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Impact of silicon on various agro-morphological and physiological parameters in maize and revealing its role in enhancing water stress tolerance

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Abstract

Silicon (Si) is the second most abundant element in earth's crust and is considered as beneficial element for providing tolerance against various biotic and abiotic stresses. The aim of the present study was to investigate the role of silicon in water stress tolerance in maize as depicted through agro- morphological/ physiological parameters. We evaluated 15 diverse maize genotypes/ inbred lines under rain-fed conditions with, as well as without, Si application. Significant differences were observed in various agro-morphological and physiological parameters under Si^+ and Si^- conditions. The number of kernel per ear was significantly higher in Si+ conditions. The various physiological parameters observed include; anthesis- silking interval, relative water content, stomatal density and canopy temperature. All these parameters indicated the positive impact of Si on water stress tolerance in case of maize genotypes under study. These results specified that Si plays an important role in giving tolerance against drought/ water stress. The study can be further extended to investigate the molecular mechanism involved in Si induced water stress tolerance in maize.

Key words: Silicon, Maize, Drought, Abiotic stress tolerance

Introduction

Maize (*Zea mays* L.) is an important cereal and fodder crop occupying 27% of the world acreage and accounts for about 34% of the world grain production. It is world's third most important cereal crop while drought is second important constraint of maize production in the developing countries. Drought affects the organ growth and leads to reduction in leaf and silk elongation hence decrease in light interception and increase in anthesis-silking interval, finally affecting corn production (Boyer, 1970; Saab and Sharp, 1989). Many of the world's poorest people farm in areas with inadequate rainfall. The major global research focus to overcome the moisture stress is a real challenge for the scientists as it leads to extensive yield losses.

The role of various macro- and micro- nutrients in enhancing the yield has been understood very well. The role of silicon (Si) on drought tolerance was examined by Hattori et al. (2005) in *Sorghum bicolor*, their results clearly indicated that the Si applied sorghum could extract a large amount of water from drier soils and can maintain a higher stomatal conductance. Similar results were obtained by Ma and co-workers in 2004 in cucumber; they concluded that Si enhances the net photosynthetic rate of cucumber under drought stress. Si has also been found to reduce the oxidative membrane damage and improves the water use efficiency up to 35% in maize (Gao et al., 2004). Kaya et al. (2006) reported that in case of maize, on application of Si, relative water content was enhanced, indicating retention of water in cells that increases moisture stress tolerance. They also proposed that Si plays important role in regulation of calcium concentration in plants which maintains membrane integrity in water stressed plants. Liang (1999) observed that Si maintains optimum supply of essential nutrients that may be due to change in soil pH. Pei et al. (2010) reported that in case of wheat, grown in water stress conditions, Si application stimulates antioxidant defense. Kvedaras et al. (2007) have shown that the Si does not only enhance the tolerance to water stress but also improves the resistance of sugarcane plants

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to insect attack (Stalk borer). Gong et al. (2006) determined that the application of silicates in the saline culture improves the growth of shoots and correlated it with the Si deposition in the exodermis and endodermis in rice (*Oryza sativa* L.) seedlings. Hence the present study was undertaken to understand and divulge the role of Si in inducing water stress tolerance in maize.

Material and Methods

Plant material

Fifteen diverse genotypes (inbreed lines) of maize (Table 1) were procured from Indian Agriculture Research Institute (IARI), New Delhi and evaluated at The Energy and Resources Institute (TERI) New Delhi, experimental field station at Gaul Pahari, Gurgaon (Haryana) India.

Field Evaluation

The sowing of these genotypes was done in the first week of July in a randomized block design. The genotypes were evaluated under rain-fed conditions with and without application of Si. Each of the fifteen genotypes was replicated twice under both Si^+ and Si^- conditions. Calcium silicate (Ca_2SiO_4) fertilizer was applied in soil before sowing as a source of silicon at the rate of 700Kg per hectare. All other standard cultivation practices were followed except irrigation and the experiment was conducted under rain-fed conditions. The experiment was conducted to reveal potential of Si in enhancing tolerance against moisture stress, which was provided by growing plants in rainfed condition.

Agro-morphological and physiological observations

Various agro-morphological parameters (germination percentage, plant height, days to maturity, and kernels per ear) and physiological parameters (anthesis-silking interval, canopy temperature, stomatal density and relative water content) were recorded to evaluate the differences among these parameters due to application of calcium silicate/ silicon. The observations were recorded from five randomly selected plants of each genotype in both replications in Si fortified as well as controlled (Si^-) conditions.

Recording of various physiological observations

Anthesis-silking interval

The date of anthesis as well as silking was recorded and the interval was calculated:

Anthesis Silking interval = Date of anthesis – Date of silking Or Date of silking- Date of anthesis.

Canopy temperature

Canopy temperature was recorded from 5 plants of each genotype in each replication using Infra-Red Thermometer (9V Infra-Red Thermometer Gun).

Stomatal density

Epidermal impression was prepared by coating the leaf surface with nail polish which was peel off, once nail polish was dried, it was mounted onto a slide by a cello tape. The impression approach was used to determine leaf stomatal density using AIM Research Binocular Microscope, (Make - AIM Scientific) which was expressed as the number of stomata per unit leaf area (Radoglou and Jarvis, 1990).

