Response characteristics of leaf assimilate supply and silk sucrose metabolism in maize to drought stress

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Abstract

Maize silk, is the receptive organs of pollen and is particularly sensitive to drought stress during extension, resulting in delay of silking, which leads to the failure encounters of pollen and silk. Many studies have shown that sucrose metabolism and related enzyme activities play an important role in drought tolerance and extension of maize silk. The purpose of this paper is to clarify the response characteristics of leaf assimilate supply and silk sucrose metabolism in maize to drought stress. In this experiment, we investigated the response characteristics of photosynthetic attributes, sucrose metabolism and related enzyme activities to silk drought-tolerant extension by using two local hybrids with different drought tolerance in flowering. Significant decreased in the net photosynthetic (Pn), increased content of sucrose in silk were observed when the crop encountered drought stress. This suggests that the hydrolysis of sucrose was inhibited, also demonstrated the activities of sucrose synthetase (hydrolysis, SS-I) is much greater than the sucrose synthetase (synthesis, SS-II) under drought condition. In addition, the activities of cell wall invertase (CWI) and acid/vacuolar invertase (AI) were decreased, resulting in insufficient hydrolysis of sucrose into glucose and fructose, leading to the accumulation of sucrose content in silk. Therefore, this study revealed the characteristics of sucrose metabolism in drought adaptation during silk extension.

Keywords:

Zea mays, silk extension, drought tolerance, sucrose synthetase, glucose and fructose

Introduction

Maize (*Zea mays* L.) is one of major food crops and an important source of human nutrition, animal feed, and industrial applications worldwide, and plays a critical role in ensuring food security (Wang et al. 2018). However, drought stress is often encountered in the cropping process in arid and semi-arid areas, especially silk extension is sensitive to drourht stress, which may lead to the delay of silking and enlarge the interval of anthesis to silking (ASI), and results in kernel abortion and final grain yield loss (Cakir. 2004; Turc et al. 2016). Drought stress in flowering is the key period for complex reproductive growth and yield formation, and the drought tolerance mechanism at maize flowering has become topical in crop science (Jin et al., 2016). The silk is a receptive organ of pollen and an important part of maize. In addition, silk development is a process of rapid extension from the basal to the top, which requires large amount of photoassimilates for energy supply. However, flowering under drought stress decreased the photocopolytic compound supply capacity of leaves, and also affected the sucrose hydrolysis utilization efficiency of silk, and the latter effect was more critical (Muller et al. 2011). Therefore, sucrose metabolism and related enzymes are very important in response to drought tolerance development of maize silk.

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This study explored the response characteristics of leaf assimilate supply, and sucrose metabolism and related enzymes in maize silk under drought conditions, and so as to provide a theoretical basis for illustrating the important role of sucrose metabolism pathway in drought tolerance of maize silk extension.

Methods

Experiment design

The experiment was conducted by pot culture on 26-Jun-2020 at the experimental station of Anhui Agricultural University (31°86'N, 117°25'E) on an *eutic planosol* soil (FAO classification) in Hefei city, Anhui Province, China. The maize plants were subjected to the following two water treatments: soil relative water content of 75 ± 5% (referred to as CK) during whole growth development, and 50 ± 5% (moderate drought stress, referred to as D) during flowering (without drought stress in other developmental periods). The soil relative water contents were monitored using a soil moisture meter (TDR 350, Spectrum Technologies, Inc, USA) every day. Fertilizer was applied adequately (without nutrient stress) at sowing in supplying 150 kg ha^{-1} for N (Urea), 120 kg ha^{-1} for P (P_2O_5), and 120 kg ha^{-1} for K (K_2O) according to the results of soil nutrient content analysis and local standards before sowing. Two local summer maize hybrids, AnNong 591 (referred to as AN591) and ZhongDan 909 (referred to as ZD909) were selected as the research materials.

Sampling strategy

Maize plants were labelled at 6^{th}-leaf stage (V6) to ensure that subsequent samples to be chosen from maize plants at the same developmental stage. The silk is joined to the ear's ovary, the ear was evenly divided into three positions according to the length, namely, the basal, middle and top positions, corresponding to the basal, middle and top of silk. Three maize plants were sampled from each treatment in silking phase. Immediately after sampling, the samples were stored in liquid nitrogen and then transferred to a -80 °C refrigerator for cryopreservation.

Data collection

Photosynthetic attributes of ear leaf were measured from 9:00 am to 11:00 am by Portable Photosynthetic Apparatus (Lico-6400, LI-COR Biosciences, USA). The contents of sucrose (Suc), glucose (Glu) and fructose (Fru) and the activities of sucrose synthetase (hydrolysis, SS-I; synthesis, SS-II), cell wall invertase (CWI) and acid/vacuolar invertase (AI) of silk in different parts were determined by ELISA kit.

