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Foliar Nutrients Enhance Physiological Responses and Yield of Maize (*Zea mays* L.) under Drought at Tassel Initiation

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Abstract

Drought stress at the reproductive stage significantly reduces the yield and quality of maize. Thus, this study aimed to evaluate the physiological responses and yield of maize following foliar applications of K, Ca, and Zn under drought stress conditions, prior to the critical tassel initiation stage. The experiment was arranged in a Randomised Complete Block Design (RCBD) with four replications. The eight treatments were as follows: T1: Well-watered control; T2: Drought stress at tassel initiation; T3–T4: Foliar K⁺ at 2% and 4%; T5–T6: Foliar Ca²⁺ at 0.1% and 0.2%; and T7–T8: Foliar Zn²⁺ at 0.3% and 0.6% at the critical tassel initiation stage under drought conditions. Physiological responses, including net photosynthetic rate (Pn), transpiration rate (E), and stomatal conductance (g_s) were maintained under drought stress conditions through foliar applications of T3 and T4 treatments. Furthermore, T3 and T4 treatments significantly increased the total soluble sugar content in the silks, while decreasing proline content in the silks under drought stress conditions. Moreover, compared to the well-watered control (T1), yield under drought stress was effectively maintained in the T3, T4, T7, and T8 treatments. Correlation analysis revealed that yield was significantly and negatively correlated with proline content in the silks. Specifically, an increase in yield, g_s, and E was associated with a decrease in silk proline content. In conclusion, T3 and T4 treatments effectively induced physiological responses in maize under drought conditions, thereby maintaining yield. These treatments reduced the proline content in the silks. Furthermore, they maintained g_s and E under stress.

Keywords: Drought stress, Foliar nutrient application, Maize, Physiological responses, Yield

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Introduction

Demand for maize in Thailand's animal feed industry has outpaced domestic supply. Although Thailand produces approximately 4.95 million tons of maize annually, output remains constrained by limited planting areas (Office of Agricultural Economics, 2023). A major challenge in maize production is that cultivation primarily occurs in non-irrigated areas (Office of Agricultural Economics, 2022). Additionally, the planting sites experienced severe drought stress due to reduced average rainfall in 2019 and 2020. This shortage was pronounced during the early and late rainy seasons, critical periods coinciding with tassel initiation and reproductive development (Meteorological Department, 2022). Effect of drought stress-inducing reduced total root mass, photosynthetic rate, chlorophyll content, and seed weight (Ghatak et al., 2017). Especially drought stress during the flowering period and grain filling period had decreased grain yield (Souza et al.,

2016). Drought stress induces stomatal closure and reduces transpiration, thereby limiting CO₂ assimilation and net photosynthesis (Pirasteh-Anosheh et al., 2016). However, plant nutrients regulate stomatal function and directly modulate plant responses to drought stress (Bouranis et al., 2012). Potassium application supports plant growth mechanisms and enhances maize yield (Ali et al., 2016). Potassium is essential under drought conditions due to its key role in regulating stomatal movement and leaf transpiration (Sardans and Peñuelas, 2007). Calcium application enhances plant growth and activates key physiological mechanisms to mitigate abiotic stress (Naeem et al., 2017). And zinc application plays a critical role in maintaining pollination and seed set, thereby enhancing overall crop yield and its components (Amanullah et al., 2016). Foliar treatments can alleviate drought stress in plants; however, previous studies have not fully examined how drought impacts maize behavior and physiology. Thus, this study aimed to evaluate the physiological responses and yield of maize following foliar applications of K, Ca, and Zn under drought stress conditions, prior to the critical tassel initiation stage.

