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Silicon: A key nutrient for sustainable rice and sugarcane production: A Review

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ABSTRACT

Silicon (Si), the second most abundant element in the Earth's crust and soils. However, its beneficial role in stimulating the growth and development of many plant species is widely recognized. Silicon effectively mitigates various abiotic stresses, including iron, manganese, and aluminum toxicities, as well as salinity, drought, chilling, and freezing stresses. Despite this, the mechanisms underlying Si-mediated alleviation of abiotic stresses remain poorly understood. This review highlights the role of Si in enhancing stress resistance and emphasizes its importance in rice and sugarcane production. Exploring silicon as a critical nutrient offers promising opportunities to enhance stress tolerance, improve yields, and promote sustainable practices, addressing global food security and environmental challenges.

Keywords: *Silicon, rice, sugarcane, abiotic, biotic stress, iron, manganese, aluminium, NUE, water stress and salt stress*

1. Introduction

Silicon (Si) is the second most abundant element in the Earth's crust, with an average concentration of 27.6% in the lithosphere and 23-35% in soils. It plays a crucial role in soil formation through weathering and the conversion of silicon into secondary minerals. Silicon is found in primary silicate minerals, secondary aluminosilicates, and various forms of SiO_2. Soil silicon content varies based on soil type, climate, geological materials, and rock composition. Sandy soils typically contain over 40% silicon, while highly weathered tropical soils have as little as 9% [6].

Silicon is a tetravalent Si^{+4} element, which is not found in free state. It occurs as the oxide silica, SiO_2 in various forms like quartz, agate, and flint. In soil solutions the prevailing form is monosilicic acid $Si(OH)_4$, which is in equilibrium with quartz (SiO_2) and the concentrations in the soil solution are usually range from 14 to 20 mg L^{-1} Si [12].

$$\mathrm{SiO_2Si(OH)_4(Soil)} \rightleftarrows \begin{array}{c}\text{Monosilicic acid}\\ \text{(Soluble present in soil solution)}\end{array}$$

All soil-grown plants contain silicon (Si), but its concentration in plant shoots varies significantly among species, ranging from 0.1% to 10% of dry weight. Although not considered essential, Si is a beneficial element, especially for Poaceae crops, playing a key role in amino acid and protein metabolism. Si strengthens plants, enhances disease, pest, and stress resistance, improves crop yield and quality, and neutralizes aluminum toxicity in acidic soils. Silicon fertilizers benefit both plants and soil by boosting plant defence mechanisms and optimizing soil fertility. However, because Si is not highly mobile in plants, a continuous supply is essential for healthy growth throughout all stages [21].

2. Silicon in Soils

Silicon (Si) in soils undergoes various transformations, including the conversion of soluble forms to insoluble ones through adsorption and reactions with soil components like clay minerals, Fe^{3+}, Al^{3+}, Mn^{4+} oxides, and organic matter. Aluminum oxides are more effective than iron oxides in adsorbing Si, influencing its availability in soil solutions. In waterlogged soils, Si concentration increases slightly after flooding but decreases over time. High organic matter and decomposing silicon-rich residues like rice straw can enhance Si content in flooded soils. In natural waters, silicon concentration is typically below 120 mg L^{-1} due to sorption by hydrous oxides and recombination with aluminum silicates [2].

Silicon controls the chemical and biological properties of soil with reduced leaching of phosphorous (P) and potassium (K), improved microbial activity, increased stability of soil organic matter, improved soil texture, improved water holding capacity, increased stability against soil erosion and increased cationic exchange capacity [27].

2.1. Causes of Silicon Deficiency in Soils

- Soil parent materials contain inadequate quantity of available silicon.
- Soluble silicon being continuously leached out in strongly weathered soils. In highly weathered soils, free SiO_2 may become depleted from soils leaving sesquioxides of iron and aluminum as the major residual minerals.
- A long period of intensive crop cultivation (double or triple cropping) depletes the available soil silicon.
- Removal of rice straw from the field in intensively cultivated rice fields.

3. Factors Affecting Availability of Silicon in Soils

There are various factors that can affect the transformation and availability of Si in soils like soil reaction, nature and type of clay minerals, amount of oxides of Fe, Al and Mn, moisture content, organic matter content, liming, nutrient supply etc.