Statistical analyses

In assessing differences between the results, tests with $p < 0.05$ were considered statistically significant. All analyses were conducted with Microsoft Excel (Microsoft Excel 2016, Microsoft, USA) and SPSS (IBM SPSS Statistics Version 24, IBM, USA) statistical software.

Results

Drought stress treatment had a significant effect on net photosynthetic (Pn), transpiration rate (Tr), stomatal conductance (Gs) and CO_2 intercellular concentration (Ci) values of ear leaf (Figure 1). The net photosynthetic (Pn), transpiration rate (Tr) and stomatal conductance (Gs) of ear leaf of AN591 and ZD909 decreased of 26.7% and 43.3% (Pn), 34.1% and 54.5% (Tr), 22.9% and 42.8% (Gs), respectively, while the CO_2 intercellular concentration (Ci) increased of 15.8% and 39.8% (Ci) under drought condition. The effect of drought stress on AN591 was less than that on ZD909 for two hybrids, suggesting that AN591 has stronger photosynthetic capacity than ZD909 under drought condition.

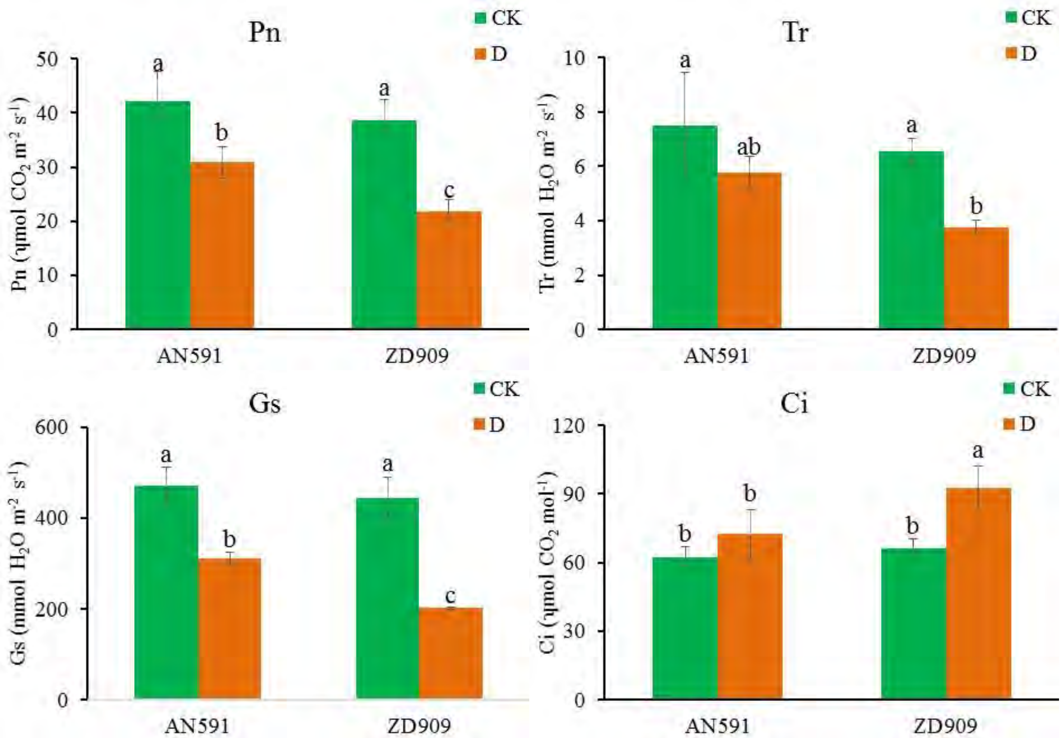

Figure 1. Photosynthetic attributes i.e. Pn, Tr, Gs and Ci of the ear leaf for AN591 and ZD909 (vertical lines indicate error bars).

The content of sucrose, glucose and fructose in silk at different positions (basal, middle and top position) of maize silk were significantly affected by drought stress (Figure 2). The sucrose contents of AN591 and ZD909 at basal, middle and top basal position increased 36.2%, 41.8%, 61.1% and 33.3%, 37.6%, 48.1%, respectively. In contrast, glucose and fructose contents of AN591 and ZD909 at basal, middle and top basal position decreased of 4.2%, 4.5%,9.9% and15.2%, 17.9%, 21.5% (glucose), 37.0%, 38.2%, 37.6% and 16.1%, 12.7%, 15.9% (fructose) under drought condition. The results indicated that the ability of sucrose to hydrolyze into glucose and fructose was reduced, and the energy supply was insufficient for silk development.

