

A Comprehensive Review on the Potential Effect of Silicon Fertilizer and its Significance for Agriculture

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ABSTRACT: Silicon (Si) is one of the most prevalent elements in the Plant's crust which is mostly made up of silicates. Si is not regarded as needed for plant growth and development; nonetheless, there is growing evidence in the literature that this metalloid is advantageous to plants, particularly when plants are under stress. Silicon (Si) is notoriously difficult to eradicate from the nutritional substrate of plants, it has been impossible to demonstrate that plants cannot finish their life cycles without Silicon. Nevertheless, plants get advantages from the presence of Silicon, and it has been shown that Si may boost the plant's resistance to both biotic and abiotic challenges, providing the plant with protection and stability. By analyzing the data that is currently accessible in the published research, this investigation will explore the positive impact of silicon on plant growth. Si transporters are responsible for mediating the movement of Silicon, which is taken up in silicic acid. The amorphous SiO₂ structures known as phytolites are generated inside the plant. The decomposition of plants results in the return of phytolites to the soil, which in turn results in the return of Silicon to the soil, where subsequent generations of plants can take it up. Many other kinds of proteins work in concert with Si to protect plants from various pathogens. These data indicate that Silicon must be classified as a necessary plant nutrient rather than just a helpful one. In this study, we highlight the function of Silicon in the soil as well as in plants, particularly with a focus on micronutrients, metabolites, Si fertilizer, crop quality, Prophylactic effects from crop diseases, phytolites, and their importance, the role of Silicon in plant roots, the role of Silicon in plant protection, stabilization, and enhancing plant health and performances, and the role of Silicon in phytolites.

Keywords: Silicon Fertilizer, Advance Agriculture, Silicon in Soil

Introduction

Silicon, the second most common element on Earth, may be abundant as a component of the clay minerals that make up the bulk of most soils. It is absorbed by plants as silicic acid [Si (OH)₄] at pH

Values below 9 ($pK_a = 9.8$) and has a concentration in the soil solution of 0.1 to 1.4 mM [1]. Si is present in the tissues of all plants growing in soil. The quantity of Si accessible to plants has decreased due to repeated cropping and the use of artificial fertilizers [2]. Si fertilizers are commonly used to increase the yields of Si-accumulating plants like rice and sugarcane since silicon shortage in soils is now understood to be a limiting factor in crop output [3].

It is undeniable that Silicon deserves more attention from scientists and farmers; however, this is hindered by divergent opinions on whether agricultural soils are deficient in Silicon, whether the plant in question will accumulate Si and it is debatable whether Silicon should be regarded as a fertilizer, bio-stimulant, or plant protectant [4]. As scientists and farmers get a deeper understanding of Silicon and its applications, it is feasible that this element, which is commonly overlooked despite being a near-essential component, will be acknowledged as a practical means of improving plant health and performance. Numerous studies have shown that Si positively impacts plant growth, productivity, photosynthesis, balanced nutrient availability, and the processes for scavenging reactive oxygen species [5,6]. Because of its efficacy in mitigating the damaging effects of water, salt, and heavy-metal stressors and providing resistance to insect infestation and disease [7–14], Si has been widely used in a wide range of crops. Si is said to increase lignin buildup in stems, making them stronger. In rice, stem strengthening prevents lodging, thereby minimizing reciprocal shade, sustaining canopy photosynthesis, and enhancing yield [15,16]. When applied to *Triticum aestivum* plants, Ahmad and Haddad [17] found that the antioxidant system improved. Under high-Zn stress, Song et al. [18] found that adding Si restored leaf chloroplast order and chlorophyll content. It was observed by Vila et al. [19] that *Oryza sativa* chlorophyll levels increased due to an interaction between Silicon and nitrogen. The presence of Si has been linked to a boost in plant resistance to insect and pest invasion. Deposits of amorphous Si in plant tissues provide a physical barrier, increasing the plant stiffness and abrasiveness and making them less palatable to insects [20, 22]. Si also appears to boost proline and glycine betaine concentrations in various species under drought and salt conditions to buffer their detrimental effects [23,24]. However, research on maize and borage found that glycine betaine levels dropped when the plants were subjected to drought and salt stress, respectively [25,26]. There is no denying that silicon fertilizer boosts crop yields and it is a standard agronomic technique in several regions. As a result, scientists have doubled their efforts to figure out the best ways to apply silicon fertilizer to various agricultural and horticulture crops and establish best practices. This review provides the findings from various investigations conducted over the years on the presence of Silicon in soils and plants. The assimilation and role of Silicon in plants, the critical levels of Silicon in soils and plants, the procedures to estimate the plant-available Silicon in soils, and the potential sources of Silicon are some of the topics covered in this article [27]. Other issues that are covered include the chemical dynamics of the various forms of Silicon in soils, with a focus on monosilicic acid (H_4SiO_4). Different sorts of Silicon usage have their special and unique qualities to make it a great potential source in agriculture. It could ameliorate the various abiotic stressors better than bulk material, as shown in Fig. 1.

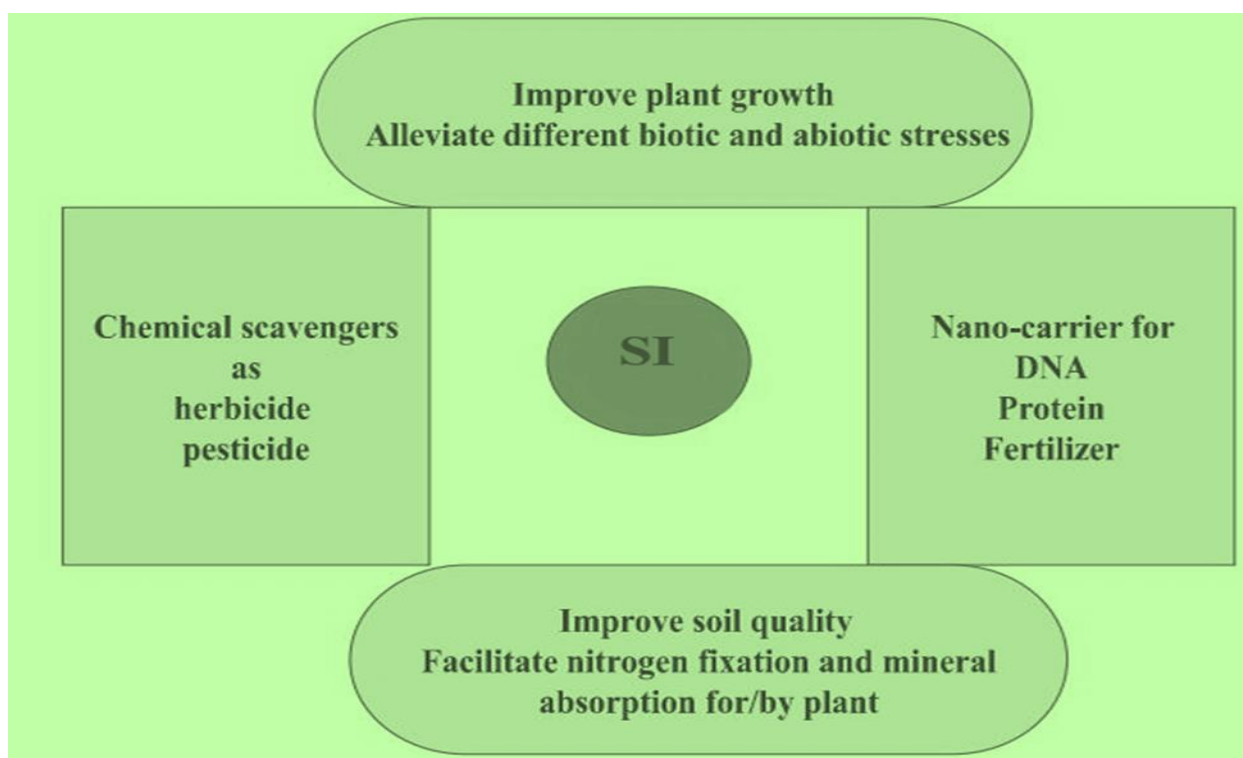


Figure1: Schematic representation of Silicon [27].

