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Study of photosynthesis, leaf water exchange and yield of field grown common winter wheat varieties under dry prone conditions

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Abstract

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Field experiment was conducted with six common winter wheat varieties in IPGR, Sadovo during 2020-2021 vegetation period. The gas exchange, relative chlorophyll content, canopy temperature depression, morphometry and leaf water exchange of the flag leaves were measured. After harvest the yield components were determinated. The main objective of this study was to determine the effect of water stress on response of photosynthetic activity, water exchange and yield in common winter wheat varieties. The better photosynthetic activity, presented by the parameters photosynthetic assimilation rate (A), intercellular (sub-stomatal) CO_2 concentration (Ci) and stomatal conductance (Gs) during grain filling stage was reported for the varieties Sashez, Nadita and Yailzla compared to a standard Sadovo 1. The highest values of the morphometric parameters fresh weight, dry weight and relative chlorophyll content of flag leaves were expressed at the varieties Nadita и Enola. From the analysis of the results for photosynthetic activity, leaf morphometry and water exchange, the most tolerant reaction to dry prone conditions can be determined in variety Nadita. The highest average yield was estimated for the varieties Avenue, Nadita and Enola. It was determinated the more intense physiological activity correlate with better yield in the varieties Nadita, Enola and Yailzla.

Keywords: common winter wheat; grain yield; leaf gas exchange; relative chlorophyll content; canopy temperature depression; water exchange

Introduction

Wheat, ranking second among cereals, is important staple food crop and it provides 20% of the protein in human nutrition (Braun et al., 2010). Wheat is one of the most cultivated crops in the world and in particular in areas with a lack of moisture from temperate to subtropical areas of the Earth. In this regard, the key determinant for good wheat performance is adaptation to a wide range of climatic conditions (Metwali et al., 2011; Ahmed et al., 2019). Drought is the most widespread abiotic factor contributing to major yield losses in agricultural systems worldwide. The rise in global temperature and variability in precipitation has made farming extremely challenging and increase food insecurity particularly in poor and developing countries (Chaves et al., 2003; Naumann et al., 2018). With the growth of world population, global food demand is estimated to increase by 100–110% from 2005 to 2050 (Tilman et al., 2011). However, the rising atmospheric CO_2 concentrations are coincident with the increase in temperature, altered precipitation, and intense extreme events, which may have opposite effects on sustainable food production (Bencke-Malato et al., 2019). Therefore, it is a challenge to improve crop productivity to meet the growing human food demand on the background of global climate change (Saha et al., 2015). Drought stress is characterized by the reduction of water content, diminished leaf water potential and turgor loss, closure of stomata and decrease in cell enlargement and growth (Jaleel et al., 2009). Photosynthesis is the most important source of biomass accumulation in all plants, algae and cyanobacteria, and it is one of the most sensitive physiological processes to abiotic stress (Pan et al., 2012). The photosynthetic rate, the transpiration rate, and the stomatal behavior are changed in varying degrees when plants are subjected to drought and N stresses. The effects of drought stress on photosynthesis can be divided into stomatal limitation and non-stomatal limitation (Flexas et al., 2006), It is generally acknowledged that reducing CO_2 diffusion from the atmosphere to the site of carboxylation due to stomatal closure and reduced mesophyll conductance, which in turn, contributes to a decrease in photosynthesis under water stress conditions (Chaves & Oliveira, 2004; Ashraf & Harris, 2013). Improving drought tolerance in plants is, therefore, of fundamental importance and an area of immense interest for plant scientists. Plants either succumb to negative effects of water scarcity or deploy profound changes at morphological, physiological, and metabolic levels to minimize the damage (Marchin et al., 2020).

The main objective of this study was to determine the effect of water stress on response of leaf gas exchange, leaf chlorophyll content, water exchange and yield in common winter wheat varieties.

Material and Methods

Field experiment was carried out during 2020-2021 vegetation period with six common winter wheat (*Triticum aestivum* L.) varieties in Institute of Plant Genetic Resources-Sadovo. The varieties were produced through conventional breeding method of inter-varietal hybridization. Varietal experiment was performed on a block scheme in four replications, with size of the experimental plot of 10 m^2. Seeds were sown at planting rate of 550 seeds per m^2. The studied genotypes were compared with the complex standard variety Sadovo 1. The analysis of yield and thousand-kernels weight (TKW) was performed on harvested plants at the end of July.

