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REVIEW ARTICLE

Silicon as a key driver of phytolith and phytolith-occluded carbon sequestration for climate change mitigation in rice ecosystems - a review

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Abstract

Anthropogenic activities have increased atmospheric greenhouse gases, especially carbon dioxide, leading to global warming and climate change in recent years. Silica, a principal element in the Earth's crust, is an essential resource for plant growth and development. Silica is absorbed by plants as mono-silicic acid (H_4SiO_4) and deposited as opal stone/phytolith in the cellular spaces and vascular bundles of plant parts. The highest phytolith content of rice plants is observed in straw, which is incorporated into the soil during harvest and acts as a resilience material. The Lsi1 and Lsi2 transporters and significant and secondary plant nutrients underwent Polymerization with adsorbed Si to form a phytolith structure in rice. These phytoliths give structural support, function as a defence mechanism, impart biotic and abiotic stresses, and reduce the toxicity of certain heavy metals and salinization of soil. Phytolith-occluded carbon (PhytOC) is formed through occlusion, contributing to the geochemical carbon cycle and climate change mitigation. Over the past sixty years, the annual carbon sequestration varied between 0.81×106 and 3.88×106 Mg-e-CO_2 and a maximum of 37×108 Mg-e-CO_2within phytoliths in rice crops in China. Research in archaeology, palaeobotany, geology and paleoecology has focused on phytoliths because silica is a non-degradable base preserved as microfossils. Using silicon-rich organic and inorganic sources enhances the Aboveground Net Primary Productivity (ANPP) and Phytolith C sequestration in the rice ecosystem.

Keywords

carbon sequestration; climate change; phytolith; phytolith occluded carbon;

Introduction

Augmenting greenhouse gases, especially carbon dioxide (CO_2), in the atmosphere due to human interventions, industrial activities, land use conversion and soil cultivation is the reason for the elevated temperatures observed both in the atmosphere and on the Earths' surface. Terrestrial carbon sequestration is crucial for mitigating climate change because 30% of CO_2 is emitted by terrestrial ecosystems (1, 2). Soil carbon storage decides the CO_2 level in the air and on earth and indirectly affects climate change (3). Silica is considered a beneficial element. Some examples of silica-accumulating plants are rice, maize, wheat, sugarcane and barley. Plants absorb silicon as monosilicic acid (H_4SiO_4), especially in these silica-accumulating plants and assimilate it as a phytolith (4). Phytoliths are silica or opal stones formed during the biomineralization of silica in the plant, especially those that accumulate silica (5). Phytoliths predominantly comprise silicon dioxide (SiO_2), organic carbon (OC), water (H_2O), aluminium (Al), and iron (Fe), with proportions ranging from 66% to 91%, 1 to 6%, 0 to 11%,0.01 to 4.55% and 0 to 2.1%, respectively (6) and their composition varies with plant species (7).

Phytolith structure and composition, particularly in silica and calcium carbonate content, is crucial for identifying plant species and reconstructing past ecosystems. Different phytoliths reflect specific taxonomic attributes, aiding in understanding plant diversity and environmental adaptations. These variations also indicate ecological conditions, influencing nutrient cycling and habitat preferences (8). Phytoliths are composed of silica and other elements, can survive for long periods, and are resilient to decomposition in rice ecosystems (9), helping plants withstand various stresses (10). Phytolith helps to overcome multiple biotic and abiotic stresses. Archaeology, palaeobotany, geology and pale ecological research on Phytoliths are carried out because silica is a non-degradable pedestal preserved as microfossils in various substrates (11). The maximum CO_2 sequestration of 0.26 Tg CO_2 per year in rice straw phytolith was noticed in China. Recent research pointed out that carbon is occluded as PhytOC during the absorption of phytolith in rice plant parts and is considered a carbon pool in the rice ecosystem and bang on the global carbon cycle (12).

PhytOC has persisted in soil for thousands of years, and research on radioactive carbon (C) isotopes has been carried out over the last decades. PhytOC carbon sequestration ranged from 7.2-8.8 kg/ha/yr(13). Soil properties, nutrients, and climate are crucial in forming phytoliths and (PhytOC). Nutrient-rich soils, especially those containing sufficient silica and essential minerals, encourage strong phytolith production, which enhances carbon storage. In contrast, nutrient-poor or highly acidic soils can impede phytolith formation due to limited resources. Climatic factors, including moisture levels and temperature, also impact this process; generally, warmer and wetter climates promote the more significant accumulation of phytoliths and PhytOC. Therefore, both nutrient availability and climatic conditions work together to influence the efficiency of PhytOC formation in plants (12). The phytolith-enriched sheath and rice leaves can produce biochar as an amendment (14). PhytOC enhances phytolith content in soil and plant parts, varying from 0.94×10^6 tonnes CO2/yr to 2.17×10^6 tonnes CO_2/yr. Fertilization and selection of rice varieties impact phytOC in geochemical sequestration and climate change mitigation (15).

Application of silicate fertilizers at 1.87 gm Si/pot and NPK fertilizers increased the uptake of rice's nitrogen, phosphorus, phytolith, and phytOC production compared to the control (16). The application of silica fertilizers to paddy crops, especially in silica-deficient soil, increases the PhytOC fluxes from 8.04 × 104 to 7.41 × 105 Mg-e-CO_2 and basalt powder from 0.005 to 0.041 Mg CO_2/ha (17, 18). Phytolith and PhytOC production was increased due to applying phosphorus fertilizer, silica-rich amendment, organic mulching, basalt powder and NPK fertilizers (17-21). The rice phytolith potential in the long-term carbon sequestration process and carbon sequestration rate was 0.12 Mg-e-CO_2/ha/year.

