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Influence of climate variations on some physiological and morphological characteristics of winter wheat

Irena Jug[1], Danijel Jug[1], Boris Đurđević[1], Bojan Stipešević[1], Srđan Šeremešić[2], Vesna Dragičević[3], Borivoj Pejić[2], Ivica Đalović[4]

[1]*Faculty of Agriculture, Osijek, Kralja Petra Svačića 1d, 31000, Osijek, Croatia (ijug@pfos.hr)*
[2]*Faculty of Agriculture Novi Sad, Trg D. Obradovića 8, 21000 Novi Sad, Serbia*
[3]*Maize research Institute, Zemun Polje, Belgrade-Zemun, Serbia*
[4]*Institute of Field and Vegetable Crops, Maxim Gorki 30, 21 000 Novi Sad, Serbia*

Abstract
Temperature and precipitation regimes are the key factors affecting the agricultural productivity. The impact of climate variations on some physiological and mophological attributes of winter wheat was studied through field experiments conducted at the North-eastern Croatia over three climatic different years (2002, 2003 and 2004, respectively). Concentration of chloroplast pigments and all morphological traits were strongly influenced by climatic conditions. The highest concentration of chloroplast pigments was recorded in 2002, and the lowest value was measured in 2003. The plant height, stem length, number of fertile and sterile spikelet was higher in 2004, and the lowest values were recorded in 2003. Statistically significant differences were found between plant heights and stem length in all investigated years. All physiological parameters were highly significantly correlated, and their dependence is linear and positive. The concentration of chloroplast pigments had highly significant and positive correlations with plant height, stem length, spike length, number of fertile spikelet, number of grains per spike and yield. Very significant, positive correlations were observed between all physiological and morphological parameters of wheat with plant density and yield. Number of seeds per plant was significantly correlated with the concentration of chloroplast pigments and length of spike. The number of fertile spikelet in the spike was significantly correlated with all tested indicators except the number of sterile spikelet, which are significantly negatively correlated with the concentration of chloroplast pigments. In this study very significant correlation was determined between plant density in heading and yield.

Key words: climate variations, winter wheat, chloroplast pigments, morphological traits

Introduction

Croatia has very favorable agroecological condition for winter wheat growth, especially at the area of Slavonia and Baranja region. In crop production structure winter wheat is, together with maize, the most grown crop, covering area of around 200 000 ha each year. The growing number of researches is directly connected with winter wheat production in unfavorable weather and production conditions, with the main goal of increasing crop yield, with lesser production costs. The achieved yields are more and more connected with photosynthetic potential and photosynthetic plant activity (Sabo et al., 2002; Jug et al., 2008). The external factors with their variability and intensity significantly impact plant's growth and development, and yield quantity is determined not only by crop's genome, but also with different agroecological conditions and applied agrotechnology (Vukadinović et al., 1989).

The photosynthesis is determined by numerous internal and external factor, such as: plant's development conditions, degree of adaptability to environmental conditions, water and nutrient supply, temperature, quality and quantity of the light, CO_2 and O_2 concentration, etc. Chloroplast pigments concentration in the winter wheat is inherited characteristic, moderated by numerous environmental factors (Jug et al., 2010). Numerous researches have been pointing out dependency of chloroplast pigments concentrations by growth and development of the crop, and pigment concentration and photosynthesis intensity are in close dependency with ontogenetic winter wheat growth. The large number of photosynthetic productivity factors has different impact at different genotypes in different agroecologic conditions (Jug et al., 2008). The most important for photosynthesis activity are light, nutrition, water supply and temperature.

The aim of this study was to examine the impact of fluctuations of temperature and precipitation regimes on winter wheat morphological (plant height, length of stalk, length of spike) and physiological properties (chlorophyll a, chlorophyll b, chlorophyll (a+b) and carotenoids) and determine the correlation between the investigated properties of winter wheat.