1. Silicon as Micronutrient

Plants benefit from Silicon because it buffers the effects of metal toxicity and other biotic and abiotic stressors. Si can externally reduce metal availability to the plant by precipitating in the growth media and internally influence the distribution of metals inside the plant, mitigating harm under excessive metal concentrations. Recently, in hydroponics, researchers have evaluated different plant species to determine the physiological significance of Si in connection to micronutrient deficient symptoms. Synchrotron X-ray fluorescence (S-XRF) and high-resolution secondary ion mass spectrometry (NanoSIMS) were recently used to map the distributions of Si, Fe, Zn, Mn, and Cu in the node, internode, and leaf sheath of rice (*Oryza sativa*) cultivated with Si in hydroponics [28]. Overall, Si was shown to be localized to the cell wall, and no Si was discovered in the vacuoles, suggesting that Si transporters do not reside in the tonoplast [29]. In addition, Si was discovered to accumulate in the cytoplasm of the basic parenchyma of the internode, in the form of oval granules that are believed to represent the starch grains [29]. Fe and Mn were found in the basic parenchyma cells, whereas Zn was found in the vacuoles of the parenchyma cell bridge surrounding the expanded and disseminated vascular bundles. Fe was shown to be significantly co-localized with phosphorus in the vacuoles, which explains the poor mobility of Fe in plants. Cu distribution pattern is strikingly distinct from the other transition metals, with a high degree of localization occurring mostly in the cell walls and in a variety of vascular bundles. The Si function in metal accumulation at non-toxic concentrations and the possibility of the deposited metal being transmitted to the shoot can be better understood with the help of a comparable investigation of roots. In addition, it is important to consider how incorporating Si influences the surrounding metal molecules (such as citrate) involved in long-distance transport in plants.

Further research in this area, however, necessitates the development of novel tools and techniques, such as S-XRF or NanoSIMS, which, when paired with conventional analysis, will help clarify the

function of Si in micronutrient insufficiency. The amount of Silicon that pools in the soil, the factors that determine the amount of Silicon that is bioavailable in the soil, and the potential mechanisms by which Silicon reduces the absorption, accumulation, and translocation of heavy metals in plants are all things that need to be investigated. Si has a significant impact on the availability, accumulation, and translocation of heavy metals through plant roots by acting in a various way. These include biological factors that affect the bioavailability of silica in the soil, altering soil characteristics such as pH, enzyme activities, and microbial communities. As a result, lowering the fraction of bioavailable heavy metals in soils; co-precipitation of silica with heavy metals; conversion of heavy metals to less soluble forms. There is data that indicates that the pH of the soil can effectively prevent the supply of heavy metals among the components of the soil [63]. Adding Silicon to soil could led to an increase in the pH of the soil, while also leading to a decrease in the amount of organic matter and the electrical conductivity [64,65]. The nature of the mineral Si is alkaline, and its surface can easily carry exchangeable cations in large amounts and exchangeable H⁺ in small quantities. Leading to a strong hydrolysis of exchangeable cations in the soil, which produces a high proportion of NaOH in the soil solution and further raises the pH of the soil [65].

2. Direct Impact of Si on Soil

Soil conditions determine the relative abundance of Silicon in rocks, Varing from 23 to 47 percent (basalt to orthoquartzite) [38]. Heavy weathering causes certain soils, such as latosols or latosolic red soils in the tropics, to undergo desilification and fertilization processes. Limestones and carbonites are two examples of carbonaceous minerals found to contain traces of the element silicon [38,39]. Specifically, silcretes are soil with a high Si content (more than 46%). Much less Silicon may be found in the petrocalcic horizon than in the silcretes (8%), and even less can be found in the minerals of some intensely weathered Oxisols [40,38]. A few soils have low levels of Si, specifically the form of Si that is unusable by plants, but this is not the case for most soils. [40]. Soils of this kind include the highly weathered and leached Oxisols and Ultisols, which are acidic and have low base saturation [41], and the highly organic and mineral-poor Histosols [42]. Plants also have trouble accessing Si in soils containing a lot of quartz sand or exposed to prolonged plant productivity [17,43]. Si can improve the availability of phosphorus in Artic soils because of non-agricultural or human management techniques [45], and biogeochemical conditions are the primary determinants of Si fractions and availability in soils [44]. Si is partitioned into the liquid, adsorbed, and solid phases in soils [39,46,47]. In their discussion of the crystalline forms of Si, Sauer and Burghardt [47] they included silica. Until recently [43,48,49], the only crystalline form was that of primary and secondary silicates, abundant in mineral soils formed from rocks and sediments. Most silica products are either quartz or disordered silica (Fig. 2). Amorphous, weakly crystalline, and microcrystalline Si fractions are also present in the solid phase [39,43]. Soluble Si components are distributed throughout the soil solution, while adsorbed Si components are bound to Fe and Al oxides/hydroxides on soil particles. Soil profile and the processes that create it significantly influence the soil's silicon concentration and abundance. Sand particles (mainly SiO₂), primary crystallines such as olivine, augite, hornblende, quartz, feldspars-orthoclase, plagioclase, albite, and mica, and secondary silicate are clay minerals like illite, vermiculite, montmorillonite, chlorite, and kaolinite make up most mineral soils. These silicates are often very poorly soluble and biogeochemically inert. In contrast to mono silicic acid (H₄SiO₄), which is soluble in water, polymerized silicic acid is only partially water soluble in soil.

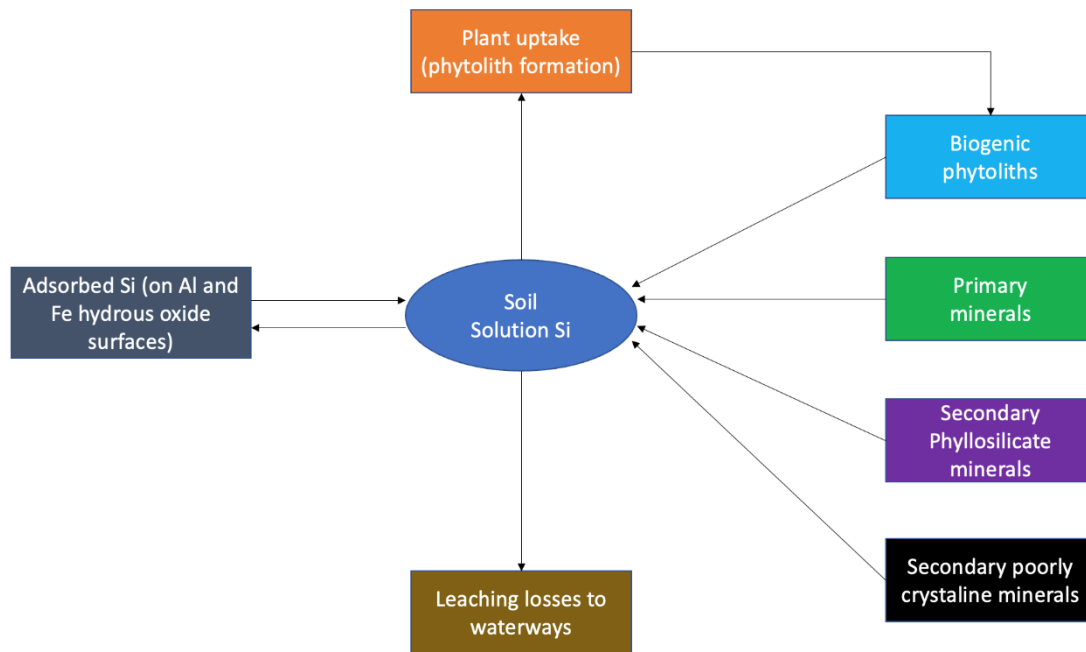


Figure 2: A schematic presentation of the connection between soil solution Si and the other principal pools of Si in soils.

Both Tubaa et al. [52] and Babu et al. [53] showed that the quantities of Silicon that could be removed from soils collected in the Midwest and the south of the United States varied depending on the extraction method that was used. According to the findings of Tubaa et al. [52], 0.1 M citric acid was able to consistently extract the maximum quantity of Silicon from soil samples taken from some states in the United States (Fig. 2.4). Citric acid was found to have a higher amount of extractable Silicon than acetic acid (24 hours of rest followed by 2 hours of shaking was found to be more effective than 1 hour of shaking), followed by sodium acetate, ammonium acetate, calcium chloride, and finally water. This information was found in a study conducted by Babu et al. [53]—Like that, the 0.025 M citric acid solution was able to extract greater quantities of Silicon from calcareous soils when compared to the Na acetate–acetic acid (pH 4) and the 0.19 M Na_2CO_3 –0.5 M NaHCO_3 (pH 8.5) solutions [54].