The leaf gas exchange parameters were measured using a portable intelligent photosynthesis system LCpro T. Intact flag leaves from each genotype were selected to measure the photosynthetic assimilation rate (A), transpiration rate (E), intercellular (sub-stomatal) CO_2 concentration (Ci) and stomatal conductance (Gs). The instantaneous water use efficiency (iWUE) was calculated as ratio between A/E. These parameters were estimated two times, as follows first time during vegetation stage medium milk of the grains (Zadoks scale №75) and second time during vegetation stage soft dough of the grains (Zadoks scale №85). The measurements were done from the middle part of each leaf. The data was collected between 09:00 AM and 11:00 AM. The range of the ambient conditions measured in chamber was as follows: an air temperature was 26.0-28.0°C and 27.0-28.5°C, an average air relative humidity (RH) was 17.3**±1.5** mbar and 14.4±1.7 mbar, photosynthetic active radiation (PAR) was 1100-1400 μmol m^{-2}s^{-1} and 1800-2000 μmol m^{-2}s^{-1} and an ambient CO_2 concentration was 403-422 vpm and 389-397 vpm.

Relative leaf chlorophyll content, expressed as Chlorophyll content index (CCI) was measured with a chlorophyll content meter-CCM 200 plus. The physiological assessment was carried out in vivo on the field. The measurements were performed according to the same scheme, as the measurements of the photosynthetic activity. From each genotype measurements of 15 flag leaves (n = 15) were made.

The canopy temperature depression (CTD)-leaf canopy temperature and air temperature were measured from LCpro T, as from the values of the two temperatures CTD was calculated according to the following formula CTD = T° air-T° leaf, proposed by Blum et al. (1982) and Amani et al. (1996).

Leaf morphometry parameters and water exchange – fresh weight (FW), dry weight (DW) and relative water content (RWC) (Turner, 1981; Beadle, 1993). The last parameter was determined in percent by the formula:

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

where FW– initial leaf weight (g); TW – leaf weight in full turgor after 24 h immersed in water (g); DW – dry weight of leaf after dried in dry chamber for 8h at 105°C (g).

Statistical data processing was performed with the software product Microsoft Excel for Windows 10. The standard error of means for physiological parameters and ANOVA for mean difference of the yield component were calculated.

Results and Discussion

Weather condition during physiological measurements

The weather conditions in the two consecutive days during which all physiological measurements were performed, respectively for a first and a second date were unfavorable mainly in terms of atmospheric and soil moisture. Three weeks before first plant readings on the field only 6.5 l/m^2 total rainfall was calculated. The average atmospheric humidity was below 60.0%, the wind speed was on average 14.4 km/h and the average daily temperature was 18.0°C three days before measurements. The weather conditions between first and second measurements were more favorable as follows total rainfall was 21.6 l/m^2 and the atmospheric humidity was 66.0%. Also, the average temperature was 17.0°C, but again there was a wind – 17.7 km/h.

Leaf gas exchange measurements

The better photosynthetic activity during milk maturity was reported for the varieties Sashez, Nadita and to a lesser extend in Yailzla (Table1), in these varieties the ratio between the parameters Ci, gs and net photosynthesis (A) is the most optimal compared to the standard Sadovo 1 and Avenue. A higher net photosynthesis and stomatal conductivity and a lower intercellular CO_2 content were observed at relatively close PAR values between 1171 and 1324. Zhao et al. (2020) report that net photosynthetic rate (Pn), intercellular carbon concentration (Ci), stomatal conductance (Gs) and transpiration (E), significantly decreased under moderate and severe stress. In this case, varieties Sashez and Nadita showed better drought resistance.

Under heat and drought stress conditions, wheat plants closing their stomata, which resulted in reduced transpiration, water loss and causes low amount of CO_2 fixation that led to reduction in photosynthesis and ultimately chlorophyll content (Zulkiffal et al., 2021).

