Review Article

Mitigation of Drought Stress by Use of Silicon Element in Wheat (*Triticum aestivum* L.)

Abstract

Drought stress is a menacing type of abiotic stress caused by low rainfall, high temperature, etc., where water sparsity condition occurs in soil, affecting the process of plant growth and development. Drought stress has become a serious issue that must be considered before it becomes a significant threat to agricultural production. Wheat is India's second most crucial cereal crop; even its production is affected due to prevailing drought conditions in the fields, which causes many physiological, morphological & biochemical changes in the plant, indirectly affecting yield. Many methods are adopted to improve wheat crop efficiency even under drought-stress conditions, such as releasing resistant varieties, following advanced agronomic practices, using elements, etc. Still, the most recent method is to use the silicon element to mitigate the drought stress conditions in wheat crops. Silicon had not been regarded as an essential plant element; However, when applied to plants, it still promotes proper root growth, provides resistance against many diseases, decreases the abiotic stress effect on plants & increases the crop's growth and yield. So, in recent times, many research experiments have been performed in pots & laboratories where silicon is applied to wheat crops in the form of priming, fertilization & foliar spray in different stages of the crop to know its efficiency. Even silicon is also supplied to wheat crops in the form of nanoparticles. In the end, though, the silicon can be sprayed in any form and prevents the harm that drought stress does to wheat crops. Ultimately, Silicon is helping the wheat crop mitigate drought stress and produce better yields by enhancing its growth.