2.1. Availability of Silicon in Soil

Clay particles, as well as iron and aluminium hydroxides, are examples of solid phases in soils capable of absorbing dissolved fractions of silicon [70,71]. The slight decrease in Silicon in the soil solution might be attributed to the adsorption of secondary clay minerals, as mentioned in [43,72]. On the other hand, the adsorption potential of the Fe and Al hydroxides is Excellent, and they are capable of removing significant quantities of dissolved Silicon from the soil solution [50]. The monosilicic acid's ability to bind to the oxides in the soil affected the soil's pH, redox potential, and metallic form. The number of monosilicic acids absorbed by oxides increases when the pH of the soil rises from 4 to 9, and this amount is substantially larger when the oxides of metals in the soil are based on Al rather than Fe. Ponnampertuma [73] discovered that increasing the amount of time that soil was waterlogged led to a decrease in the amount of element hydroxyl (Eh), as well as an increase in the solubility of Silicon in soil [74,75]. Generally, silicic acid may be adsorbed onto secondary Fe-based oxides; however, a far greater quantity of silicic acid can be adsorbed onto short-range, ordered ferrihydrite

than crystalline goethite [39,76]. This results in Creating a bi-dendatesilicate inner-sphere complex [77-79]. This occurs because the OH group on the Fe-oxide surface is replaced with H₄SiO₄. When the surface of the Fe-oxide reacts with the orthosilicic acid in a certain way, polysilicic acid is formed [50]. Iron oxides can control the H₄SiO₄ level in the soluble phase to some extent [40,75,80,81]. This is possible due to the abundance of iron oxides in soil, despite their silicon adsorption ability being less effective than that of aluminum oxides.

Silicon Interaction with Other Elements in Plants

Silicon was applied to the plants at differing concentrations and intervals. Samples of plants at the seedling, vegetative, and blooming stages were tested for their protein and carbohydrate content, as well as their nitrogen, phosphorus, potassium, calcium, magnesium, Iron, manganese, and silicon levels.

Silicon's inclusion appears to have paved the way for more phosphorus use, as evidenced by the image. The application of non-diffusible colloidal silica, discovered by Butkwitsch et al. [56] increased wheat's phosphorus uptake. He hypothesized that wheat's ability to absorb phosphorus from a nutrient solution would improve if non-colloidal Silicon were present. Brenchley et al. [57] found that supplementing the barley's soil with Silicon in silicate enhanced the grain's capacity to absorb phosphorus. When radioactive Silicon was applied to wheat, Rothbur et al. [58] discovered that silicate increased the plant's ability to absorb phosphorus, demonstrating the metabolic link between the two plants.

While some plant varieties benefit from Silicon (Si) because it helps them grow even when they're subjected to drought, this element was not found to be helpful by Gunes and his co-researcher [59]. Genetically improving sunflowers' sensitivity to drought may depend on the accumulation of components in various cultivars. Uptake of Si, P, K, S, Ca, and Mg were all unaffected by the interaction between treatment and cultivar ($P > 0.05$). The average Si content of the sunflower cultivars was 4.32 mg plant⁻¹ when grown in controlled conditions. The Silicon uptake by the cultivars was drastically reduced by drought stress, reaching only 1.90 mg plant⁻¹, still it was increased by the application of Silicon under drought stress circumstances, reaching an average of 2.46 mg plant⁻¹. Sunflower cultivars that were subjected to drought stress showed decreased uptake of the elements P, K, S, Ca, and Mg; however, uptake of these elements was increased when Si was applied, Except for P. Si, P, K, S, Ca, and Mg uptake results show a great deal of genotypic heterogeneity between cultivars exposed to control, drought, and drought combined with Si treatment. The treatment by cultivar interaction significantly affected the uptake of Iron, Copper, Zinc, and manganese (P less than 0.01). Significant variation in iron uptake across the control, drought, and drought plus Si treatments was observed between the cultivars. Drought stress greatly reduced iron uptake in all cultivars, but Si application restored iron uptake. These cultivars are "Tarsan," "Meric," "Sirena," "C207," and "Sanay," and the number "TR-3080." There was a large amount of genotypic heterogeneity in copper uptake among the cultivars that were influenced by the treatments. In addition, the drought stress inhibited the cultivars' copper uptake. However, when the cultivar was subjected to dryness stress, the addition of Si increased copper uptake. Those names are "Meric," "Sirena," "C-207," and "Vanko," in that order. Zinc and manganese absorption varied widely between therapies. In general, drought stifled their absorption, while silicon injection had inconsistent effects. In a study involving plants under stress from ultraviolet-B (UV-B) radiation, Shen et al. [60] found that silicon (Si) increased nutrient uptake. Soybean (*Glycine max* L.) cultivars 'Kennong 18' (K 18) and 'Zhonghuang 13' (ZH 13) were grown in

hydroponic cultures with and without the addition of Si. They were exposed to either natural or artificial levels of ultraviolet-B (UV-B, 280-315 nm). When plants were exposed to UV-B radiation at levels that mimicked a loss of 30% of the ozone layer in the stratosphere, leaf nitrogen (N) and phosphorus (P) concentrations were raised by 9% and 16%, respectively; leaf magnesium (Mg) contents were lowered by 9%; and leaf calcium (Ca) concentrations were raised by 24%. Due to UV-B radiation, the root system received a disproportionately higher share of the plant's available phosphorus (P), potassium (K), and calcium. This was likely done to ensure a steady supply of nutrients was being taken in despite the pressure. In response to UV-B light, the plant's dry mass is moved to the shoots, while the allocation of tissue phosphorus and calcium to the roots is enhanced by Silicon's 11% increase in the uptake of these elements. Increases in wet and dry mass of the 'K 18' cultivar were attributed to the cumulative effects of Si. Depending on the type of soils used, bananas grown on Guadeloupe's eastern slopes can have an average leaf silicon concentration of 2.7–3.9 g kg⁻¹, while bananas grown on the island's western slopes can have an average leaf silicon concentration of 7.7–9.6 g kg⁻¹ [61]. Variations in Si concentration have no discernible effect on the mineral content of the leaves, which is, on the whole, quite comparable. Mg concentrations are between 2.9% and 3.2% by weight, potassium concentrations are between 28.3% and 33.3%, calcium concentrations are between 4.1% and 6.6%, and phosphorus concentrations are between 1.8% and 2.2%. The largest variation was for Mn, which varied from 0.37 to 1.5 g kg⁻¹. Si plays an important role in ecosystems, helping to control things like carbon flux, carbon sequestration, and the N:P stoichiometry [62,66,67]. A particular stoichiometry exists between carbon, nitrogen, and phosphorus in C-deficient marine algae and C-free immature leaves of higher plants (106:16:1) [68,69]. However, only one study examines silicon's effects on plant's carbon to nitrogen and nitrogen to phosphorus ratios, and it focuses on emergent macrophytes [158]. Carbon, nitrogen, and phosphorus ratio changes may have ecological repercussions. Changes in the quality of the litter that accumulates on the ground have consequences for Decomposition dynamics. This can be seen in both living plants and dead organic matter. In addition, the connection between silicon weathering and plant uptake (via buildup in the plant-soil system) is typically overlooked but is an important part of global biogeochemical cycles. This information gap motivated us to test the impact of silica availability on *P. australis* biomass production and elemental stoichiometry by adding three different silica concentrations to a pot and observing the results. Roots secrete citrate and malate, and Kostic et al. [166] study these factors along with the rhizosphere soil, tissue P content, and expression of the root Pi transporter genes (TaPHT1.1 and TaPHT1.2). Shoot phosphorus concentration was adequate in the phosphorus-fertilized plant range due to an increase in silicon supply in the form of sodium silicate. Compared to silicon's efficacy in addressing low soil pH and high Al³⁺, liming's impact on soil pH was comparable. The *in-planta* effect of Si on regulating the expression of TaPHT1.1 and TaPHT1.2 was several times larger than P fertilization and liming, leading to a doubling of the amount of P taken up by the plant. In addition, the malate and citrate secretion rate was greatly increased by Si, which had a multiplicative effect on the root's acquisition of Pi. Increased expression of genes involved in nitrogen assimilation (OsGS2, OsFd-GOGAT, OsNADH-GOGAT2, OsGDH2, and OsNR1) was observed in rice grown in a nitrogen-deficient environment. When Silicon was present, there was no change in the relative expressions of N-uptake genes (OsNTR1.1 and OsAMT1;1), and there was a slight decrease in the relative expressions of N-uptake genes (OsNTR1.1 and OsAMT1;1). This novel Ca-Si interaction pattern was recently observed in water-cultured cabbage (*Brassica oleracea* var. *capitata*) by da Silva et al. [167]. The findings of this study were published in the scientific journal *Plant Physiology*. Adding Silicon decreased calcium accumulation in the plant's aerial parts. It increased it in the roots of cabbage that

