Adaptation 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

1. 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 [1,75,76,77], plants respond differently to soil dry conditions, these responses include lower photosynthetic activity because of reduced leaf size, reduced stem elongation and root proliferation, and decreased plant water use efficiency. Thus, the plants undergo several changes under water deficit conditions like reduced plant growth, water loss due to improved temperature, decreased metabolic activities, less nutrient uptake and deposition, source and sink relationship in plants is disturbed due to reduced photosynthesis and increased water loss this all is going to impact the crop's growth and yield [2] . 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 [3]. 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. In the first week of September 2023, about thirty percent of India's land area was experiencing different levels of drought. A minimum of 11.5% of the area experienced "severe," "extreme," and "exceptional" dry conditions, and 18.9% experienced "abnormal" to "moderate" dry conditions given by DEWS (drought early warning system). 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. Drought stress damages wheat crops from germination to maturity in every stage [4]. 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 [5] 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 [6], 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 [6]. 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 [7], 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. [8]. 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 [9]. Silicon is present in mineral rocks such as basalt and orthoquartzite and in some carbonaceous rocks [10]; gets deposited in the soil by weathering. Due to leaching and erosion, the silicon content gets reduced in the soil [11]. Silicon in the soil is present in silicates and silicic acid [12]. It is an inert element [13], 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 [14]. 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 [15]. The silicon content in the soil helps improve water-holding capacity, soil texture, soil aggression, etc., [14]. 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" [16]. 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 [15]; 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%) [17]. Among monocot and dicot plants, monocots uptake more Si than dicots [7]. According to Si [18], plants in the Poaceae and Cucurbitaceae families are high accumulators. Si excluders are present in families like Brassicaceae and Solanaceae plants [18]. 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) [7]. 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) [12]. 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 [19]. 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. [20]. 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 [21], 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 [22], the Si transporter in wheat crops is TaLsi1. In barley, HvLsi2 aids in Si discharge [23]. The mechanism of Si transporters under less moisture conditions and their deposition are clearly explained below with some figures.

1. 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 [13]. 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 [24]. 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 [13]. In wheat, barley, and oats, the Si accumulation occurs in seminal roots where the endodermis' inner tangential walls are present in proximal ends [25]. In wheat crops, Si accumulation helps to increase the root length [26]. 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

[27], [13]. According to [19], 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.

