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THE ROLE OF SILICON (SI) IN INCREASING DROUGHT TOLERANCE IN WHEAT

ULOGA SILICIJA (SI) U POVEĆANJU OTPORNOSTI PŠENICE NA SUŠU

J. Duvnjak and Valentina Španić

ABSTRACT

Global warming reduces surface water and dries out soils thus affecting wheat production by decreasing its grain yield and quality. Therefore, for ensuring global food security it is important to enhance drought tolerance in wheat. In this context, the alleviating effects of Silicon (Si) on drought stress has been observed in wheat. It has been reported that Si is also involved in physiological functions of wheat where it may improve antioxidant defense. Accordingly, Si fertilization could provide a relatively cheap method of improving wheat drought tolerance although Si is the second most abundant element, it is not readily available for uptake by plants. This study provides an overview of the currently available information on Si-mediated defense responses under drought stress.

Key words: wheat, silicon, drought stress

SAŽETAK

Globalno zatopljenje smanjuje površinsku vodu i isušuje tlo što utječe na proizvodnju pšenice smanjujući urod i kvalitetu zrna. Stoga je za osiguranje svjetske proizvodnje hrane važno povećati otpornost pšenice na sušu. U tom kontekstu, ublažavajući učinci silicija (Si) na sušni stres zabilježeni su u pšenici. Zabilježeno je da je Si također uključen u fiziološke procese u pšenici gdje može poboljšati antioksidacijsku obranu. U skladu s tim, gnojidba silicijem mogla bi pružiti relativno jeftinu metodu poboljšanja tolerancije pšenice na sušu, iako je silicij drugi najzastupljeniji element, nije lako dostupan za unos u biljke. Ovaj pregledni rad daje uvid u trenutno dostupne informacije o Si-posredovanim obrambenim odgovorima na sušni stres.

Ključne riječi: pšenica, silicij, sušni stres

INTRODUCTION

Climate change is leading to an uncertain future of the world's resources, due to an increase of the average global surface temperature. Abiotic stresses such as drought, salinity and high temperatures cause large losses in wheat production (Abhinandan et al., 2018). Drought stress can impair various metabolic processes in plants, whereas they have developed various defence mechanisms that contribute to drought resistance, including the formation of longer roots, increased biomass, enhanced antioxidant metabolism, accumulation of osmoprotectants that facilitate osmotic adaptation, and the expression of various genes in respond to stress (Kulkarni et al., 2017). Breeding for drought resistance is complicated by the fact that multiple abiotic stresses could act at the same time in the field.

After oxygen, elemental silicon (Si) is the second most abundant element in the earth, which mainly consists of silicates. It is not considered essential for the growth and development of plants, but recently, more studies showed its beneficial role for plants, especially in stressful conditions (Zargar et al., 2019). Silicon alleviates effects of abiotic stress (drought and heavy metals), and in addition, it improves the strength of plants and their resistance to exogenous stresses (Luyckx et al., 2017). Effectiveness of silicon absorption in wheat cultivation is not sufficiently investigated. The aim of this article is to review the role of silicon in increasing drought tolerance and to explore the possibility of breeding for increased efficiency of silicon absorption into the plant, thus improving grain yield and quality of wheat under stressful conditions.

Drought impact on wheat

Drought is a stress that dramatically decreases productivity and quality of main crops (Waraich et al., 2011), such as winter wheat (Vuković et al., 2022). According to Jamali et al. (2020) plants suffer from drought stress when loss of water by leaves transpiration exceeds the water uptake through roots. The impact of drought stress could be reflected on morphological, physiological and molecular traits of wheat through all developmental stages whenever the shortage of water is evident. In the early stage of wheat development, during germination stage, delay or inhibition of germination, and seedling vigour of wheat might occur (Almaghrabi, 2012) leading to poor establishment of the plants. Further, in the early vegetative phases drought can affect a reduction of tillering and surface area of the leaves, while in later phenophases, it results in abortion of pollen and spikelets, consequently reducing the number of grains in ears and 1000 kernel weight, which will have a direct negative impact on the grain yield (Praba et al., 2009). Overall, leaf water potential, stomatal conductance, and photosynthesis could be reduced followed by earlier leaf senescence and shorter grain filling stage (Plaut et al., 2004), thus lessening growth and yield of wheat (Chen et al., 2012) with decreases by 17-70% (Nouri-Ganbalani et al., 2009). According to Pradhan et al., (2012) reproductive and grain-filling phases are the most sensitive to drought. Anjum et al. (2003) reported that during drought stress, limitation of photosynthesis will occur through closure of stomata which decreases the uptake of carbon dioxide by leaves and also prevent the transpiration loss of water. Also, under elevated reactive oxygen species (ROS) production, modification of various cellular mechanisms will appear including degradation of proteins, inhibition of enzymes, oxidative damage to DNA and RNA, and membrane lipid peroxidation (Huseynova, 2012). Metabolism of antioxidant enzymes against oxidative stress is one strategy for maintaining normal cellular function (Horváth et al., 2007). For example, according to Pandey et al. (2015), drought tolerance is associated with glutathione (GSH) redox state maintained by ascorbate (AsA)-GSH pathway. Further, plants have osmotic adjustments due to accumulation of osmolytes in cells as a result of stressful conditions (Sanders and Arndt, 2012).