Materials and methods

This experiment was conducted at the north-eastern part of Croatia, in Baranja Region, at experimental field near Knezevo (N: 45°82′, E: 18°64′) for winter wheat (*Triticum aestivum* L.), cultivar Demetra, during three years (2001/2002, 2002/2003, 2003/2004). The main experimental set-up was a complete randomized block design in four replications. The experimental site soil is classified as a calcareous chernozem on loess substrate (FAO, 1990). The soil analyses presented very favorable chemical properties (pH in H_2O = 8.1, pH in 1mol dm^{-3} KCl = 7.5; humus = 2.6%, $CaCO_3$ = 2.1%; AL-soluble P_2O_5 and K_2O = 18.7 and 28.4 mg $100g^{-1}$, respectively). The size of basic experimental plot was 900 m^2 (Jug, 2006). The winter wheat was sown at the planned rate of 700 germinating seeds m^{-2}, at the inter-row distance of 16.5 cm. The fertilization was uniform across treatments and years, and it consisted of $N:P_2O_5:K_2O$ = 120:130:130 kg ha^{-1} (500 kg N ha^{-1} 8:26:26 in autumn, 150 kg KAN ha^{-1} in tillering and 150 kg KAN ha^{-1} in period of stem elongation).

The samples of winter wheat for physiological parameters were sampled in Feekes 6.0. The positions for leaf collection were chosen by the appearance and condition of the crop, with precautions needed for proper average sample collection. For chloroplast pigments analysis the 0.1 g of fresh weight (FW) of the most developed leaf was taken. The concentration of chlorophyll a, chlorophyll b, chlorophyll a+b and carotenoids were determined spectro-photometrically (at wave lengths 662, 644 and 440 nm) from an acetone extract using the methods of Holm and Wettstain and expressed in mg per g of fresh mass (Arsenijević-Maksimović and Pajević, 2002).

The samples of winter wheat for morphological traits were sampled in different phenological stage. Plant density (number of plants of winter wheat in the earing – according to Feekes 11) was determined by counting all primary and secondary stem but also on the surface of 0.25 m^2 in four repetitions. Plant height of winter wheat, stem length, number of spikelets per spike, spike length and number of grains per spike was measured in 20 plants (2x10 plants per each plot in four repetitions). The winter wheat grain yield was achieved by weighing of the total grain mass from each plot (scale with d=1 kg t^{-1}). The final yield was recalculated for 1 ha area and standardized for 14% of the grain moisture.

All parameters were analyzed with two way analysis of variance (ANOVA) with calculation of LSD values for P<0.05 significance levels. Correlation between parameters was tested with standard multiple correlation analysis.

Results and discussion

Weather characteristics were mainly specific in comparison with long-term means. Total precipitation from September to July in 2002 was 441 mm, 407 mm in 2003 and 717 mm in 2004. According to long term means (30 yr.), where total precipitation was 572 mm from September to July, year 2004 was characterized as humid year. The first two years of research (2002 and 2003) were below average amount of precipitation according 30-yr means. Climate conditions in 2003 were extremely unfavorable for winter wheat primarily because the insufficient amount of precipitation in growing season (126 mm) and higher average temperatures in May, June and July (Table 1). Total precipitation in growing season was 174 mm less than 30-yr means (300 mm). Due to low amount of precipitation during the growing season this year can be characterized as dry year. Total precipitation in growing season in 2002 (270 mm) was in range of 30-yr means (300 mm). Mean air temperatures were higher for 2ºC in 2002 and 2003 (Table 1) then the 30-yr average. Mean air temperature in 2004 was the same as long term means temperature (15ºC).

Table 1. Total precipitation (mm) and temperature (º C) from September through February (winter) and the growing season (March through July) at Kneževo site during 2001/2002, 2002/2003, 2003/2004 and long-term means (LTM: 1965-2005).

	2002	2003	2004	LTM	2002	2003	2004	LTM
	Precipitation (mm)				Temperature (ºC)			
Winter season	171	281	330	272	6	9	6	6
March	10	4	35	41	9	6	6	6
April	64	9	120	46	11	11	11	11
May	86	33	77	60	19	20	17	17
June	49	19	114	92	22	25	20	20
July	61	61	41	61	24	23	22	21
Growing season	270	126	387	300	17	17	15	15

Varying of chlorophyll a, carotenoids and chlorophyll (a+b) (Table 2) was strongly influenced by agro climatic conditions. The highest concentration was recorded in 2002 (chlorophyll a=1.753 mg per g FW, chlorophyll a+b=2.234 mg per g FW and carotenoids 0.656 mg per g FW) and the lowest value was measured in 2003 (chlorophyll a=1.269 mg per g FW, chlorophyll a+b=1.656 mg per g FW and carotenoids 0.455 mg per g FW).