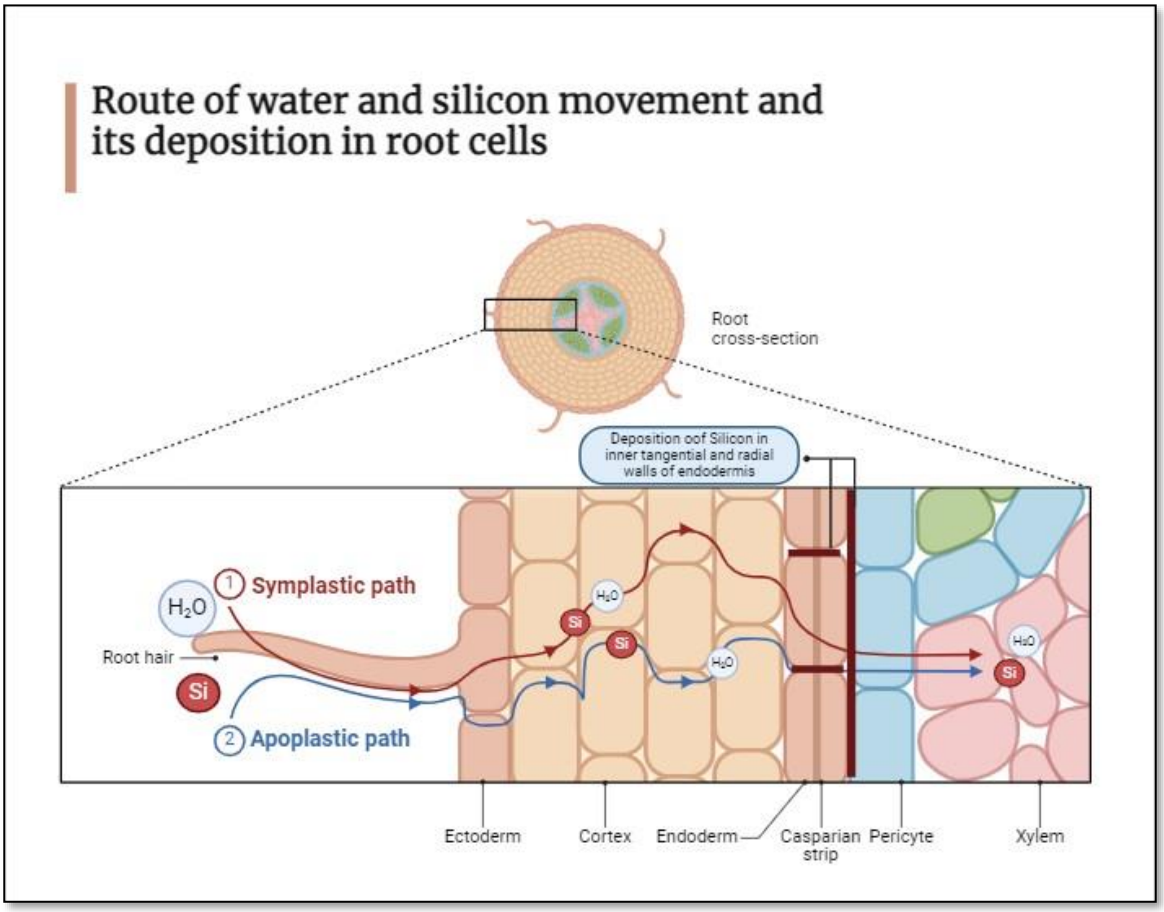

Fig 1: Deposition of Silicon in roots

2.1 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 [13]. 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 [13]. 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 [28]. Most silica deposition takes place in cell walls [12]

