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The Silicon: The role on growth and yield of cereals under different abiotic stresses

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Abstract

Nevertheless, Silicon (Si) is not an essential element, however, its beneficial role may not be ignored. Si alleviates a variety of abiotic stresses such as salinity stress, metal toxicity, moisture stress, radiation damage, high temperature and freezing etc. These beneficial effects are primarily attributed to the high accumulation of silica on the tissue surface. In view of the importance of silicon in pushing up production and other beneficiary effects on growth and yield of crops. Therefore, review of the research works done on silicon are summarized below.

Keywords: Silicon, cereals, growth, photosynthesis, osmotic potential, transpiration, water and salt stress

Introduction

Silicon (Si) is the second most abundant mineral element in soil and silicon dioxide (SiO_2) accounts for 50-70% of total soil mass. Si performs a wide range of ecological functions, including complex roles in plant processes and mediating interactions with the environment and other organisms. The accumulation of Si varies greatly between different plant species, ranging from 0.1 to 10% dry weight. Based on the concentration of Si in the tissue, plants can be classified into three categories *viz*. accumulators (such as rice, wheat, maize, and sorghum), intermediate (such as cucumber, bitter gourd and melon) and excluders (such as tomato, potato, canola and lentil).

Plants are subjected to a variety of environmental stresses during the period of their active growth and development. Silicon has been reported to increase plants' ability to withstand a variety of stress conditions, including drought or moisture stress, salt stress, heat stress, heavy metal stress etc. Drought, the most common climatic extreme that hinders crop growth and productivity, is a recurring phenomenon with serious consequences for both humans and natural ecosystems. In this context, silicon has been shown to alleviate drought stress in a variety of crop plant species, including rice, wheat, maize and sorghum etc. Silicon application during drought stress may promote aquaporin gene expression and counteract ROS-induced aquaporin activity inhibition in plants. Under drought stress, silicon supply can alter osmoregulation by either causing an increase in the accumulation of soluble sugars and/or amino acids in the xylem sap, which increases the osmotic driving force or by triggering the K^+ translocation to the xylem sap via the SKOR (Stelar K^+ Outward Rectifier) gene. The application of silicon can improve root hydraulic conductivity by modifying root growth and increasing the root/shoot ratio along with increasing aquaporin activity and osmotic driving force. Higher root hydraulic conductance increases water uptake and transport, which aids in maintaining a higher photosynthetic rate and improving plant resistance to water deficiency (Luyckx *et al*. 2017 [25]; Chen *et al*. 2018) [7]. Si application can also reduce drought stress by increasing plant mineral nutrient uptake and changing plant gas exchange properties (Rizwan *et al*. 2015) [33]. Exogenous Si application improves seed germination and biochemical processes and protects seedlings from oxidative stress by enhancing antioxidant defence under drought stress. Calcium silicate application in the soil increases seed germination in the maize plant under drought stress (Zargar and Agnihotri 2013) [40]. application of Si encourages the photosynthetic rate, water use efficiency (WUE), osmotic potential and leaf and root water while decreasing the rate of transpiration, the permeability of membrane under water-scarce conditions in different species of crop viz., Paddy (Agarie *et al*. 1998; Ming *et al*. 2012) [3, 28], wheat (Gong and Chen 2012; Maghsoudi *et al*. 2016) [26], melon (Neocleous 2015) [30], tomato (Silva *et al*. 2012; Shi *et al*. 2014) [35, 34], Fennel (Asgharipour and Mosapour 2016) [6] and oil palm (Putra and Purwanto 2015) [32] white lupin plants (Abdalla 2011a, b) [1, 2].

However, in few plants such as rice, soybean and pepper (*Capsicum annuum* L.) Si supply promotes both transpiration and net photosynthetic rates under moisture-stress conditions (Rizwan *et al*. 2015) [33]. Si reduces salt stress in plants through a variety of mechanisms. The chief mechanisms associated with Si-mediated tolerance to salt stress are reduction in toxicity of ions, maintenance of favourable water balance, increased uptake and assimilation of minerals, regulation of compatible solute and phytohormone biosynthesis, modification in gas exchange attributes and gene expression. One of the most important mechanisms of plant resistance to salt stress is reduced uptake and accumulation of Na^+ ions. It has been widely reported that an increased supply of Si reduces Na^+ uptake by plants under salt stress and increases the K^+/Na^+ ratio (Ali *et al*., 2009; Gurmani *et al*., 2013; Chen *et al*., 2014 and Garg & Bhandari, 2015) [4, 17, 12, 8, 12].