Keywords: Drought stress, Wheat crop, Silicon element, Foliar spray, Resistance

Introduction

The yield of a plant is mainly dependent on its growth and development. But many factors affect plant growth, including abiotic & biotic stress. Biotic stress includes factors like bacteria, fungi, viruses, nematodes, insects, etc., and there are many abiotic factors, low & high temperature, light, water, salt content, metals, etc., when the range of these factors in the environment exceeds the actual amount that's when the abiotic stress condition occurs. Due to this sudden climate change, plants cannot tolerate these situations. Among these factors, we are going to discuss drought stress mainly. Nowadays, drought-prone areas in our country are increasing day by day; if we don't take this seriously, this may become a significant problem. Drought stress conditions prevail when water availability to the plants is low due to the minimum or no rainfall. According to Kumawat et al. (2018), plants respond differently to soil dry conditions. These responses include lower photosynthetic activity, reduced leaf size, reduced stem elongation and root proliferation, and decreased plant water use efficiency. Thus, the plants undergo several physiological, morphological, biochemical, and molecular changes that impact the crop's growth and yield Bijalwan et al. (2022). The health of the soil is impacted by drought in addition to the plants. Longer dry spell in the soil increases the temperature by which the decomposition of soil organic matter is affected, and also, there will be the emission of more Co_2 from the soil Al-Kaisi et al. (2017). Plant growth depends on soil health, so the crop yield will be higher if both soil and plant health are in good position. India is among the nation's most badly impacted by the drought. By 2022, over two-thirds of India's land area was drought-prone. The gross domestic product has been reduced by 2.5% over 20yrs & the drought-prone area has increased by 57% since 1997. It mostly impacts India's rainfed agriculture, accounting for about 60% of sown area. India's core drought-prone states include Telangana, Rajasthan, Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, Maharashtra, Karnataka, Odisha, Gujarat, and Jharkhand. Due to severe drought stress, many field crops, orchards, etc. are impacted in many states; among these is the wheat crop, which is our primary cereal crop. From germination to maturity in every stage, drought stress damage wheat crops Duvnjak et al. (2023). It disturbs seed germination and root growth, the photosynthesis process is reduced, water scarcity during critical periods and grain filling stage affects the yield of the crop, and the biochemical process is also altered Dhakal et al. (2021) due to this growth and production of the crop is being reduced. Drought-tolerant cultivars and modifications to agronomic techniques like plant density, sowing interval, and soil management can mitigate the impact of drought on wheat crops. In addition to these techniques, we may also give wheat crops silicon components to boost growth and yield under drought stress. Despite being a plentiful element, silicon has not yet been recognized as a necessary component for plants. However, it is essential to the growth and development of plants. According to Tayyab et al. (2018), it aids the wheat crop in overcoming biotic and abiotic stress. It can even be absorbed by wheat plants rapidly. Although its exact function in a plant is unknown, research is being done to determine how silicon can benefit plants. For the time being, silicon can help the wheat crop cope with the stress caused by the drought. It helps the wheat crop adopt some changes at morphological, biochemical & physiological levels Tayyab et al. (2018). After oxygen, silicon (Si) is regarded as the second-richest mineral element. In the crust of the earth, it takes around 28%. It exists in both available and non-available forms. Accumulation of silicon mainly occurs by weathering some particular rocks Zargar et al. (2019), and even it is also present in the dead remains of plant tissues, which are decomposed by microorganisms and again accumulate in the soil. The way that silicon is absorbed and accumulated in plants varies by species. Plants can utilize orthosilicic acid as a source of silicon. Plant roots absorb it at pH values less than 9, with a concentration range of 0.2–0.6 mM. Tayade and associates (2022). Since its participation in metabolic activities is not supported by any evidence, silicon is not regarded as an essential element. Its reaction in plants to biotic and abiotic stressors, however, makes it regarded as a quasi-element. et al. Thakral (2021). Silicon is present in mineral rocks such as basalt and orthoquartzite and in some carbonaceous rocks Schaller et al. (2021); it gets deposited in the soil by weathering. Due to leaching and erosion, the silicon content gets reduced in the soil Caubet et al. (2020). Silicon in the soil is present in silicates and silicic acid Zexer et al. (2023). It is an inert element Rushil Mandlik et al. (2020), present in three forms in the soil: solid, liquid, and absorbed. The solid form is not available to the plant & liquid form is considered to be a valuable and available form Ashraf et al. (2010). It consists of mono silicic acid (H_4SiO_4) with a pH of ≤9.0. it is also absorbed by plants & gets polymerized to silica gel. Applying compost and manure to the soil will improve the silicon content. Yuvaraj et al. (2020). The silicon content in the soil helps improve water-holding capacity, soil texture, soil aggression, etc., Ashraf et al. (2010). Despite being the most prevalent element in the surroundings, silicon is not regarded as one of the necessary elements in plants. However, nowadays, it is gaining importance. It is understood that it plays a vital role in plant growth and development even under adverse conditions, so it is known to be "quasi-element" Malik et al. (2021). Silicon is undertaken by the plants as mono silicic acid (H_4SiO_4). The amount of silicon cumulated in the plants is greater when compared to other elements Yuvaraj et al. (2020); it entirely depends on the crop species in the soil. Based on the Si accumulation, there are three types of plants-accumulators (>4%), intermediate (2-4%), and excluders (<2%) Ma et al. (2002). Among monocot and dicot plants, monocots uptake more Si than dicots Zargar et al. (2019). According to Si Hodson et al. (2005), plants in the Poaceae and Cucurbitaceae families are high accumulators. Si excluders are present in families like Brassicaceae and Solanaceae plants Hodson et al. (2005). Plants uptake the available Si element from the soil with the help of their roots. It occurs in three ways- passive (uptake of silicon is more when compared to water), active (equal amounts of silicon and water are taken), and rejective (water uptake is more when compared to silicon) Zargar et al. (2019). Plant roots have some Si transporters APQs in their cells, which help transport mono silicic acid from soil solution to all plant parts. There are two types of transporters: the first type is aquaporin (Lsi1, Lsi6), and the second type is an H^+ antiporter (Lsi2, Lsi3) Zexer et al. (2023). The transporters present in the plants are Lsi1, Lsi2 & Lsi6; this helps move Si from soil solution to roots & from root cells to all other plant parts Ma et al. (2007). Lsi1 & Lsi6 perform passive transportation in plants. Lsi1 aids in the transfer of Si via xylem from soil solution to root cells. The sole distinction between them is where they are located in the roots; Lsi2 aids in the extraction of Si from root cells. Ma and associates (2011). Both exodermal and endodermal cells have Lsi1 on the distal side and Lsi2 on the proximal side. Lsi6 aids in the transport of Si to different areas of plants and is found in roots, leaf sheaths, leaf blades, etc. Silicon is moved and fixed in the plant sections in this way. According to Bokor et al. (2015), ZmLsi1 in maize is utilized by roots to absorb silicon from the soil, while ZmLsi6 is found in leaves and aids in xylem unloading. According to Montpetit et al. (2012), the Si transporter in wheat crops is TaLsi1. In barley, HvLsi2 aids in Si discharge Mitani et al. (2009).