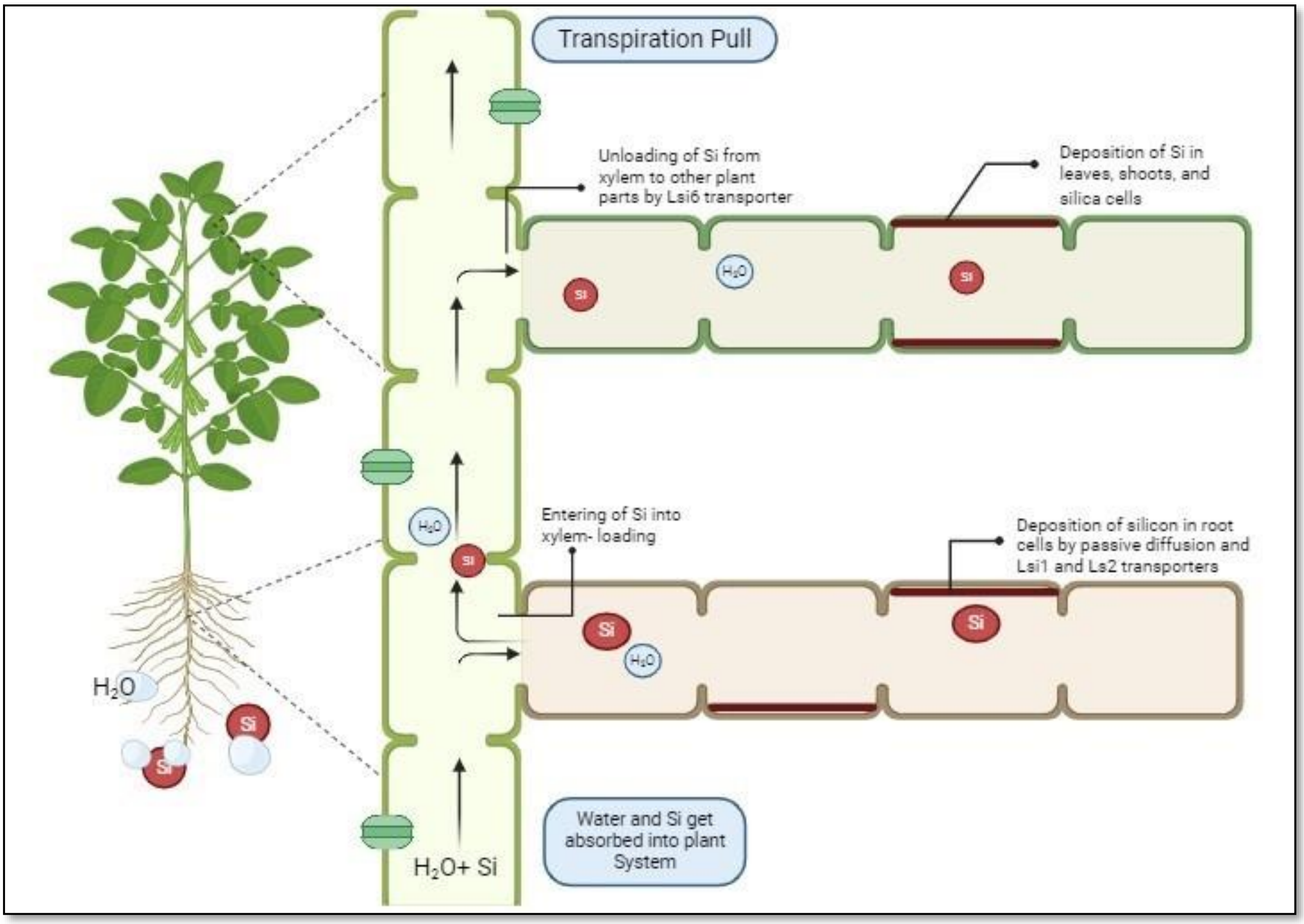

Fig 2: Loading and unloading of silicon in plant system

2.2 Deposition in leaves

The deposition is more common in transpiration organs when compared to absorptive organs [13]. 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 [29]. 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 the apex to the base of the leaf, Si deposition is reduced [30]. In younger leaves, silica and motor cells exhibit Si deposition; in older leaves, all cells exhibit Si deposition [31]. Even silicon accumulates under the cuticle as a thick layer that controls the stomatal opening and closing.

