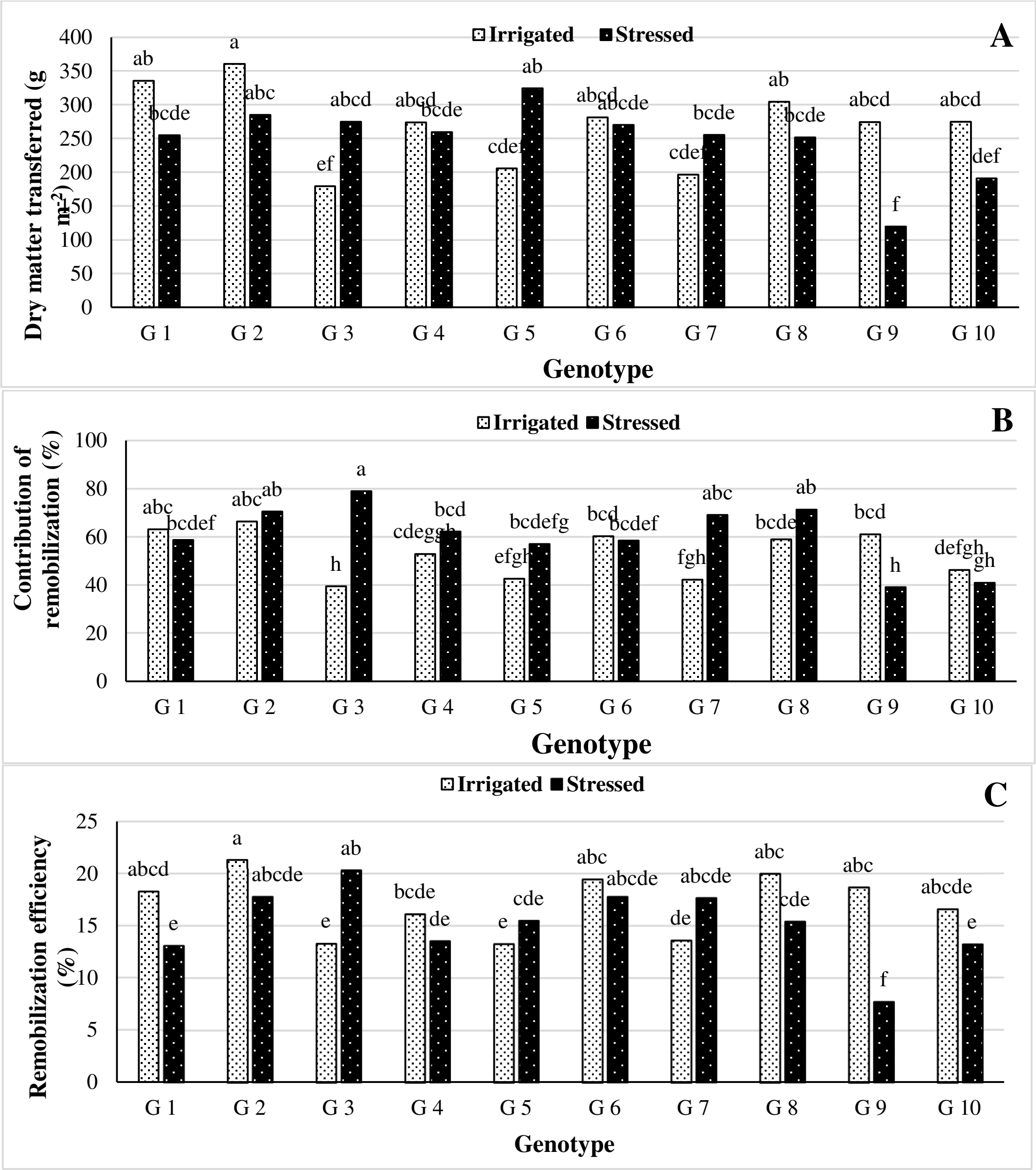

Figure 2. Dry matter transferred (A), the contribution of remobilization (B), and remobilization efficiency (C) of wheat genotypes under water stress conditions

Different letters indicate significant differences among the genotypes according to the LSD test ($P < 0.05$)

Absolute and relative contribution of current photosynthesis

The analysis of variance showed that the effects of year, water deficit treatment and genotype, and the effects of the interaction between water deficit treatment and genotype on the absolute and relative contribution of current photosynthesis were significant ($p \leq 0.01$) (Table 6). Current photosynthesis contributed less under water deficit than under irrigated conditions for all genotypes, whereas it contributed most under irrigated conditions in the case of genotype 5. In genotype 9, unlike other genotypes, current photosynthesis contributed more under water deficit than under irrigated conditions, but the difference was not significant (Figure 3 A). Under water deficit, the relative contribution of current photosynthesis was lower than under irrigated conditions for most genotypes. Only in genotype 9, a significantly higher relative contribution of current photosynthesis was observed (Figure 3 B).