had an abundance of calcium while adding Silicon increased calcium accumulation in the plant's aerial parts and had no effect on the root accumulation in cabbage that lacked an adequate supply of calcium. Silicon applied to cucumber roots increased the expression of key genes involved in the biosynthesis of organic acids that act as powerful iron chelators, thereby increasing apoplastic iron mobility. ICD, which is responsible for citric acid, and MDH, responsible for malic acid, are two examples of these genes [168]. Cucumber (FRO encoding transmembrane protein involved in Fe³⁺ reduction and IRT1 encoding Fe²⁺ transporter) and common corn salad (*Valerianella locusta*) both respond to silicon supplementation by upregulating genes in the Strategy 1 cluster [169,170]. Furthermore, it was recently reported by Nikolic et al. [171] that Si alleviates Fe deficiency in barley, a Strategy 2 species, by increasing the expression of genes involved in Fe uptake and transport in roots. Phytosiderophore (PS) biosynthesis genes include HvNAS1 and HvDMAS1, PS transporter gene HvTOM1, and PS uptake and efflux transporter gene HvYS1. More HvYS1 and HvDMAS1 transcripts were also found in leaf tissue when Si was present. The metals are transported from the root to the shoot thanks to these genes. It's worth noting that Si's impact on the transcript regulation of both the strategy 1 and strategy 2 genes showed a significant dependence on time. Song et al. [172] showed that two rice cultivars with varying tolerance levels to zinc excess had their shoot zinc concentrations significantly reduced by increasing their supply of silica. A lower zinc concentration in the shoots was associated with a reduced rate of zinc translocation from the roots to the shoots, even though root zinc concentrations were higher. On the other hand, it is believed that the reduction in Si-mediated defence against Zn toxicity is the fundamental reason why Si-mediated antioxidant defence capability and membrane integrity are strengthened. In cowpea, soybean, and sunflower, Silicon mitigates manganese toxicity by increasing manganese localization in leaf tissues, as reported by Blamey et al. [173]. Manganese is sequestered directly into apoplastic forms, making it safe for use in this context. Thus, cytoplasmic or apoplastic manganese accumulation is decreased, as is apoplastic Mn²⁺. High Mn levels impeded photosynthesis in various ways. Among these mechanisms are the dampening of light-harvesting processes, the reduction of chlorophyll and ATP synthesis, the disruption of the stability and structure of phosphoribulokinase, and the slowing of phosphoribulokinase activity.

An increased Si concentration is needed to reduce Al toxicity in soybeans at low pH, as reported by Baylis et al. [174]. The authors hypothesized that the higher affinity of Si for Al in production at low pH was to blame for this increased requirement for Si [175]. Late-breaking research on the Al-Si interaction in maize confirmed silicic acid's beneficial effects [176]. Aluminium and Silicon interacting in the root apoplast is a complex process regulated by several interrelated factors, such as the apoplast pH and the concentrations of aluminium and Silicon. Si was added to maize to buffer H⁺ in the root apoplast, as postulated by Rowatt and his team [177]. The increased pH at the root's surface stimulated HAS synthesis. Similarly, Cocker et al. [178] proposed that Si-induced synthesis of harmless HAS in the wheat root apoplast may be a more likely mechanism for restricting Al availability. Yan et al. [179] investigated the function of Si in bypass flow and root-to-shoot Na⁺ translocation in rice using *lsi1* and *lsi2* mutants that lacked *OsLsi1* and *OsLsi2*, respectively and their wild type counterparts (WTs). In the presence of extreme salt stress, silica promoted growth in both wild-type and mutant plants but did not affect the sodium translocation from roots to shoots. The researchers concluded that the endodermis of the root is the primary site where Si-induced Na⁺ bypass flow occurs. At low pH values (up to eight), adding a milligram of Si to tomato significantly decreased the root concentration of Selenium (Se), at higher pH levels, the effect was nullified Wang et al. [180]. The silica-

influx transporter's preference for the segregated form present at the given pH may help explain this pH-dependent differential in the silica impact. Lower Se accumulation in the tomato roots due to Si/Se uptake antagonism and the lack of Si effect on Se accumulation in the shoot reported by Wang et al. may be explained by the presence of the fully functional Si influx transporter (SLsi1), and the absence of functional Si efflux transporter (SLsi2; involved in xylem loading of Si) in tomatoes [181].

3. Effects of Silicon directly on plants

Silicon is a beneficial plant nutrient, and yield responses to its application on Si-deficient soils have been frequently demonstrated in Si-accumulator crops such as rice, sugarcane, maize, and wheat as well as a wide range of other crops [82]. Silicon can be found in rice, sugarcane, maize, and wheat. According to their capacity to take up silica, plants may be divided into three categories: efficient silica-accumulating crops, passive silica-accumulators, and silica-repellent cultivars [83]. There is a wide range of variation in the amount of silica that plants can deposit, ranging from 0.1% to 10.0% of their dry weight [84,85]. The variation in the amount of Silicon accumulated in different species can be partly explained by the fact that different species' roots have varying capacities for absorbing Silicon. Since the pioneering discovery of genes (LSi1, LSi2, and LSi6) that demonstrated the Si uptake and transport in plants a decade ago, scientists have worked hard to understand the molecular pathway behind Si uptake and transport among cultivars [87,88]. This has been the case since the pioneering discovery of genes (LSi1, LSi2, and LSi6) that demonstrated the Si uptake and transport in plants. Different studies have been done to investigate how and why Silicon is beneficial to the growth and development of plants [89]. Silicon is not only considered essential for plant growth and development, but literature pieces of evidence have shown that this metalloid is beneficial for plant growth, particularly in stressful conditions [90].

The presence of Silicon in polluted soil was shown to affect the bioavailability of hazardous substances. Its presence, whether in the form of sodium meta-silicate or alkaline Si particles, increase pH of the rhizosphere, which in turn causes a decrease in the availability of metal concentration in the soil [91]; alternatively, the soluble form of Silicon in the soil can be converted to produce viscous metasilicic acid (HSiO), which prevents the release of toxic metals [92]. According to Kidd et al., 2001 [93], Silicon increases the levels of phenolic compounds such as catechin and quercetin. These compounds chelate with aluminium compounds to reduce aluminium's toxicity in several plant species such as barley, maize, rice, sorghum, pea, and soybeans [94]. However, Wang et al., 2004 [95] revealed that the presence of hydroxyl aluminum silicate in the apoplast also helps with Al detoxification. The Compartment of metals or a reduction in the absorption of metals by the root, leading to an apparent buildup in the endodermis is an important factor in metal stress resistance [96]. It is widely known that Silicon improves plant resistance and reduces plant damage caused by diseases, insects, or non-insect pests by upregulating Plant resistance mechanism [160]. This is in addition to the fact that Silicon has other Useful positive quality. Si can improve a plant's resilience to insect pests by controlling the powerful interactions between salicylic acid and jasmonic acid [161]. Priming is a strategy that can be used to increase Si-induced resistance in plants against insect pests [162,163]. Priming is the process of developing and stabilizing a plant's defensive reactions to make them more powerful and quick in response to future herbivorous assaults [164]. The formation of secondary metabolites, regarded as the first line of defense against an attack by a pest made easier by silicon. Herbivore-induced plant volatiles, or HIPVs, are produced by various plant species in reaction to being chewed on by insects. Si is the agent that causes this volatiles to be amplified or altered. These

reactions are well coordinated with the synthesis of JA and SA and the signalling route they use. Additionally, Silicon raises the number of defence-related enzymes and their activities. These enzymes include polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), trypsin protease inhibitor, and peroxidase (POD). These enzymes are activated by Silicon in response to insect threats [165]. In fig.3, describing the process of schematic representation of Si transport in plants in different stages.