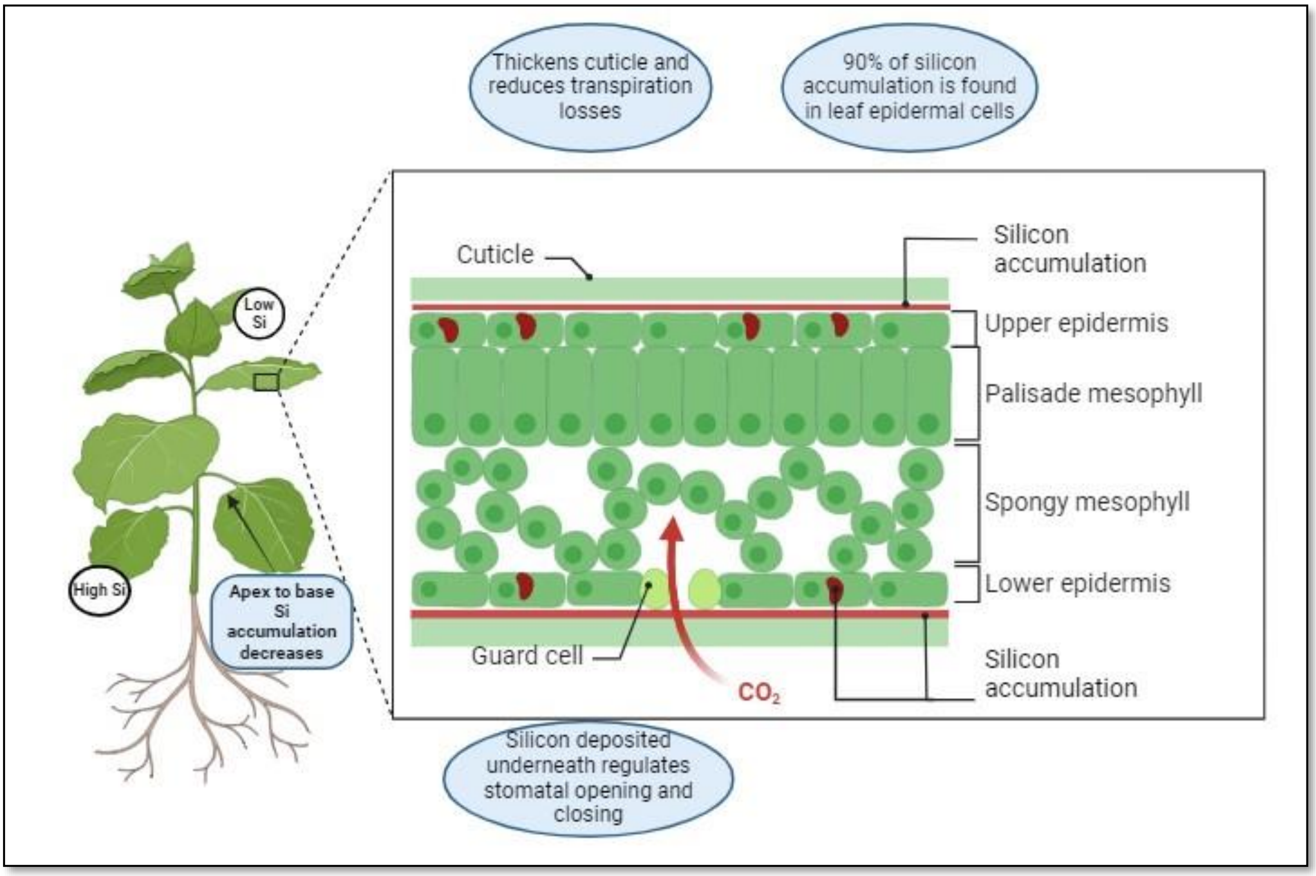

Fig 3: Deposition of Silicon in leaves

2.3 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) [32]. Elements that are differentiated include silica cells. According to [17] and [13], 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 [33]. A concentration gradient is produced in the silica cells through the polymerization and deposition of Si [33].

2.4 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 [34]. However, the transporters used for Si deposition in trichomes are not known. Like this, Si accumulates are present in different parts of plants and provides strength so that they can tolerate adverse conditions. [35] performed an experiment on wheat where they applied silicon in both well-watered and water deficit conditions, where both conditions showed a positive impact of silicon on the wheat crop. The plants prefer silicon both under well-watered and water-stress conditions.

2. Effect of silicon on wheat crop under both biotic and abiotic stress.

Silicon stimulates the processes in plants that provide crops with biotic and abiotic resistance when it is deposited in their plant parts [36]. 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. [37], [38]. According to [39] and [40], 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. [41]. [42] 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	[43]
Drought	Morphology, physical-biochemical, and antioxidant activities get enhanced	[44]
Low temperatures	Improved membrane permeability, retention of water in the leaf tissues, developed antioxidant defence system, lower lipid peroxidation	[45]
Microbes Rhizobacteria	Provided systemic resistance and helped in free nitrogen fixation	[46]
Powdery mildew	Suppressed disease improved plant growth Provides resistance to crop by tissue lignification.	[47]
Leaf streak	Peroxidase activity improved and provided resistance to the disease	[48]
Spot Bloch		[49]
Salinity	Increased synthesis of dry matter and chlorophyll content	[50]
Heavy metals	Decreases its uptake from soil and its deposition in plants. Enhanced protection against oxidants	[51] [52]
Green bug	The formation of hard and abrasive leaves resulted in decreased crop damage	[53]

