



## The Role of Silicon under Biotic and Abiotic Stress Conditions

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**Abstract:** Biotic and abiotic stress factors can adversely affect the agricultural productivity leading to physiological and biochemical damage to crops. Therefore, the most effective way is to increase the resistance to stresses. Silicon plays a role in reducing the effects of abiotic and biotic stresses (drought, salt stress, disease and insect stress etc.) on plants. Silicon is accumulated in the cell walls and intercellular spaces and thus it has beneficial effects on disease infestations in especially small grains. The application of silicon may reduce the effects of environmental stresses on plants while making effective use of plant nutrients such as nitrogen and phosphorous. Also, silicon may reduce the toxic effects of heavy metals in soil. It may protect the foliage and increase light uptake and reduce respiration. Therefore, in this review, we discussed the effects of silicon on abiotic and biotic stresses in especially field crops.

**Keywords:** Biotic stress, drought, resistance, salt stress, silicon

### 1. Introduction

It was emphasized that the second most abundant mineral in earth's crust is silicon in terms of quantity (Mcginnity, 2015) (Figure 1) and it is mostly in Si(OH)<sub>4</sub> form. However, silicon is not grouped as an active mineral for plant growth. Although silicon limitation does not affect the plant growth, silicon application increases yield on many crops. For example, calcium and silicon foliar fertilizer is advantageous for sugar beet production and shows benefits in terms of biological and sugar yields (Artyszak et al., 2014).

Silicon has increased yield by 22% in potato (Luz et al., 2008), 30% in rice and 45% in sugarcane (Kingston, 2008) and increased doses lead to improvement in leaf structure (Luz et al., 2008). The application of silicon in canola improved yield and oil content and reduced pesticide and fungicide usage (Lynch, 2008). Silicon plays an important role in strengthening the cell walls of the plants and enhances resistance to both pests and diseases in wheat, rice, maize and vegetable crops (Laing and Adandonon, 2008).

Silicon can play an important role in overcoming the effects of various environmental stresses (Figure 2). It reduces manganese (Mn), cadmium (Cd), arsenic (As), aluminum (Al), zinc (Zn) and phosphorus (P) deficiency and, increases the resistance to lodging, diseases and insects. Besides, silicon increases plant resistance to abiotic stresses, such as drought and salt stress.

The positive effects of silicon on plant growth, development, yield and disease resistance are observed in both monocots and dicots. Silicon application influences the nutrient content of sunflower by increasing the accumulation of both macro and micro nutrients (Savić and Marjanović-Jeromela, 2013).

In relation to plant structure, it was explained by Taiz and Zeiger (2002) that silicon is found at different concentrations within plant tissue and it improves growth and fertility of plants. Primarily, silicon is founded in the endoplasmic reticulum, cell walls (Raven, 2003) and intercellular spaces. As an easily understandable mechanism, it has important role in the support of cell walls by

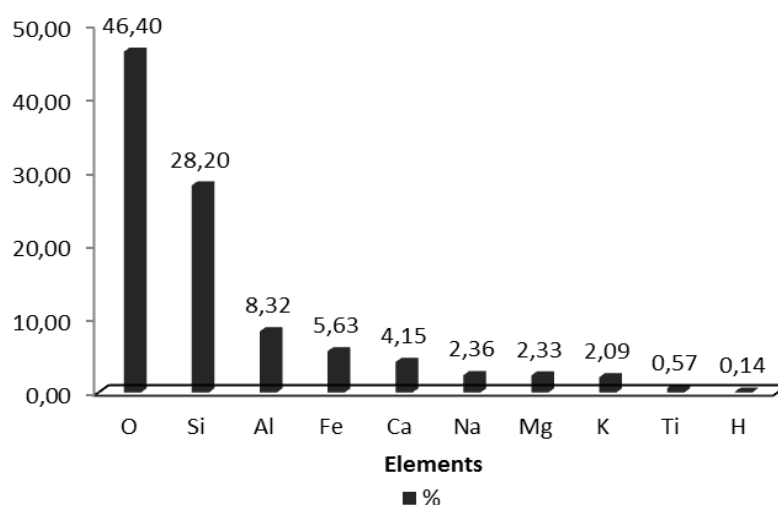


Figure 1. Elements in the earth's crust (Modified from Sharma, 2016)