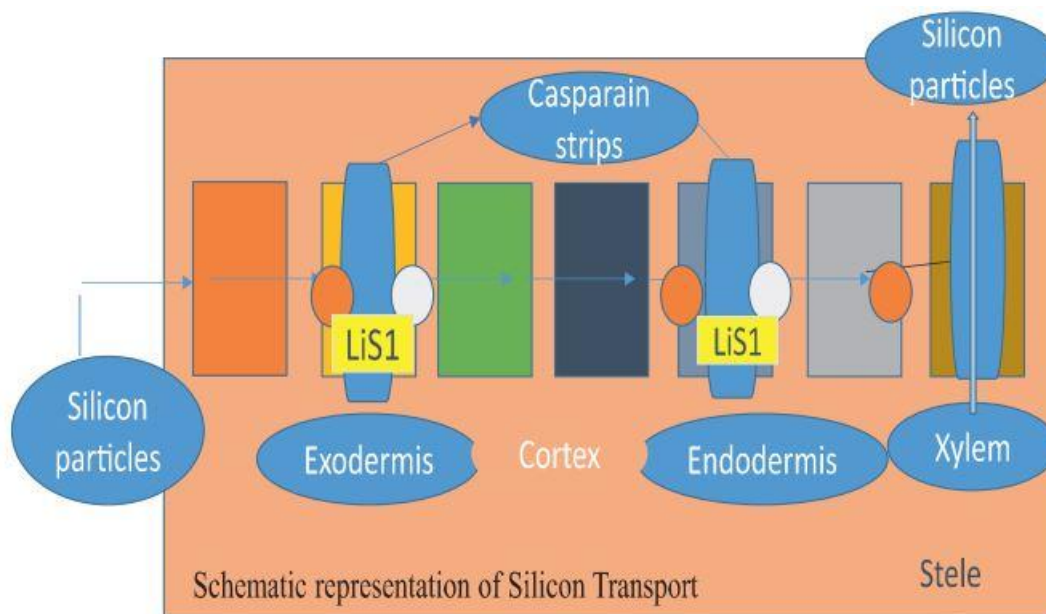


Figure 3. Schematic representation of Si transport in plants [92].

Dongfeng et al. [97] investigated the impact of slags on the ultrastructural alterations that occurred in rice leaves that had been naturally infected by *Bipolaris oryzae*. This fungus is responsible for brown spots. And discovered that both slag-based Si fertilizers that were evaluated significantly boosted rice growth and yield, while simultaneously reducing the incidence of brown spots, with steel slag exhibiting a larger impact than iron slag. More prominent cell silicification, an increase in the number of silica cells, and a more pronounced and bigger papilla were all results of applying slags to rice leaves. Rice leaves that had not been treated with slag exhibited disordered mesophyll cells due to the invasion of the fungus *Bipolaris oryzae*, which also destroyed chloroplasts and changes to the cell walls. The application of slag-maintained mesophyll cells resulted in a silicon layer that was largely undamaged and thicker. It is possible to conclude that adding fertilizer composed of slag to paddy soil lacking silicon is required to improve rice yield and resistance to brown spots.

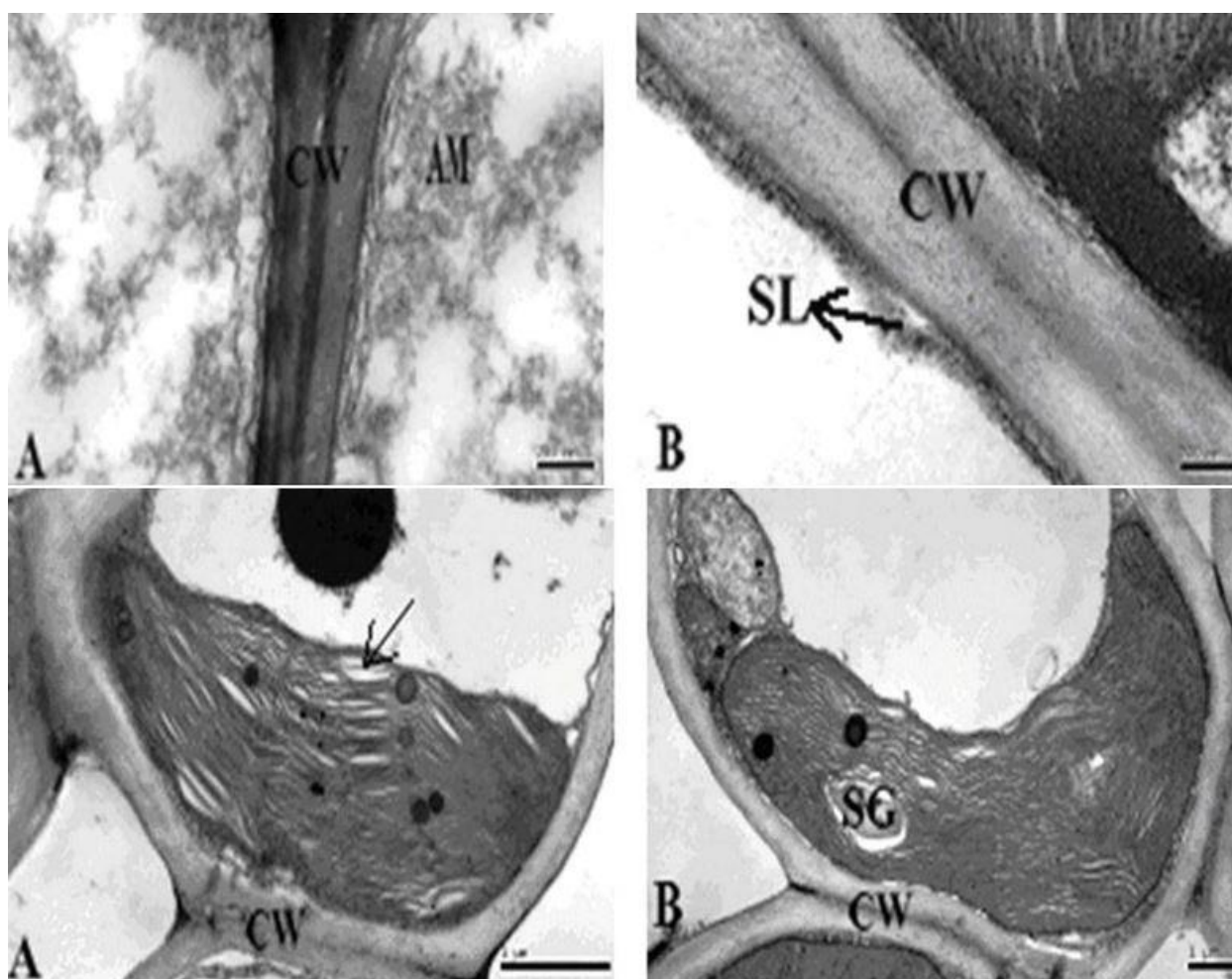


Figure 4: Transmission electron micrographs of cell wall from rice leaves (a,b) and chloroplasts from leaves of rice (c,d) [91]

Figure 4 shows that the thickness of the Si layers in epidermal cell walls that had been treated with silica grew due to the silica treatment. The silicon layers are found in the epidermal cell walls are rumoured to confer enhanced host resistance to brown spots. This align with the previous reports that the cuticular silicon double layer developed on rice leaf cells constituted a physical barrier to impede fungal penetration and colonization of the rice plant. At the jointing stage, rice leaves were naturally infected with brown spot disease, which is caused by the fungus *Bipolaris oryzae*. The leaves of rice plants that had not been treated with slag exhibited signs of illness five days sooner than those that had been treated with slag. At anthesis, the ultrastructural features revealed that the chloroplast thylakoid lamellae of the mesophyll cells of untreated rice leaves had been inflated and that the stroma and grana lamellae of the chloroplast had been deformed. On the other hand, the chloroplast structure of the mesophyll cells of Si-treated leaves remained basically unaffected. It has been found that the severity of brown spots is inversely connected with the amount of Si that is present in rice tissue.

Table 1: Effect of Si and Si-NPs on plant species' growth, physiochemical and yield attributes.