This article aims to provide the available information on the effect of Silicon on cereals under abiotic stress conditions.

Effect of silicon on cereals under abiotic stress conditions

Wheat

Thorn *et al*., (2021) [38] reported that during osmotic stress, Si was found to improve growth marginally in high Si accumulators. However, there was no significant effect of Si on growth during drought stress. It was also discovered that osmotic stress reduced Si accumulation in all landraces while drought increased it. Overall, these findings indicate that the beneficial effect of Si commonly reported in similar studies is not universal and that the use of Si fertiliser as a solution to agricultural drought stress necessitates a thorough understanding of genotype-specific responses to Si. Gong *et al*., (2003) [14] reported that Plants grown in Si applied soil maintained higher relative water content (RWC), water potential, and leaf area under stress conditions than those grown in non-Si applied soil. Furthermore, drought had no effect on the dry materials of Si-treated plants, whereas those of plants grown in pots without Si were significantly reduced, owing primarily to shoot growth inhibition. Drought-stressed wheat grown in pots with Si had a significantly higher leaf weight ratio (LWR) and lower specific leaf area (SLA) than stressed plants grown in the absence of Si. This demonstrates that the leaves of stressed plants grown in pots with Si were thicker than those grown in pots without Si. This may have a beneficial effect by lowering transpirational water loss while maintaining high RWC and water potential. As a result, applying Si may be one of the available options for improving crop growth and increasing production in arid or semi-arid areas. Othmani *et al*., (2021) [31] reported that the presence of Si reduced chlorophyll content, relative water content, shoot length, and root length by 21.81%, 31.08%, 51.31%, and 54.62%, respectively, when compared to the control treatment. With the addition of Si, electrolyte leakage increases by 25.19%. In addition, Si application improves chlorophyll content, relative water content, and leaf area in a pot experiment. Mustafa *et al*., (2021) [29]. Foliar application of Silicon (Si) reduces the losses caused by terminal heat stress in wheat by elevating the antioxidant mechanism as well as the production of osmoprotectants.

Rice

Mauad *et al*., (2016) [27] in upland rice plants exposed to water stress, silicon fertilisation decreased proline concentration in the vegetative and reproductive phases and enhanced peroxidase activity in the reproductive phase, which may be a sign of stress tolerance. Emam *et al*., (2014) [10] Si pretreatments reduced the negative effects of the drought and increased yield quality by increasing the amounts of amylose, phenolic compounds, flavonoids, and oil contents along with a decrease in grain water uptake during cooking. In Addition, rice straw treated with silicon had higher amounts of total carbohydrates, protein, phytate, calcium, and phosphorus ions as well as lignin, cellulose, and pectin as compared to plants under drought stress. Agarie *et al*., (1998) [3] in rice leaves, Si is involved in the cell water relations, such as mechanical characteristics and water permeability and contributes to the prevention of electrolyte leakage (El) through the biosynthesis and functions of cell walls. The El caused by higher temperature (42.5 °C) was found to be lower in the leaves grown with Si than in the leaves grown without Si, implying that silicon plays a role in the thermal stability of lipids in cell membranes. These findings suggested that when rice plants are exposed to environmental stress, silicon prevents structural and functional deterioration of cell membranes. Farooq *et al*., (2015) [11] revealed that unfavourable growing conditions due to the combined stress of salinity and B toxicity had a significant impact on rice physiological characteristics. Si application mitigated the negative effects of stress by lowering toxic ion uptake and transpiration rate. Increased relative water content (RWC) and photosynthetic efficiency as a result of increased Si uptake resulted in improved growth performance. Si had a significant effect on the activities of enzymatic antioxidants with increased ascorbate peroxidase, increased guaiacol peroxidase, and decreased catalase activity, implying that stress was relieved by reduced oxidative damage.