Plant Deposition of Silicon

Silicification is the term used to describe the Si buildup in mono-silicic acid. The xylem transports Si from the roots to the shoot. In the shoot, Si polymerisation occurs when mono-silicic acid gets converted to silica gel due to increased concentration by high water loss Rushil Mandlik et al. (2020). Silicification mainly occurs in different sites like cell walls, roots, shoots, leaves, silica cells, trichomes, etc., in storage tissues, epidermis, vascular tissues, etc.; biogenic opal is formed when silicic acid is condensed to hydrated silica mineral. Sometimes silica is formed without transpiration. Sorghum root and leaf cells have this instance (Kumar et al., 2017). The position of deposition of silicon in roots varies from crop to crop. In rice, it occurs in inner tangential walls and endodermis radial walls Rushil Mandlik et al. (2020). In wheat, barley, and oats, the Si accumulation occurs in seminal roots where endodermis' inner tangential walls are present in proximal ends Bennett et al. (1982). In wheat crops, Si accumulation helps to increase the root length Bijanzadeh et al. (2018). Different types of influx transporter genes regulate the uptake of silicon from soil and deposit it in root cells by passive diffusion from roots silicon gets transported to other plant parts with the help of xylem loading Tripathi et.al (2021) Rushil Mandlik et al. (2020). According to Ma et al. (2007), silica transporters such as Lsi1 and Lsi2 aid in the uptake of silica through roots. No part of soil Si intake has been demonstrated by root hairs.

