Silicon Mitigate Salinity Stress on Gerbera Cut Flower

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Abstract

Gerbera *(Gerbera jamesonii)* is an important ornamental flower in global flower market, it is one of the most herbaceous, perennial herb belongs to Asteraceae (compositae) family. Gerbera is very popular and widely used as a decorative garden plant or as a cut flower; can be used in landscapes as bedding plants for borders or as a cut flower for table arrangement. Silicon (Si) is a spread widely element and the second most abundant after oxygen in the soil, covering approximately 28 % of the Earth's crust. Silicon is not an essential nutrient, but it is known to have beneficial effects when added to plants. In the soil, most sources of silicon are present as crystalline aluminosilicates, which are inert, insoluble, and not directly available for plants. Silicon provides strength to the plant by making the plant tissues strong and rigid. Salinity is one of the abiotic stresses that negatively influence agricultural production. Recent review has proved that supplementary application of silicon involved in ornamental plants tolerance such as gerbera against salinity, it positively increases the activity of antioxidant enzymes, decreases the plasma membrane permeability, resulted in decreasing levels of lipid peroxidation. Also, reduces the transpiration ratio and increases root activities. Decreases in transpiration lead to decreased osmotic stresses in plant cells and root activities improved, because of root activities, uptake of nutrients by plants improved and salt toxicity decreased.

Keywords: Silicon, Gerbera plants, Abiotic stress, an antioxidant enzyme.

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التخفيف من الاجهاد الملحي على نبات الجربيرا باستخدام السيليكون

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ملخص

يعد نبات الجربيرا من أزهار الزينة المهمة في سوق الأزهار العالمي، ويصنف على أنه نبات عشبي معمر ينتمي إلى العائلة المركبة. يستخدم على نطاق واسع في الحدائق أو أزهار القطف، وكذلك يمكن استخدامه في المناظر الطبيعية كأسيجة أو لترتيب الطاولات. يعتبر السيليكون (Si) عنصر منتشر على نطاق واسع وهو العنصر الثاني بعد الأوكسجين في التربة يغطي حوالي 28% من القشرة الأرضية. لا يعتبر السيليكون من العناصر الأساسية للنبات ولكن ذو تأثير مفيد عند اضافته للنباتات. يوجد السيليكون في التربة على صوره سيليكات الألمنيوم بشكل خامل غير قابل للذوبان، وليس متاح للنبات. عند اضافته للنبات يقوي الأنسجة ويجعلها أكثر صلابة. الاجهاد الملحي من العوامل الغير حيوية والتي تؤثر على الإنتاج الزراعي. حيث أنه عند معاملة النباتات بالسيليكون يؤدي إلى زيادة نشاط الأنزيمات المضادة للأكسدة داخل النبات، كما أنه يقلل من نسبه التبخر وزيادة نشاط الجذور تحت الاجهاد الملحي. إضافة الى انخفاض النتح الذي بدوره يؤدي إلى التقليل من الاجهاد الاسموزي في الخلايا النباتية ويحسن من نشاط الجذور حيث يؤدي إلى زيادة امتصاص العناصر الغذائية بواسطة النبات وتقليل سمية النباتات.

الكلمات الدالة: السيليكون، نباتات الجربيرا ، الإجهاد اللاأحيائي، إنزيم مضاد للأكسدة.

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Introduction

Gerbera (*Gerbera jamesonii*), grown throughout the world in a wide range of climatic conditions (Sujatha et al., 2002). Gerbera belongs to the family compositae (Asteraceae) (Cardoso and Silva, 2013). It is a native of South Africa and tropical Asia, gerbera comprises 45 species, this plant is widely created for commercial use as cut, pot and garden flowers (Keditsu, 2013; Khalaj et al., 2011; and Vidalie, 2007).

Agricultural productivity is largely affected by major biotic and abiotic factors including drought, salinity, extreme temperatures and pathogens (Shrivastava and Kumar, 2015). Salinity is one of the most important environmental factors, which limit growth and productivity of plants (Kaya et al., 2003).