Material and Methods

The experiment was arranged in a Randomised Complete Block Design (RCBD) with four replications. The eight treatments were as follows: T1: Well-watered control; T2: Drought stress at tassel initiation; T3–T4: Foliar K⁺ at 2% and 4%; T5–T6: Foliar Ca²⁺ at 0.1% and 0.2%; and T7–T8: Foliar Zn²⁺ at 0.3% and 0.6% at the critical tassel initiation stage under drought conditions. The field experiment was conducted at the research station of Syngenta Seeds (Thailand) Co., Ltd., located in U-Thong District, Suphan Buri Province, Thailand. Hybrid parent seeds were provided by Syngenta Seeds (Thailand) Co., Ltd. Plants were grown at a spacing of 0.20x0.20x0.60 m, with experimental plot dimensions of 34 m². Compound fertilizer (15–15–15 N–P–K) was applied at 60 kg ha⁻¹ at 5 days after germination (DAG) and at 40 kg ha⁻¹ at 40 DAG. Additionally, nitrogen (urea, 46–0–0) was applied at rates of 45 kg ha⁻¹ at 20 DAG and 15 kg ha⁻¹ at 40 DAG. The growing season spanned from May to August 2020, with a cumulative rainfall of 487 mm. Prior to tassel initiation, foliar treatments were applied at the V15 stage (55 days after seeding; DAS). Drought stress was subsequently imposed at the VT stage (65 DAS) for 14 days, after which all plots were rewatered. A drought condition was observed in August, with total rainfall dropping to 58.83 mm. Physiological, growth, and yield parameters were evaluated on day 7 of drought stress. Net photosynthetic rate (P_n), transpiration rate (E), and stomatal conductance (g_s) were measured using a portable photosynthesis system (LI-6400). Total soluble sugar content was determined via the anthrone method, and proline content was quantified using the Bates method (Irigoyen et al., 1992).

Results and Discussion

Physiological Responses

The experiment revealed that foliar application with T3 and T4 significantly increased the photosynthetic rate (20.862, and 21.751 μmole CO₂ m⁻² s⁻¹, respectively), stomatal conductance (0.054, and 0.055 mole H₂O m⁻² s⁻¹, respectively), and transpiration rate (3.407 and 3.477 mmole H₂O m⁻² s⁻¹, respectively) compared to the drought stress treatment (T2) (13.881 μmole CO₂ m⁻² s⁻¹, 0.002 mole H₂O m⁻² s⁻¹, and 1.100 mmole H₂O m⁻² s⁻¹, respectively). (**Table 1**) Osmotic adjustment was maintained through K⁺ treatment, which induced solute accumulation. This avoidance mechanism could enhance water uptake, transpiration rate, stomatal conductance, and photosynthetic rate (Wang et al., 2013). Foliar spray treatments T3 and T4 significantly increased the total soluble sugar content in the silks (13.382 and 12.597 mg g⁻¹ FW, respectively) compared to the drought stress treatment (T2) and other foliar treatments (T5–T8). Furthermore, foliar spray treatments T3 and T4 resulted in a lower proline content in the silks (7.683, and 5.898 μmol g⁻¹ FW, respectively) than the drought stress treatment (T2), showing no significant difference from the well-watered control (T1). (**Fig. 1**) Foliar application of K⁺ promoted the translocation and

partitioning of sugars from leaves to the stalk and silks (Wang et al., 2013). And proline accumulated in maize under drought stress to stabilize cell membranes and maintain protein conformation (Ramachandra Reddy et al., 2004). Foliar spray treatments T3, T4, T7, and T8 resulted in a significantly higher grain yield than the drought stress treatment (T2), showing no significant difference from the well-watered control (T1). (**Fig. 1**) Potassium treatment maintained growth and crop yield in maize (Ali et al., 2016). Additionally, zinc application sustained grain yield and harvest index under drought conditions (Chattha et al., 2017).

Table 1 Effect of foliar treatments before critical tassel initiation stage on Pn, g and E under drought stress condition

Treatment	Net photosynthesis rate, Pn ($\mu\text{mole m}^{-2} \text{s}^{-1}$)	Stomatal conductance, g _s ($\text{mole H}_2\text{O m}^{-2} \text{s}^{-1}$)	Transpiration rate, E ($\text{mmole H}_2\text{O m}^{-2} \text{s}^{-1}$)
T1	22.364 a	0.059 a	3.825 a
T2	13.881 c	0.002 d	1.100 d
T3	20.862 a	0.054 a	3.407 a
T4	21.751 a	0.055 a	3.477 a
T5	18.908 ab	0.022 b	2.557 b
T6	15.389 bc	0.002 d	1.956 c
T7	6.854 d	0.008 c	1.780 c
T8	12.886 c	0.007 cd	1.810 c
Mean	16.612	0.026	2.489
LSD _{0.05}	1.877*	0.0026*	0.206*
%CV.	15.98	14.35	11.70

Notes: *: significantly different at $p < 0.05$, a, b, c, d, e and f compared with LSD ($P < 0.05$)