Statistically significant differences were found in the concentration of chlorophyll a and carotenoids in 2002 compared to 2003 and 2004. Concentration of chlorophyll a+b was significantly higher in 2002 compared with 2003 and 2004. Differences in chlorophyll a+b concentration were significant between 2003 (1.656 mg per g FW) and 2004 (1.911 mg per g FW). Other differences in the concentration of chloroplast pigments were not statistically significant (Table 2).

Under conditions of sufficient moisture in the soil, plants turgidity is favorable, which is a very important factor in creating leaf mass and total production of photosynthesis. In drought conditions, as it was in 2003, due to stress caused by water deficit leads to poor development of the plant. Studies have shown that the photosynthetic rate of leaves decreases as relative water content and water potential decrease (Cornic and Massacci, 1996). Limitation of net photosynthetic rate in low moisture stressed plant is mainly through stomatal closure (Cornic and Massacci, 1996; Cornic, 2000) and by metabolic impairment (Flexas and Medrano, 2002). Availability of soil moisture and nutrients for a longer period in moisture conserved plots, which resulted in increased chlorophyll synthesis. In water stressed plants, loss in chlorophyll is associated with a reduction in the flux of nitrogen into the tissue as well as alterations in the activity of enzyme systems such as nitrate reductase (Begum and Paul, 1993). Akram et al. (2010) reported that chlorophyll content in wheat leaves was significantly increased under drought conditions which are contrary to our results.

Table 2. Physiological and morphological properties, plant density, number of grains per spike and yield of winter wheat in three climatic different years

characters	2002	2003	2004
chlorophyll a (mg g $^{-1}$ FW)	1.753 a[†]	1.269 b	1.472 b
chlorophyll b (mg g $^{-1}$ FW)	0.481	0.386	0.439
chlorophyll a+b (mg g $^{-1}$ FW)	2.234 a	1.656 c	1.911 b
carotenoid (mg g $^{-1}$ FW)	0.66 a	0.46 b	0.54 b
plant height (cm)	66.51 b	41.61 c	84.34 a
stem length (cm)	59.94 b	36.30 c	77.88 a
spike length (cm)	6.57 a	5.30 b	6.46 a
number of fertile spikelet	14.31 a	12.65 b	14.76 a
number of sterile spikelet	1.9 b	2.0 ab	2.5 a
number of grains per spike	35.53	29.73	31.43
plant density (plant per m^2)	559 a	426 c	511 b
yield (t ha^{-1})	6.70 a	2.52 b	6.66 a

[†]the means of the same lowercase letter are not statistically significant at the $P<0.05$ level

Wheat is particularly sensitive to stress injury and the crop is often grown in areas where high temperatures limit productivity. The impact of heat stress on seedling growth and leaf development has been established from the temperature sensitivity of pigmentation and the inhibition of the chloroplast function in wheat (Mohanty and Mohanty, 1988). Photosynthesis is known to be one of the most heat-sensitive processes and it can be completely inhibited by high temperature and these photosynthesis decreases could result from the inhibition of photosystem II (PSII) activity, which has been shown to be the most thermally labile component of the electron transport chain (Havaux et al.,1991, Camejo et al., 2005). In this study, the highest concentration of chlorophyll a, chlorophyll b, chlorophyll a+b and carotenoid was in the year with higher temperatures than 30-yr means. Increased temperature had a positive effect on the synthesis of chloroplast pigments.