In Jordan, agricultural land is limited to 8% of the total land area, which is heavily dependent on irrigation due to the arid climate conditions, approximately 20% of irrigated lands affected by salinity, which comprises one-third of food-producing land (Ammari et al., 2013). However, the total area cultivated with gerbera plants in Jordan is estimated at about 20 du (40 plastic house); according to JCFA (2020). The annual production and income of gerbera for the last three years are illustrated in the table 1.

Table(1) Annual production and income of gerbera in Jordan (JCFA, 2020)

Year	Annual production (flower)	Annual income (JD)
2018 (1/1-2018)-(31/12/2018)	3,527, 362	215,169.082
2019 (1/1-2019)-(31/12/2019)	2,847, 280	210,698.72
2020 (1/1-2020)-(31/7/2020)	610, 360	40,894.12

Salinity stress leads to ionic imbalances, insufficient water use, and nutrient (e.g. N, Ca, K, P, Fe, and Zn) deficiency, which ultimately leads to oxidative stress in plants (Rehman et al., 2019). Under normal physiological conditions, reactive oxygen species (ROS) produced in plant cells either in a radical or non-radical form (Winterbourn, 2019). Gerbera plant classified as moderately sensitive to salinity, so the maximum salinity (electrical conductivity (EC) of nutrient solution) is 1.5–2.8 $dS \bullet m^{-1}$ without yield reduction (Bilal et al., 2020; Carmassi et al., 2013b; Sonneveld et al., 1999; and Baas et al., 1995).

Savvas et al. (2002) found that when the electrical conductivity (EC) in the gerbera plant root zone of increased from 1.8-3.2 $dS \bullet m^{-1}$, resulted in decreased in number of flowers per plant and the mean flower weight , then restricted the fresh weight of flowers per plant. Silicon is the only element safe to plants when excessive uptake occurs. Deficient levels of silicon makes the plant weaker in structure and induce abnormalities in growth and reproduction (Ma and Yamaji, 2006).

Plant description

Gerbera plant is a perennial and herbaceous plant in Mediterranean area, has cylindrical, smooth stem with full green pigmentation (Akter et al., 2012). Leaves arranged in basal rosettes, petiolate, oblong-spatulate and lobed; color ranges from deep green to light green in color (Infoagro, 2015; Akter et al., 2012). Gerbera plant requires between 90-150 days for flowering, depending on the sowing date and soil conditions, (Infoagro, 2015). There are many different gerbera colors including red, yellow, white, pink, dark orange, and even violet. The flower size varies from 6 cm to 9.5 cm in diameter (Cardoso and Silva, 2013; Akter et al., 2012). Gerbera propagates by seed (Seed germination has traditionally, non-uniform flowering) division, and recently tissue culture. Breeding programs (Keditsu, 2013) reported a significant increase in uniformity of seed germination and the percent of germination. Gerbera has many medicinal uses such as to treat cold, fever, and have broad-spectrum anti-tumor and anti-bacterial activity and improving indoor air quality (Nungki et al., 2015).

Silicon in nature and soil

In soil solutions, silicon- mostly- is present as uncharged monomeric silicic acid at rates from about 0.1 mM to 0.6 mM (Epstein, 1994). The major soluble forms of Si in the soil are monosilicic acid (H_4SiO_4) and poly acids (Matychenkov and Snyder, 1996). In highly weathered soils (Tropical soils), free silicon dioxide (SiO_2) may become depleted from soils leaving sesquioxides of iron and aluminum as the major residual minerals (Janislampi, 2012). However, silicon amendments can be important for increasing crop yields in some soils (Korndörfer and Lepsch, 2001). Sahebi et al. (2015) indicated that increasing concentration of the monosilicic acid in the soil solution, improves the ability of plants to absorb phosphates directly. The amount of monosilicic acid is increased because of chemical resemblance between phosphate and silicate anions causing a competitive reaction in the soil (Matychenkov and Snyder, 1996). Plants can absorb phosphates directly when an increase of the monosolic acid in soil solution occurred (Sahebi et al., 2015).