Table 6. Analysis of variance of physiological traits of remobilization of assimilates of wheat genotypes under different levels of water deficit

SOV	DF	Dry matter transferred	Contribution of Remobilization	Remobilization Efficiency	Absolute current photosynthesis	Relative current photosynthesis contribution
Year	1	494211.67**	11554.82**	958.69**	365200.37**	**11540.97****
Repetition (year)	4	755.16	127.87	11.19	9106.51	**128.01**
Stress	1	12108.24^{ns}	1599.72**	105.39*	365200.02**	**1599.91****
Year × Stress	1	264798.07**	1731.94**	503.47**	666556.07**	**1732.14****
Genotype	9	16966.01**	674.08**	47.88**	23525.66**	**674.28****
Year × Genotype	9	32473.88**	1204.65**	72.47**	31875.91**	**1204.69****
Genotype × Stress	9	23012.69**	914.02**	79.13**	26085.04**	**913.94****
Year × Stress × Genotype	9	12361.83^{ns}	1204.65*	72.47**	31875.11^{ns}	**447.06***
Error	76	6364.17	206.9	17.33	8142.69	**206.88**
CV	-	30.82	25.25	25.84	44.93	**33.42**

**, *, ns: significantly different at the 1% and 5% of probability, and non-significant, respectively.

SOV = Sources of variation; DF = degrees of freedom; CV = coefficient of variation (%)

