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Effects of Salt Stress on the Photosynthesis of Maize and Sorghum

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Abstract. In this study, the effects of salt stress on the photosynthetic processes in sorghum (*Sorghum bicolor* L. *Albanus concep*) and maize (*Zea mays* L. *Mayflower*) were compared. The plants were grown in half-strength Hoagland solutions containing different NaCl concentrations (0, 50, 150 and 250 mM NaCl) for 6 days. Pulse Amplitude Modulated chlorophyll fluorescence, photooxidation of P_{700} and pigment analysis were used for characterization of the salinity effects on the studied plants. The treatment of plants with the high concentrations of NaCl led to an inhibition of the chlorophyll fluorescence parameters like the photochemical quenching, the rate of photosynthesis and the linear electron transport in sorghum and maize. All these changes corresponded to decrease in the pigment content and changes in chlorophyll *a/b* ratio. The analysis of the P_{700} photooxidation revealed that the photosystem I photochemistry was inhibited at the highest NaCl concentration in both studied plants. Data also revealed that sorghum is more sensitive to salt stress than maize. The reasons for different effects of salt stress on the maize and sorghum are described.

Key words: chlorophyll fluorescence, pigment content, salt stress, sorghum, maize.

Introduction

Salt stress is one of the major abiotic stress factors that restricts growth and yields of many crop plants (Acosta-Motos et al., 2017; Ashraf & Harris, 2013). Over the past years the climate changes have led to increase of soil salts (especially sodium salts), making much of the cultivated land unsuitable for agricultural purposes. This has become a major environmental problem worldwide, as the soil salinity affects about 30% of irrigated and 6% of the total area (Daliakopoulos et al., 2016). In Bulgaria, saline soils occupy approximately 33 310 ha (Shishkov & Kolev, 2014), as they are most common in the Plovdiv region - along the Maritza River. There are also affected areas around Burgas, Varna, Veliko Turnovo, Pleven, Sliven, Stara Zagora and Yambol. Depending on their electrical conductivity (EC), saline soils are divided into some classes: non-saline (< 2 mS/cm), slightly saline (2 – 4 mS/cm), moderately saline (4 - 8 mS/cm), very saline (8 - 16 mS/cm) and highly saline (> 16 mS/cm) (Ivushkin et al., 2019). The extent of salt-induced negative effects in plants is determined by the salt concentrations in the soil, the duration of

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stress and the genotype of plants species (Acosta-Motos et al., 2017; Dulai et al., 2019; Munns, 2005).

The subjects of this study were two important crops from family *Poaceae*: maize (*Zea mays* L. *Mayflower*) and sorghum (*Sorghum bicolor* L. *Albanus concep*). Sorghum is a herbaceous plant that is used for food, feed, alcoholic beverages and biofuel. Moreover, sorghum is the fifth most spread crop in the world (Mundia et al., 2019). Areas occupied by sorghum are not as widespread as other cereals in Bulgaria (about 6 000 ha), but they have increased in recent years, especially due to the recurrent of droughts and high temperatures of the south part of the country (Slanev, 2018). Maize is also representative of the cereal family and is used for grain, silage and green fodder. Today, it is the world's second-largest cereal crop (Gong et al., 2015). In recent years, the arable land with maize in Bulgaria are about 418,000 ha (Tanev, 2017). Unlike sorghum, it is not dry-resistant crop and high yields cannot be obtained without irrigation.

Further a positive relationship between the photosynthetic capability and crop production has been well documented (Long et al., 2006). At the same time, it has been found that the photosynthesis is very sensitive to soil salinity (Ashraf & Harris, 2013; Dulai et al., 2019; Kalaji et al., 2018). Previous studies revealed that salt stress affects differently the amount of photosynthetic pigments in plants, as in salt-tolerant species, the content of chlorophylls and carotenoids increases, while in salt-sensitive species, it decreases (Akram & Ashraf, 2011; Lu et al., 2003; Santos, 2004; Sudhir & Murthy, 2004).

