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RECEIVED 01 October 2025

ACCEPTED 20 October 2025

PUBLISHED 29 October 2025

CITATION
Mukarram M, Corpas FJ and Lux A (2025)
Editorial: New avenues of silicon's role in
plant biology: trends and controversies.
Front. Plant Sci. 16:1717302.
doi: 10.3389/fpls.2025.1717302

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Editorial: New avenues of silicon's role in plant biology: trends and controversies

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KEYWORDS

silicon, abiotic stress, oxidative damage, silicon nanoparticle, SiNPs, beneficial elements

Editorial on the Research Topic

New avenues of silicon's role in plant biology: trends and controversies

1 Silicon paradox in plant biology

Silicon (Si) is a paradoxical element in plant biology: abundant in soils yet historically omitted from essential nutrient lists (Epstein, 1999). Over the past few decades, evidence has established Si as a *quasi-essential* element that can enhance plant growth, yield, and resilience under stress (Manivannan et al., 2023). Several Si-accumulating plants, such as *Oryza sativa*, uptake astonishing amounts of Si (up to ~10% of their dry weight, exceeding even macronutrients like N or K) (Hodson et al., 2005). Yet how Si confers these advantages remains an active area of debate. Is Si primarily fortifying cell walls and acting as a mechanical barrier, or is it integral to plant stress physiology? This core controversy of anatomical vs physiological modes of Si action is a rapidly evolving frontier. Researchers are probing Si's *modus operandi*, crosstalk with signalling molecules (e.g., reactive oxygen species (ROS) and phytohormones), and its stress-mitigating potential. The present Research Topic aims to advance our understanding of these phenomena. Articles in this Research Topic tackle Si from diverse angles, ranging from stress mitigation and nutrient dynamics to molecular mechanisms and innovative Si delivery methods, reflecting the breadth of current Si research.

2 Silicon in environmental stress mitigation

In this Research Topic, Ansari et al. probed how Si application mitigated Cd- and Pb-induced oxidative burst (MDA, H₂O₂, electrolyte leakage) and metal uptake in *Capsicum annuum*. Possible mechanistic reasons may include metal immobilisation, altering uptake kinetics, or even influencing signal proteins to regulate Si uptake (de Tombeur et al., 2021; Mukarram et al., 2024; Yamaji et al., 2024). Also, these plants had enhanced antioxidant

enzymes. Further, [Tritean et al.](#) embedded rice husk silica nanoparticles (SiNPs) in an alginate seed film to create a slow-release Si source. SiNPs-coated *Vigna radiata* seeds exhibited more vigorous early growth than controls under high salt conditions, owing to enhanced metabolic activity, proton pump function, and ROS scavenging in the seedlings. This seed priming strategy with Si opens new avenues for protecting crops against stress right from the outset.

3 Silicon and nutrient dynamics

[He et al.](#) present field evidence that moderate (750–1500 kg/ha) Si fertilisation can enhance both the yield and quality of a high-value crop (*Nicotiana tabacum*). Si increased the N and K use efficiency by up to p~40%, having clear agronomic significance for reducing fertiliser waste and environmental runoff. Si-treated leaves had higher sugar-to-alkaloid ratios and mineral balance (higher desirable K, lower Cl). These modulations resulted in the increased high-grade *Nicotiana tabacum* leaves (~95%), yield (15.7%), and economic output (30.8%) over no Si application. However, the highest dose (3000 kg/ha) slightly depressed leaf quality by elevating nicotine and upsetting the sugar-alkali balance. This dose-dependent response underscores the need to optimise Si

nutrition, as more is not always better. [He et al.](#)'s findings align with a broader recognition that Si can improve plant nutrient status, better resource use, and product quality ([Pavlovic et al., 2021](#); [Schaller et al., 2024](#)).

4 Silicon's *modus operandi*

What mechanistic magic underlies silicon's broad benefits? [Zexer et al.](#) revealed that silica aggregates alongside the short-chain, less-polymerised lignin monomers in root endodermal cell walls. Alternatively, the lignin at these sites polymerises into more extensive, highly cross-linked doughnut-shaped structures in Si-absence. The authors suggested that silicic acid interrupts the typical polymerisation of lignin and nucleates silica gel. This finding reinforces the hypothesised "Si-C trade-off" in plant defence strategies ([de Tombeur et al., 2025](#)). Si seems to reallocate costly carbon-based compounds (like lignin, phenolics, or tannins) with Si deposits as a more energy-efficient means of fortifying tissues. On the physiological side, [Ansari et al.](#) noted Si's passive exclusion of toxins and its active induction of defence genes. Increased activities of SOD, CAT, and other enzymes in Si-treated plants are a common observation under various stresses ([Ansari et al.; Yan et al., 2023](#)). Si has further been reported to



FIGURE 1

Biochemical and physiological pathways of silicon (Si) in plants. Si enhances plant resilience through stress mitigation, improved nutrient use, and structural reinforcement of cell walls, while innovative delivery systems improve Si efficacy. These combined effects promote growth, crop quality, and sustainable agriculture. Green upward arrows indicate upregulation/increment, while the red downward arrows indicate downregulation/reduction in the adjacent phenomena/process. CAT, catalase; POD, peroxidase; SOD, superoxide dismutase; MDA, malondialdehyde; ROS, reactive oxygen species (Created in <https://BioRender.com>).

regulate signalling molecules (H_2O_2 and NO) to prime plant stress response (Mukarram et al., 2022) (Figure 1).