Implication of Silicon on Rice and its Phytolith Content

Rice is an indispensable crop for food and nutrition, covering around 164 million hectares globally as of 2014 (22). Silicon is crucial for silica-accumulating plants, especially in the *Poaceae* family, as it strengthens cell walls and enhances structural support. It improves resistance to pests, diseases and stresses like drought while aiding nutrient uptake for overall plant health. In crops like rice, wheat and maize, silicon is critical to maintaining productivity and resilience. Its protective role makes it vital for both agriculture and ecosystems. Crop wastes derived from rice (Rice straw and husks) are used for cattle feed and firewood in factories. In the Earths' crust, silicon comprises 27.7% of the Earth's crust by mass and ranks as the second most abundant element. Rice requires silica fertilization, removes 230-470 kg/ha of silicon and increases the availability of primary and secondary nutrients. Silicon induces photosynthesis, aids in phosphorus absorption from the soil, reduces nutrient toxicities and helps rice withstand water logging conditions (Fig.1.) (23). Silica positively influences phosphorus availability by absorption, solubilization and phosphorus release from plant to soil (24).

Silica occurs as silicon dioxide and silicate compounds in the Earth and plants. It should be absorbed as ortho silicic acid ($Si(OH)_4$), stored in the leaves, stems and culms of rice and other silica-accumulating plants. The assimilated silicic acid is stored as plant opal or silica stones or "Phytolith" in rice plants' leaves, stem culms and roots and is considered one of the silicon sources (26). Silica assimilates in the cell wall, intra and inter-cellular lumen and inter-cellular cortex region (27). Silicon provides mechanical strength and rigidity to the rice plants and prevents lodging (28). The production of chlorophyll and oxidative mechanisms are responsible for increasing the productivity of rice crops (29). Rice responds well to silicate fertilizers and the genes *LSi1, LSi2* and *LSi6* are responsible for transporting silicon from the roots to panicles through apoplast and vascular bundles (Fig. 2.) (30, 31). Polymerization occurs in the rice plant when excess mono silicic acid (H_4SiO_4) or Si $(OH)_4$ forms amorphous silica particles (Phytolith) in the cuticle along with cellulose and hemicellulose (32).

The deposited phytolith gives mechanical strength, decreases the feeding habits of herbivores and imparts biotic and biotic stress (Fig.1.) in rice plants. Phytoliths, when occluded with small amounts of carbon (C), nitrogen (N) and sulphur (S), enhance their functionality in various ways. Carbon contributes to phytoliths' structural integrity and stability, while nitrogen supports plant metabolism and promotes growth. Sulphur enhances phytolith resilience against biotic and abiotic stresses, including metal toxicity and salinization. Together, these elements improve soil health by facilitating nutrient cycling and interacting beneficially with soil microorganisms. Incorporating C, N and S into phytoliths supports plant health and environmental adaptability (34,35).