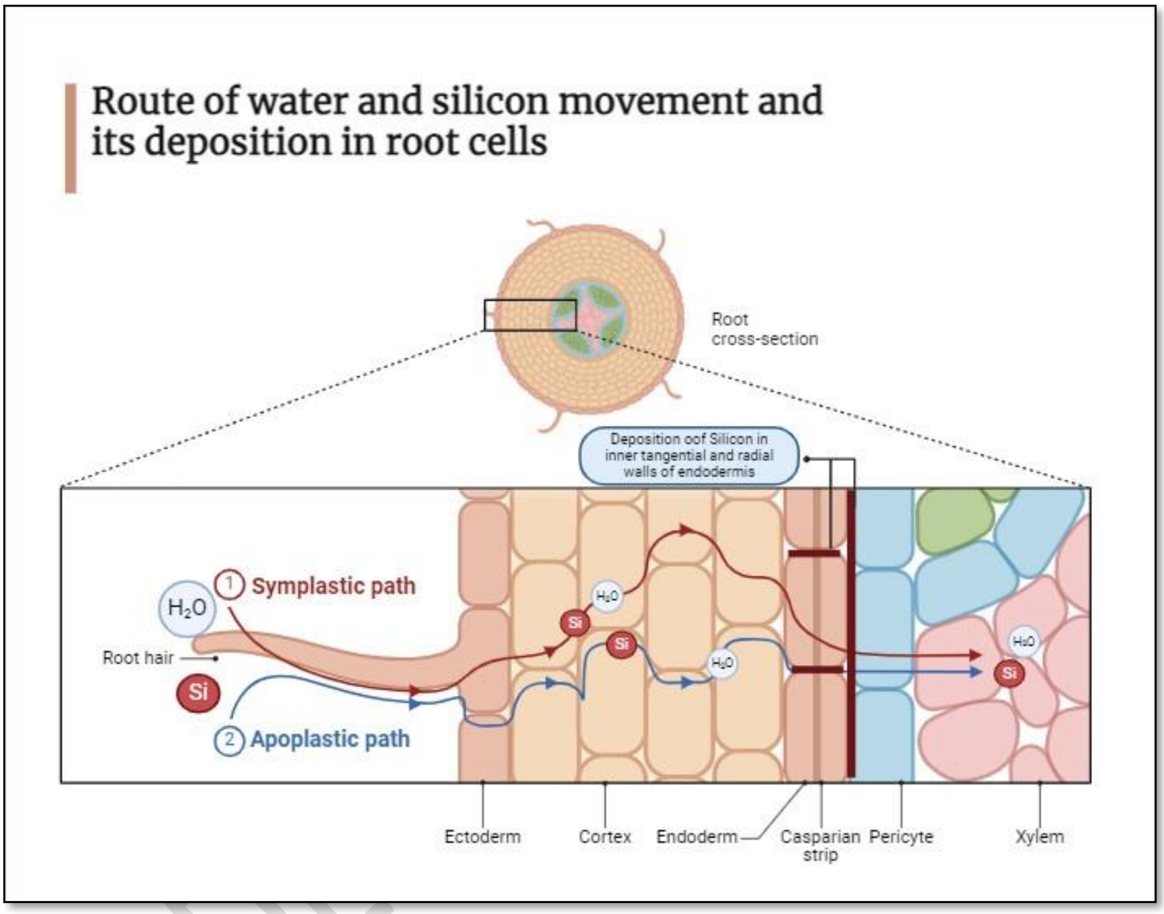

Image1: Deposition of Silicon in roots

Loading and unloading of silicon into xylem and aerial tissue

Transpiration pull is necessary for silicon deposition. Since the xylem moves water, it serves as the primary conduit for the movement of Si from the root to the shoot portions Rushil Mandlik et al. (2020). Si loading and unloading depend on the concentration gradient, crop species, and transpiration pull. Two processes were involved. The first is loading, when Si gets dissolved in cortical cells with the help of transporters and passive diffusion, and from there, it goes into the xylem Rushil Mandlik et al. (2020). However, the role of the transporter responsible for Si loading into the xylem is unknown. The second process is unloading, where

Si from the xylem is deposited into different plant cell parts with the help of the Lsi6 transporter Feng et al. (2011). Most silica deposition takes place in cell walls Zexer et al. (2023)