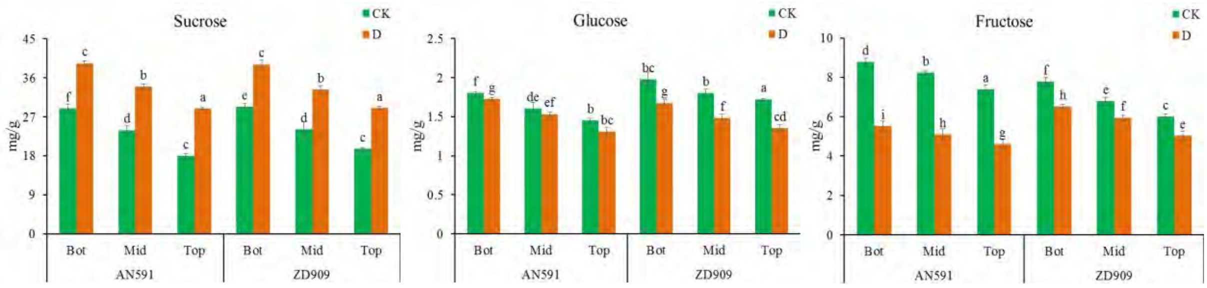

Figure 2. The content of sucrose, glucose and fructose in silk at different positions (basal, middle and top position) of the ear for AN591 and ZD909 (vertical lines indicate error bars).

The activities of sucrose synthetase (hydrolysis, SS-I; synthesis, SS-II), cell wall invertase (CWI) and acid/vacuolar invertase (AI) in silk were decreased by 25% to 55% under drought condition (Figure 3), and the effect of drought stress of sucrose synthetase synthesis (SS-II) capacity is far greater than the hydrolysis (SS-I) capacity, which further verified that the accumulation of the content of sucrose in silk. Moreover, the effect of drought stress on SS-I, SS-II, CWI and AI at top silk was more than 35% (35% to 55%), at middle silk was between 30% and 40%, at basal silk was less than 35% (25% to 35%).

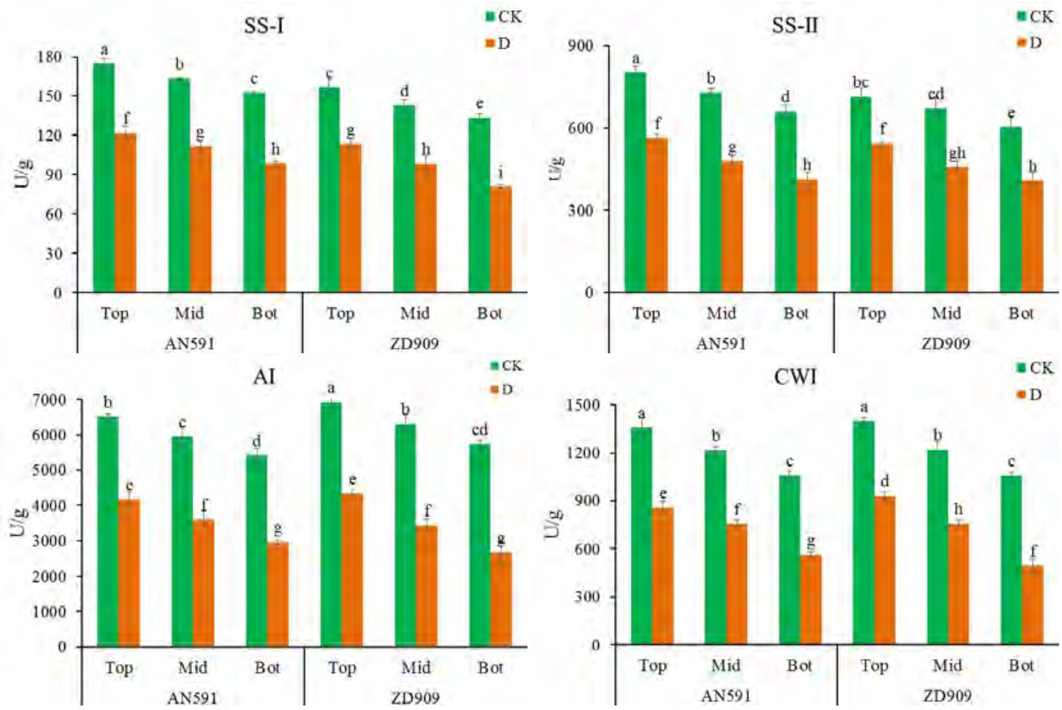

Figure 3. The activities of sucrose synthetase (hydrolysis, SS-I; synthesis, SS-II), cell wall invertase (CWI) and acid/vacuolar invertase (AI)

Conclusion

The drought stress resulted in decreased net photosynthetic (Pn) of ear leaf, and a decrease in carbohydrate synthesis available for transportation. However, the content of sucrose increased in silk, mainly because the effect of sucrose synthetase (hydrolysis, SS-I) is much greater than the sucrose synthetase (synthesis, SS-II) under drought condition. In addition, the activities of cell wall invertase (CWI) and acid/vacuolar invertase (AI) were decreased, caused insufficient hydrolysis of sucrose into glucose and fructose, resulting in the reduction of silk extension.

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