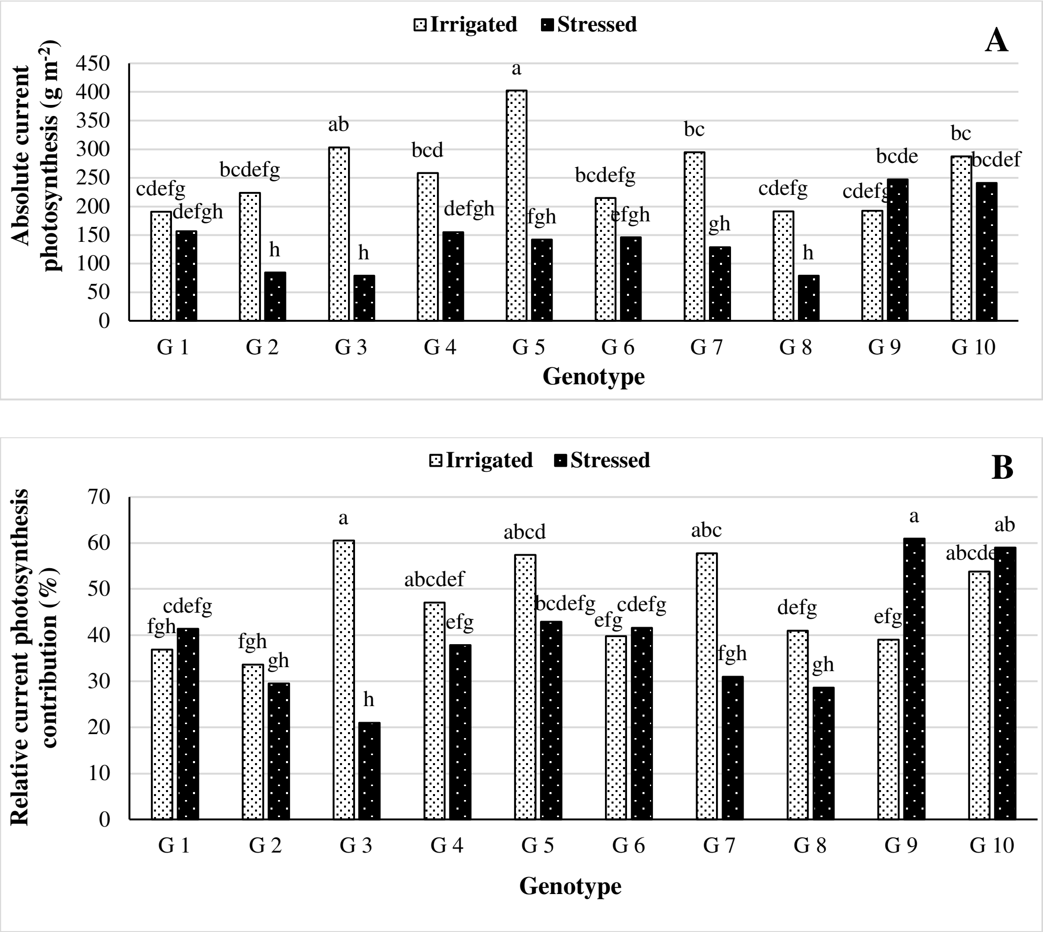

Figure 3. Absolute current photosynthesis (A) and relative current photosynthesis contribution (B) of wheat genotypes under water stress conditions

Different letters indicate significant differences among the genotypes according to the LSD test ($P < 0.05$)

Correlation between grain yield and remobilization

Correlation coefficients between remobilization traits and grain yield are shown in Table 7. Under water deficit, a significant positive correlation between grain yield, and translocated dry matter, remobilization efficiency, and the contribution of remobilization indicate the importance of selecting cultivars that remobilize more stored assimilates from vegetative organs to seeds under stress.

Table 7. Correlation of remobilization traits of assimilates with grain yield of wheat genotypes under irrigated conditions (top of the table) and water deficit conditions (bottom of the table)

Correlated traits	**Dry matter translocated**	**Contribution of remobilization**	**Remobilization efficiency**	**Contribution of current photosynthesis**	**Relative contribution of current photosynthesis**	**Grain yield**
Dry matter translocated	1	0.824**	0.954**	-0.505**	-0.824**	0.198
Contribution of remobilization	0.686**	1	0.748**	-0.841**	-1.000**	-0.319*
Remobilization efficiency	0.911*	0.787**	1	-0.423**	-0.748**	0.256*
Contribution of current photosynthesis	-0.182	-0.743**	-0.743**	1	-0.243	0.726**
Relative contribution of current photosynthesis	-0.686**	-1.000**	-0.787**	0.743**	1	0.319*
Grain yield	0.844**	0.243*	.680**	0.373**	-0.243	1

**, *: Significant at the 1% and 5% probability level, respectively

Discussion

The results of the present study showed that stopping irrigation at the spike emergence stage significantly reduced the yield and yield components of wheat genotypes. Under water deficit, premature aging of photosynthetic organs and consequently reduced contribution of current photosynthesis reduces total biomass production (Pireivatlou *et al.*, 2010). Adverse effects of water deficit on physiological traits and reduction of photosynthesis under stress conditions reduce grain yield (Pour-Aboughadareh *et al.*, 2020). Grain yield is determined by yield components such as number of spikes per unit area, number of grains per spike and single grain weight. Water deficit affects the phenology and growth rate of wheat and ultimately grain yield and its components (Khayatnezhad and Gholamin, 2020). Allahverdiyev *et al.* (2018) reported that drought stress had a negligible effect on plant height, spike length, number of spikelets per spike, and spike width, but biological yield, spike weight, number of seeds per spike, 1000-seed weight, and number of seeds per spike were severely affected. Water restriction effectively reduces the number of fertile spikelets due to the adverse effects of water depletion on the aborted of flowers of each spikelet, and is less productive at the beginning of the spikelet (Ahmad *et al.*, 2018). The number of seeds per spike is also an essential component of yield, which is significantly more affected than other components of grain yield under water deficit conditions. Moreover, water deficit after the emergence of spikes may reduce the number of seeds per spike by sterilizing the florets (Ganadi and Jalali, 2013).

Drought stress also dries pollen grains, and increases the percentage of empty grains or decreases the number of grains (Itam *et al.*, 2020). Cultivars with a higher 1000-seed weight can be used in breeding programs to increase this trait, and a higher 1000-seed weight can indicate better grain yield of cultivars under drought stress conditions (Pour-Aboughadareh *et al.*, 2020). Genotype is an essential factor affecting plant growth, and genotypes that store more photosynthetic material in their organs will have higher grain yield (Guo *et al.*, 2018). In the present study, it was observed that grain yield and yield components of the genotypes are different under water deficit conditions, which is in accordance with Pour-Aboughadareh *et al.* (2020) who reported that different wheat genotypes showed different responses to drought stress. On the other hand, wheat cultivars with high biomass weight and high harvest index can produce higher grain yield under both irrigated and water deficit conditions (see also Reynolds *et al*., 2009).