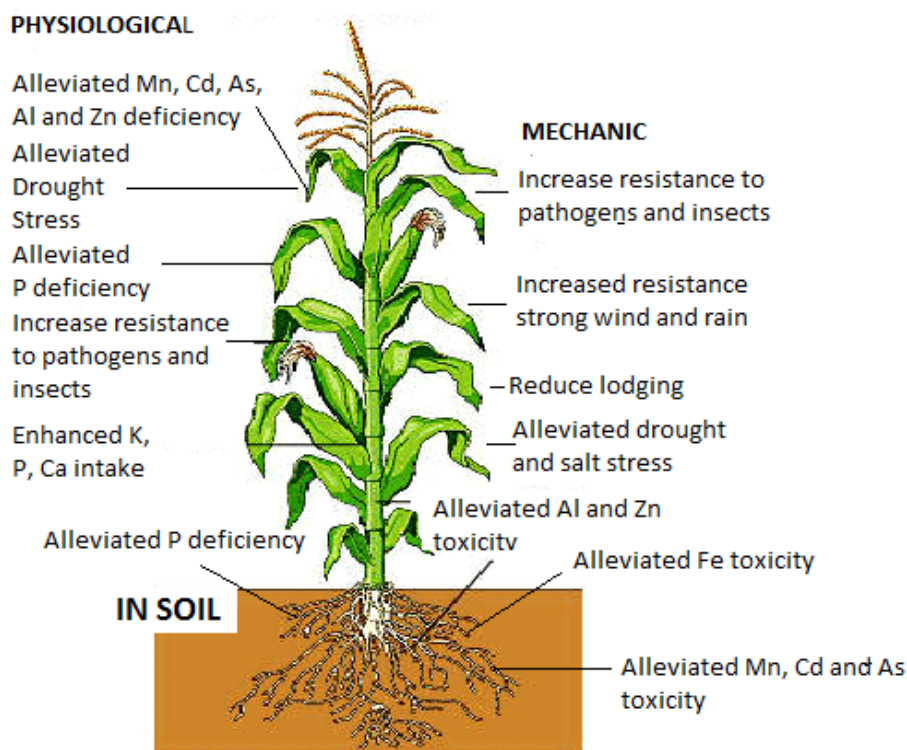


Figure 2. Beneficial effects of silicon [Modified from McGinnity (2015)]

forming complexes with polyphenols. Moreover, silicone reduces the adverse toxic effects of heavy metals. After silicon application, leaves would stand up and benefit from sunlight more efficiently. So, plant performs better photosynthesis and more production (Ding et al., 2007).

Silicon stored in the bulliform cells and dumbbell cells improves the strength and rigidity

of cell wall, and accordingly increases the resistance of rice to diseases, pests, and lodging (Epstein, 1999; Jones, 2012). Especially bulliform cell are located near the midrib on grass leaf such as rice. The cell group affects leaf folding and, leaves are less exposed to sunlight during drought (Mauseth, 2017).

Currie and Perry (2007) stated that silicon as an organically dynamic component activating natural

defense mechanism and, reviewed the transport of the silicon in plants such as rice, known as silicon accumulator. Two different silicon mechanisms were emphasized. These are low affinity transporter which is responsible for the uptake of silicic acid from the soil to the root cortical cells and, second transporter which is responsible for xylem loading via passive diffusion (Ma, 2004).

## 2. Biotic Stresses

Silicon controls fungal diseases of monocots, such as rice and other grasses. The effect of silicon on some important Graminae species are shown in Table 1. *Curvularia*, *Helminthosporium*, and *Fusarium* are associated with grain discoloration. The grain weights increased and grain discoloration reduced by silicon applications (Korndörfer et al., 1999). At the same time, it reduced crop susceptibility to stem borer, leaf hopper and spider mites because of storing beneath the leaf cuticle and acts as a barrier. This barrier limits fungus or insect penetration. Other researchers explained that silicon improved pest and disease resistance of plants via enhancement of phenolic compounds, lignin and phytoalexins (Mcginnity, 2015; Pozza et al., 2015).

The application of silicon to cotton leads to reduced pathogen influence on the photosynthesis and antioxidative system (Curvelo et al., 2013). Additionally, silicon protects cotton against angular leaf spot, caused by *Xanthomonas citri* subsp. *malvacearum* which is the major bacterial disease of cotton (Oliveira et al., 2012).

## 3. Abiotic Stresses

### 3.1. Silicon and drought stress

The beneficial effects of silicon are mostly on abiotic stresses such as drought (Ma, 2004). Wheats treated with silicon fertilizer grown in drought conditions displayed higher stomatal conductance, relative water content, and water potential than drought stressed plants without silicon application. Silicon enhances root resistance to drought and promotes faster root growth (Mcginnity, 2015). Silicon film reduces water loss via decrease in the width of stomatal

pores and decreases transpiration (Meena et al., 2014). A sufficient silicon application is essential to enhance water stress resistance by improving uptake of major elements (Guntzer et al., 2012). In upland rice, it was reported that application of silicon reduces the proline content and enhances the peroxidase activity (Mauad et al., 2016). In plants grown under drought stress conditions, added silicon causes higher fresh weight, dry weight and leaf soluble protein. Also, silicon increases soluble sugar content (Ding et al., 2007).