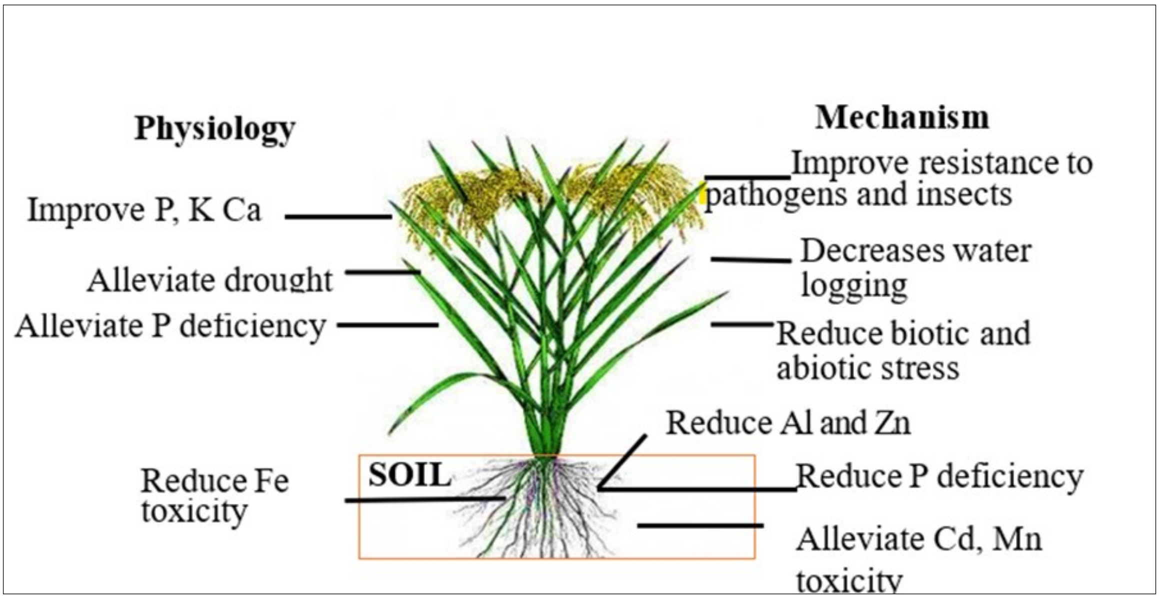

Fig. 1. Rice crop needs silicon for its nutrition availability and for defence

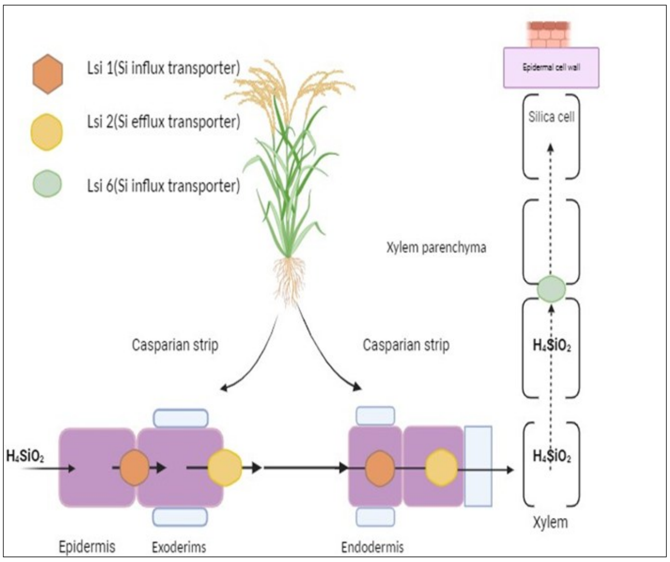

Fig.2. Silicon aids in the establishment of rice phytolith production in different plant parts via silicon transporters

Contrivance of Phytolith Advancement in Silica Accumulating Plants

Silicon is absorbed by the plant as mono-silicic acid in a solution with water and is transported through the vascular system (36). The silicic acid is accumulated as solid hydrated silica as phytolith (37). In the ocean, the phytolith gets re-solubilized and sequestrated (38). The *Lsi_1* and *Lsi_2* transporters, along with primary and secondary nutrients, are involved in the accumulation of silica in soil solution and further Polymerization takes place during the formation of the phytolith structure (39). The development of phytolith structure includes silicon transfer from the root to vascular, silicon assimilation in the phytolith wall, advancement of phytolith structure by creating spaces for transport of silicon and other nutrients and nutrients isolation in the phytolith by desiccation and coagulation (Fig. 3.). The organic matter, carbon, silicon and nutrients are fused through chemical bonds in rice (40). The gene transporters, viz., *$OsLsi_1$, $OsLsi_2$, $OsLsi_3$ and $OsLsi_6$* are involved in the phytochrome gene structure for phytolith formation (41).