The most appropriate relationship between the level of transpiration and CTD in drought stress, in this case a high transpiration and a high value of CTD was reported for Nadita and Enola. This ratio indicated the least effect of weather conditions on them. In the Sashez and Yailzla, which also have planophytic leaves, high transpiration did not lead to high CTD, so they experience more stress from environmental conditions at this time, which did not affect their photosynthesis. The variety Avenue had low transpiration with high CTD due to it small erect leaves. The calculated an instantaneous WUE indicator has the highest value in the varieties Nadita, Sashez and Yaizla, which confirms their advantage.

The second measurement at dough maturity stage of plan development showed trend to decrease in the parameters net photosynthesis (A), stomatal conductance (gs) and intercellular CO_2 content (Ci), respectively by 22.6%, 27.2% and 10.0% (Table 2). Ahmad et al. (2020) was presented results for considerably reduction of net photosynthesis in rainfed condition. As for the varieties Yailzla and Sadovo 1 was read less reduction of the net photosynthesis. The varieties Yailzla, Nadita and Sashez had the most intensive photosynthetic apparatus, but the differences between all studied varieties are lower than in the previous data collection. Also, in the Yailzla variety, the relation of transpiration intensity and CTD is indicative of a tolerant drought response, but this does not lead to a better instantaneous WUE. The varieties Enola and Sashez were characterized with better reaction by this indicator (Table 2).

Leaf morphometry and chlorophyll content index measurements

A higher value of the morphometric parameters fresh and dry weight of flag leaves was observed for the varieties Nadita, Enola and the standard Sadovo 1 at milk maturity stage. On the other hand, the lowest values were reported at variety Avenue (Table 3). According to these results, the CCI measurements were higher in the same genotypes, as notes the significantly lowest result for variety Avenue (Table 3). Abdullah et al. (2011) and Qayyum et al. (2021), observed reduction in total chlorophyll in dry zones at anthesis and grain

Table 1. Leaf gas exchange parameters of common winter wheat varieties at grain filing stage- Zadoks scale №75

Varieties	Ci, vpm	E, mmol m^{-2} s^{-1}	Gs, mmol m^{-2} s^{-1}	A, µmol m^{-2} s^{-1}	CTD, t°	A/E ratio
Sadovo 1	237.7±10.8	1.90±0.15	0.10±0.010	8.54±0.99	-2.04±0.06	4.49±0.31
Enola	248.2±14.1	2.19±0.19	0.14±0.015	10.20±0.95	-1.47±0.04	4.66±0.41
Nadita	230.9±7.6	2.19±0.08	0.14±0.011	11.20±0.36	-1.88±0.03	5.10±0.22
Sashez	202.3±11.5	2.35±0.12	0.15±0.017	13.04±0.86	-2.27±0.07	5.54±0.38
Yailzla	220.1±11.6	2.05±0.09	0.11±0.009	10.59±0.72	-2.57±0.06	5.17±0.27
Avenue	256.5±10.5	1.97±0.05	0.13±0.005	9.06±0.60	-1.84±0.04	4.60±0.20

The data are presented as means±standard error (n = 10)

Table 2. Leaf gas exchange parameters of common winter wheat varieties at grain filing stage-Zadoks scale №85

Varieties	Ci, vpm	E, mmol m^{-2} s^{-1}	Gs, mmol m^{-2} s^{-1}	A, µmol m^{-2} s^{-1}	CTD, t°	A/E ratio
Sadovo 1	193.1±5	2.05±0.16	0.09±0.009	8.08±0.65	-4.58±0.08	3.94±0.24
Enola	203.6±13	1.56±0.10	0.06±0.006	6.36±0.74	-4.63±0.07	4.06±0.21
Nadita	227.8±8	2.38±0.06	0.10±0.006	8.45±0.25	-4.08±0.09	3.55±0.30
Sashez	197.3±7	2.00±0.05	0.09±0.004	8.29±0.19	-4.49±0.11	4.14±0.15
Yailzla	220.8±7	2.66±0.15	0.12±0.011	9.39±0.52	-3.88±0.06	3.53±0.22
Avenue	229.3±6	2.40±0.07	0.10±0.005	7.94±0.37	-3.71±0.07	3.30±0.18

The data are presented as means±standard error (n = 10) filling phase in genotypes durum wheat and bread wheat in condition of the drought stress.