(Schizaphis graminum)	

3.1 Impact of silicon on Wheat crop under drought Stress

One major environmental stress that impacts the growth and development of all crops is drought. So, to reduce the impact of drought stress many mechanisms like escaping (completing the crop life cycle in advance), avoiding (by growing the crop and providing the water required), and gaining tolerance (growing tolerant varieties or applying some chemicals) [54] and among them, silicon-based applications are performing well. Si will enhance seed germination and seedling growth in the presence of drought stress [55]. Water deficit circumstances in pots were enhanced by Si in terms of water status, CO_2 assimilation, antioxidant enzyme activities (SOD, CAT, APX), and nonenzymatic antioxidants [56], [57] found that the buildup of Si in leaf cells reduces transpiration loss. Si addition was shown to decrease malondialdehyde levels, H_2O_2, and electrolyte leakage (oxidative stress) [58], [57] 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 [56]. Modifying the signal pathways is another benefit. [59]. Applying silicon during the anthesis phase alters the crop's physiological process and boosts production, according to [60]. Si treatment also causes the roots to grow longer [26]. The previous research evidence which shows the impact of silicon on growth, biochemical, and yield attributes of wheat crops under drought stress conditions is mentioned in Table 2.

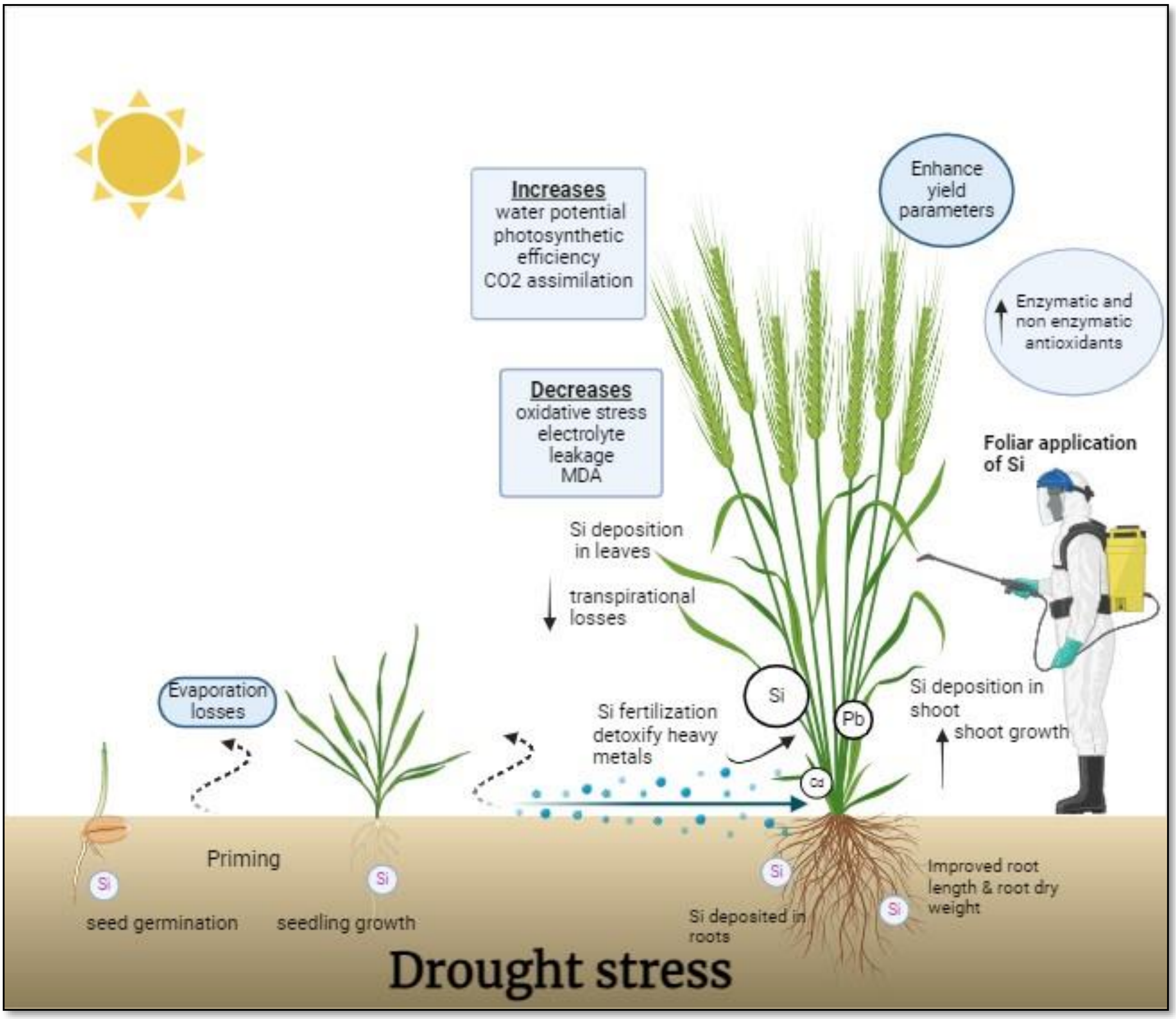

Fig 4: The impact of silicon on wheat crops during drought conditions

3. 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. [61]. 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.	[62]
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.	[44]
Si-NPs (Silicon nanoparticles)- seed priming	900mg/L	It improved the plant height, biological weight, and yield attributes	[63]
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.	[60]
Foliar spray	1%	Foliar application of Si at critical stages like crown root initiation and grain development has shown better results	[64]
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	[65]
Organosilicon fertilizer (OSiFs)		Has shown a better effect on detoxifying the Cd and Pb in wheat crop	[66]

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	[67]
Nano-silica		Improved the water use efficiency and grain yield in crop	[68]
$K_2Si_2O_5$ foliar application	2%	Enhance the physiological, biochemical, and morphological changes when drought stress is present.	[69]