Sources of silicon

Silicon is available from natural resources: organic, inorganic fertilizers, and industrial by-products (Gascho, 2001). By-products involve potassium silicate, which used in fruit tree production to help against plant disease (Mitre et al., 2010), and improve horticultural traits in ornamental sunflowers, zinnia, and gerbera (Kamenidou, 2010). Rice hulls are derived from plant residues have sufficient silicon concentration (Tubana, 2016). Rice hulls help in mitigation the side effects of the disease (as anthracnose) and improve some growth and fruit parameters of capsicum grown in a hydroponics system (Jayawardaba et al., 2016). Diatoms, a group of algae, accumulates amorphous silica when fossilized (Mills, 2017).

Uptake, transportation, deposition, and accumulation of Si in plants

All plants contain Si at different concentrations ranging from 0.1% to 10% dry weight, depending on species (Epstein, 1994) due to the differences in capability for absorption of silicon (Ma and Yamaji, 2008). Plants mainly absorb and utilize silicon in the form of orthosilicic acid Si $(OH)_4$, but Si mainly exists in soil as silica and silicates, most of which cannot be absorbed by plants (unavailable) (Zhu and Gong, 2014).

Generally, there are three main mechanisms by which plants absorb Si through root—active, passive, and rejective (Zhu and Gong, 2014). When plants having uptake of silicon higher than water are classified as active such as rice and barley, but when the rate of silicon and water uptake is similar are classified as passive such as oat, and those with lower rates classified as rejective (Kaur and Greger, 2019).

Plant species classified into three categories according to silicon content (accumulator, intermediate, and non-accumulator) (Yan et al., 2018) (Table 2). Tropical and subtropical soils have low silicon concentrations due to highly weathering and leaching processes (Epstein, 1999),while an estimated 210–224 million tons of Si is taken out annually from the world's arable soils (Meena et al., 2014).

Table (2) Plant categories based on silicon uptake capacity (Yan et al., 2018)

Accumulator (>1.5% Si) Dry weight	Intermediate (1.5-0.5% Si) Dry weight	Non-Accumulator (<0.5% Si) Dry weight
Rice	Cucumber	Tomato
Wheat	Rose	Pansy
Lentils	Squash	Grapes
Spinach	Chrysanthemum	Gerbera
Sugarcane	Zinnia	Petunia
Mosses	Marigold	Snapdragon

Effect of Silicon on plant growth and quality

Silicon plays an important role in plant growth and quality. Kamenidou et al. (2010) found that the application of Si enhanced the growth and quality of important floricultural crops such as ‘Acapella’ gerbera (Gerbera jamesonii L.). The effect of weekly application of potassium silicate drenches at 100 mg/L Si on the morphological characteristic of different species of floriculture grown in a soilless substrate; they found that, a significant height response with Si treatment (Mattson and Leatherwood, 2010). Silicon supplementation increases stem diameters of chrysanthemum (Chrysanthemum ×morifolium) (Moon et al., 2008), and gerbera (Savvas et al., 2002). Moreover, Si additions increased both stem and flower diameter of greenhouse-grown sunflower (Kamenidou et al., 2008) and zinnia (Zinnia elegans) (Kamenidou et al., 2009). Silicon concentration in leaf tissue varied from 237 $mg \cdot Kg^{-1}$ Si for petunia (Petunia ×hybrida Vilm) to 11,700 $mg \cdot Kg^{-1}$ for zinnia (Frantz et al., 2008). Addition of silicon solution in a closed hydroponic system improved stem quality of cut rose (Ehret et al., 2005).

Effect of silicon on strength of tissue

Silicon deposited in plant cell walls as amorphous silica oxide (SiO_2, nH_2O) form (Pilon-Smits et al., 2009). A considerable relationship between cell wall macromolecules and silicon was found (Yamamoto et al., 2012). Intra or extracellular silica in plants is useful for improving mechanical strength and alleviating biotic and abiotic stress (He et al., 2013). Deposition of Si in the leaves enhances the strength and rigidity of cell walls, decreases water loss from the cuticle, and increases the resistance to lodging, low and high temperature, radiation, UV, drought stresses and increased postharvest quality (Ma and Takahashi, 2002).