A leaf RWC is propose as more important indicator of water status than other water potential parameters under drought conditions. During plant development drought stress significantly reduced RWC values (Siddique et al., 2000). The highest RWC was calculated for Nadita, followed by the varieties Enola and Yailzla, as Nadita and Enola combined high growth intensity and good hydration (Table 3). On the other hand, the varieties Yailzla, Sashez and Avenue were responded, as the drought tolerant varieties with smaller leaves and medium leaf hydration.

The next measurement showed increase of the leaf morphometric parameters and chlorophyll content index in all study varieties, as the same time was observed decrease of leaf RWC. These results indicated for stable reaction on unfavorable ambient conditions (Table 4). The varieties Nadita, Enola and Yailzla revealed more tolerant reaction related to active growth and higher water status in soft dough stage.

From the analysis of the results for photosynthetic activity, leaf morphometry and water exchange, the most tolerant reaction to dry prone conditions can be determined in variety Nadita. The lower instantaneous WUE in the second data reading at variety Nadita, does not affect the accumulation of biomass. The varieties Sashez, Yailzla and Enola are characterized by a tolerant reaction, the first two having more intensive photosynthetic activity and instantaneous WUE. A variety Enola has good morphometric parameters and RWC, and longer vegetation period compared to the other varieties, which gives an advantage in the accumulated biomass.

Yield components

The grain yield is an indicator for winter common wheat that is influenced by the interaction of the variety of the environmental conditions (Reynolds et al., 2011). Figure 1 presents the results obtained from yield and thousand kernels weight for the study period. The data showed that significantly the highest average yield of the four replications was estimated for the varieties Avenue-829.0 kg/da, Nadita-808.7 kg/da and Enola-791.5 kg/da, and the lowest value was for the variety Sashez-712.1 kg/da. Bonchev (2020) proved, that the conditions of the year have the largest share in the formation of seed yield of the Bulgarian common winter wheat. These results indicated, that despite lower value of the most physiological parameters received for a variety Avenue, this variety possess strong adaptive mechanisms at ambient drought stress. All the same, was determinate the more intense physiological activity correlate with better yield in the varieties Nadita, Enola and Yailzla.

The highest TKW were estimated of the varieties Sadovo 1, Sashez and Yailzla (Figure 1), and in this regard the values of a parameter TKW reveal a strong negative correlation with yield of the varieties (r= -0.924). Guttieri et al. (2001) and Lopes et al. (2012) reported that under rain-fed conditions positive significant correlations were observed between yield and TKW, however sometimes negative association

Table 3. Leaf morphometry, RWC and chlorophyll content index of common winter wheat varieties at grain filing stage-Zadoks scale №75