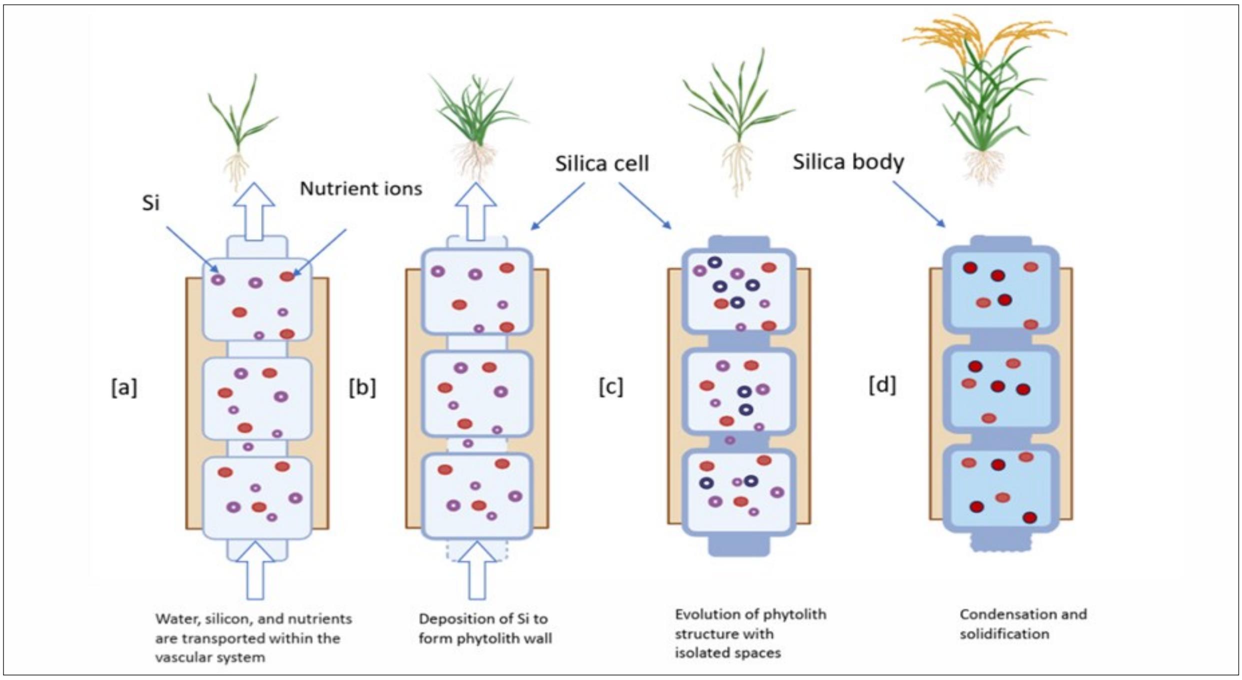

Fig.3. Fruition of phytolith in plant's cell – silicon in the soil as a sign

Modules of Phytolith in Different Organs of Rice Plants and its Cultivars

The maximum silica accumulation was noticed in the bracts, leaf blade, and leaf sheath and the minimum was seen in the roots. The phytolith content of rice straw ranged from 29.3 to 143.3 mg/g with a mean value of 80 mg/g (15). The Al and Fe contents of the phytolith ranged from 0.003 to 0.009% and 0.012 and 0.034%, respectively and varied with rice cultivars. The Al and Fe contents of the phytolith decreased in the order of sheaths > leaves = stems = grains and sheaths > stems = leaves = grains, respectively (42). The Phytolith content of paddy straw was analyzed using EDS, and distinct solid bodies indiscrete solid deposits around phytolith and small round spike-shaped phytolith (43) Fe, Al, K Si, O and C were observed (34).

Si, Al, Fe and water play a significant role in establishing organic carbon in rice phytoliths (44). The mean water content of the phytolith varied from 5.4 to 14.5% and the highest and lowest were noticed in stems and grains, respectively. The average Al content of phytoliths ranged from 0.012 to 0.043%, with the maximum phytolith Al content observed in rice sheaths and leaves, followed by grains and stems (42). The SiO_2 content of phytolith in grains, leaf sheaths, leaves, and stems were 94.71, 92.50, 88.47 and 83.04%, respectively. The Mg, Fe and OC contents in phytoliths varied from 0.0043 to 0.0082%, 0.017 to 0.009% and 1.93 to 2.46%, respectively and the contents decreased from sheaths and leaves = grains > stems (42). The results on phytolith correlation with the elemental composition of rice cultivars envisaged that the R^2value for Phytolith Vs. Al, Phytolith Vs. Fe, and Phytolith Vs. Mg were 0.6494, 0.572, and 0.3194, respectively (15). Application of silicon (150, 300, and 600 kg/ha) increased the phytolith from 24.23 to 53.85 g/kg in rice and the maximum accumulation was in the stem. (17).

A study on 71 different rice cultivars across nine provinces confirmed that the concentration of phytolith in rice straw ranged from 29.3 to 143.3 mg/gwith a mean phytolith concentration of 80 mg/g(15). Geographical location, soil composition, climate and agricultural management practices influence the phytolith content in plants (45). The silicon dynamics in soil-rice systems varied based on the phytolith's solubility and parts of the plants. The phytolith content of straw, root, husk and grain in 15 rice cultivars ranged from 0.14 to 26.4 mg/g, with the highest content recorded in rice straw followed by husk, root and grain (Fig. 4.).

Edifice of Rice Phytolith in Different Organs of Rice Plants and Disparity with Cultivars and Species

The rice phytolith shapes include double-peaked, bulliform and paralleled dumbbell structures, which vary across different organs (47). Bulliform cells, fucoid cells, or prickle hairs of rice phytoliths are found in the silica cells of vascular bundles or as silica bodies in various cells. The highest silica accumulation occurs during the reproductive period (32). The shapes of phytolith in husks and leaves were double-peaked and bulliform (49). The phytolith shapes were described by *O. sativa and O. rufipogon* as bulliform with unique buff-shaped ribbons encircling the half side and bulliform containing a spherical fan and round bow with a tubercle on the divergent side, respectively.

The contours of *O. sativa*, *O. rufipogon* and Xishuangbanna *O. rufipogon* from 20 different cultivars are presented. The results deliberated that bulliform phytoliths with minor variations in the lower part and lateral side were noticed in all the rice cultivars (48). The SEM images of paddy straw phytolith were observed. The shapes varied as globular (6-9 lm), small round spike (2-3 lm), a cluster of 2/3/5, cross-shaped, boat-shaped, 6-8 number of encircled lens-shaped, lens shape merged with round shape, cross-shaped on the veins (6-7 lm), hook-shaped appear equidistantly on the veins, irregular silica bodies with small round (50) spike-shaped on smooth-surface and arrangement of regular pattern of globular (34). Double-peaked, bulliform and paralleled dumbbell phytolith shapes were observed in paddy straw (47).

Phytolith Occluded Carbon in Phytolith Assembly-A Basis for Terrestrial Soil Organic Carbon (SOC) Pool

Silica-accumulating plants have silica in their internal structure as mono silicic acid (Si (OH)4), forming phytolith and occluding carbon within these phytoliths, called PhytOC. The PhytOC persist in soil for decades, contributing to carbon sequestration and climate change mitigation (51). The PhytOC content in rice varies by species, ranging from 0.13 to 0.21 mg/g, as determined by elemental analysis (53).