One of the sensitive sites of photosynthesis under salt stress is the photosynthetic apparatus (Jusovic et al., 2018; Stefanov et al., 2019), as the photosystem II (PSII) complex is considered to be the most sensitive site (Baker, 1991; Hakala et al., 2005; Lu et al., 2003; Vass, 2012). The previous studies have demonstrated that the sensitivity to salt stress of this complex depend on the type of the plants (Abdeshahian et al., 2010; Al-Taweel et al., 2007; Jajoo, 2014; Loreto et al., 2003; Saleem et al., 2011). The study of Mehta et al. (2010) has shown that salt stress affects the heterogeneity of PSII with respect to the antenna size. The changes in both the donor and the acceptor side of PSII have been also reported (Jajoo, 2014). In recent years, the studies with wheat plants have shown that the changes in the functions of the photosynthetic apparatus have been accompanied by an increase in the energy transfer to the photosystem I (PSI), as a result of unstacking of the thylakoid membranes and/or a change in the size of PSI antenna (Jusovic et al., 2018; Meng et al., 2016).

The aim of this study was to compare the impact of salt stress on the photosynthetic processes of two economically important crops: the maize (*Zea mays* L. *Mayflower*) and the sorghum (*Sorghum bicolor* L. *Albanus concep*). For this purpose, we examined the influence of three concentrations of NaCl (50 mM, 150 mM and 250 mM NaCl) on the pigment content, chlorophyll fluorescence and PSI photochemistry (photooxidation of P_{700}). The experimental results evaluated the degree of soil salinization at which the investigated plant species can be grown.

Materials and Methods

Plant growth conditions and treatments

The experiments were carried out with hybrids of maize (*Zea mays* L. *Mayflower*) and sorghum (*Sorghum bicolor* L. *Albanus concep*). The plants were grown in half-strength Hoagland solutions. The plants were grown in a photothermostat with controlled conditions: a 12 h light/dark photoperiod, a light intensity of 150 μmol/m^2.s, 28°C (daily)/25°C (night) temperature and a 55% relative humidity. The effects of different concentrations of NaCl (50 mM, 150 mM and 250 mM) for 6 days were investigated. The treatments of plants with NaCl were performed on 15 days old plants. Electrical conductivity (EC) of nutrient solutions with different amounts of NaCl were experimentally established (Table 1).

Table 1. Electric conductivity (EC) of half-strength Hoagland solutions with different amount of NaCl. The values marked with different letters have statistically significant differences at $p < 0.05$.

NaCl (mM)	0	50	150	250
EC (mS/cm)	1.01 ± 0.07[d]	5.99 ± 0.82[c]	14.70 ± 1.40[b]	23.20 ± 1.23[a]

The pigments were extracted from leaves with an ice-cold 80% (v/v) acetone in the dark. Then the homogenates were centrifuged at 2500xg for 8 min at 4 °C. The total chlorophyll content and total carotenoids were determined spectrophotometrically at 470 nm, 646.8 nm, and 663.2 nm. For determination of the pigment amount, the equations of Lichtenthaler (1987) were used. The pigment ratios chlorophyll *a/b* (*chl a/b*) and carotenoids/chlorophylls (*car/chl*) were also determined. The measurements were made on spectrophotometer (SPECORD 210 PLUS, Edition 2010, Analytik-Jena AG, Germany).

Room temperature chlorophyll fluorescence

The chlorophyll fluorescence at room temperature of dark-adapted leaves was measured using a pulse amplitude modulated fluorometer (model 101/103, Walz GmbH, Effeltrich, Germany). The dark adaptation of leaves was 20 min. The maximum fluorescence levels in the light-adapted state (Fm′) were determined by a 0.8 s saturated pulse at 2800 µmol/m^{2}s PPFD. The actinic light was 150 µmol/m^{2}s PPFD. The following parameters were determined: the coefficient of photochemical quenching – $q_P = (Fm' - F')/Fv'$; the linear electron transport rate – $ETR = (Fm' - F')/Fm' \times 150 \times 0.5$. The determination of the parameters was made as in Stefanov et al. (2016). The chlorophyll fluorescence decay ratio $R_{Fd} = Fd/Fs$ was determined according to Lichtenthaler et al. (2005), where Fd is fluorescence decrease from Fm to a steady state chlorophyll fluorescence (Fs) after continuous saturated illumination (2800 µmol/m^2.s PPFD). This ratio (R_{Fd}) correlates with the net assimilation of CO_2 (Lichtenthaler et al., 2005).

P_{700} photooxidation

The measurements of PSI photochemistry by the oxidation-reduction properties of P_{700} were made using a PAM-101/103 fluorometer (Walz, Effeltrich, Germany) equipped with an ED-800T emitter-detector system. The oxidation–reduction kinetics of P_{700} were determined by the illumination of dark-adapted (for 20 min at room temperature) leaf discs with a far-red light supplied by a photodiode (102-FR, Walz, Effeltrich, Germany). The relative changes of P_{700}^+ ($\Delta A/A$) was assessed by measuring of the far-red light induced absorbance changes around 830 nm as described in Dankov et al. (2009).