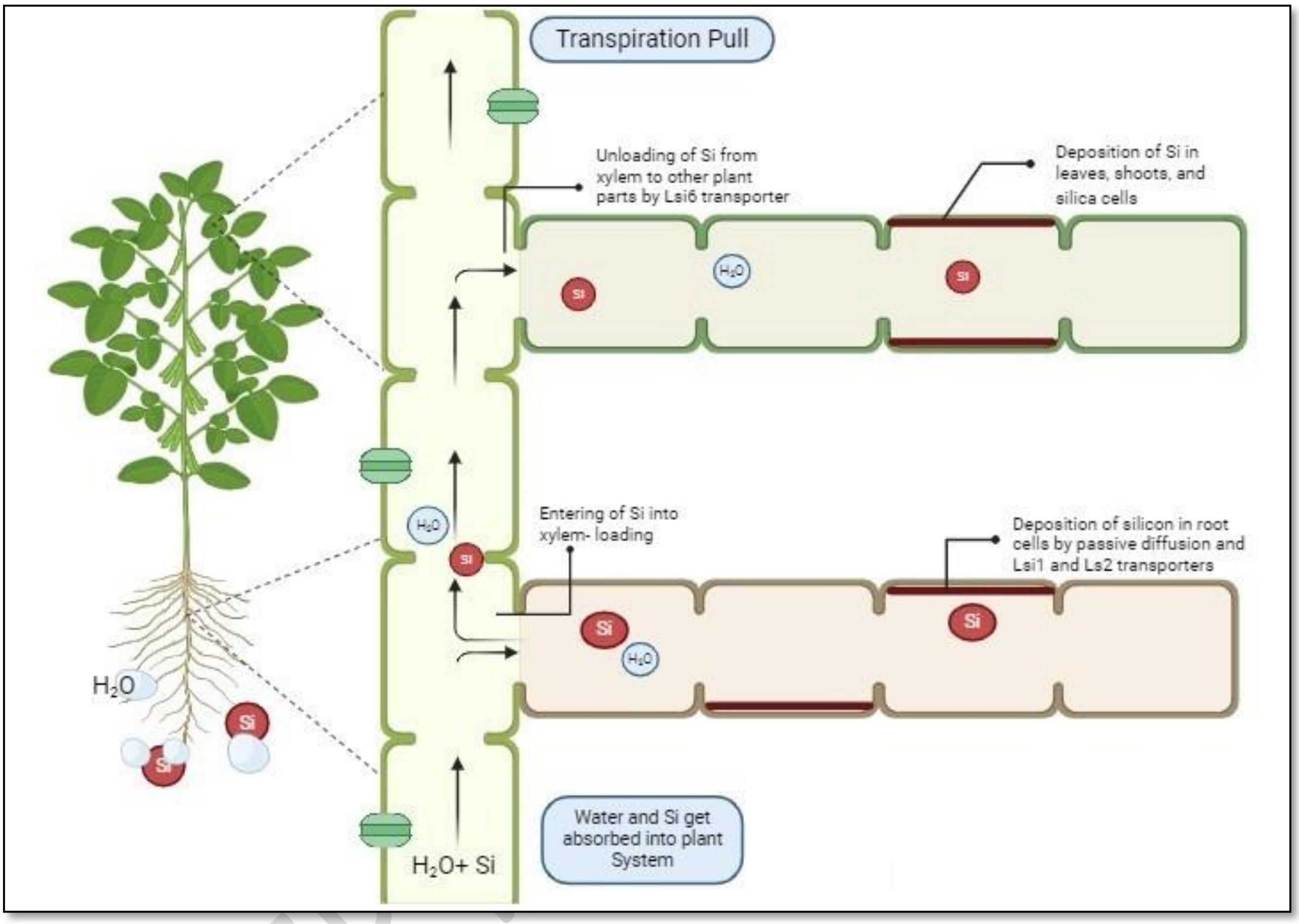

Image2: Loading and unloading of silicon in plant system

Deposition in leaves

The deposition is more common in transpiration organs when compared to absorptive organs Rushil Mandlik et al. (2020). Silicon gets deposited in the leaf blade; the leaf sheath makes them more prominent and thicker, which reduces water loss by transpiration and even water consumption during stress conditions. It is shown that more than 90% of silicification occurs in leaf epidermal cells Yoshida et al. (1962). Age and location have an impact on the quantity of Si deposition in leaves. Older leaves have a more significant amount of Si accumulation when compared to younger leaves, and from apex to base of the leaf, Si deposition is reduced Sangster (1970). In younger leaves, silica and motor cells exhibit Si deposition; in older leaves, all cells exhibit Si deposition. Sangster and associates (2001). Even silicon accumulates under the cuticle as a thick layer that controls the stomatal opening and closing.