### 3.2. Silicon and salt stress

In many review and research articles, it was emphasized that water status of leaf and water-use efficiency of crops are increased by silicon application in many salt-stressed plants (Coşkun et al., 2016). Silicon application can improve antioxidant activities such as SOD (superoxide dismutase), APX (ascorbate peroxidase), DHAR (dehydroascorbate), GPX (guaiacol peroxidase), CAT (catalase) and GR (glutathione reductase) under salt stressed conditions. When the effects of silicon on cereals evaluated in terms of abiotic stress, application of silicon enhances plant growth in wheat under salt stress conditions (Ali et al., 2013). Silicon application causes greater adaptation (Ahmed et al., 2013) and, it alleviates salt stress, enhances chlorophyll content and photosynthetic activity in salt-stressed maize (Moussa, 2006).

Although reports on the effects of silicon on dicots are very few, it was shown that silicon was effective to prevent salt stress in sunflower (Ali et al., 2013). The effect was attributed to an increased antioxidant activity (Moghadam Ali et al., 2013). Silicon may improve growth and physiological characteristics of cowpea and kidney bean under salt stress (Amador et al., 2005).

### 3.3. Silicon and other stress factors

Silicon can remove the negative effects of other stresses including physical stresses (high temperature, freezing, drought, lodging, radiation, irradiation, UV) and chemical stresses (salt, nutrient imbalance, metal toxicity) in *Borago officinalis* L. (Shahnaz et al., 2011 and reviews,

**Table 1.** The effects of Si on crops and diseases (Romero et al., 2011; Meena et al., 2014; Mcginnity, 2015)

Crop	Disease
Wheat	<i>Septoria nodorum</i> , <i>Erysiphe graminis</i> , <i>Blumeria graminis</i> , <i>Phaeosphaeria nodorum</i> and <i>Mycosphaerella graminicola</i> , <i>Oculimacula yallundae</i>
Corn	<i>Pythium aphanidermatum</i> , <i>Fusarium moniliforme</i>
Rice	<i>Magnaporthe grisea</i> , <i>Leptosphaeria salvinii</i> , <i>Fusarium</i> , <i>Cochliobolus miyabeanus</i>
Cowpea	<i>Uromyces phaeseoli typia</i> Arth.
Pea	<i>Mycosphaerella pinodes</i>
Sugarcane	<i>Puccinia melanocephala</i> , <i>Leptosphaeria sacchari</i> , <i>Phyllosticta sp. (anamorph)</i>

Mcginnity, 2015; Sahebi et al., 2015). Also, silicon application in *Salvia* is efficient in diminishing the injury caused by heat stress (Soundararajan et al., 2014). Probably, because of the strengthening effects on cell wall. Silicon has indicated a significant effect on lodging especially in rice, wheat and barley by enhancing the amount of light and photosynthesis (Mitani and Ma, 2005; Fallah, 2012; Salman et al., 2012; Mcginnity, 2015; Dorairaj et al., 2017). Some researchers reported a highly significant role of supplied silicon in enhancing the biosynthesis of phenolic compounds under UV-B stress. The result of experiments showed that silicon application was significant in alleviating the adverse effects of UV-B. Significant advances have been made in alleviating the effects of UV-B by exogenous silicon application on soybean, wheat and maize (Yao et al., 2011; Malčovská et al., 2014; Shen et al., 2014).

Silicon affects the uptake of cadmium, copper and zinc (Liang et al., 2007). The silicon concentration in the higher pH reduced Cd uptake by plants (Chen et al., 2000). Moreover, silicon application reduced the apoplastic Mn levels in cowpea (Horst et al., 1999). The most significant effects of silicon on metal toxicity are by reducing Cd and copper (Cu) uptake and root-to-shoot translocation by increasing metal adsorption and Zn and Mn uptake (Rizwan, 2012). It was revealed that silicon reduced Cd uptake by the plants as well as decreased shoot to grain translocation of Cd (Adrees et al., 2015).

#### 4. Conclusion

Silicon has numerous functions on plant physiology, and its most significant effects are focused on cell wall. The presence of silicon in the cell wall increases their strength, resistance to salinity, drought tolerance, and photosynthetic activity. It supports root and foliage growth and leads to prevention of oxidative stress by antioxidant enzymes. Exogenous application of silicon was effective in mitigating several responses of biotic and abiotic stress damages by improving the plant water uptake and transport. The other important role of silicon in reducing the adverse effects of stress may be by improving soil conditions. Therefore, silicon could be used as a growth regulator to improve plant growth and resistance under stress conditions. There is need for applied research to evaluate water use efficiency and drought tolerance and resistance to disease and insects on more crops.

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