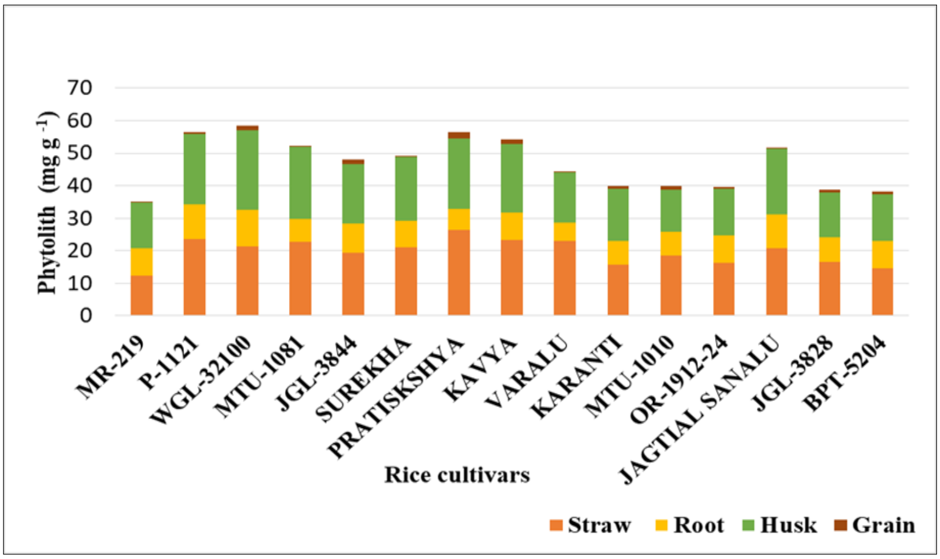

Fig. 4. Phytolith amassing in organs of rice cultivars and its impact on rice ecosystem

The sub-compartmentation of OC and phytolith occluded carbon using Tomography. The results revealed that silica augmented compactly packed bundle-sheath cells mingled. Loosely arranged mesophyll cells are seen in rice plants (54). The CO_2 fluxes of 8.62 μmol/m^2/s, which diffused over the rice field, were observed during the aerobic decomposition of assimilated fresh phytolith (55), ash phytolith and aged phytolith soil OC in the root zone and later it gets penetrated with water and then transmuted.

The phytolith accumulated in the rice straw underwent some chemical reactions, as shown in Fig. 5. The soluble forms of CO_2, including H_2CO_3, HCO_3 - and CO_3^{2-}-are produced in this reaction. During its decomposition and its straw cycle, an acidic environment is created. The pH should be very low and drive the CO_2 buffering capacity. During this process, CO_2 buffer capacity is decreased. It enhances emission (Reaction.1). If the paddy straw areas are burnt in the field, the organic matter will be converted to CO_2 and produce alkaline conditions with high pH. The open burning of rice straw in the field produces ash with high soil pH and increases the solubility of CO_2. Finally, phytolith-occluded alkali ions are formed (56).

Plant growth environment (climate, surface vegetation, and soil) and plant genetics increase the carbon content of phytolith and are linked to carbon sequestration efficiency (57). Silicon absorption mechanisms and root silicification processes are responsible for phytolith-occluded carbon content in crops (58). The phytolith and phytOC ranged from 12.46 to 23.6% and 1.4 to 3.3% for straw, 5.5 to 11.4% and 1.1 to 2.7% for roots, 13.1 to 24.3% and 2.1 to 6.3% for husk and 0.2 to 1.9% and 0.7 to 1.4% for grains, respectively (Fig. 6). Rice straw has high PhytOC than husk, roots, and grains and high phytolith content was observed in husk and straw (59) (Fig. 6). The carbon sequestration rate of 76.4 g e-CO_2 pot^{-1} was noted in high phytolith content rice cultivars and mean PhytOC content was 5.0 mg/g (60).

The maximum Si-phytolith content was found in rice straw and the minimum in grains, ranging from 14.47 to 26.39% in straw, 7.05 to 11.4% in roots, 13.13 to 24.38% in husk and 0.14 to 1.94% in grains (61). The rice husk recorded the highest PhytOC in phytoliths, followed by straw, root and grains, with the ranged values of 1.87-3.37%, 1.13-2.27%, 2.13-6.3% and 0.7-1.43%, respectively. The utmost phytOC content of 3.37% was noticed in the rice cv. M-219 straw than others (59).

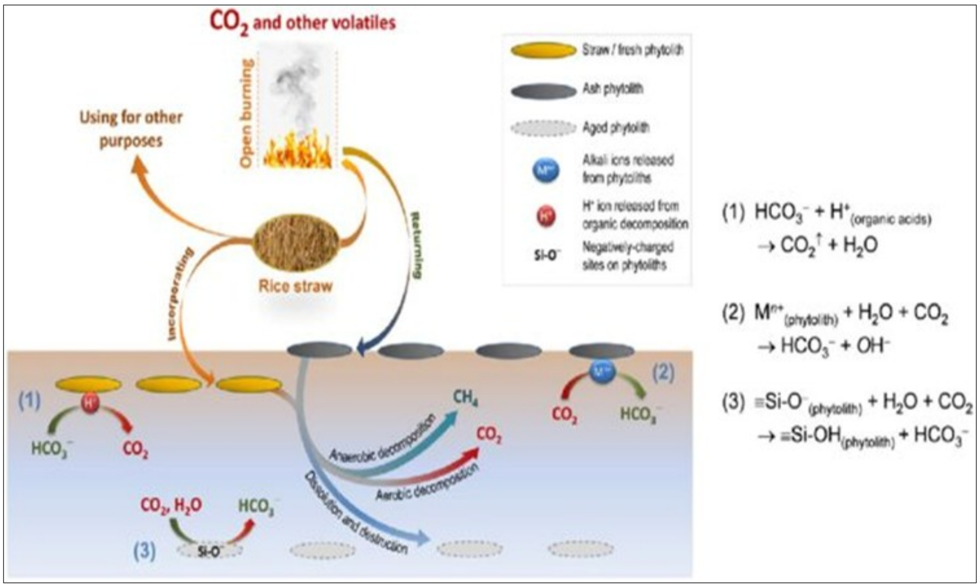

Fig. 5. Chemistry behind phytolith occluded carbon development in soil -as a source of CO_2 flux in rice ecosystem.

