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Effects of Silicon on Growth of Wheat Under Drought

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ABSTRACT

Plants of wheat growing in pots with silicon (Si) applied before sowing had greater plant height, leaf area, and dry materials compared to those without Si applied in well watering conditions. Drought stress was applied by withholding watering for 12 days from 26-day old seedlings. In the stress conditions, plants growing in Si-applied soil could maintain higher relative water content (RWC), water potential and leaf area compared to those without Si applied. Moreover, the Si applied plant dry materials were not significantly changed by drought while those of plants growing in pots without Si applied were significantly decreased, and this was mainly due to growth inhibition of the shoots. Drought stressed wheat growing in pots with Si applied had a significantly greater leaf weight ratio (LWR) and lower specific leaf area (SLA) compared to those of stressed plants in the

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absence of applied Si. This demonstrates that the leaves of stressed plants growing in pots with Si applied were thicker compared to those without Si applied. This may have a beneficial effect by reducing the transpirational loss of water and maintain high RWC and water potential. Therefore, application of Si may be one of the available pathways to improve growth of this crop and increase its production in arid or semi arid areas.

Key Words: Drought; Growth; Silicon; Wheat (*Triticum aestivum* L.)

INTRODUCTION

Approximately one third of the world land surface is arid or semi arid, and in China, this ratio is higher up to 47%.[1] Wheat is one of the main crops of human beings, and is growing at the areas of which about 70% are arid and semi arid.[2] Drought often causes decrease or unsteadiness of wheat production. Therefore, studying the drought-tolerance and fertility of wheat is very significant to solve the problem of food supplies.

Silicon (Si) is the second most abundant element on the surface of the earth. It is not considered to be an essential element for higher plant.[3] However, there is increasing evidence that Si is not only a cell wall incrustation, responsible for the rigidity of leaves in monocots, but is also involved in physiological processes.[4,5] Studies have shown that Si promotes the growth of plants.[6,7] In many cases the growth stimulation is due to the protection that Si affords plants against the detrimental effects of abiotic and biotic stresses. Much work has shown that Si could control disease,[8,9] control pest,[10,11] alleviate toxicity of heavy metal,[3] alleviate salt stress,[12,13] alleviate freezing stress.[14] As to drought stress, several authors have suggested that Si may increase the drought-tolerance of plants.[5,15,16] However, little attention has been concentrated on this field. In this paper, we report that Si stimulated the growth of wheat in well watering conditions and improved its growth under drought. Application of Si may be an available pathway to increase production of this crop in arid or semi arid areas.

MATERIALS AND METHODS

Plant Growth

After sterilization of the surface with 1% sodium hypochlorite for 10 min and germinated for 24 h, seeds of the wheat (*Triticum aestivum* L. cv. 8139, provided by the Institute of Agriculture, Dingxi County of Gansu Province,

P.R. China) was sown in plastic pots each filled with 8 kg soil. The pot (Upper diameter, 23 cm; Lower diameter, 17 cm; Height, 26 cm) had several holes in its bottom, which permitted superfluous water to pass through. Before sowing, the soil was mingled sufficiently, divided into several parts each with 8 kg weight and then sodium silicate or sodium sulfate (in order to supplement Na introduced by adding sodium silicate) was added (kg^{-1} soil): "CK" (control) and "DR" (drought) treatments, 7.14 mmol of sodium sulfate; "Si" and "DR + Si," 7.14 mmol of sodium silicate. All pots were watered sufficiently with tap water before sowing. Each treatment was replicated three times and the experiment was carried out as a complete randomized block design. All pots were watered sufficiently every 3–4 days until 26-day old seedling, and thereafter, the "CK" and "Si" treatments were still well watered with tap water as before, but the "DR" and "DR + Si" treatments were subjected to drought by withholding watering until harvesting. This experiment was conducted in the greenhouse of the campus of Lanzhou University. The air temperature, humidity, and photosynthetic active radiation at noon often fell in 27–32°C, 40–50%, 1.5–2.0 mmol photos, and the night temperature often fell to 15°C.

Assays

Soil samples were air dried, ground and passed through a 1-mm mesh stainless steel sieve for chemical analysis. The pH of the soils was determined with a glass electrode (soil/water, 1 : 1), organic matter by the method of Mebius,[17] total nitrogen (N) by the Kjeldahl digestion procedure (salicylic acid modification),[18] available phosphorous (P) by the Olsen method,[19] potassium extracted by Li's method[20] and analyzed by atomic absorption spectrophotometry. Deionized water was used to extract soil (1 : 5 ratio) for available Si and then measured colorimetrically.[20] Some chemical properties of the soil were shown in Table 1.

The plants were harvested 38 days from seedling emergence. Leaf area was measured with an area meter (Delta T Devices, Cambridge, UK). Relative water content and water potential were measured on the final fully expanded leaves. The dry weights of plant, leaves, and roots were obtained by drying the plants at 80°C for 48 h.

RESULTS AND DISCUSSION

As shown in Table 2, the plant height was significantly increased by Si in the well-watered conditions. However, it was decreased by drought no matter in the presence or absence of added Si, and there showed no difference

Table 1. Some chemical properties of soil used for the present experiment. The soil samples were taken before application of sodium silicate or sulfate.

pH	Organic matter (%, w/w)	Total N (%, w/w)	Available P ($mg\,kg^{-1}$)	Available K ($mg\,kg^{-1}$)	Slowly available K ($mg\,kg^{-1}$)	Available Si ($mg\ Si\,kg^{-1}$)
6.74 ± 0.03	3.01 ± 0.01	0.24 ± 0.02	99.5 ± 4.3	186.4 ± 0.8	993.6 ± 2.4	178.8 ± 17.2

Notes: The data given are mean $\pm$ SE of three replications.