Application of potassium silicate (K_2SiO_3) at 100ppm had increased in the thickness of xylem in Zinnia elegans than untreated plants. The increment may be attributed to the silicon deposition in epidermal and in turn strengthening storage and vascular tissues (El-Serafy, 2015). About 90% of the total absorbed Si, accumulated in the epidermis of leaf and cell walls, which accounts for 10% of the dry weight of grass shoots (Ma and Takahashi, 2002). Savvas et al. (2002) found that silicon improved quality of gerbera flowers by providing mechanical strength to the stems since stem diameter increased with increasing silicon concentration in the nutrient solution.

Babalar et al., (2016), found that the significant effect of silicon supplementation on the gerbera plant strengthened lower part of the stem but had no effect on the top of the stem. Silicon affects the mechanical properties of cell walls, permeability to water; it is involved in the biosynthesis of cell wall components (Liang et al., 2015). In addition, it had significant influence on metabolism and concentration of polyphenols in the xylem cell walls. Silicon doesn't only involve in the strength of cell walls, but it, also, increases the elasticity of the wall during cell growth (Broadley et al., 2012). Babalar et al. (2016) demonstrated that application of silicon could enhance the mechanical strength of inflorescence stem and improve the cut flower quality in gerbera.

Effect of silicon on flowering parameters and post-harvest quality

Savvas et al. (2002) illustrated that the higher percentage of flowers grading as class I and peduncle stem thickness increased in Gerbera when potassium silicate (1.25 mM) was included in the hydroponic nutrient solution. The maximum value of flower number per gerbera plant reached when treated by 7.3g/ pot calcium silicate and flower diameter reaches the maximum value when treated by 3.6g/pot, compared to the control (Moyer et al., 2008).

Foliar application of potassium silicate ($KSiO_3$), sodium silicate ($NaSiO_3$), and rice husk ash on gerbera plant, resulted in thicker flower peduncles, increased height, and earlier flowered more than control (Kamenidou et al., 2010). The short vase life of gerbera cut flowers leads to difficulties with long-distance transportation and subsequent marketing (Aghajani and Jafarpour, 2016). The effect of different levels of silicon on gerbera flower longevity; when the increasing concentration of silicon to 2mM Si in the vase solution significantly raised the longevity and significantly reduced the fresh weight alters of gerbera flower comparison to the control while increasing the rate to 3mM Si decreased the vase life comparison the control by decreasing ethylene biosynthesis (Kazemi et al., 2012c). Pre-harvest treatment of different sources of Si as well as salicylic acid and methyl jasmonate as postharvest treatment can significantly affect the marketability of cut gerbera flowers (Aghajani and Jafarpour, 2016). Richter (2001) found that supplying different gerbera cultivars with silicon can extend vase life. In addition, the number of flowers with a bent neck can be decreased. Foliar sprays of sodium silicate at 50–100 mg L^{-1} resulted in taller gerbera plants combined with larger flower diameters and drenches potassium silicate at 200 mg L^{-1} resulted in increased basal and apical diameters in flower peduncles (Kamenidou et al., 2010).

Silicon and salinity stress

Salinity stress is one of the most common environmental stresses that deterioration to the agriculture industry worldwide. The elevated supply of Si (2 mM) improved the quality of the gerbera flowers when salinity was low (0.8mM) (Savvas et al. 2007). Reezi et al. (2009) found that the flower number increased when the application of 50 ppm Si in nutrient solution compared with unstressed conditions. Supplementary of silicate in gerbera plant resulted in slightly increased plant growth, similar to those obtained in plants under the control treatment (without salinity) and root fresh weight was slightly higher than salinized plants (Savvas et al. 2002). Foliar application of Si reduced the effect of salinity on the flower vase life of gerbera in case of using low-quality water (Torkashvand and Shirghani, 2015) and high-quality water (Oliveira et al., 2012).

Mechanisms of silicon in mitigation of salinity stress

The exogenous application of silicon (Si) has been used as an eco-friendly approach (Almeida et al., 2017). In general, under salinity conditions, the soil has a high level of sodium (Na^+) ions and chloride (Cl^-) ions content, leads to plants have low water potential and salt deposition in the other plant cellular regions (Romero-Aranda et al., 2001). Sodium (Na^+) and chloride (Cl^-) ions move to the aerial parts of plants through transpiration, and when Na^+ and Cl^- are at a toxic threshold, several tissues of a plant can be damaged (Sahebi et al., 2015). Shi et al. (2013) reported that Si decreases the apoplastic transportation of sodium ions (Na^+) and chloride ions (Cl^-) under salinity stress.