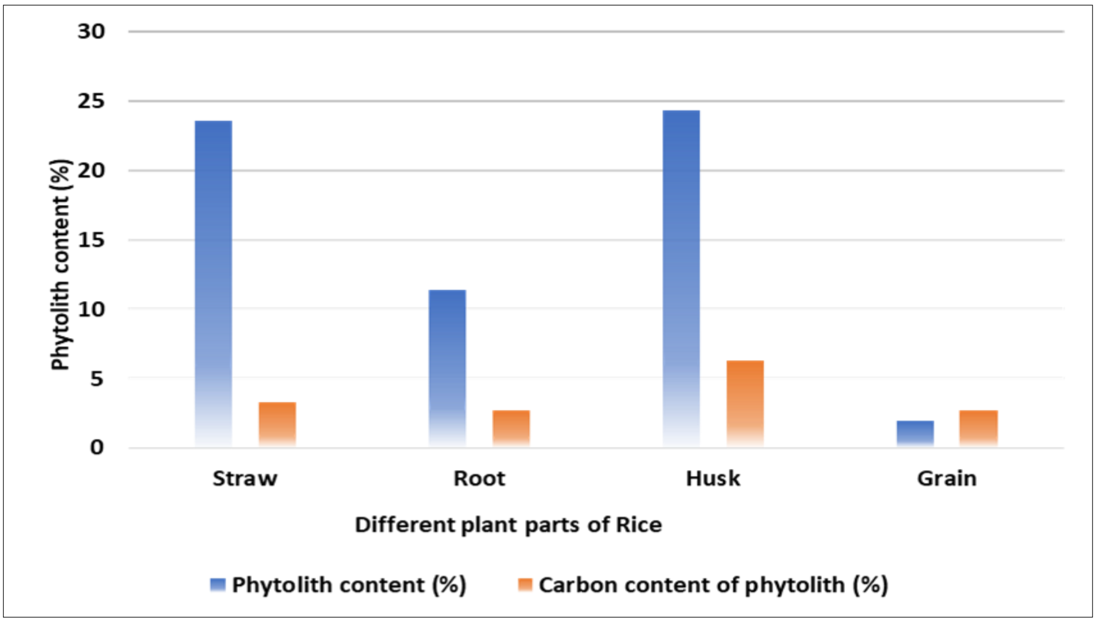

Fig. 6. Rice plant organs with different rates of Phytolith and PhytOC absorption as silicon-enriched sustainable carbon

A study on the relationship between phytolith content and carbon content in intensively cultivated soils in India showed no significant positive correlation between phytoliths and carbon content in phytoliths. However, a strong correlation was observed between phytolith and PhytOC content ($R^2 = 0.76$, $p < 0.01$), with a significant positive correlation ($R^2 = 0.40$, $p < 0.01$) between phytolith carbon content and PhytOC content in rice (17).

Preservation of Carbon Pool and Fluxes in Rice Ecosystem through Phytolith and Phytolith-Occluded Carbon for Climate Change Mitigation

Climate change relies upon the soil carbon pool, and phytOC is an essential source (63). PhytOC is very sustainable and skirmishes to decay compared to other crude C fractions in the soil (64). After the rice harvest, the straw waste is incorporated into the soil and the phytolith is released into the earth. The PhytOC in phytolith persists in the soil for over 6,000 years (65). This persistence contributes significantly to terrestrial C sinks, accounting for up to 82% of total carbon sequestration (66). The sustainable carbon sequestration mechanism for atmospheric CO_2 is established through phytolith storage in plant biomass and soil pools. The phytolith-occluded carbon pools and fluxes varied from 0.01% to 0.04% and 0.14 - 2.32 teramoles (Tmol). Annual net land PhytOC accumulation rate was < 0.01 - 0.05 Tmol/yr. The soil had the most significant quantities of PhytOC from 8.69 - 128.25 Tmol and rice biomass from 1.11 - 23.05 Tmol.

Silicon fertilizers can be applied to recover phytolith carbon sink in rice ecosystems and reduce CO2 emission into the atmosphere (67). The phytolith and PhytOC production flux in the rice ecosystem ranged from 643.30 to 1893.99 kg/ha/yr and 16.10 to 109.51 kgCO_2 ha/yr, respectively. The phytolith and PhytOC production fluctuation were recorded to be the highest in long duration varieties than in medium and short duration rice cultivars. For example, Japonica rice varieties display a coefficient of variation of 29.16 Mg CO_2/ha/year, compared to 24.1 Mg CO_2/ha/year in Indica varieties (53).