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(i) Soil Reaction: Soil pH significantly influences the release of silicon (Si) into the soil solution. While Si solubility in pure water is unaffected between pH 2 and 9, in soils, Si concentration decreases from 33 to 11 mg L^{-1} as pH rises from 5.4 to 7.2. However, Si concentration increases outside this range, peaking around pH 8 to 9. Additionally, soil pH affects Si adsorption by hydrous oxides of Fe, Al and Mn, further influencing its availability [27].

(ii) Oxides of Fe, Al and Mn: Soils containing higher amounts of iron, aluminum and manganese oxides will decrease the availability of Si in soils and hence uptake by the plants [37].

(iii) Liming: The application of lime and liming materials to acid soils has been found to decrease the concentration of Si in soils and also its uptake by the plants. This may be due to lime-induced increased pH [37].

(iv) Moisture Content: Higher soil water content enhances silicon uptake, particularly in rice. Prolonged soil submergence increases Si concentration in the soil solution due to the release of adsorbed Si from the reduction of ferric oxides to ferrous forms. However, in acid soils, submergence can decrease Si concentration in the solution due to a rise in pH [23].

4. Silicon in Plant Nutrition

Silicon (Si) nutrition in plants depends on its uptake, distribution, metabolism, and effects of deficiency or toxicity. Silicon uptake varies widely among plants, with SiO_2 content in shoot dry weight being 10-15% in rice, 1-3% in sugarcane and 0.5% in legumes. In silicon-accumulating plants like rice, silicon uptake is linked to root metabolism. Si is essential for the growth and nutrition of crops like rice, sugarcane, tomato, and cucumber. Silicon requirements are lower during the vegetative stage but higher during the reproductive stages. A lack of Si can affect grain or fruit yields, leaf development, pollen viability and delay senescence**.**

Silicon plays an important role in plant metabolism, amino acid and protein metabolism, and metabolism of polyphenols in the xylem cell walls [46]. Proper silicon nutrition is responsible for increasing the stability of DNA and RNA molecules. Silicon has also been shown to result in higher concentrations of chlorophyll per unit area of leaf tissue. The increase in the content of sugar in sugarbeets and sugarcane as a result of silicon fertilizer application may be assessed as a biochemical influence of silicon as well. The silicon nutrition for orange resulted in a significant increase in fruit sugar (brix) [22].

Silicon also has various beneficial effects in relation to diseases and insect incidences. Leaf erectness and lodging, transpiration, weight of grain *etc*., which ultimately influence the yield of crops favourably. The supply of silicon may also reduce the toxic effect of Fe and Mn in crops. Silicon also promotes transpiration other nutrients like phosphorous in the plants [20].

4.1. Role of Silicon in Rice

Rice is a high silicon-accumulating plant, with Si being agronomically essential for improving and sustaining its productivity. Si enhances rice yield, improves nutrient availability (*e.g.*, N, P, K, Ca, Mg, S and Zn), reduces nutrient toxicity (Fe, Mn and Al), and mitigates biotic and abiotic stresses. As Si is not very mobile in plants, a continuous supply is necessary for long-term sustainable production, especially in laterite-derived paddy soils to alleviate iron toxicity and prevent crop lodging. Silicon also increases resistance to salt stress. The critical Si level is 40 mg kg^{-1} in soil and 5% in rice leaf and straw [5].

4.1.1. Silicon Deficiency Symptoms in Rice

In wetland rice lacking Si, the vegetative growth and yield are drastically reduced and deficiency symptoms like necrosis of older leaves and wilting of plants may occur [11]. The other symptoms:

- Soft and droopy leaves and culms.
- Increased occurrence of disease.
- Keep leaves erect.
- Reduction in the number of panicle and filled spikelet's per panicle.
- Smaller grain yield.
- Lodging.

4.2. Role of Silicon in Sugarcane

Silicon is considered an agronomically essential nutrient for the sustainable crop production of sugarcane [34]. The response to Si application was greatest when the soluble silica supply of the soil was low or when soluble levels of toxic manganese depressed the silicon levels in the plant.

Silicon enhances plant vigor and growth, resulting in darker green foliage, increased height, weight, stem diameter, and the number of millable stalks. It reduces lodging and improves tolerance to cold, drought, and frost damage. Si improves water economy by reducing leaf transpiration, alleviates Mn, Fe and Al toxicity, and neutralizes soil acidity (with silicate applications), boosting microbial activity and the release of organically bound nutrients like N, P and S. Additionally, it enhances P availability and solubility and increases sugar content in sugarcane [39].