Growth medium	Scientific Plant species Name	Response of plant to applied Silicon	Ref

Silicon as SiO Seedling, priming	<i>Larix olgensis</i>	Increase in plant height, tap root length, number of lateral roots, and chlorophyll contents	[98]
Soil, field	<i>Zea mays</i>	Root elongation and silica deposition in the control plant was observed	[99]
Soil was sandy clay loam	<i>Triticum aestivum</i>	Significantly reduced plant height, spike length, shoot fresh weight, and the number of spikelets/spike, eventually enhancing wheat yield	[100]
Seeds, Petri plate	<i>Lens culinaris</i> <i>Lycopersicum esculentum</i>	Better germination index and early growth of plants under salinity stress	[101-102]
Seedling, irrigation	<i>Crataegus aronia</i>	An increase in plant growth and concentrations of photosynthetic pigments, with the decrease in water potential and oxidative stress indicator, the MDA content	[103]
Si-priming Under high tunnel and field conditions	<i>Arabidopsis thaliana</i>	Reduction in powdery mildews and high yield	[104]
Spikelet formation, fertilization, and grain filling processes	<i>Oryza sativa</i>	Improve rice grain yield through increasing spikelet formation, fertilization, and grain filling	[105]
Nano-Si Seeds, Petri plate	<i>Lycopersicum esculentum</i>	Improved root and shoot growth	[106]
Seedlings, nutrient solution	<i>Solanum lycopersicum</i>	Rise in fresh weight, chlorophyll contents, photosynthesis rate, and leaf water potential of the plant	[107]
Plant, foliar spray	<i>Ocimum basilicum</i>	NPs mitigated the effects of salinity stress	[108]
Seeds, pod	<i>Vicia faba</i>	Improved flowering results in high yield	[109]
SiO -NP fertilizer Encapsulated farmyard manure with NPK fertilizers	<i>Helianthus annuus</i>	Significantly effective at improving the reduction in the growth characteristics	[110]

Three Si fertilization treatments and control	<i>Elaeis guineensis</i>	Enhanced Si accumulation in oil palm seedlings and maximum accumulation was observed in the aerial parts, especially the leaves with the highest accumulation of 0.89 % dry weight	[111]
Si-fertilizer: OPTYSIL Laboratory trial Small field trial	<i>Triticum aestivum Brassica napus</i>	Induce drought tolerance with the increase in pod number, average seed yield/plant, thousand grain weight, and decrease electrolyte leakage	[112]
SAAT: a stable Silicic acid Foliar spray, Hydroponically or soil solution, vegetative stage	<i>Oryza sativa, Saccharum officinarum, Solanum tuberosum, Solanum lycopersicum, Triticum aestivum, Eleusine coracana</i>	Increase in root mass, leaf area, chlorophyll content, nutrient uptake (P, Ca, K, and Si), yield good quality	[113-115]
Elkem: as Silicon material, Greenhouse, field experiment	<i>Oryza sativa</i>	Induce resistance against insect and their infections with the increase in antioxidants, specific and nonspecific or both	[116]
Silixol: foliar fertilizer Field trial, vegetative, booting, and seed development stage	<i>Triticum aestivum</i>	Mitigate drought stress with increased relative water content, chlorophyll contents, root elongation, K and P contents of both straw and seeds	[117]
foliar spray of Silicon (Si) using calcium metasilicate powder	<i>Saccharum officinarum</i>	improved sugarcane plant performance suitably favored stomatal dynamics for photosynthesis and plant productivity	[118]

Nanthana et al. [119] demonstrated how a lack of silicon can restrict rice grain productivity through processes including creating spikelets, applying fertilizer, and filling grains. Rice grain production might be improved by using Si fertilizer, which would increase spikelet development, fertilization, and grain filling. The use of Silicon boosted grain production by 44% in Chainat 1 (CNT1) and 23% in Pathumthani 1. (PTT1). CNT1 had a lower total number of spikelets in the absence of Si treatment, and the fertilized and filled spikelets responded more strongly to Si than PTT1 did. The number of spikelets and grains that were successfully fertilized and filled led to an increase in grain output across both genotypes. There were close links between Si concentration in the shoots, flag leaf, and husk, which were positively connected with grain yield, the number of spikelets, and fertilized and filled grains. These associations were present in all three plant parts: shoots, flag leaf, and husk. Compared to the expression of plants that did not have any Si provided applying Si fertilizer resulted in a 202% rise in the level of Lsi6 expression in CNT1 and a 114% increase in Lsi6 expression in PTT1.

The sandy clay loam soil that Munir et al. [120] found in their experiment where a pH value was 8.01 on average, an electrical conductivity (EC) of 2.36 dSm^{-1} , and a calcium carbonate (CaCO_3) concentration of 2.16%. The organic matter content of the soil was significantly low (less than 1%). Phosphorus (P) and potassium (K) had average values of 230 and 5.21 mg/kg, respectively, regarding extractable phosphorus and potassium. In a randomized complete block design (RCBD) factorial fashion with three replications, silicon potassium metasilicate (K_2SiO_3) was applied at the rate of 0 and 12 kg/ha with three canal water irrigation frequencies including two, three, and four. According to the findings, drought stress dramatically decreased plant height, spike length, shoot fresh weight, and the number of spikelets per spike, which ultimately reduced wheat production. With the application of Si, the concentration of K^+ in the shoot (28.65 mg/g) and grains (3.51 mg/g) increased, which helped to maintain water potential in the plant even under reduced moisture levels in plants and soil, which resulted in the production of more yield and biomass under conditions of drought stress. Krishan et al. [121] disclosed the results of an experiment in which sugarcane was treated with a foliar spray of Silicon (Si) made from calcium metasilicate powder (Wollastonite, $\text{CaO}\cdot\text{SiO}_2$) to mitigate the negative impacts of restricted water irrigation. On regularly grown sugarcane plants that were 45 days old, a foliar spray containing Silicon at concentrations of 0, 50, 100, and 500 ppm was administered. In addition, these plants were grown at a field capacity of just half (50%) employing water irrigation for an exact period of up to ninety days while exposed to open environmental factors. As a direct result of this, the plant growth development, leaf relative water content (%), photosynthetic pigments, SPAD unit, photosynthetic performance, chlorophyll fluorescence variable yield (Fv/Fm), and biomass yield were all negatively affected by the restricted irrigation. It is noteworthy that it contains increased values of proline, hydrogen peroxide (H_2O_2), malondialdehyde (MDA), and antioxidative defense enzymes molecules such as catalase (CAT), ascorbate peroxidase (APx), and superoxide dismutase (SOD). Sugarcane plants were protected from the harmful effects of limited water irrigation stress by a foliar spray of Silicon, which quenched the harmful effect of water deficit and improved sugarcane plant performance by enhancing the operation of antioxidant defense machinery. Stomatal dynamics were also favorably influenced, which favored photosynthesis and plant productivity. Imran et al. [122] demonstrated that co-inoculants of *Enterobacter* sp. UPMSSB7, mycorrhizae (*Glomus mosseae*), and the addition of Si were investigated to enhance the development of rubber seedlings. When compared to the control treatment, the results of this study demonstrated that co-inoculation resulted in substantial improvements (Phosphorus (P) < 0.01) in stem height, chlorophyll content, leaf area, root and shoot dry weight, total root length, root surface area, and root volume. Similarly, it increased compared to the control treatment, the co-inoculation resulted in a substantial (P < 0.01) increase in both the silicon content of the shoot and root and the nitrogen, phosphorus, and potassium content of the leaf. Only Si did not influence the development of the seedlings or the amount of nutrients they contained. There was not a significant difference in the population of *Enterobacter* sp. UPMSSB7 in the rhizosphere of seedlings as a result of co-inoculation and *Enterobacter* sp. UPMSSB7 with Si treatment. Compared to both the control and the single inoculations with Si, the mycorrhizae root colonization and spore density were considerably enhanced (P 0.01) when co-inoculation was performed. As a result, our findings indicated that using co-inoculants containing *Enterobacter* sp. and mycorrhizae to stimulate the growth of rubber seedlings would be a method that is kind to the environment. Figure 5 displays a scanning electron micrograph showing root colonization by *Enterobacter* sp. UPMSSB7 (shown by the arrows) in rubber seedlings subjected to treatment including co-inoculation.