Drought resistance is defined as the ability of plant to survive in conditions of long-term, pronounced lack of water in the soil. The early flowering time is the most used approach for avoiding the stress period, which allows the plants to pass the critical period before drought in the summer months, that is, to complete their life cycle before the onset of severe drought stress. Other strategies to increase drought resistance, such as slowing down biological processes or by accumulating some compounds such as proline have not resulted in great success (Mwadzingeni et al., 2016). Further, under drought stress conditions, wheat varieties with developed root system and good management of water can give higher yields (Nezhadahmadi et al., 2013). Also, integration of physiological traits, genetic and genomic tools, and transgenic approaches may also help to improve resistance to drought in wheat (Farooq et al., 2014). The priority is to create new high-yielding drought-resistant wheat varieties, especially in regions where climate change is predicted to result in more frequent drought conditions in the future.

THE ROLE AND ASSIMILATION OF SILICON IN INCREASING DROUGHT TOLERANCE

Nutrition for plants has an important role to maintain healthy growth as well as to enhance the stress tolerance whereas silicon (Si) is nutritive element that enhances plant tolerance to biotic as well as abiotic stresses (Ma, 2004). Increased intake of silicon in wheat maintains the balance between nitrogen and carbon, which is important for ensuring high grain quality under stressful conditions resulting in indirect effects on rheological properties (Marylyn et al., 2021).

Although silicon is the second most abundant element, it is not readily available for uptake by plants. Silicon is measured as an immobile element in the phloem and its redistribution in plants is very low (Pilon et al., 2013). Plants absorb silicon in the form of silicic acid, which is translocated to the shoots, and after water loss, polymerizes as a gel on the surface of leaves and stems (Ma et al., 2001). It is also absorbed in the form of sodium silicate and silica gel with active or passive uptake. Active intake of silicon takes place through the root system, while passively it is unfolded through the absorption of silicon through the stem and leaves (Marylyn et al., 2021). The most common examples of crops that actively absorb silicon are wheat and rice.

The intake of silicon in plants is influenced by climatic factors, soil type and its particle size (Ma et al., 2001). Further, formulations of fertilizers containing silicon are available in solid, liquid and powder form, i.e. in granular, liquid and powder formulations. After applying the granules to the soil, they dissolve and the plant absorbs them through the root system. Their effectiveness depends on the characteristics of the roots and soil conditions. Liquid formulations can be applied through irrigation in the form of sprinklers or similar. Their effectiveness depends on plant characteristics such as plant size, and environmental conditions such as temperature and wind. Silicon applied to the soil is assimilated and distributed throughout the plant, while in the case of foliar application it is concentrated only on the leaves of the plant (Pilon et al., 2013).

In addition to the method of application, the timing of silicon fertilizer application is also important. Application of silicon during tillering and flowering resulted in increased drought resistance (Maghsoudi et al., 2016).

SILICON INFLUENCE ON PHYSIOLOGICAL MECHANISM IN PLANTS

Saud et al. (2014) reported that silicon increased drought resistance in plants by mechanisms of photosynthetic activity, stomatal conductance, leaf uprightness and xylem vessel structure under high transpiration rates. Above-mentioned parameters are widely used as physiological indicators (traits) for the selection of drought-resistant varieties.

One of the important indicators why drought stress inhibited plant growth was result of disturbance in the balance between the production of reactive oxygen species (ROS) and antioxidant defence (Iturbe-Ormaetxe et al., 1998). Furthermore, due to drought stress, increased production of ROS occurred that resulted in damage to plant cell structure and nucleic acid (Asada, 2006). Enzymes that inactivate free oxygen radicals in the cell were superoxide dismutase (SOD), catalase (CAT), and ascorbate peroxidase (APX) (Gill and Tuteja, 2010). Some investigations showed that silicon enhanced the activity of SOD, CAT and peroxidase (POD) enzymes thus reducing stress damage (Gong et al., 2008, Shen et al., 2010). Dongyun et al. (2015) reported that the application of silicon in plants exposed to drought stress resulted in a higher chlorophyll content in the leaf, lower levels of lipid peroxidation and H_2O_2 in the flag leaf, compared to control untreated plants. They further found out that silicon increased the ascorbate content (AsA), reduced glutathione (GSH), as well as elevated total phenols and flavonoids in content of flag leaves. Dongyun et al. (2015) concluded that exogenous application of silicon could alleviate oxidative stress in the later stages of wheat growth by modifying the biosynthesis of ROS as well as regulating transcription through various defence pathways, such as antioxidant enzymes and secondary flavonoid metabolism. Gong et al. (2005) reported that activities of SOD, APX and CAT enzymes decreased in the leaf of wheat at tillering stage, while Shen et al. (2010) reported that plants supplied with exogenous silicon usually had higher SOD, CAT, and APX activities, compared to plants that were exposed to drought stress without application of silicon at the heading stage. Further, different responses in enzyme activity could be attributed to different developmental stages of wheat (Gong et al., 2008).

CONCLUSION

The potential of silicon in mitigating the effects of drought is still not sufficiently explored. Although silicon is the second most abundant element in the earth crust, plants can only adopt it in the form of dihydrogen orthosilicate (H_2SiO_4). Since most soils are deficient in this form of silicon, it has to be added through fertilization. Attention should be paid to the development of the roots, due to the fact that genotypes with better and more branched roots have greater potential for absorption of silicon from the soil.

It is important to create new drought-tolerant wheat varieties with improved ability to withstand long-term water shortages. If new varieties with improved ability to absorb silicon were to be developed, mandatory inclusion of silicon in fertilizers could be encouraged, which would ultimately result in an increase in grain yield and quality, and improved resistance to drought. Ultimately, incorporating silicon into inorganic fertilizer applied in the key stages of growth could increase wheat productivity.

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