Table 1. Critical soil and leaf sheath Si values for sugar cane [25]

Silicon status	Soil extracts			Sheath Si	
	$Ca[H_2PO_4]_2$	HOAc	H_2SO_4	TCA soluble ppm fresh	Total (%) oven dry
Deficiency probable	<50	<20	<40	<30	<0.5
Deficiency questionable	50 to 150	20 to 40	40 to 100	30 to 40	0.5 to 0.7
Deficiency unlikely	> 150	> 40	> 100	> 40	>0.7

4.2.1. Silicon Deficiency Symptoms in Sugarcane

Silicon deficiency disorder in sugarcane is called leaf freckling, comprising small rust-coloured or brownish spots on the leaves of cane. In severe cases, it was found that affected lower leaves died prematurely and cane yield was reduced.

5. Plant Absorption of Silicon

Plants absorb silicon from the soil solution in the form of monosilicic acid, also called orthosilicic acid (H_4SiO_4). This has no electric charge and is not very much mobile in plant. The largest amount of silicon is absorbed by sugarcane (300-700 kg of Si ha^{-1}), rice (150-300 kg of Si ha^{-1}) and wheat (50-150 kg of Si ha^{-1}) [4].

On an average, plants absorb from 50 to 200 kg of Si ha^{-1}. Such values of silicon absorbed cannot be fully explained by passive absorption (such as diffusion or mass flow) because the upper 20 cm soil layer contains only an average of 0.1 to 1.6 kg Si ha^{-1} as monosilicic acid.

Silicon in plants is transported from the roots to the shoots through the xylem, primarily in the form of soluble monosilicic acid. This acid can passively enter cells, although its active transport has been little studied. After being absorbed by the roots, monosilicic acid is rapidly translocated to the leaves via the transpiration stream. In the leaves, silicon accumulates in the epidermal tissue, forming a fine layer of silicon-cellulose membrane, which strengthens plant structures and protects them through a double-cuticular layer. As the silicon concentration increases, monosilicic acid polymerizes into biogenic opal (amorphous SiO_2), which is hydrated. This polymerization process involves the gradual dehydration of monosilicic acid, leading to the formation of polysilicic acid [32].

$$n(Si(OH)_4 \longrightarrow (SiO_2)+2n(H_2O)$$

5.1. Accumulation of Silicon in Plants

The accumulation of silicon in plants involves the uptake, transport, and deposition of silicon from the soil into various plant tissues. Silicon is absorbed by the roots in the form of mono silicic acid (H_4SiO_4), which is then transported through the plant via the xylem, often alongside water in the transpiration stream. Once silicon reaches the leaves, it accumulates predominantly in the epidermal cells, where it forms a layer of silicon, often in the form of biogenic opal (SiO_2), which is amorphous and hydrated. This accumulation typically occurs in the cell walls, particularly in the form of a silicon-cellulose membrane, providing structural support to the plant. The concentration of silicon in the plant increases with higher availability in the soil. Silicon plays a crucial role in enhancing mechanical strength, improving resistance to abiotic stresses (such as drought and salinity), and offering protection against biotic stresses (including pests and diseases). Additionally, silicon can polymerize in the plant, forming solid deposits that help reinforce cell walls and other plant structures [26].

6. Effect of Silicon on Biotic Stresses

Silicon has been found to suppress many plant diseases and insect attacks. The effect of silicon on plant resistance to pests is considered to be due either to accumulation of absorbed silicon in the epidermal tissue or expression of patho gensis-induced host-defence responses.

Table 2. Diseases suppressed by silicon in rice

S.No.	Disease	Pathogen	Source
1	Brown leaf spot	*Helminthosporium oryzae*	[13]
2	Brown spot (husk discoloration)	*Cochiobolus miyabeanus*	[13]
3	Grain discoloration	*Fusarium, Epicoccum,* etc.	[4]
4	Leaf and neck blast	*Magnaportha grisea*	[45]
5	Leaf scald	*Gerlachia oryzae*	[45]
6	Sheath blight	*Thanatephorus cucumeris* (*Rhizoctonia solani*)	[33]
7	Rice Stem rot	*Magnaporthe salvanii*	[9]

Table 3. Diseases suppressed by silicon in sugarcane

S.No.	Disease	Pathogen	Source
1	Leaf freckle	Probably a nutrient disorder	[10]
2	Sugarcane rust	*Puccinia melanocephala*	[7]
3	Sugarcane ring spot	*Leptosphaeria sacchari*	[31]