Relative water content

It determines the amount of water that is retained in cells and is calculated by:

RWC (%) = [(W-DW) / (TW-DW)] x 100

Where, W – sample fresh weight; TW – sample turgid weight; DW – sample dry weight

The weight was done using electronics balance (Microbalance – Sartorius - BT - 224S).

Statistical analysis

Experiment was laid in 2 X 4 factorial Randomized Block Design (RBD). Analysis of variance was performed by online statistical package (Web Agri Stat Package-WASP1) of ICAR-Goa Regional Centre, Goa, India. Least significant difference (LSD) was calculated and means were compared. Same package calculated CV, by using formula CV=(Standard deviation/mean)X 100.

Table 1. List of maize genotypes evaluated for water stress tolerance.

Sr. No.	Genotype	Sr. No.	Genotype
1	MGU 201	9	MGU 209
2	MGU 202	10	MGU 210
3	MGU 203	11	MGU 211
4	MGU 204	12	MGU 212
5	MGU 205	13	MGU 213
6	MGU 206	14	MGU 214
7	MGU 207	15	MGU 215
8	MGU 208		

Table 2. Impact of silicon on agro-morphological traits under water stress conditions.

Trait/Treatment	Germination %	Plant height	Days to maturity	Kernels per ear
Silicon treated (Si^+)	80.967	1.967	1.870	1.954**
Control (Si^-)	78.400	1.983	1.868	1.656
CD (5%)	4.534	0.189	0.191	0.294
CV	10.777	18.116	19.322	30.816

CD (Critical difference at 5% level of significance); CV (Coefficient of variation); ** (indicates significant difference in the trait due to application of silicon); All observations, except germination %, were transformed to logarithmic values and analyzed

Results and Discussion

We observed significant difference for number of kernels per ear under Si fortified and controlled conditions at 30 % coefficient of variation (Table 2). These findings are in line with the earlier reports by Elawad and Green (1979) and Savant et al. (1997), who have observed that soluble Si enhances the growth, development and yield of several plant species including equisetum, rice, sugarcane, wheat, and some dicotyledonous species.

The germination percentage and plant vigor was higher under Si fortified conditions as compared to control but it was non-significant. Further, no significant difference was observed for plant height and days to maturity under Si fortified and controlled conditions (Table 2). Gong et al. (2003) have reported increase in the plant height in case of wheat grown in pots with Si under well watered conditions, however no significant changes in the dry materials under drought conditions were observed on application of Si.

To examine the impact of silicon on water stress tolerance, various physiological observations were recorded; anthesis silking interval, relative water content, stomatal density and canopy temperature. Under Si applied conditions the anthesis-silking interval and canopy temperature was lesser and significantly different from the controlled conditions (Table 3). As indicated in the earlier studies (Boyer, 1970; Saab and Sharp, 1989) drought leads to reduction in leaf and silk elongation hence decrease in light interception and increase in anthesis-silking interval finally affecting corn production. Hence lesser the anthesis-silking interval, more water stress tolerant will be the genotype; and thus lesser anthesis-silking interval due to Si application suggests the role of Si in providing water stress tolerance in maize. The relative water content under Si applied conditions was higher and significantly different from control. Gong et al. (2003) have observed that in case of wheat grown under water stress conditions under Si applied conditions maintain higher relative water content and water potential.

In the present study, we have not observed any significant difference for the stomatal density among plants grown under Si^+ and controlled conditions (Table 3). Gao et al. (2006) have also reported that Si does not affect the stomatal morphology and density, and it is presumed that Si plays a role in decreasing the transpiration rate by changing the stomatal movement rather than its density. Similar to this hypothesis, significant difference was observed for canopy temperature among maize genotypes for Si^+ and Si^- conditions under the present study.

Our results indicate that Si induces tolerance against moisture stress. The relative water content and canopy temperature are the two standard parameters to differentiate drought tolerant genotypes. To the best of our knowledge this is the first report to provide an evidence of decrease in the canopy temperatures in maize due to Si application. These preliminary findings supported by the past results indicate that Si not only enhances tolerance to water stress but also increases yield in case of maize.

Table 3. Impact of silicon on physiological parameters under water stress conditions.

Trait/Treatment	Anthesis silking interval	Canopy temperature	Stomatal density	Relative water content
Silicon treated (Si^+)	0.606**	1.338**	1.672	66.167**
Control (Si^-)	0.700	1.354	1.665	61.167
CD (5%)	0.090	0.011	0.018	1.383
CV	26.129	11.610	2.022	4.114

CD (Critical difference at 5% level of significance); CV (Coefficient of variation); ** (indicates significant difference in the trait due to application of silicon); All observations, except germination %, were transformed to logarithmic values and analyzed

Conclusion

Si induced water stress tolerance has been studied in several crops. In our study we have seen the impact of Si on various agro-morphological and physiological parameters in maize. Our preliminary studies have shown that application of Si does not only improve the agronomic traits but also improves the physiological parameters corresponding to drought tolerance in maize. Further work is needed to understand the genetic mechanism behind Si induced water stress tolerance in maize.

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