Table 2. Changes of the plant height, RWC, water potential, and leaf area under drought in the presence or absence of added silicon.

	Plant height (cm)	RWC (%)	Water potential (–MPa)	Leaf area (cm^2)
CK	25.3 ± 2.2a	89.5 ± 1.0a	0.59 ± 0.06a	35.4 ± 2.4a
DR	23.3 ± 2.4a	82.8 ± 1.3b	1.40 ± 0.05b	26.8 ± 1.3b
Si	31.9 ± 2.2b	90.3 ± 0.8a	0.58 ± 0.03a	45.2 ± 2.3c
DR + Si	23.5 ± 1.2a	85.5 ± 1.3c	1.00 ± 0.07c	35.1 ± 5.5a

Note: The RWC, water potential, and leaf area were measured on the recently full-expanded leaves when harvesting the plants. Means (±SE) followed by different letters are significantly different at the $P = 0.05$ level according to T test.

between the "DR" treatment and "DR + Si" treatment. Silicon did not change the RWC and water potential without drought stress. But drought stress decreased them, and they were higher in the presence than absence of added Si. Therefore, Si could improve water status under drought conditions. The leaf area was also significantly increased by Si in the well-watered conditions. Although the leaf area of the "DR + Si" treated plants was significantly decreased by drought with compared to that of the "Si" treated plants, yet it could still maintain higher compared to the "DR" treatment and even could compare beauty with the "CK" treatment.

The dry weights of the whole plant, leaves, and roots were changed by drought and applying Si. As can be seen in Table 3, the dry materials of the plant and leaves were decreased by drought in the absence of added Si, while they were not significantly changed in the presence of added Si. In addition, compared to the non-Si treatments, Si treatments ("Si" and "DR + Si")

Table 3. Effects of drought and silicon on the plant dry materials and their distribution in leaves and roots.

	Whole plant	Leaves	Roots
CK	145.3 ± 4.1a	115.7 ± 7.8a	20.2 ± 4.2a
DR	127.5 ± 4.9b	96.5 ± 4.9b	21.7 ± 2.8a
Si	178.8 ± 9.4c	152.2 ± 8.0c	16.6 ± 2.7a
DR + Si	172.8 ± 10.6c	141.8 ± 13.7c	17.8 ± 3.0a

Note: Mean ± SE is calculated from 5–6 plants and expressed in unit of mg dry weight. Means (±SE) followed by different letters share the same meaning as Table 2.

significantly increased their dry materials. The root dry weights were slightly increased by drought in the presence or absence of additional Si with compared to their corresponding control. In a whole, Si enhanced the growth of wheat mainly due to its stimulation to the growth of shoot, and Si treatment could confer wheat with higher dry masses compared to that of non-Si treatment plants. The growth stimulation of Si maybe attributes its involvement in cell elongation and/or cell division.[8,21]

The efficiency with which a plant deploys its assimilatory surface to produce dry material can be estimated from the ratio of leaf area to whole plant dry weight known as the leaf area ratio, (LAR).[22] Leaf area ratio was lower in the stressed wheat, no matter in the presence or absence of added Si (Table 4). This indicated that drought decreased the assimilatory efficiency. Leaf area ratio contains two component ratios: leaf dry weight/whole plant dry weight and leaf area/leaf dry weight known as the LWR and specific leaf area, (SLA), respectively. Multiplication of the two terms gives LAR. Leaf weight ratio can be used to estimate the distribution of photosynthesis between leaves and the rest of the plant and SLA is a measure of leaf area on a dry weight basis.[23] As can be seen, silicon treatments ("Si" and "DR + Si") increased the LWR with compared to the non-Si treatments. This value was not significantly changed by drought in the presence of Si, and it maintained higher with compared to the "DR" treatment. Under well watering conditions, SLA was not significantly changed in the presence with compared to that of absence of added Si. However, drought decreased this value (Table 4). It is remarkable that in the presence of additional Si, the SLA decreased to 247.7 cm^2 (g leaf dry weight)$^{-1}$. That is to say, drought stressed wheat growing in pots with applied Si had a significantly greater LWR and lower SLA compared to those of stressed plants in the absence of additional Si. This demonstrates that the

Table 4. Changes of the LAR, LWR, and SLA under the drought conditions in the presence or absence of added silicon.

	LAR	LWR	SLA
CK	246.0 ± 7.5a	0.80 ± 0.01a	309.2 ± 18.3ac
DR	209.9 ± 5.3b	0.75 ± 0.01b	277.4 ± 6.2b
Si	252.7 ± 4.0a	0.85 ± 0.00c	296.9 ± 4.0c
DR + Si	204.1 ± 12.1b	0.82 ± 0.04ac	247.7 ± 11.7d

Note: Leaf area ratio is expressed in units of cm^2 (g plant dry weight)$^{-1}$. Leaf weight ratio is g leaf dry weight (g whole plant dry weight)$^{-1}$ and SLA is cm^2 (g leaf dry weight)$^{-1}$. Means (±SE) followed by different letters share the same meaning as Table 2.

leaves of stressed plants growing in pots with applied Si were thicker compared to those without Si applied. This may have a beneficial effect by reducing the transpirational loss of water, as has been shown in Table 2. The "DR + Si" treated plants had high leaf areas and this maybe beneficial to maintain high assimilatory capability with compared to the "DR" treated plants.

CONCLUSIONS

Our data have shown that application of Si can increase dry matter of wheat in well watering conditions, and it can also improve the growth of this crop in drought conditions by maintaining high leaf areas to insure high assimilatory capability, thickening leaves which is beneficial to reduce the transpirational loss of water. Therefore, application of Si may be an available pathway to increase production of this crop in arid or semi arid areas.

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