Silicon mitigates salt stress by inhibition of sodium ion (Na^+) transport to the leaves and specific accumulation of Na^+ in the roots (Tuna et al., 2008). Shi et al., (2005) found that treatment of plants with silicon under saline stress has a smaller specific leaf area and a larger leaf weight ratio when compared with untreated plants. Silicon increases salinity tolerance capacity of rose plant by increased photosynthetic activity, improving water status and stimulation of antioxidant system by reducing salt uptake and increasing K uptake (Tahir et al., 2006).

Abiotic stresses cause oxidative stress in plants that induce the production of reactive oxygen species (ROS) (Mc Cord, 2000). The application of silicon increases the activity of an antioxidant enzyme in plants under salinity (Liang et al., 2003). Sahebi et al., (2015) reported that silicon decrease the permeability of the plasma membrane in plants leaf cells resulted in decreasing levels of lipid peroxidation. Sahebi et al. (2015) indicated that the treatment of various plants with silicon under salinity stress reduces the transpiration ratio and increases root activities, decreases in transpiration lead to decreased osmotic stresses in plant cells and root activities improved, as a result of root activities, uptake of nutrients by plants increased and salt toxicity decreased (Figure 3).

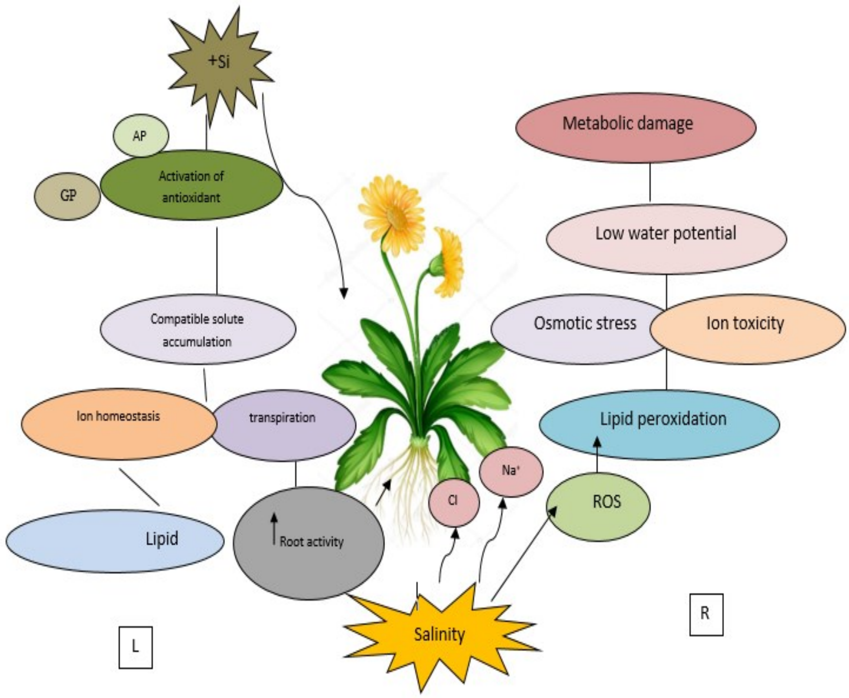

Figure (3) A schematic model for the mechanism of silicon in plant under salinity

The right (R) side refers to effect of salinity on plant, the lift side (L) refers to the effect of exogenous silicon on plant under salinity.

The main purpose of this review is to understand the role of silicon in the growth and development of gerbera plants and clarify the effect of silicon in mitigate salinity stresses. Treatment of plants with silicon under salinity stress decreases transpiration, which, in turn, decreases osmotic stresses in plant cells and improves root activities. This may be attributed to improving uptake of nutrients by plants and decreasing salt toxicity, then, growth, quality and prolonged vase life of gerbera cut flowers improved.

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