Maize

Amin *et al*., (2018) [5] observed that the application of silicon significantly improved the photosynthetic rate and decreased the transpiration rate, while also increasing plant height, stem diameter, number of leaves, cob length, number of grains per cob, seed index (100-grain weight), grain yield and biological yield. As a result of silicon application to drought-stressed maize plants, growth and yield were increased, which was likely due to an increase in photosynthetic rate and a decrease in transpiration. Khan *et al*., (2018) [20] silicon supplementation reduced both osmotic and oxidative stress in maize crop by enhancing the effectiveness of defensive machinery under salinity stress. Under normal and salinity stress circumstances, silicon treatment also increased the water-use efficiency in both of the genotypes that were studied. The study's findings imply that silicon-treated maize plants had a higher chance of surviving in salinity conditions and that their photosynthetic and biochemical apparatus functioned significantly better than that of silicon-untreated plants. Ali *et al*., (2021) showed a new dimension in terms of Silicon's beneficial role in maize plants grown under salinity stress. The addition of Si reduced salt toxicity, which was more noticeable in cultivar P1574 than in cultivar Hycorn 11 as evidenced by an increasing trend in Relative Water Content, Membrane Stability Index, and Superoxide Dismutase, Peroxidase, Ascorbate peroxidase and catalase activities. Additionally, the decrease in the Na+/K+ ratio, the uptake of Na^+ ions at the surface of maize roots, their transport in plant tissues and the resulting substantial reduction in Na^+ ion accumulation were all factors in the Si-induced mitigation of salt stress.

Barley

Laifa *et al*., (2021) [21] The analysis of growth parameters, water status, photosynthetic gas exchange, photosynthetic pigment contents, lipid peroxidation and chlorophyll fluorescence revealed that silicon is promising support for reversing the negative effects of salt stress. As a result, Si can be considered an effective solution for dealing with salinity stress. Liang *et al*., (1996) [22] exogenous application of Si resulted in higher dry matter production and net photosynthetic rate in barley growing under salt stress conditions. The electrolytic leakage percentage in the leaves of two barley cultivars treated with 120 mM NaCl/L and 1.0 mM Si/L was significantly lower than in the leaves treated with 120 mM NaCl/L alone, indicating that added Si reduced the membrane permeability of salt-stressed barley. Silicon may also enhance potassium (K) uptake while inhibiting sodium (Na) uptake by salt-stressed barley, reducing salt toxicity and increasing salt tolerance in the plants. Heidari and Haddad (2015) [19] concluded that silicon plays a role in enhancing drought tolerance in barley plants by increasing the activity of antioxidant enzymes and the expression of stress-related genes, which results in a reduction in the activity of reactive oxygen species (ROS) produced under drought stress.

Table 1: Mechanism involved in the Si palliation of drought stress in cereals

Mechanism of resistance	Crop Species	Response
Improving seed germination	Maize	Effect of Si remained non-significant [40]
	Rice	Seed germination improved by 8-10% [41]
Enhancing root system	Rice	Root length increased by 40-65% [9]
		root surface area increased by 19-38% [9]
		root volume increased by 22-40% [9]
	Upland rice	Dry weight of the root increased by 23% [28]
	Sorghum	Dry weight of root increased by 74% [39]; 93% [36]; 110% [37]
		Root diameter increased by 16% [37]
	Wheat	Dry weight of the root remained non-significant [14]
Enhancing shoot growth	Upland rice	Dry weight of the shoot increased by 18% [28]
	Sorghum	Dry weight of shoot increased by 41% [39]; 71% [36]; 78% [37]
	Wheat	The increase in plant height remained non-significant [14]
	Rice	Shoot weight positively increased by 97-103% [9]
		Plant height increased by 4-9% [10]
Improving root/shoot ratio	Upland rice	Positively improved by 9% [28]
	Sorghum	Positively improved by 4% [39]
		Remained non-significant [36,37]
Improving osmotic adjustment	Sorghum	Root osmotic adjustment improved by 7% [39]
		Leaf osmotic adjustment improved by 15% [23]
		Root xylem osmotic adjustment remained non-significant [23]
	Upland rice	Root osmotic adjustment improved by 134% [28]
		Leaf osmotic adjustment improved by 63% [28]
Improving water use efficiency (WUE)	Rice	Positively increased by 119% [9]
	Maize	Positively increased by 30% [16]
	Sorghum	Remained non-significant [18]
	Upland rice	Positively increased by 176% [28]
Enhancing water potential	Sorghum	Water potential increased by 13% [23];16% [18]
	Wheat	Water potential increased by 15% [15];40% [14]
	Rice	Water potential increased by 15% [9]
Improving net photosynthetic rate	Upland rice	Photosynthesis improved by 260% [28]
	Wheat	Photosynthesis improved by 59% [15]
	Sorghum	Photosynthesis improved by 17% [24]; 118% [18]
	Rice	Photosynthesis improved by 37% [9]
Improving hydraulic conductance	Sorghum	Hydraulic conductance of the whole plant improved by 52% [23]
		Hydraulic conductance of root improved by 19% [24]

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