Carbon sequestration Potential of Rice through Phytoliths and PhytOC Sink

PhytOC exhibits high resistance to decomposition, potentially persisting in soil for thousands of years after plant decay, thus serving as a significant long-term carbon sink (5, 68-71). This soil phytOC accumulation represents a crucial and enduring carbon sink mechanism in croplands and grass-dominated ecosystems (45, 60, 66, 72-73). The carbon sequestration potential in rice ranged from 0.03 to 0.13 Mg-e-CO_2/ha/year across five rice cultivars. Globally, rice-growing regions sequester about 1.94×10^7 Mg-e-CO_2 annually. The Carbon fluctuation of rice phytoliths, annual carbon sequestration, and sequestration within phytolith were 0.03–0.13 Mg-e-CO_2/ha/year, 0.81×106 to 3.88×10^6 Mg-e-CO_2 and 2.37×10^8 Mg-e-CO_2 respectively during the 60 years in China (60). The annual C flux of rice phytoliths from the atmosphere was 1.94×10^7 Mg-e-CO_2 and is involved in climate change mitigation (74). The CO_2 sequestered in Chinese croplands was 4.39 ± 1.56 T g/yr and crop management practices could enhance the phytolith potential and carbon sequestration (75). The distribution of silica in various plant species found in China, which plays an important role in the carbon sequestration process, was studied, and results showed that herbs had the highest silicon accumulator, followed by trees and shrubs (76). The carbon sequestration potential in PhytOC (77) reached $0.48 \pm 0.20 \times 10^6$ t CO_2/year and 44 percent rest upon the vegetation. Applying silicate fertilizers significantly enhanced the phytOC level and carbon bio-sequestration in paddy soil from 0.94×10^6 tonnes CO_2/yr to 2.17×10^6 tonnes CO_2/yr (46). The phytolith content of rice cultivars encompassed a carbon sequestration rate that ranged from 0.05 to 0.12 Mg-e-CO_2/ha/year (79).

Worldwide, the annual latent sink rate of phytOC through rice phytolith was estimated at 16.4 Tg-e-CO_2, with a biome total of 156.7± 91.6 Tg CO_2/yr (46). The phytolith capacity in rice for carbon bio-sequestration ranged from 0.03 to 0.13 Mg-e-CO_2/ha/year in five different rice cultivars (60). Silicate fertilizers boost PhytOC levels by supplying extra silica, which enhances phytolith formation in rice plants. This increased production leads to more significant carbon sequestration as more phytoliths accumulate in the soil. Silica also helps plants withstand environmental stresses, promoting overall health and carbon capture. Successful applications in rice-growing regions like Indonesia and China have shown improved PhytOC levels and soil health, demonstrating the potential of silicate fertilizers to enhance carbon sequestration while supporting sustainable agriculture (80-82). Phytolith C sequestration recovery in the rice ecosystem was achieved by selecting cultivars, applying silicon-rich fertilizers and applying organic manure, especially biochar (83-85).

The PhytOC content ranged from 0.002 to 0.82 mg/g in different rice organs and Carbon sequestration rates were 0.05 to 0.12 Mg-e-CO_2/ha/year; the disparity might rest on silicon content and dry matter production. Rice plays a significant role in enduring C-seizure and climate transformation through the PhytOC Asia, Africa and South America contribute to the Phytolith carbon sink (46). Rice cultivars decide the PhytOC sequestration and the report of (46) depicted in (Fig. 7) that the Kavya cultivar recorded the lowest PhytOC sequestration value of 0.055 Mg-e-CO_2/ha/year and the Surekha rice cultivar with highest PhytOC sequestration value of 0.119Mg-e-CO_2/ha/year. The PhytOC in soils through rice phytolith enhances the approximate universal annual latent sink rate of 1.64 x 107 Mg-e-CO_2/ha/year. Application of slag-type silicate fertilizers in rice crops suppressed the methane emission from 158 mg CH_4/m^2/h to 116 mg CH_4/m^2/h due to the increased carbon dioxide activity and iron concentration in soil (86). Methane flux declined by 20 percent in control tillage and 36 percent in the no-tillage system in all seasons.

Bio-silicification Processes- a Dynamic Role in Long-Term Capture of Carbon Dioxide as Phytoc in Climate Change Mitigation

Phytolith occluded carbon refers to carbon restricted within phytoliths, which are microscopic silica structures found in plants (87) and derived from photosynthesis, converting atmospheric carbon dioxide into organic forms (88). PhytOC has the prospective a striking task in carbon sequestration in rice ecosystems (87) and indirectly on climate change mitigation (89). PhytOC operates as a sink for soil carbon, reducing CO2 emissions and supplying nutrients for rice production. Improved management practices and mitigation technologies in the rice ecosystem could help reduce emissions (90).