Table 4. Pests suppressed by silicon in rice

S.No.	Pest	Insect	Source
1	Stem borer	*Chilo suppressalis* *Scirpophaga incertulas*	[36]
2	Green leaf hopper	*Chlorops oryzae*	[24]
3	Brown plant hopper	*Nephotettix cinticeps*	[43]
4	Leaf spider	*Tetranychus* spp.	[36]
5	Mites		[44]

Table 5. Pests suppressed by silicon in sugarcane

S.No.	Pest	Insect	Source
2	Stalk borer	*Diatraea succharira*	[9]
3	Stem borer	*Eldana saccharira*	[25]

Silicon alone significantly reduced the incidence of neck blasts by 40%. When combined with fungicides, silicon showed even greater effectiveness: Si plus one fungicide application reduced neck blast by 75-90%, while two applications reduced it by 76-94%. With three to five fungicide applications, the reduction in neck blast ranged from 94% to 98%. Despite these differences in disease reduction, no significant yield differences were observed between Si alone or Si combined with fungicides, as all treatments resulted in a significant yield increase compared to the control. In another experiment, Si applied before seeding at 0 and 1000 kg ha^{-1}, combined with two foliar applications of edifenfos at various rates, led to a 54-75% reduction in leaf blast compared to the untreated control [38].

7. Effect of Silicon on Abiotic Stresses

Silicon is known to efficiency mitigate various abiotic stress such as Mn, Al, Fe, heavy metal toxicities, salinity, drought, chilling and freezing stresses.

7.1. Silicon Alleviates Metal Toxicity

Many metals found naturally in the soil can be potentially toxic to plants. These metals often become a problem when there is a change in the soil environment, such as the acidification ofsoil. This low pH environment solubilises iron (Fe), Manganese (Mn) and Aluminium (Al) [14].

7.1.1. Iron (Fe) Toxicity

In humid tropical and subtropical regions like South Asia, Fe^{2+} toxicity is a major physiological issue that hinders rice growth, particularly in early spring [47]. Fe^{2+} toxicity harms plants by inhibiting the elongation of rice roots. [47] reported that the formation of iron plaque on rice root surfaces reduces root activity and nutrient uptake, causing damage to epidermal and cortex cells. However, iron plaque can also serve as a nutrient reservoir, potentially enhancing root growth. The contrasting effects of iron plaque on rice growth may depend on factors such as rice cultivar, Fe^{2+} concentration, and exposure duration, with the overall impact varying based on the amount, thickness of the plaque, and nutrient availability.

Silicon enhanced the oxidative power of rice roots, resulting in enhanced oxidation of Fe from ferrous iron to insoluble ferric iron. Therefore, excess Fe uptake was indirectly prevented by Si application [28].

[30] reported that iron (Fe) in the iron plaque primarily existed in the form of Fe^{2+} under their experimental treatments. The Fe treatment significantly increased the concentrations of both Fe^{2+} and Fe^{3+} in the iron plaque on the surface of rice roots. However, the addition of 1 mmol L^{-1} silicon to the Fe^{2+} solution reduced the concentrations of Fe^{2+} and Fe^{3+} in the iron plaque by 25.9% and 20.2%, respectively.

7.1.2. Aluminum (Al) Toxicity

Excess aluminum (Al) is toxic to plants, causing root stunting and reducing the availability of essential nutrients like phosphorus (P), sulfur (S), and other cations due to competitive interactions. Silicon (Si) has been shown to ameliorate Al toxicity in both soil and solution-cultured plants. The presence of Si reduces Al uptake, likely by forming Al-Si complexes in the growth substrate, which decreases Al availability. Additionally, Si has been suggested to alter the plant's cation-anion balance and increase tissue concentrations of organic acids, contributing to the protective effect of Si under Al toxicity [42].

7.1.3. Manganese (Mn)Toxicity

An alleviative function of Si on Mn toxicity has been observed in hydroponically cultured rice.In rice, Si reduced Mn uptake by promoting the Mn oxidizing power of the roots. [28] reported that when silicon levels in tissue are low, Mn^{2+} tends to be distributed non-homogenously and accumulates to toxic levels in leaves. However sufficient levels of Si seem to prevent the toxic levels of Mn^{2+}.