Statistical analysis

Mean values ± SE were calculated from the data of at least two independent experiments with four replicates of each variant. Statistically significant differences between variants of studied parameters were identified by analysis of variance (ANOVA) followed by a Tukey's post-hoc tests for each parameter. Prior to the tests, the assumptions for the normality of raw data and the homogeneity of the variances were checked. The homogeneity of variance test was used to verify the parametric distribution of data. Values of $p < 0.05$ were considered as significantly different.

Results and Discussion

Photosynthetic pigment content

The influence of different NaCl concentrations on the pigment content of studied hybrids of maize and sorghum is shown on Table 2. Data revealed that the treatment with the lowest studied NaCl concentration (50 mM) led to a slightly increase of photosynthetic pigments. In opposite, the pigment content decreased after the treatment with higher NaCl concentrations, as the effect on the carotenoids was smaller than the chlorophylls. The experiments with sunflower callus cultures indicated that the impact of salt stress on chlorophyll amount is a result from more stronger influence on the chlorophyll biosynthesis rather than the chlorophyll degradation (Akram & Ashraf, 2011; Santos, 2004**)**. In addition, it has been also shown that the decrease in the total chlorophyll content in salt-stressed leaves is mainly due to the degradation of chlorophyll *a*, which is much more sensitive to salinization than the chlorophyll *b* (Misra et al., 1990).

The variation in the pigment composition after salt treatment influenced the ratio *chl a/b*. Similar increase of the *chl a/b* ratio under salinization was registered in wheat (Shahbaz et al., 2008). In previous investigations have been shown that changes in membrane stacking and amount of light harvesting complex of PSII can also influence on this ratio (Apostolova et al., 2006; Stoichkova et al., 2006). Having in main this statement, it could be suggested that NaCl treatment of maize and sorghum can influence the membrane stacking. Previous investigations also revealed that the high salt level reduces the number and the thickness of stacked granal thylakoid membranes as well as the disintegration of grana **(**Lee et al., 2013; Meng et al., 2016; Stefanov et al., 2019).

Influence of the salt stress on the photosynthetic apparatus

The influence of different NaCl concentrations on the function of photosynthetic apparatus is shown on Fig. 1. The reduction in the pigment composition at the highest NaCl concentration (250 mM) corresponds with a strongly inhibition of the functions of photosynthetic apparatus in both studied crop plants. Data revealed an inhibition of the photochemical quenching (q_p) with 31% for the maize and 68% for the sorghum, which is a result from a decrease of the open PSII centers, and corresponds with an inhibition of the electron transport rate (ETR). At the same time, a decrease of the parameter R_{Fd} and the amount of P_{700}^+ were also registered. The inhibition of all studied parameters (R_{Fd}, q_p, ETR and ΔA/A) was stronger in the sorghum than in the maize (Fig. 1). The salt-induced effects on the functions of photosynthetic apparatus could be a result from changes in the structure and the composition of the thylakoid membranes (Stefanov et al., 2019). In addition, experimental results showed smaller salt-induced changes after the treatment with 150 mM NaCl, while after the treatment with 50 mM NaCl the values of studied parameters were similar to those of untreated plants.

Table 2. Effect of different NaCl concentrations on the pigment content in leaves of maize (*Zea mays* L. *Mayflower*) and sorghum (*Sorghum bicolor* L. *Albanus concep*). The plants were treated for six days. The values in the same column are marked with different letters have statistically significant differences at $p < 0.05$.