In this regard, Pour-Aboughadareh *et al.* (2020) reported that different wheat genotypes showed different responses to drought stress. Drought stress in comparison with the control, significantly reduced grain filling period, plant height, peduncle length, number of spikes, number of seeds per spike, 1000-seed weight, grain yield, biomass, and harvest index in all genotypes. In cereals, drought stress at any stage of the plant growth period between the beginning of the spike, and maturity reduces grain yield. The results of Khayatnezhad and Gholamin (2020) showed that drought stress significantly reduced growth-related factors, and the most significant impact on yield was related to 50 % of plant water requirement water stress. Also, the response of genotypes to changes in growth and functional traits under stress was different. Harvest index indicates the percentage of photosynthetic material allocation to grains, which can be reduced by drought stress index due to a more significant reduction in grain yield than straw production (Anwaar *et al*., 2020). Saeidi and Abdolo (2015) reported that water deficit after the pollination stage caused a significant decrease in harvest index and grain yield in wheat cultivars.

In this study, it was observed that the potential of translocated dry matter, current photosynthesis, remobilization, and remobilization efficiency varied among the genotypes under both irrigated and water deficit conditions. According to the results, there is an inverse relationship between current photosynthesis and remobilization. In other words, remobilization does not take place as long as the photosynthesis of the plant is not limited, because the transfer of photosynthetic material to the seeds requires less energy. In general, any factor that affects the rate of current photosynthesis also involves the accumulation and remobilization of photosynthetic material (Pampana *et al*., 2007). The results show that current photosynthesis and remobilization are affected by environment, so by changing the conditions of the genotypes, they behave differently. Various researchers have noted the positive role of current photosynthesis and the different potential of genotypes (Ovenden *et al*., 2017; Liu *et al*., 2020). Water stress has a negative effect on current photosynthesis, so it increases the need to remobilize non-structural carbohydrates from stem to seed. Various researchers have reported an increase in the remobilization of assimilates from branches to growing seeds, and an increase in grain filling rate under drought stress conditions (Ardalani *et al*., 2016; Abdoli *et al*., 2013). Meanwhile, genotypes with larger amounts of assimilates accumulated and higher rates of remobilization were less affected by end-of-season stresses (Yang and Zhang, 2006). It seems that in drought stress due to early maturity, accelerated aging, and lower leaf litter, more dry matter is translocated to the growing seeds in the spike (Ovenden *et al*., 2017). The remobilization efficiency in this study also varied amongst genotypes, and under water deficit, the genotypes reacted differently. The increase in remobilization efficiency under stress conditions is probably due to the reduction of current photosynthesis and the rise in the remobilization of assimilates. The results of other researchers show that there is a wide genetic diversity among different wheat genotypes for the storage and remobilization of carbohydrates (Pampana *et al*., 2007; Savić *et al*., 2017). Therefore, knowledge of genetic diversity can be used to enhance the capacity for storage and carbon remobilization in breeding programs (Ardalani *et al*., 2016). Liu *et al*. (2020) reported that the remobilization of water-soluble carbohydrates was affected by the days after pollination, water stress and their interaction, and the accumulation and remobilization of soluble carbohydrates according to the growth stage, water conditions, and stem internodes was different. Also, drought stress reduced the accumulation of soluble carbohydrates and significantly increased the soluble carbohydrate remobilization during grain filling. Allahverdiyev *et al.* (2018) also reported that drought stress accelerated dry matter remobilization, and the lowest dry matter remobilization was observed in tall and late genotypes with low harvest index.

Conclusions

Present results showed that water deficit in the stage of spike formation caused a decrease in the yield, yield components, and transfer of photosynthetic materials in the studied wheat genotypes. The genetic differences between the genotypes caused the difference in terms of the studied traits, so that among the studied genotypes, G 5 had the highest number of grains and grain yield. In general, the results indicate that part of the higher grain yield in drought-tolerant cultivars is due to the remobilization of non-structural carbohydrates from the stem to the grain. Therefore, the selection of cultivars that have a high ratio of allocation of photosynthetic materials to the spike, and a high remobilization under stress conditions from stem to grain, is one of the ways to choose drought tolerant cultivars and help to produce more under stress conditions.

Authors' Contributions

A.S., E.N., P.C.S. and S.M.: wrote the manuscript. S.Y.: statistical analysis. A.H.M.: Consulting in examining physiological traits.

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

We are very grateful to Islamic Azad University for its generous financial support.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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