All morphological traits were under significant influence of fluctuations of temperature and precipitation regimes. The plant height was higher in 2004 (84.34 cm) and the lowest in 2003 (41.61 cm). Statistically significant differences were found in the plant height between all investigated years. The stem length was greater in 2004 (77.88 cm) and the lowest in 2003 (36.30 cm). All the differences in the length of the stem were statistically significant (Table 2). The spike length was higher in 2002 (6.57 cm) and the lowest in 2003 (5.30 cm). Statistically significant differences were found in the length of spike between all investigated years. Number of fertile and sterile spikelets was under significant influence of agroecological conditions in investigated years. The highest value was recorded in 2004 (number of fertile spikelet=14.76; number of sterile spikelet=2.5) and were significantly higher than in 2003 (number of fertile spikelet=12.65; number of sterile spikelet=2) (Table 2).

Grain yield is a complex trait and highly influenced by many genetic factors and environmental fluctuations. The highest yield was detected in 2002 (6.70 t ha^{-1}), and the lowest yield in 2003 (2.52 t ha^{-1}) (Table 2). Moisture deficits that frequently occur from March through July in 2003 reduced the yield of winter wheat, which is in accordance with numerous authors who emphasized the importance of climatic conditions during the growing season (Sabo et al., 2006; Jug et al., 2011).

Between the morphological and physiological characteristics, yield components, plant density and yield were found numerous correlations (Table 3). All physiological parameters were highly significantly correlated, and their dependence is linear and positive. Increasing concentrations of photosynthetic pigments increased productivity, and hence habitus plants were higher. The concentration of chloroplast pigments had highly significant and positive correlations with plant height, stem length, spike length, number of fertile spikelet, number of grains per spike and yield. Kaya et al. (2002) have been found a strong positive correlation between peduncle length and grain yield. In other cases, such relationship has been found inverse (Briggs and Aytenfisu, 1980) or no relationship (Villegas et al., 2006) depending on the environment.

Table 3: The correlation coefficient between all investigated parameters

	1	2	3	4	5	6	7	8	9	10	11	12
1	1.00											
2	0.94	1.00										
3	0.86	0.84	1.00									
4	0.93	0.90	0.97	1.00								
5	0.93	0.85	0.85	0.89	1.00							
6	0.65	0.58	0.44	0.48	0.62	1.00						
7	0.88	0.81	0.93	0.94	0.80	0.86	1.00					
8	-0.09	-0.10	-0.84	-0.38	-0.15	0.51	0.30	1.00				
9	0.69	0.59	0.52	0.63	0.59	0.28	0.65	-0.05	1.00			
10	0.89	0.78	0.72	0.76	0.87	0.89	0.93	0.22	0.56	1.00		
11	0.80	0.68	0.53	0.58	0.77	0.98	0.89	0.41	0.30	0.91	1.00	
12	0.98	0.92	0.80	0.88	0.94	0.70	0.92	0.01	0.73	0.91	0.78	1.00

Legend: 1-chlorophyll a; 2-chlorophyll b; 3-carotenoids; 4-chlorophyll (a+b); 5-plant density; 6-plant height; 7-number of fertile spikelet; 8-number of sterile spikelet; 9-number of grains per spike; 10-yield; 11-stem length; 12-spike length

Very significant, positive correlations were observed between all physiological and morphological parameters of wheat with plant density and yield. Number of seeds per plant was significantly correlated with the concentration of chloroplast pigments and length of spike (Table 3). The number of fertile spikelet in the spike was significantly correlated with all tested indicators except the number of sterile spikelet, which are significantly negatively correlated with the concentration of chloroplast pigments. In this study very significant correlation was determined between plant density in heading and yield. Yousaf et al., (2008) reported positive genotypic and phenotypic correlation of yield with number of spikelets and number of grains per spikelet. The same authors reported negative but highly significant correlations of yield with plant height.

Conclusion

This research has proved a highly significant influence of agro climatic conditions on the chloroplast pigments concentrations (except chlorophyll b concentration), yield traits (except number of grains per spike), plant density and yield, respectively. The lowest values of all physiological and morphological parameters were detected in drought conditions, in 2003. Grain yield in 2003 was lower than in other investigated years. All physiological and morphological parameters were highly significantly correlated with each other. Very significant, positive correlations were observed between all physiological and morphological parameters of wheat with plant density and yield.

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