	Chl (mg/g DW)	Car (mg/g DW)	Chl *a/b*	Car/Chl
Mayflower				
Control	21.36 ± 2.00 [bc]	4.48 ± 0.30 [bc]	4.40 ± 0.09 [d]	0.21 ± 0.01 [bc]
50 mM NaCl	24.73± 1.31 [ab]	4.98± 0.28 [ab]	4.88 ± 0.09 [bc]	0.20 ± 0.02 [bc]
150 mM NaCl	17.26 ± 1.25 [c]	3.91 ± 0.18 [c]	5.05 ± 0.12 [ab]	0.23 ± 0.02 [bc]
250 mM NaCl	7.78 ± 0.28 [d]	2.74 ± 0.03 [d]	4.06 ± 0.03 [e]	0.35 ± 0.01 [a]
Albanus				
Control	25.55 ± 1.94 [ab]	5.60 ± 0.39 [a]	4.73 ± 0.04 [c]	0.22 ± 0.01 [bc]
50 mM NaCl	27.57 ± 1.64 [a]	5.50 ± 0.30 [a]	5.09 ± 0.06 [ab]	0.20 ± 0.01 [c]
150 mM NaCl	19.12 ± 1.67 [c]	4.21 ± 0.37 [bc]	5.14 ± 0.06 [a]	0.22 ± 0.01 [bc]
250 mM NaCl	7.98 ± 0.73 [d]	1.96 ± 0.15 [e]	3.78 ± 0.13 [e]	0.24 ± 0.01 [b]

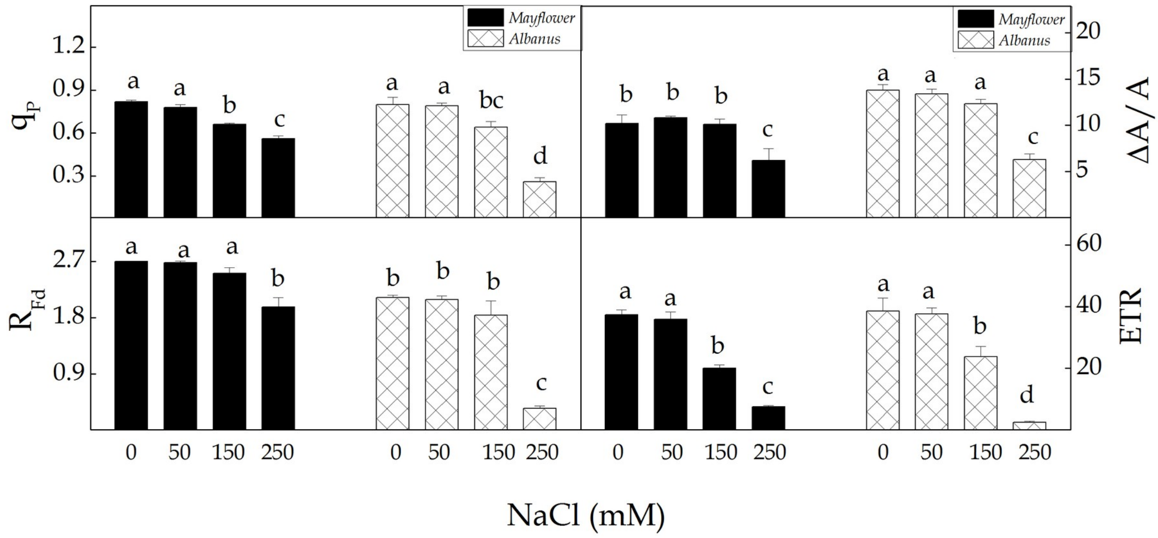

Fig. 1. Effect of different NaCl concentrations on the functions of photosynthetic apparatus of maize (*Zea mays* L. *Mayflower*) and sorghum (*Sorghum bicolor* L. *Albanus concep*). R_{Fd} - ratio of chlorophyll fluorescence decay, ETR - linear electron transport rate, q_P - photochemical quenching coefficient and ΔA/A - relative changes in the amount of P_{700}^{+}. The plants were treated for six days. The values marked with different letters have statistically significant differences for respectively parameter at $p < 0.05$.

Conclusions

Data revealed that the treatment of maize and sorghum plants with the highest concentration of NaCl (250 mM) lead to a decrease of chlorophylls and carotenoids, an inhibition of the rate of photosynthesis (R_{Fd}), the linear electron transport rate (ETR) and the photochemical quenching (q_P). At the same time, the photochemistry of PSI is also influenced at the highest NaCl concentration. The results indicated that the applied middle concentration (150 mM NaCl) decrease the investigated photosynthetic parameters to a smaller extent. In addition, results also showed that the lowest NaCl concentration (50 mM NaCl) does not influence the pigment content and the functions of photosynthetic apparatus of both studied crops.

On the base of the results in this study, it could be concluded that *Sorghum bicolor* L., *Albanus concep* and *Zea mays* L. *Mayflower* can grow at very saline soil (EC from 8 to 16 mS/cm) but in highly saline soil (EC more than 16 mS/cm) the maize is more salt tolerant than sorghum.

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