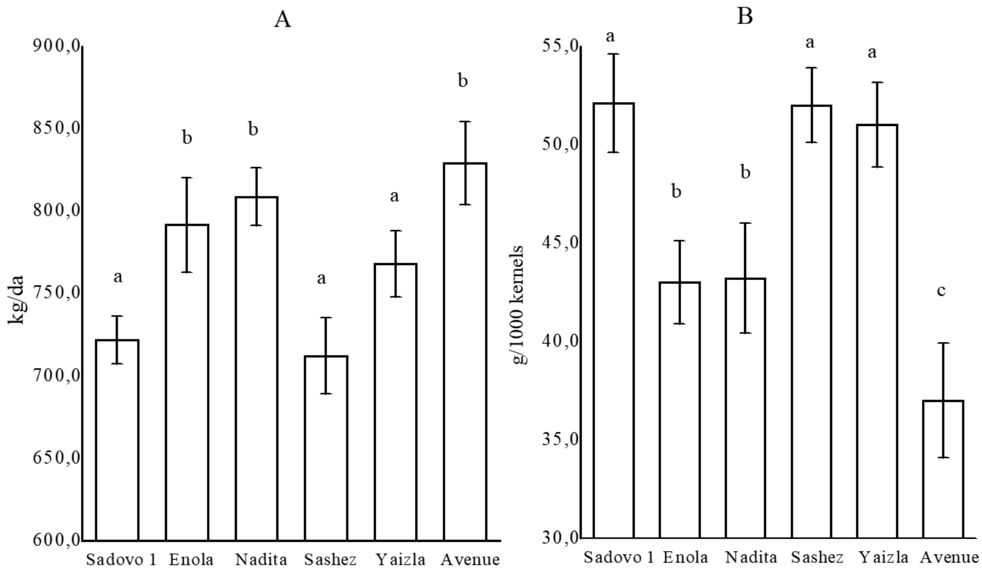
Varieties	FW, mg	DW, mg	RWC, %	CCI
Sadovo 1	882.0±18.2	262.0±10.0	74.0±3.2	37.7±1.74
Enola	930.0±25.1	261.0±14.2	80.4±2.8	42.3±2.38
Nadita	1051.0±34.2	293.0±13.2	81.0±2.5	44.7±1.38
Sashez	778.0±21.3	231.0±9.8	76.1±2.7	32.2±0.85
Yailzla	768.0±20.0	221.0±13.0	77.5±3.0	36.3±1.13
Avenue	518.0±19.1	156.0±11.0	72.5±2.0	25.0±1.47

The data are presented as means±standard error; (n = 10) for DW, RWC and DW and (n = 20) for CCI

Table 4. Leaf morphometry, RWC and chlorophyll content index of common winter wheat varieties at grain filing stage-Zadoks scale №85

Varieties	FW, mg	DW, mg	RWC, %	CCI
Sadovo 1	1054.0±28.7	365.0±15.0	71.3±2.3	40.9±1.85
Enola	1110.0±31.1	372.0±18.0	76.2±2.5	45.5±2.00
Nadita	1203.0±34.1	401.0±14.2	78.2±3.1	48.2±1.54
Sashez	958.0±27.8	318.0±13.8	72.1±1.9	40.8±1.23
Yailzla	942.0±25.6	308.0±12.3	75.2±2.7	41.6±1.34
Avenue	774.0±21.2	281.0±13.1	70.1±3.1	35.2±1.17

The data are presented as means±standard error; (n = 10) for DW, RWC and DW and (n = 20) for CCI



LSD 5 % 65.7; LSD 1% 90.8; LSD 0.1% 125.5

LSD 5 % 2,3; LSD 1% 3.2; LSD 0.1% 125.5

Fig. 1. Yield components of common winter wheat varieties grown in field experiment: (A)Yield; (B) TKW-1000 kernels weight; The data are presented as means±standard error. The different letters represent significance difference

were estimated. In this case, it can conclude that the better physiological activity at part of the varieties during grain filling stage show strong positive correlation with TKW. However, the RWC showed positive correlation (r=0.525) with the yield of all study varieties and stay most stable parameter for yield monitoring at drought stress.

Conclusions

The more intensive photosynthetic activity, presented by the parameters photosynthetic assimilation rate (A), intercellular (sub-stomatal) CO_2 concentration (Ci) and stomatal conductance (Gs) during grain filling stage was reported for the varieties Sashez, Nadita and Yailzla compared to a standard Sadovo 1.

The most appropriate relationship between the transpiration level and CTD in drought stress, was reported for the varieties Nadita and Enola.

The highest value of the morphometric parameters fresh weight, dry weight and relative chlorophyll content of flag leaves were expressed at the varieties Nadita и Enola

The highest RWC was calculated for varieties Nadita, Enola and Yailzla, as Nadita and Enola combined high growth intensity and good hydration.

From the analysis of the results for photosynthetic activity, leaf morphometry and water exchange, the most tolerant reaction to dry conditions can be determined in variety Nadita. The varieties Sashez, Yailzla and Enola are characterized by a tolerant reaction, the first two having better photosynthetic activity and water use efficiency.

The highest average yield was estimated for the varieties Avenue, Nadita and Enola.

It was determinate the more intense physiological activity correlates with better yield in the varieties Nadita, Enola and Yailzla.

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