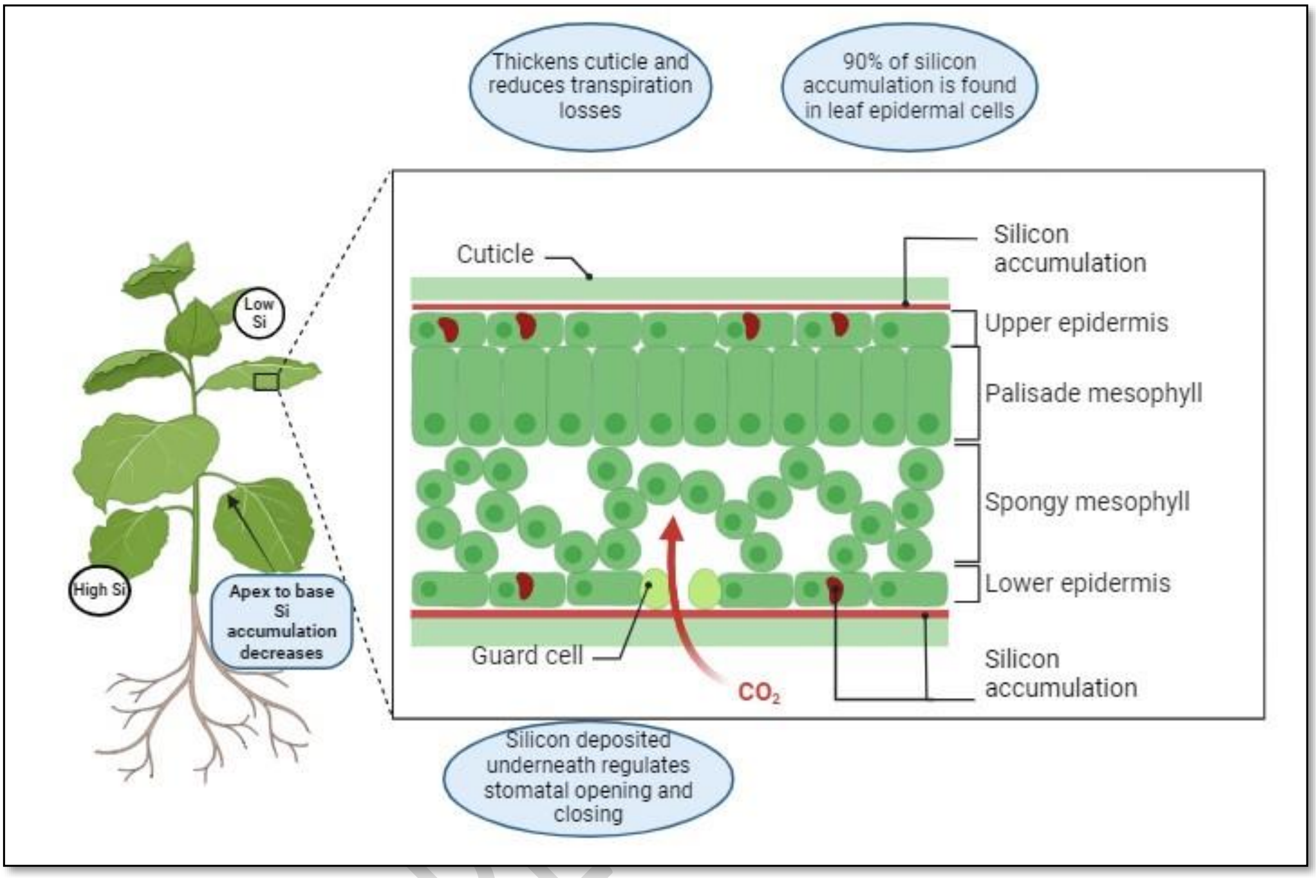

Image3: Deposition of Silicon in leaves

Deposition in silica cells

Based on deposition, there are three categories of epidermal silica cells: differentiated elements (silica cells and exothermic components), bulliform (vascular bundles and leaf blade), and fundamental (epidermal cells). Prat (1948). Elements that are differentiated include silica cells. According to Ma et al. (2002) and Rushil Mandlik et al. (2020), these are the first cells in the plant to experience silicification following its occurrence in all other regions. Deposition is limited to the period of leaf development. Peptides and proteins are required to polymerize silicic acid into silica, which is necessary for the deposition of Si in silica cells Gallagher et al. (2015). A concentration gradient is produced in the silica cells through the polymerization and deposition of Si Gallagher et al. (2015).

Deposition of silicon in trichomes

Si & Ca accumulate and give rigidity to the trichome cells, which provides stiffness to the leaves so the proper infrared rays can be observed and warm the tissues, primarily found in Cucurbitaceae Abe (2019). However, the transporters used for Si deposition in trichomes are not known. Like this, Si accumulates in different parts of plants and provides strength so that they can tolerate adverse conditions.

Effect of silicon on wheat crop

Silicon stimulates the processes in plants that provide crops with biotic and abiotic resistance when it is deposited there. (2016) Tubana et al. When Si is combined with other metal ions (Al, Mn, and Cd) in soil solution, it reduces the uptake and accumulation of harmful ions in plants. (2012) Rizwan et al., Lindsay (1979). According to Bélanger et al. (2003) and Rodrigues et al. (2015), the mechanical barrier hypothesis is created when silicon accumulates in the epidermal cells of the shoot and leaf portions, giving them strength and functioning as a barrier or protective layer against biotic and abiotic stress. Plants manufacture R genes as a defence mechanism to give them resistance to some infections, but studies have revealed that Si controls the R genes to and for movements. Chain and others (2009). Janislampi et al. (2012) evaluated the effect of Si on growth and drought stress in various crops, including wheat, rice, soybeans, and maize, in Utah. The table below lists the roles that silicon plays in wheat crops.

Table 1 shows the impact of silicon on wheat crops under various biotic and abiotic conditions.

Stress	**The role of silicon in Wheat crop**	**References**
Drought	Oxidative damage is reduced	Gong et al. (2008)
Drought	Morphology, physical-biochemical, and antioxidant activities get enhanced	Ahmad et al. (2020)
Low temperatures	Improved membrane permeability, retention of water in the leaf tissues, developed antioxidant defence system, lower lipid peroxidation	Liang et al. (2008)
Microbes Rhizobacteria	Provided systemic resistance and helped in free nitrogen fixation	Van Wees et al. (2008)
Powdery mildew Leaf streak Spot Bloch	Suppressed disease improved plant growth Provides resistance to crop by tissue lignification. Peroxidase activity improved and provided resistance to the disease	Guével et al. (2007) Silva et al. (2010)

		Domiciano et al. (2010)
Salinity	Increased synthesis of dry matter and chlorophyll content	Tuna et al. (2008)
Heavy metals	Decreases its uptake from soil and its deposition in plants. Enhanced protection against oxidants	Greger et al. (2016) Singh et al. (2020)
Green bug *(Schizaphis graminum)*	The formation of hard and abrasive leaves resulted in decreased crop damage	Goussain et al. (2005)