K_2SiO_3 applied with three canal water irrigation frequencies	12kg/ha	Improved water potential, k^+ amount in shoot and grain.	[70]
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	[71]

4. Economic potential of silicon application in wheat crop

The impact of silicon was not only to provide tolerance to wheat crops under drought stress but also to improve yield and economic returns. If silicon application has economic potential, then it will be in favor of the farmers who have drought-prone areas. The research was conducted in Rajasthan for two years in the wheat crop by [72] where they applied five different stages of silicon on three different stages of wheat i.e. crown root initiation (CRI), tillering, and jointing stages. The results showed that 8g/l of silicon application at tillering had shown a higher yield with a B: C ratio of 2.32. Another experiment was conducted by [73] where silicon application was done on four drought and heat-stress tolerant cultivars and also two drought and heat-stress-susceptible cultivars. The silicon application has improved the grain yield and harvest index of wheat cultivars. One more experiment also showed a higher harvest index in wheat crops by 5.8% in treatment with silicon application at lower water application which was conducted by [70]. An experiment was also conducted on organic spring wheat cultivars by

[74] where silicon was applied as seed dressing and also as foliar spray the results showed that seed dressing had shown better impact on organic wheat and it had improved yield by 42%.

5. Conclusion

Adverse effects of water deficit conditions on wheat can be managed by silicon application. Silicification helps minimize drought stress's detrimental effect on wheat crops. The application of silicon in wheat crops under adverse conditions strengthens the crop to cope with the surrounding environment. Si gets accumulated as a layer in different plant parts like leaves, shoots, roots, etc., and doesn't allow excess loss of water, improves nutrient content, and provides rigidity. It is applied to wheat crops in different forms as priming, soil, foliar, fertigation, and also in combination with other nutrients. Among all those foliar applications had shown a better impact on wheat crops under water deficit conditions. Si application not only improves morphological, biochemical, and growth attributes, but it also improves the yield and economic attributes like harvest index and B: C ratio of wheat crops under drought stress.

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