7.2. Alleviation of Salt Stress

Al toxicity is a major factor limiting crop production in acid soils. Ionic Al inhibits root growth and nutrient uptake. Alleviative effect of Si on Al toxicity has been observed in sorghum, barley, maize, rice and soybean. The alleviative effect was more apparent with increasing Si concentration. Concentration of toxic Al^{3+} was found to decrease by the addition of silicic acid [27]. These results suggest that interaction between Si and Al occurs in the solution, presumably by the formation of Al-Si complexes, a non-toxic form.

7.3. Alleviation of Water Stress

Drought stress usually causes a decrease in crop production. It inhibits the photosynthesis of plants, causeschanges of chlorophyll contents and components and damage of photosynthetic apparatus. It also inhibits the-photochemical activities and decreases the activities of enzymes in the Calvin cycle.With respect to drought stress, relevant work is limited [17].

Silicon application reduces injury to rice caused by climatic Stresses such, low or high temperature and low light. Damage usually results from lodging and sterility. Deposition of Si in rice increases the thickness of the culm wall and the size of the vascular bundle and can help to prevent lodging.

Silicon deposited at the hull decreases the transpiration of panicles by about 30% at either milky or maturity stage and prevents excess water loss. This is the means by which Si application can significantly increase the percentage of ripened grain.

8. Elemental Stoichiometry and Nutrient Use Efficiency

Elemental stoichiometry, which governs the conversion of nutrients into plant biomass, plays a crucial role in plant metabolism [29]. Silicon (Si) application has been shown to alter the C:N:P ratio in plants, influencing nutrient accumulation and promoting a more balanced nutritional equilibrium. Si fertilization in sugarcane, for example, was found to affect C:N, C:Si, and C:P ratios, with Si supply reducing carbon (C) concentrations in plant sections such as sheaths and tips, indicating Si's role in replacing carbon to strengthen cell walls and improve development [16]. While Si can enhance photosynthesis and carbon storage [19], it also impacts nutrient efficiencies. In sugarcane, cultivars with lower C:P ratios exhibited higher C use efficiencies, emphasizing the role of phosphorus in plant metabolism [41]. Si also plays a significant role in mitigating water stress by altering stoichiometric ratios and boosting nutrient use efficiency, which is particularly important under drought conditions [29]. However, water scarcity can disrupt nutritional homeostasis and reduce nutrient efficiency, leading to lower plant development.

9. Effect of Silicon on Crop Growth and Yield

Numerous field experiments under different soil and climatic conditions and with various plants clearly demonstrated the benefits of application of silicon fertilizer for crop productivity and crop quality. Silicon Promotes growth, strengthens culms and roots, and favors early panicle formation, increases number of spikelets per panicle and percentage of matured rice grains and helps to maintain erect leaves which is important for higher rate of photosynthesis. [27] reported combined application of potassium silicate 0.5% spray + borax 0.5 % spray was significantly superior with respect to yield (grain and straw) and yield attributes of rice.

Worldwide, since 1960, a considerable amount of research has been conducted on the potential agronomic benefits of Si in sugarcane. Significant responses to silicon treatment in both cane and sugar yields. In Si-depleted soils, 10-50% increases in yields of sugarcane have been observed worldwide after Si-rich compounds have been applied [34].

As a result of application of silicon fertilizer, the dry weight of barley increased by 21 and 54% over 20 and 30 days of growth. A germination experiment with citrus and bahia grass has demonstrated that with increasing monosilicic acid concentration in irrigation water, the weight

Foliar application of 1 % silicon solution produced highest paddy yield (4.88 t ha^{-1}) but all three silicon applications are statistically similar while differing from control. Maximum straw yield (12.61 t ha^{-1}) was produced when 1.00 % silicon was applied it was followed by 0.50 % silicon and 0.25 %, respectively, while minimum (10.49 t ha^{-1}) was found in control (Table 6).

Table 6. Effect of silicon on rice yield and yield attributes [1]

Treatments	Panicle length (cm)	1000 grain weight (g)	Paddy yield (t ha^{-1})	Straw yield (t ha^{-1})
Si_0 (0)	25.13	15.74	4.16	10.49
Si_1 (0.25%)	25.87	17.66	4.71	10.96
Si_2 (0.5%)	26.57	17.35	4.78	11.93
Si_3 (1%)	26.88	17.98	4.88	11.93
LSD(0.05)	NS	0.33	0.214	0.016

Positive effects of Si have been observed in a number of plant species, including rice, wheat, and barley. The beneficial effects of Si differ between plant species. Beneficial effects are usually obvious in plants which actively accumulate Si in their shoots. The more the accumulation of Si in the shoots, the larger is the effect that is gained. This is because most effects of Si are expressed through the formation of silica gel, which is deposited on the surface of leaves, stems, and other organs of plants. On the other hand, the beneficial effects of Si vary with growth conditions.