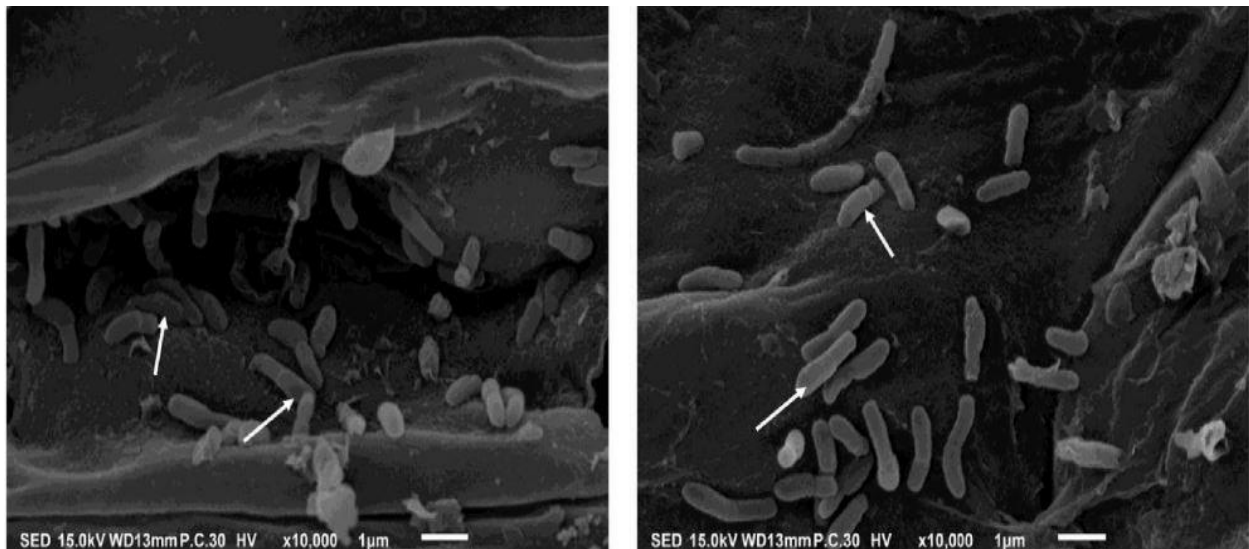


Figure 5. Scanning electron micrograph depicting root colonization by *Enterobacter* sp. UPMSSB7 (arrows) in rubber seedlings from co-inoculation treatment [123].

The growth and physiological responses of oil palm Tenera hybrid seedlings were studied by Saowapa et al. [123] under three Si fertilization treatments and a control. The treatments included (i) 0 g Ca_2SiO_4 (T0), (ii) 0.5 g Ca_2SiO_4 (T1), (iii) 3.5 g Ca_2SiO_4 (T2), and (iv) 7.0 g Ca_2SiO_4 (T3). Ca_2SiO_4 was the source of the silicon fertilizer, and it was applied to the seedlings for four consecutive months. Silicon fertilization increased the amount of Silicon found in oil palm seedlings. Most significant amount of Silicon was found in the seedlings' aerial parts, particularly their leaves, with the highest accumulation of 0.89% dry weight at the T3 stage. A more significant buildup of Si was shown to enhance the development of seedlings, as evidenced by the observation at T3 of a total fresh weight of 834.28 g and a total dry weight of 194.34 g. The chlorophyll content (0.83 gm^{-2}) and the net photosynthetic rate ($4.98 \text{ M CO}_2\text{m}^{-2}\text{s}^{-1}$) were also measured at time point T3. In the presence of Si fertilization, there was not a substantial effect on the morphology of the leaves; nevertheless, there was a significant increase in the amount of nitrogen in the seedlings. The results of the correlation analysis showed a highly significant and positive association between the accumulation of Si, the chlorophyll content, the photosynthetic rate, the total fresh weight, the total dry weight, and the nitrogen content of seedlings. This association suggests that Si fertilization improved the performance of these characteristics.

4. Effects of Si fertilizer and crop quality

Fertiliser containing Silicon (Si) is commonly used to enhance the growing conditions of plants in soil. It has been found that potassium silicate is a citrate-soluble silicate that has a good capacity for reducing the number of contents in rice and is acceptable for use as a core fertilizer [124]. It was discovered that as Si could induce the formation of reactive oxygen species (ROS) and free radicals, which brought oxidative stress. However, the effects of Si on modulating Organoarsenic arsenilic acid (ASA) generated oxidative stress as a method for as plant tolerance are still in their early stages of development. A Si supplementation plays a role in the development and oxidative stress behaviour of three distinct types of rice seedlings when subjected to ASA. We were able to determine whether or not organoarsenic is harmful to rice seedlings by evaluating the biomass and lipid peroxidation (LPO) of the shoots and roots. If it was found that organoarsenic was harmful, then we were able to shed light on the physiological function of Silicon in protective mechanisms through the evaluation of the

activities of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), as well Rice seedlings might benefit from a treatment based on Si, which would help them develop more quickly while also reducing their LPO levels (due to a reduction in their MDA content). The biochemical and mechanistic findings indicated, in part, that Si could significantly increase the capacities of antioxidant defence and improve protein metabolism in rice seedlings to moderate oxidative stress. As a result, Si contributed positively to strengthening of organoarsenic stress tolerance. These results showed that silicon fertilizer would be useful for treating ASA-contaminated rice [124]. In 2013, a 5-day method was developed for determining the soluble Si concentrations in solid fertilizer products using a sodium carbonate-ammonium nitrate extractant followed by visible spectroscopy with heteropoly blue analysis at 660 nm. AAPFCO approved this method after single-laboratory validation [125]. The method was developed using a sodium carbonate-ammonium nitrate extractant. This method was shown to correlate well with the silica uptake by plants. It can now be used for production quality control, accurate fertilizer labelling, label content compliance monitoring, and the selection of an appropriate silica fertilizer source to meet the requirements of crop production. There is now a requirement for labelling fertilizers to indicate whether or not they include beneficial compounds like Silicon.

It is still unknown how the underlying processes regulate disease protection when Si is absorbed by the root system. On the other hand, the impact of Silicon on plant resistance is caused either by an accumulation of Silicon that has been absorbed in the epidermal tissue or by an expression of metabolic or pathogenesis-mediated host defense mechanisms [126]. A thickening Si-cellulose membrane is formed as accumulated monosilicic acid polymerizes into polysilicic acid and eventually converts into amorphous silica. Plants are shielded from harm and given increased mechanistic resilience thanks to the presence of a second cuticular layer. Silicon may also form complexes with organic molecules found in the cell walls of epidermal cells, so enhancing these cells' resistance to breakdown at the hands of enzymes produced by plant pathogenic fungi or bacteria. In addition, research indicates that Silicon plays an active role in plants, which leads researchers to hypothesize that Silicon may function as a signal in mediating plant defensive reactions to pathogens. After a fungal infection, it has been proven that Silicon can enhance chitinase activity and fast activation of peroxidases and poly phenoxidases [127-128]. The strong fungistatic activity was seen in glycosidically-bound phenolics isolated from Si-amended plants and then exposed to hydrolysis by either acid or B-glucosidase. Flavonoids and momilactone phytoalexins are low-molecular-weight compounds with antifungal properties, were discovered to be produced in dicots and monocots, respectively, fertilized with Si and challenged inoculated by the pathogen in comparison to non-fertilized plants that were also challenged inoculated by the pathogen. This was in contrast to the production of these compounds in nonfertilized plants that were also challenged inoculated by the path. In addition, the proteins 1-3 glucanase, peroxidase, and PR-1 were shown to be connected with the prevention of illness. According to the findings of these investigations, there may be other processes involved in the process by which Si mediates resistance to plant diseases. For instance, it has been reported that greater levels of salicylic acid, jasmonic acid, and ethylene are induced by Si supplementation various host: pathogen interactions, which has been confirmed by microarray analysis. Recent genome-wide studies for tomato, rice, and wheat grown in soil amended with Si and compared to control plants grown in non-amended soil have shown a differential and unique expression of many genes involved in host plant defense mechanisms or metabolism [129-131]. These studies used tomato, rice, and wheat is grown in soil amended with Si. Alexander et al., [132] found

that the supply of Si facilitated the exodermis's suberization and the sclerenchyma's lignification. The suberization of the exodermis began at a distance of 4–5 cm and 8–9 cm, respectively, from the root tip (drt), regardless of whether or not Si was supplied to the plant. Twelve genes had a substantial rise in the abundance of their corresponding transcripts, whereas two genes saw a reduction in their transcript level. With an increase in silicon diet, the transcript level of a gene that codes for a leucine-rich repeat protein increased by a factor of 25. It was provided there that physiological, histochemical, and molecular-biological evidence demonstrating that Si actively influence influence on rice root architecture and gene transcription. [133] In their research on rice, Ye et al. [134] found that pretreatment with Si primes JA-dependent signalling, which ultimately results in enhanced resistance to the caterpillar *Cnaphalocrocis medinalis*. The feeding of *C. medicinalis* promotes the transcription of genes that code for silicate transporters, which suggests that the plant is trying to take up more silicate from the soil and to impact the priming of its downstream defenses.