Effect of silicon on wheat crop under drought stress

One major environmental stress that impacts the growth and development of all crops is drought. The second-most important cereal crop grown in India's more significant regions is wheat. Drought stress is one of the main causes of the declining wheat output, along with heat waves, biotic stress, and abiotic stress. A lot of research is being done to give wheat crops tolerance to drought stress. Among them, silicon-based applications are performing well as well. Si will enhance seed germination and seedling growth in the presence of drought stress Hameed et al. (2013). Water deficit circumstances in pots were enhanced by Si in terms of water status, CO2 assimilation, antioxidant enzyme activities (SOD, CAT, APX), and nonenzymatic antioxidants Gong et al. (2005). Gong et al. (2003) found that the buildup of Si in leaf cells reduces transpiration loss. Si addition was shown to decrease malondialdehyde levels, H2O2, and electrolyte leakage (oxidative stress) Pei et al (2010). Gong et al. (2003) found that silica deposition enhanced both the shoot development and root dry weight. Photosynthesis efficiency and water potential were enhanced by the application of Si (Gong et al., 2005). Modifying the signal pathways is another benefit. Ma and others (2016). Applying silicon during the anthesis phase alters the crop's physiological process and boosts production, according to Bukhari et al. (2021). Si treatment also causes the roots to grow longer (Bijanzadeh et al., 2018).