5 Advances with silicon nanoparticles (SiNPs)

Recent advancements include the development of SiNPs that offer greater effectiveness compared to traditional silicate fertilisers (Mukarram et al., 2022; Yan et al., 2023). SiNPs have a high surface area and reactivity that can improve the Si bioavailability to plants. Studies summarised by Yan et al. show that exogenous SiNPs can penetrate plant tissues more readily than bulk Si sources. SiNPs have been shown to reduce ROS levels and upregulate antioxidant enzymes (CAT, SOD, and POD) in stressed plants more than equivalent doses of conventional silicate salts (Mukarram et al., 2023; Yan et al.). These remarkable effects underscore that *size matters*.

6 Some key unanswered questions

While Si effects are well reported, we still seek to understand several key phenomena. For example, (1) how are Si effects realised at the molecular level (e.g., signalling networks for H_2O_2 , NO, or phytohormones)? (2) Do plants actively sense Si, or are its effects primarily indirect via stress alleviation? (3) What is Si's primary mode of action (structural vs metabolic)? (4) What are the long-term and ecosystem-level impacts of heavy/continued Si use? How does Si supplementation affect the soil cycle? Could there be unintended ecological effects or diminishing returns over time? Furthermore, (5) standardised protocols (e.g., for Si depletion in growth media, or for quantifying plant-available Si) should be developed to reduce variability across studies and ensure reproducibility. (6) Si research should be expanded to more plant types (non-accumulators, wild species, ecological communities) to uncover new Si facets and validate their generality. (7) Precision Si delivery systems and breeding crops with enhanced Si uptake are interesting frontiers to develop.

As the plant science community addresses the open questions and refines methodologies, we anticipate rapid progress in

demystifying how Si works and how best to harness it. We hope this Research Topic will inspire cross-disciplinary collaboration and many other interesting Si studies.

Author contributions

MM: Conceptualization, Project administration, Visualization, Writing – original draft, Writing – review & editing. FC: Project administration, Validation, Writing – review & editing. AL: Project administration, Validation, Writing – review & editing.

Conflict of interest

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References

- de Tombeur, F., Cornelis, J. T., and Lambers, H. (2021). Silicon mobilisation by root-released carboxylates. *Trends Plant Sci.* 26, 1116–1125. doi: 10.1016/j.tplants.2021.07.003
- de Tombeur, F., Plouzeau, L., Shaw, J., Hodson, M. J., Ranathunge, K., Kotula, J., et al. (2025). Anatomical and trait analyses reveal a silicon-carbon trade-off in the epidermis of sedges. *Plant Cell Environ.* 48, 2396–2410. doi: 10.1111/pce.15307
- Epstein, E. (1999). Silicon. *Annu. Rev. Plant Biol.* 50, 641–664. doi: 10.1146/annurev.arplant.50.1.641
- Hodson, M. J., White, P. J., Mead, A., and Broadley, M. R. (2005). Phylogenetic variation in the silicon composition of plants. *Ann. Bot.* 96, 1027–1046. doi: 10.1093/aob/mci255
- Manivannan, A., Soundararajan, P., and Jeong, B. R. (2023). Silicon: A “Quasi-Essential” element's role in plant physiology and development. *Front. Plant Sci.* 14, 1157185. doi: 10.3389/fpls.2023.1157185
- Mukarram, M., Ahmad, B., Choudhary, S., Konôpková, A. S., Kurjak, D., Khan, M. M. A., et al. (2024). Silicon nanoparticles vs trace elements toxicity: *Modus operandi* and its omics bases. *Front. Plant Sci.* 15, 1377964. doi: 10.3389/fpls.2024.1377964
- Mukarram, M., Khan, M. M. A., Kurjak, D., Lux, A., and Corpas, F. J. (2023). Silicon nanoparticles (SiNPs) restore photosynthesis and essential oil content by upgrading enzymatic antioxidant metabolism in lemongrass (*Cymbopogon flexuosus*) under salt stress. *Front. Plant Sci.* 14, 1116769. doi: 10.3389/fpls.2023.1116769
- Mukarram, M., Petrik, P., Mushtaq, Z., Khan, M. M. A., Gulfishan, M., and Lux, A. (2022). Silicon nanoparticles in higher plants: Uptake, action, stress tolerance, and crosstalk with phytohormones, antioxidants, and other signalling molecules. *Environ. pollut.* 310, 119855. doi: 10.1016/j.envpol.2022.119855
- Pavlovic, J., Kostic, L., Bosnic, P., Kirkby, E. A., and Nikolic, M. (2021). Interactions of silicon with essential and beneficial elements in plants. *Front. Plant Sci.* 12, 697592. doi: 10.3389/fpls.2021.697592
- Schaller, J., Webber, H., Ewert, F., Stein, M., and Puppe, D. (2024). The transformation of agriculture towards a silicon improved sustainable and resilient crop production. *NPJ Sustain. Agric.* 2, 27. doi: 10.1038/s44264-024-00035-z

Yamaji, N., Mitani-Ueno, N., Fujii, T., Shinya, T., Shao, J. F., Watanuki, S., et al. (2024). Shoot-Silicon-Signal protein to regulate root silicon uptake in rice. *Nat. Commun.* 15, 10712. doi: 10.1038/s41467-024-55322-7

Yan, G., Jin, H., Yin, C., Hua, Y., Huang, Q., Zhou, G., et al. (2023). Comparative effects of silicon and silicon nanoparticles on the antioxidant system and cadmium uptake in tomato under cadmium stress. *Sci. Total Environ.* 904, 166819. doi: 10.1016/j.scitotenv.2023.166819