Silicon can defend plants against a wide variety of pathogens, many of which have their own lives and approaches to disease. Table 3 provides a list of the several pathogenic fungi and oomycetes (Phytophthora and Pythium) that have been reported to be suppressed by the addition of Si. Fortunato et al. [136] and Rodrigues et al. [137] have also generated lists that are more comprehensive list than the one presented here. There have been reports that Silicon can manage a wide variety of foliar diseases in various plant species, including monocots and dicots [138]. The principal soil-borne disease agents that t application of Si has been treated members of the genera Pythium, Phytophthora, and Fusarium; however, seed-borne fungal pathogens that cause grain husk discoloration in rice can also be suppressed [139]. It has also been demonstrated that the use of Si can lessen the severity of bacterial illnesses (typically caused by *Xanthomonas spp.*) [137]. For instance, recent research has shown that the application of Silicon can prevent the spread of bacterial wilt in tomato and potato (*Ralstonia solanacearum*), bacterial spot in tomato (*Xanthomonas campestris* pv. *vesicatoria*), bacterial blight in rice (*Xanthomonas oryzae* pv. *oryzae*), and *Xanthomonas* wilt in banana (*X. campestris*). Several researchers have also recorded a Si-induced upregulation of the activity of antioxidant enzymes such as superoxide dismutase, ascorbate per-oxidase, peroxidase, and glutathione reductase [142-145] in the pathogen- challenged plants. These findings suggest that Si limits the pathogen-induced oxidative stress. This may be a significant consideration given that the generation of reactive oxygen species is a crucial part of the body's defensive system; nevertheless, excessive synthesis of these species can cause necrosis and damage to cells (as with abiotic stresses). Indeed, the increased antioxidant enzyme activity that is present in some plant genotypes can contribute to the plant's natural resistance to disease [146,147]. In certain instances, it has been demonstrated that the addition of Si promotes photosynthesis in plants plagued by pathogens by raising the chlorophyll content, preserving the ultrastructure of the chloroplasts, and boosting the stomatal conductance. In addition, Liu et al. [149] demonstrated that the addition of Si caused an upregulation of genes associated with photosynthesis in rice that had been inoculated with blast fungus (*Magnaporthe oryzae*). Chain et al. [150] demonstrated that this same effect occurred in wheat inoculated with powdery mildew (*Erysiphe graminis*). In rice plants infected with brown spot caused by the fungus *Cochliobolus miyabeanus*, the researcher's Van Bockhaven et al. [151] found that the pathogen actively inhibited photosynthetic processes to induce premature senescence in the infected plants. On the other hand, the inhibition of photosynthesis was severely hindered in plants treated with Si, and the levels of photorespiration rose. They hypothesized that Silicon improves

photorespiration, which preserves the photosynthetic mechanism of plants, hence preventing senescence and cell death caused by brown spot fungus.

Table 2: The Prophylactic Effects of Si Application on Various crop diseases have been reported.

Crop	Disease	Scientific Name	References
Rice	Brown spot	<i>Cochliobolus miyabeanus</i>	[152]
	Sheath blight	<i>Rhizoctonia solani</i>	[153]
	Leaf and neck blast	<i>Magnaporthe oryzae</i>	[154]
	Leaf scald	<i>Microdochium oryzae</i>	[154]
	Stem rot	<i>Sclerotium oryzae</i>	[155]
	Grain discoloration	<i>Bipolaris, Fusarium, Epicoccum</i>	[156.157]
	Stem rot	<i>Magnaporthe salvinii</i>	[158]
Sugarcane	Sugarcane rust	<i>Puccinia melanocephala</i>	[159]
	Ring spot	<i>Leptosphaeria sacchari</i>	[160]
Wheat	Powdery mildew	<i>Blumeria graminis</i> f. sp. <i>tritici</i>	[161]
	Wheat spot blotch	<i>Bipolaris sorokiniana</i>	[162]
Barley	Powdery mildew	<i>Blumeria graminis</i> f. sp. <i>hordei</i>	[163]
Sorghum	Anthraxnose	<i>Colletotrichum sublineolum</i>	[164]
Banana	Panama wilt	<i>Fusarium oxysporum</i> f. sp. <i>cubense</i>	[165]
	Black Sigatoka disease	<i>Mycosphaerella fijiensis</i>	[168]
	Root rot	<i>Cylindrocladium spathiphylli</i>	[169]
Coffee	Brown eye leaf spot	<i>Cercospora coffeicola</i>	[170]
	Leaf rust	<i>Hemileia vastatrix</i>	[171]
Soybean	Soybean rust	<i>Phakopsora pachyrhizi</i>	[172]
Cucumber	Powdery mildew	<i>Sphaerotheca fuliginea</i>	[173]

	Root rot	<i>Phytophthora melonis</i>	[174]
	Damping off	<i>Pythium aphanidermatum</i>	[175]
	Damping off	<i>Pythium ultimum</i>	[176]
Muskmelon	Powdery mildew	<i>Sphaerotheca fuliginea</i>	[178]
Zucchini	Powdery mildew	<i>Erysiphe cichoracearum</i>	[179]

5. Challenges and Future Outlooks

Silicon cannot be applied to foliage in the same way it is applied to roots to potentiate the activation of host defense mechanisms. This is because there are currently no known transporter genes that can move this element through the cuticle, followed by basipetal movement into the roots. There is a possibility that nanotechnology might give a solution to the problem of moving Silicon into the plant through its leaf. Nanoparticles (NP) have their own distinct chemical and physical characteristics, and research has already proven that the foliar application of copper (Cu) nanoparticles increase both the availability and transport of these nanoparticles [180]. In this study, the authors stated that a greater level of copper was found in the roots of plants treated with either bulked equivalent copper or NP copper foliar. This was compared to the amount of copper found in the control group. As a direct result of this, the progression of Fusarium wilt in tomato plants was stopped in its tracks in most efficiently. This suppression may be induced by silicon nanoparticles, as shown with Cu [181], according to evidence gleaned from experiments, and there is evidence to support this hypothesis. Silicon buildup in maize leaves rose as the NP concentration increased, as observed [182], and it varied from 0.57% to 0.82% of the total silicon content of the leaves. It was discovered that the development of maize was favorably impacted, which went hand in hand with the rise in silicon accumulation. There is little question that more study is required to discover whether or if administering NP to the plant's leaves would be as helpful in preventing plant diseases as adding Silicon to the plant's roots. Despite recent breakthroughs tying Silicon to host resistance through the -omics, including genomes, proteomics, and metabolomics, the specific mechanism(s) by which this element changes plant physiology through more excellent host resistance deserves additional exploration. Silicon may interact with multiple pathways of a plant's primary metabolism, which may assist plants in better coping with infections caused by soil-borne and foliar pathogens, according to the information that has been generated up to this point, which has provided novel insights into this potential. Considering the current state of plant nutriomics, it will be necessary to determine the involvement of Silicon in plant-signalling pathways. This will result in the enhancement of host defense mechanisms and make it possible to modify key regulators to increase silicon uptake. In the not-too-distant future, it will be feasible to understand the actual activities of Silicon at the molecular, cellular, organ, and even whole-plant levels.

6. Conclusion

Silicon is a naturally occurring element that may be found in high concentrations on Earth. Because it benefits plant growth, agriculture relies heavily on Silicon. The investigation of the Si-plant binomial still has a great deal to teach us. This is especially true, for instance, the cell wall-related processes that are the basis for its preventive role when subjected to stress. Establishing a signaling cascade

toward the interior of the cell and experiencing remodeling are two ways in which the plant cell wall participates actively in the plant's response to biotic and abiotic stimuli. It is so abundantly obvious that some of the positive effects of Si on plants are tied to direct or indirect impacts on the cell wall. The fact that Silicon plays a significant part in the mineral nutrition of plants is not in dispute, nor is its capacity to boost plant development and effectively lessen the intensity of plant diseases. Silicon has been shown to perform all of these functions. The evidence showing this element's effects in terms of disease suppression dramatically influence a vast variety of monocot and dicot species is now accumulating, and our understanding of how it acts in the plant is significantly increasing in research. For illness management, there is still a need for procedures that are both effective and practical in their application, sources of Silicon that are not prohibitively expensive, and techniques for determining the circumstances in which silicon fertilization will be advantageous. However, research on using Silicon to reduce plant diseases in field circumstances is still in its early stage. Further research into certain aspects of the interaction between Si-plants will be necessary to improve agricultural practices to boost crop productivity.

CONFLICTS OF INTEREST

There are no conflicts to declare.

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