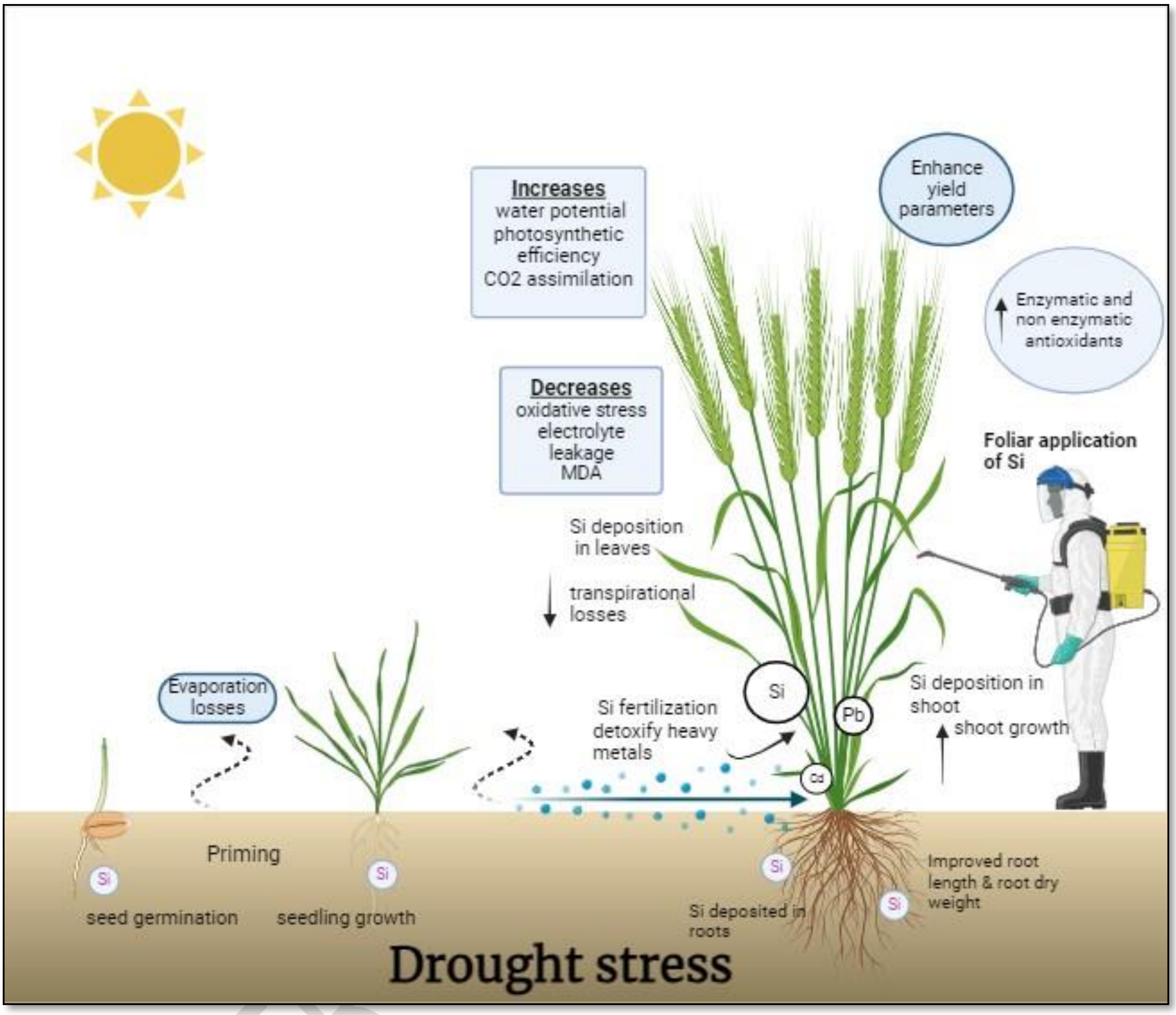

Image4: The impact of silicon on wheat crops during drought conditions

Various techniques for using silicon in wheat crops

Since silicon is known to have a part in the growth and development of plants, a great deal of study has been done on silicon, including this and other trials, to learn more about its functions, how it helps plants overcome stress, which forms it may be applied in, which is practical, etc. These studies can be conducted in a field, greenhouse, or hydroponic setting. Silicone can be sprayed on leaves, as a foliar spray, or as seed priming. Silicon can be utilized in a variety of ways, including directly, as nanoparticles, in other forms, in combination with other nutrients, etc. The use of intelligent fertilizers aids in controlling the timing, pace, and active absorption of silicon by plant roots. Floody, Calabi- (2018). Three types of intelligent fertilizers include nano fertilizers, composite fertilizers, and bioformulations.

Table 2: different experimental methods and concentrations of Silicon applied to wheat crops under drought stress.

Form of Silicon application	Concentrations	Result	References
Hydroponics			
K_2SiO_3		Silicon will also influence the availability of other nutrients in soil and plants.	Greger et al. (2018)
Pot experiments			
Foliar spray	6mM	Enhancing morphological and physiochemical activity through foliar treatment during the tillering stage allowed wheat crops to be more drought-tolerant.	Ahmad et al. (2020)
Si-NPs (Silicon nanoparticles)- seed priming	900mg/L	It improved the plant height, biological weight, and yield attributes	Raza et al. (2023)
Fertigation and foliar application	1mM & 4mM	Two wheat varieties- Chakwal-50 and Sehar-06 are grown in the greenhouse. Results show that at the anthesis stage foliar spraying of Si & under-tillering fertigation will give better output.	Bukhari et al. (2020)
Foliar spray	1%	Foliar application of Si at critical stages like crown root initiation and grain development has shown better results	Rafi et al. (2020)
Combined foliar spray of Zn & Si	4mM Zn & 40mM Si	Combined application of Zn and Si have shown improved growth, antioxidant defence, and higher yield	Sattar et al. (2021)
Organosilicon fertilizer (OSiFs)		Has shown a better effect on detoxifying the Cd and Pb in wheat crop	Huang et al. (2019)

Field experiments			
Applying Si and SA (salicylic acid) together	6mM of Si and 1Mm of SA	Co-operative effect of these elements is seen in physiological parameters and yield of wheat crop	Maghsoudi et al. (2019)
Nano-silica		Improved the water use efficiency and grain yield in crop	Ahmadian et al. (2021)
$K_2Si_2O_5$ foliar application	2%	Enhance the physiological, biochemical, and morphological changes when drought stress is present.	Aurangzaib et al., (2021)
K_2SiO_3 applied with three canal water irrigation frequencies	12kg/ha	Improved water potential, k^+ amount in shoot and grain.	Ahmad et al. (2016)
Si + cycocel	3.6g/L+ 210mg/L	Water content, leaf water potential, and Ca, Mg, and k concentration have been recorded. Yield improvement is also seen	Dehghanzadeh et al. (2023)

Conclusion

The wheat crop production is decreasing due to many factors; drought plays a keen role in this. We have studied different mechanics that get affected during drought stress in wheat crops, based on these keen studies, many scientists have started to provide or develop tolerance in wheat crops against drought. One among all those researches is the application of silicon in different forms to wheat under stress provides resistance to crop for many abiotic and biotic stress. As silicon enters the plant, it accumulates in various plant parts and provides mechanical strength. It can also be applied to crops by priming, fertilization, and foliar application. Among them, the foliar application is most commonly used. So, based on this we can conclude that Si might not be considered an essential element but under environmental threats, it seemingly plays a significant role.

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