10. Silicon Fertilizers

Inorganic materials like quartz, clays, micas, and feldspars are rich in silicon but poor sources of silicon fertilizers due to their low solubility. Calcium silicate, a by-product of industrial processes like steel and phosphorus production, is one of the most commonly used silicon fertilizers. Potassium silicate, though expensive, is highly soluble and suitable for hydroponic systems.

Rice, a known silicon accumulator, benefits significantly from silicon (Si) nutrition. Si was first recognized as a fertilizer in Japan in 1955, and since then, 1.5-2.0 t ha^{-1} of silicate fertilizer has been applied to Si-deficient paddy soils, resulting in a 5-15% increase in rice yields [34]. Rice absorbs Si in much larger quantities than macronutrients, with Si uptake being 108% greater than nitrogen (N) uptake. For a rice crop yielding 5000 kg ha^{-1}, 230-470 kg of Si per hectare is removed.

Table 7. Silicon containing fertilizers or materials

Name	Chemical formula	Content
Calcium silicate	$CaSiO_3$	14-19% Si, 20.2%Ca
Potassium silicate	K_2SiO_3	45%Si, 17%K
Sodium metasilicate	$NaSiO_3$	23%Si
Calcium silicate slag (By product of electric furnaces)	$CaSiO_3$,	14-19%Si,
Fused magnesium phosphate	$MgSiO_3$	25-32%Ca,2-4% Mg
Rice husk		9%Si, 9%P,7-9%Mg
Rice straw		Variable (4.6-7.0)

In continuous cropping with high silicon (Si) accumulator species like sugarcane, the removal of plant-available silicon (PAS) can exceed the natural supply, leading to a deficiency unless Si is replenished through fertilization [35]. Calcium silicate, commonly used as a Si fertilizer, not only provides a source of calcium but also raises soil pH, which suppresses the uptake of toxic levels of aluminum (Al) and boron (B). Additionally, it helps to eliminate harmful levels of aluminum (Al) and manganese (Mn) through precipitation, thus protecting the roots and tops of sugarcane from toxicity.

- Calcium silicate recommendation for rice 120-200 kg ha^{-1}
- Potassium silicate recommendation for rice 40-60 kg ha^{-1}

Sodium silicate recommendation for rice 100 kg ha^{-1}

Table 8. Effect of silicon fertilizers on crop production.

plant	Silicon fertilizer	Dose (kg ha^{-1})	Regime	Crop, grain Mg ha^{-1}	Straw Mg ha^{-1}	Source
Rice	Sodium silicate	0		3.52		[3]
		310		4.01		
	Rice straw ash	0	Manure	3.98		[3]
		310	Manure	4.28		
		0		3.9		[45]
		1000		4.6		
		0	K	4.3		
		1000	K	5.0		
	Sodium silicate	0		2.4		
	Calcium silicate	0	N, P&K	6.3		
		4.7	N, P &K	9.3		
Sugarcane	Calcium silicate	0			141	[41]
		830			157	
		0	P		124	
		830	P		147	
		1660	pH-5.8		151	

Table 9. Effect of silicon fertilization on economics of rice cultivation [15]

Treatments	Cost of cultivation (Rs)	Gross income (Rs)	Net income (Rs)	Return/rupee invested
Si 0	18433	34127	15694	1.85
Si 40	18518	38353	19835	2.07
Si 80	18603	41179	22576	2.21
Si 120	18688	42403	23715	2.27

11. Conclusions

Silicon plays a critical role in enhancing stress resistance in plants, with its effects largely attributed to Si deposition in leaves, stems, and hulls. The ability of plants to accumulate Si in shoots varies by species, driven by the roots' capacity for Si uptake. While Si is abundant in soil, most plants, especially dicots, fail to uptake significant amounts, limiting their benefits from Si. Enhancing Si uptake through genetic modification, as seen in Si-accumulating plants like rice, may improve stress resistance. In sugarcane, Si alleviates both abiotic stresses (e.g., Al toxicity, drought, and freezing) and biotic stresses (e.g., diseases and pests).

Future scope of study: Further research is needed to explore Si sources, its role in pest and disease resistance, genotypic differences, and its contribution to sucrose synthesis and storage in sugarcane.

Conflict of interest: None

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