Cornous Biology

Review Article

Silicon application improves drought tolerance, photosynthesis, and yield in rice (*Oryza sativa* L.)

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Silicon is required for the crop in subjects such as dry matter production, photosynthetic rate, and transpiration rate. Application of silicon to the crop promoted the growth and dry matter production, and also prevented over-transpiration and increased the water use efficiency in leaves. It curbed the photosynthetic depression and also the destruction of chlorophyll in senescent leaves. Hence application of silicon, which would maintain the photosynthetic activity, is regarded as a main reason for dry matter production in rice. Using silicon as a foliar spray under drought conditions at the flowering stage will reduce the reduction in yield and increase the yield potential. The application of Silicon in topdressing and foliar methods on the rice crop would strengthen the culm to prevent its breakage and increase yield production. It increased the diameter and width of the outer and inner layers of diameter of vascular bundles.

Keywords: *rice, silicon, dry matter production, photosynthetic rate, strengthen culm*

Introduction

Rice is a major source of Carbohydrates in food. It is a primary staple food for more than half of the world's population, which is grown in more than 100 countries. *Oryza sativa* belongs to the Poaceae family. The economic part of rice is Caryopsis. It is rich in Magnesium, Phosphorus, Manganese, Selenium, Iron, Folic acid, Thiamine, and Niacin. Hence, it can be said that it plays a vital role in combating malnutrition. In developing countries, more than 3.3 billion people depend on rice for over 20% of their daily calories (Subiramaniyam et al., 2022). Silicon is the second most abundant element in the Earth's crust. It is a beneficial element for the crop's growth. Rice is a silicon-accumulating plant. It is taken up by the plants in the form of monosilicic acid, and its transportation in the plant is influenced by 3 genes, such as LSi1, LSi2, and LSi6 (Shanmugaiah et al., 2023). It is present as a cuticle-silicon layer beneath the cuticle in the form of Silicic acid. It makes the crop tolerant to abiotic stresses such as unfavourable climatic conditions, drought stress, etc., and biotic stresses. It improves the quality of the crop, makes the crop resistant to pests and diseases, tolerant to saline conditions, and converts the nutrients present in the soil into an available form for the plant uptake. It controls lodging and decreases the toxicity of metals such as Iron and Aluminium. And also, it will reduce the senescence of rice leaves.

Silicon sources

There are different kinds of silicon fertilizers available, but the most commonly used are Calcium Silicate, Sodium Silicate, and fine Silica. Potassium Silicate, a highly soluble silicate form, can be used in hydroponic technology (growing plants in a solution medium instead of soil medium), and it can also be used as a foliar spray to prevent the excess loss of it as it is costlier. Since quartz, clays, micas, and feldspars are poorly soluble, they are considered poor-silicon fertilizers, although they are sources of silicon. In general, the most commonly used silicon fertilizer is Calcium Silicate. Rice ash, straw, and husk are some of the organic sources of silicon. In Rice straw, the silicon content ranges from 4% to 20%. Similarly, in Rice husk, it ranges from 9% to 26% (Khoshnood Motlagh et al., 2022). A biofertilizer, which is used as a silicon source, is Silicon Solubilizing Bacteria (SSB), a specified strain of the Bacillus genus of beneficial bacteria (Etesami & Jeong, 2022).

Silicon uptake

Even though the silicon fertilizer applied to the soil is important for the plant more than that the irrigation water with which the fertilizer is applied is also important and acts as a major source of silicon for the crop. It is not that the silicon efficiency for the crop depends only upon the total amount of silicon applied to it in the soil as a silicon source, but it also depends upon two other major things. They are 1. The amount of silicon which is present in the soil in an available form for the crops' uptake, and 2. Facilitating the uptake of silicon by plants. And also depending upon the soil type, the amount and source of silicon applied for the crop should be given importance (Arumugam et al., 2025). Plants taking silicon from neutral soil were found to be at a higher rate when compared to acidic and alkaline soils. In rice, uptake of silicon was higher in acidic to neutral soil (Sandhya & Prakash, 2019).