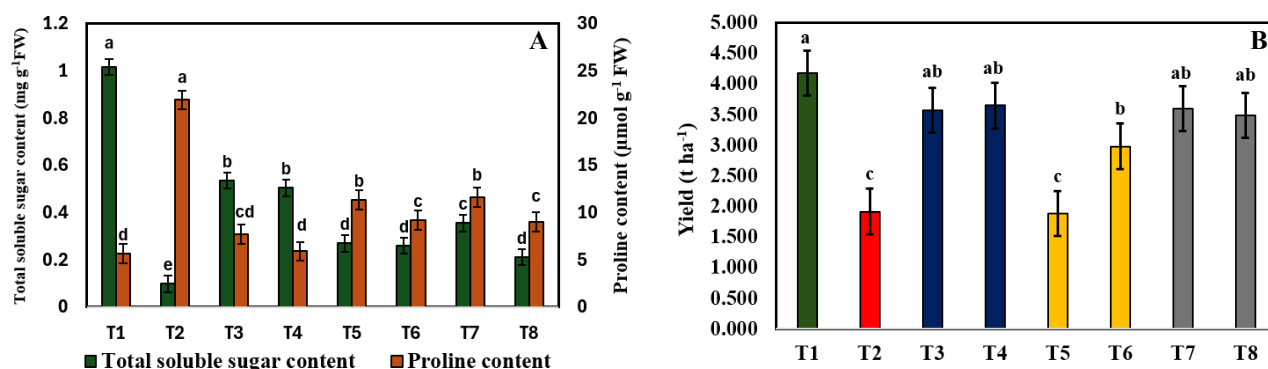


Fig. 1 Effect of foliar treatments before critical tassel initiation stage on the total soluble sugar content and proline content of silks (A), yield (B) under drought condition

The Pearson correlation analysis showed that grain yield, Pn, g_s, E, and total soluble sugar content in the silks under drought stress were significantly and negatively correlated ($r = -0.646, -0.368, -0.488, -0.601$, and -0.500 , respectively) with proline content in the silks at $p < 0.05$. (**Table 2**) Consequently, grain yield was decreased by increased proline content in the silks. However, grain yield was increased by increased total soluble sugar content in the silks under drought stress condition (**Fig. 2**). Proline is an important factor to be reducing the photodamage in the thylakoid membranes by reducing oxygen (Ramachandra Reddy et al., 2004).

Table 2 The Pearson correlation coefficient between yield and physiological responses under drought conditions

	Grain yield	Pn	g _s	E	TSCK
Pn	ns				
g _s	ns	0.693*			
E	ns	0.767*	0.880*		
TSCK	0.414*	0.360*	0.776*	0.748*	
POK	-0.646*	-0.368*	-0.488*	-0.601*	-0.500*

Notes: *: Significant difference and ns: not significant difference in correlation of physiological response, and yield at significance level $p < 0.05$

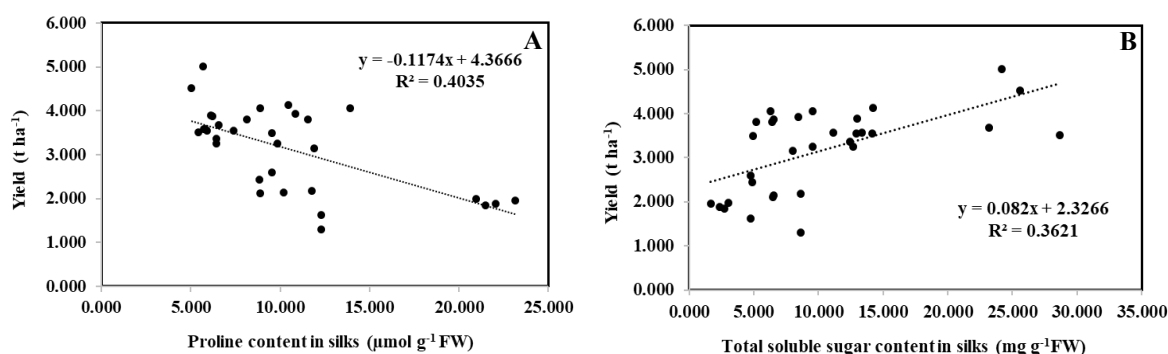


Fig. 2 The correlation of proline of silks with yield (A) and the correlation of sugar of silks with yield (B)

Conclusions and Outlook

Foliar application of K^+ at 2% and 4% effectively induced physiological responses in maize under drought conditions by reducing proline content in the silks, promoting the translocation and partitioning of total soluble sugars from leaves and stems to the silks, and maintaining net photosynthetic rate, stomatal conductance, and transpiration rate. In summary, applying K^+ as a foliar spray during the critical tassel initiation stage is recommended to mitigate drought stress and sustain maize grain yield.

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