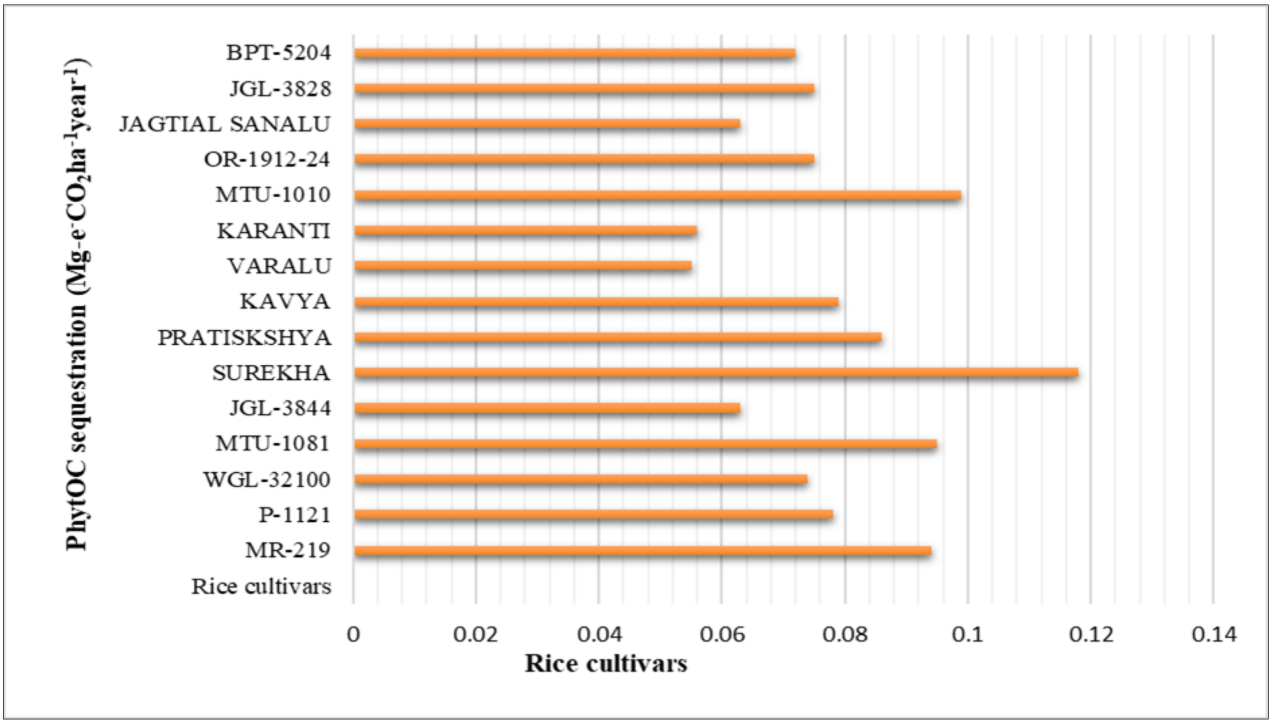

Fig. 7. Rice cultivars with varied phytOC sequestration potential

The development of no or no carbon fuel and natural and engineering strategies are needed to lower CO_2 emissions (91). PhytOC has come forward as a significant tool in the long-term seizure and retention of carbon (92), (93), presenting a promising boulevard for addressing climate change (57). Phytolith in silica accumulating plants acquire considerable latent for climate change and mitigation owing to their buoyancy against decomposition (94). The bio-silicification process forms PhytOC and is stored within rice plant tissue, representing a stable form of carbon sequestration (95).

Conclusion and Future Perspective

Rice is a staple food for almost all Asian countries, generating approximately one billion tons of straw annually. The incorporation of rice straw waste plays a crucial role in recycling nutrients, organic matter and phytoliths (silica bodies) deposited within rice plants' inter and intra-cellular tissues. Phytoliths, silica structures, persist in the soil for thousands of years and enhance photosynthesis while helping rice plants cope with various stresses. Phytoliths improve photosynthesis and conflict with multiple stresses in rice plants. Carbon, along with some nutrients deposited into the phytolith called phytOC, is involved in geochemical carbon sequestration in the rice ecosystem. Phytoliths have played an enormous role in the documentation of plants and the age of the microfossils.

Rice phytolith sequestered the carbon as 0.05-0.12 Mg-e-CO2/ha/year and wide-ranging based on varieties, climate, rhizosphere and dry matter production. Approximately 1.64×10^7 Mg-e-CO_2/ha/year of estimated global annual potential sink rate of PhytOC in soils produced through rice phytolith. The enduring earthly carbon sequestration and climate change desires phytOC and rice growing countries viz., Asia, Africa and South America are principal carbon sink backers. Improved management practices and mitigation technologies to be practised in the rice ecosystem could help reduce emissions and help mitigate climate change. Selecting high PhytOC-yielding rice cultivars presents a valuable opportunity to enhance the production of phytoliths, phytOC and the overall soil carbon pool. Applying silicon-rich fertilizer, bio wastes and organic matter improves the readily soluble Si pools and enhances phytolith, PhytOC production and soil physicochemical properties. There is an urgent need to augment phytolith and PhytOC production in the rice ecosystem, which occupies a large area worldwide, through aboveground Net Primary Productivity (ANPP) management practices.

However, research on the PhytOC accumulation in the rice ecosystem will be needed to standardize the phytOC production in different rice growing regions for global C sequestration, thereby reducing greenhouse gasses, especially carbon dioxide, in the atmosphere for mitigating climate change. The selection of long-duration rice cultivars with high PhytOC occlusion potential will pave the phytOC descend rate in India above the present sequestration rate.

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Authors' contributions

MM - Drafting the original manuscript, investigating and analyzing. CNM - supervises and does project administration reviewing and editing. SS - resources and data curation. JB, MR - resources and investigation. RT - formal analysis. AR, JR, RM and RK - formal analysis.

Compliance with ethical standards

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While preparing this work, the author(s) used Grammarly to correct the grammar. After using this tool/service, the author (s) reviewed and edited the content as needed and take(s) full responsibility for the publications' content.

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