Dry matter production

Application of silicon prevents over-transpiration and controls photosynthetic rate and increases the dry matter production by improving the water use efficiency (Simko et al., 2025). Due to the application of silicon to the rice crop, it adjusted the stomatal width of the leaf, increased the number of vascular bundles present in the culm, and increased the photosynthetic rate, which resulted in an increase in the accumulation of dry matter from root to shoot. Silicon is present in a higher concentration when compared to all other macronutrients. In the absence of Silicon, the growth of rice is reduced, and its productivity is also considerably decreased due to a reduction in fertility (Sezhiyan et al., 2023). Among the Poaceae family major amount of silicic acid uptake is shown by rice. Thus, application of silicon fertilizers in higher amounts will lead to the accumulation of silicon in the stem and provide a dry weight of about 10% to 15%. As silicon is required in large amounts by the rice crop for the dry matter production, it is known as a beneficial element for rice production (Chaiwong & Prom-u-thai, 2022). Numerous substantial impacts on the leaf, stem, panicle, petiole, husk, and grain at all growth stages of dry matter have been seen when silicon is given to rice crops. The application of calcium silicate [Ca_2SiO_4] resulted in greater dry matter production of rice (Hyun-Hwoi et al., 2023).

Drought resistance

Chlorophyll is a vital pigment that gives plants their distinctive green colour and is necessary for the process of photosynthesis (Packirisamy et al., 2023). Drought has a negative impact on this chlorophyll pigment (Ashok et al., 2018). When there is a drought, silicon is given to a rice crop that is under stress from the drought, and the results are seen. First off, the use of silicon made the thylakoid membrane in chlorophyll more stable and accelerated photosynthesis. Increasing integrity and stabilising its functions led to a rise in the rate of photosynthetic activity. additionally, regulating the breakdown of membrane protein complexes brought on by drought stress. Proline has a crucial role in the survival of rice under drought stress since it is an antioxidant molecule and takes part in cell signaling. Proline enhances the plant's ability to fight off free radicals in this situation, speeding up photosynthetic activity (Sathyabharathi et al., 2022). Shoot lipid peroxidation decreased as a result of silicon application, regardless of cultivar or dosage (Riaz et al., 2022).

Lodging resistant

The permanent displacement of crop stems from their vertical position as a result of stem buckling or root displacement is known as lodging. A proper and suitable plant height and shorter basal stems are the characteristic features for resisting lodging in a rice plant. On application of silicon, the morphology of the leaf and culm is modified, which provides mechanical strength to the cells, tissues, and the entire plant body against lodging. The Japonica rice cultivar Wuyunjing 23, the indica rice variety Takanari, IR-8 cultivar are some of the lodging-resistant cultivar species. Silicon is used to make the culm tougher, which provides complete stiffness for the plant and prevents the breaking of the culm and thus resists lodging (Shah et al., 2019). Generally, stem diameter and internode plumpness are related to lodging resistance of the stem. When the internode plumpness is greater for a rice plant, then the accumulation of dry matter in the stem will be increased. As a result, the tissues become tougher and rigid and will have stronger compression resistance. And thus, will have lodging resistance. It is known that too too-tall plant will have less lodging. This is because when the plant is too long, the plant's centre of gravity will be shifted upward, and thus lodging will be destroyed. This long growth of the stem is achieved due to the application of silicon (Hussain et al., 2021). Hence, silicon is required for a rice crop to prevent lodging.

Submergence resistance

It is a stressor that raises ethylene synthesis and accumulation levels, which results in chlorophyll degradation and decreased carbon fixation. The growth and development of rice at the tillering stage would be negatively impacted by this stress. The rice plant's submergence stress is reduced by the application of silicon. This is made possible by improvements in chloroplast ultrastructure and root morphological characteristics. Additionally, silicon increased POD and CAT activity, lowered MDA concentration, and decreased oxidase damage, reducing damage to rice crops brought by submersion stress while also enhancing yield (Pan et al., 2021).

Resistance to pests and diseases

Silicon helps reduce pest and pathogen damage by: Forming a silica barrier beneath the cuticle, impeding pathogen entry, activating enzymatic defenses like catalase (CAT) and superoxide dismutase (SOD), triggering jasmonate-mediated responses to herbivory, and supporting phytoalexin and phenolic compound synthesis. Fungal pathogens, including *Magnaporthe grisea* (rice blast), are repelled by the silica-enhanced epidermal structure of silicon-treated plants (Islam et al., 2023).

Heat stress resistant

During heat stress, the presence of silicon makes the cell membrane thermally more stable and controls the loss of electrolytic substances present in it, and maintains cell integrity (Aouz et al., 2023). Silicon modifies the osmotic potential of the cells by accumulating a high number of osmolytes in the cells and thus preventing their leakage. This can be achieved by the cells of the rice plant by application of silicon, which alters the transportation of water and makes the plant resistant to heat stress (Kumar et al., 2023).

Silicon deficiency

When a rice crop lacks silicon, it inhibits the growth and development of robust, inflexible leaves, stems, and roots, which over time reduces yield production (Winslow et al., 1997). Additionally, it causes the plant's thick, silicon-bound epidermal layer to degrade, obstructing the entry of diseases like fungi, bacteria, insects, and mites (Verma et al., 2021). When a plant is grown in less rich soil, particularly damaged paddy soil, it frequently develops a shortage of silicon. Additionally, it happens in the heavily weathered and corroded soil in tropical areas. Its symptoms include weakening of the leaves and culm, which results in the growth of floppy, drooping leaves and culm. As a result, the shadowing of leaves gradually gets darker. The crop's rate of photosynthetic growth is likewise reduced. Consequently, the yield will decrease. As the silicate epidermal layer deteriorates, the plant will be more susceptible to diseases like brown spot and blast, which are brought on by *Helminthosporium oryzae* and *Pyricularia oryzae*, respectively. Additionally, when silicon levels are low, there are fewer panicles and filled spikelets per panicle (Dorairaj et al., 2017).

Prevent iron toxicity

Many impacts are caused on the growth and development of rice when iron toxicity occurs. In order to prevent the crop damage due to iron toxicity, silicon is applied to in order to get rid of iron toxicity (Dufey et al., 2014), which would make the spikelet sterile. Iron toxicity in rice crop causes the deficiency of other mineral nutrients, such as Calcium and Magnesium, in the leaves. It subsequently brought down the net photosynthetic rate, stomatal conductance, and rate of electron transport in the rice crop. Hence, it reduced the grain yield components, which include total grain biomass, percentage of filled grains, number of grains per plant, and harvest index. Due to the application of silicon oxidizing power of crops' roots is increased, as a result, ferrous iron is converted into ferric iron, which decreases the large uptake of iron by the crop, thereby limiting iron toxicity in it (Ghouri et al., 2024).

Conclusion

Silicon is a beneficial element required for the sustainable growth and development of rice. There are different kinds of silicon sources available for the plant's uptake, among which Calcium silicate is the most commonly used silicon fertilizer. Rice is a silicon-accumulating crop. Application of silicon to a rice crop makes it tolerant to many abiotic stresses such as drought, submergence, salinity, heat, etc, and also tolerant to many biotic stresses such as pests and diseases, etc. It also decreases the toxicity of other metal ions, namely iron and aluminium, in the plant, thus preventing the exhaustion of yield. It increases the dry matter production of the rice crop, thereby increasing the yield. It binds with the cuticle present beneath the leaf and forms a thick epidermal layer. This silicate epidermal layer makes the leaves and culm tougher and rigid, and thus prevents the entry of pests and disease-causing pathogens such as fungi, bacteria, etc. Application of silicon strengthens the leaves and culm of the rice plant, thus making the plant resistant to lodging. Hence, silicon has a significant physiological role in the rice crop, *Oryza sativa*.

Author contributions

Conceptualization – Ashok Subiramaniyan, Chandrasekaran Perumal, Ashokkumar Natarajan, Selvakumar Gurunathan. Writing (original draft) - Harini Prabakaran, Ajay Ramamoorthy, Arjun Parthiban, Chidambaramoorthy Kaniraja. Writing (review & editing) - Harini Prabakaran, Ashok Subiramaniyan, Chandrasekaran Perumal, Ashokkumar Natarajan, Selvakumar Gurunathan.

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