https://doi.org/10.29321/MAJ.10.A03553

Silica Deposition in Plants

by
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Silicon has long been known to be present in considerable quantities in the ashes of plants. Richardson (1920) reported its abundance in aerial parts horsetail fern *Equisetum* and many members of the Gramineae constituting about 50 to 70 per cent of their ashes in the form of its oxide. According to him, amongst all elements in plant materials, silicon, perhaps shows the greatest variation from one part to another of the same plant as also from one plant to another of the same variety.

In timothy (*Phleum pratense* L.) the base of the internode has no silicified epidermal cells but 50 to 100 such cells per mm^2., are found in the middle portion and 500 to 600 per mm^2., in the upper part. In the deposition of silica the transition from the middle region to the strongly silicated upper zone is a sudden one (Arber, 1935). In 31 inbred lines of corn (*Zea mays* L.) grown under normal conditions the silica content of the leaf blade has been observed to vary from 0.66 to 2.08 per cent and that of the leaf margin from 0.65 to 7.00 per cent of the dry weight of the tissues (Sprague, 1955), thus confirming the earlier observations of Richardson (1920).

Silicon occurs in plants in the form of its oxide ($SiO_2 . nH_2O$) which is popularly termed as silica. Hence, the term silica has been freely used in this paper. The silicate absorbed from the soil is dehydrated into SiO_2 at the cuticular surface of the stems and leaves of plants (Steele, 1934). Silica deposits are more frequently found in tropical plants than in those of the temperate zones (Frey-Wyssling, 1930a, b). The high soil temperature of the tropics is believed to facilitate the dissolution of silicic acid and subsequent absorption by plants. Frey-Wyssling (19'0a, b) considered that this absorbed silicon is not metabolically useful to the plants but gets accumulated in tissues as deposits of no immediate value.

Silicification of plant cells is well recognized. Haberlandt (1914) described certain special cells arranged in spherical groups and named them as "silica corpuscles". These cells have definite portions of their walls thickened and silicified. They have been reported to be fairly large and discernible even with a hand lens in many species of *Aristolochia* and *Loranthus europaeus* as well. These silica corpuscles have been found to lie either in the neighbourhood of bundle ends or actually intersected by them. The distal ends of terminal tracheids penetrate into the centre of such corpuscles.

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Part I of Curzon Lectures delivered in November, 1968.

The fibrous strands of Orchidaceae, Scitamineae, Palmae and Hymenophyllaceae have all been reported to be accompanied by small tongue-shaped silica cells, described as "stegmata" (Mettenius, 1964). Haberlandt (1914) observed that the walls of these cells next to the fibres get extensively thickened in the beginning. Later, however, the entire cavity is more or less filled with a mass of silica and seems to be devoid of any organic matter.

Mobius (1908) described the small spherical concretions of silica occurring in the leaves of *Callisia repens* and found them to possess a rough surface and located in the flattened cells cut off on the outer side of the periclinal walls of ordinary epidermal elements. Each cell contains several concretions, which are separated from one another by out-growths from the cell-wall. The cell cavity is thus transformed into a system of passages in which the silica concretions are enclosed.

In *Gramineae*, silica occurs mostly in the epidermal cells (Arber, 1934). This family is characterised by the deposition of silica in the cell walls as well as in the cell lumina (Esau, 1953). In bamboo, the silicated internode is so hard that it is sometimes used as a whet-stone. Arber (1934) believed that the firmness and persistance of the glumes enclosing the grass flower might be connected with the silicious character of the tissue. Since these glumes harden early, she remarked that the crowded flowers suffer from "confinement in youth". Besides the epidermis, silica may also be deposited in other parts of a plant. In bamboo, Arber (1934) observed that the hollow internodes contain a silica residue apparently left over from the "watery fluid" which collects in the cavities of the internodes. There is still obscurity regarding its origin although its presence has long been known in the Indian *Materia Medica*.

Lanning *et al* (1958) have reported a new type of silica deposition in sub-epidermal layers of the leaf blades of sorghum and wheat. The depositions at the leaf edges of these plants are also found to be silica. The princkles of lantana (*Lantana camera* L.) and sunflower (*Helianthus annus* L.) are similarly silicified (Lanning *et al.*, 1958).

Although deposition of silica in the roots of plants is said to be rare, Arber (1934) recorded the presence of silica crystoliths in the endodermal walls of roots of certain Andropogoneae. Artschwager (1925, 1948) reported the occurrence of silica knobs topping the endodermal thickenings in sugarcane and sorghum roots. Ponnaiya (1960) has confirmed the presence of silica in the endodermal layers of the roots of sorghum and has stated that it forms a complete silica cylinder in mature roots, the silica knobs giving it a papillate appearance. In *Setaria italica* also the presence of silica has been reported in the root but in the exodermal layer (Ponnaiya and Rathnasamy 1962).

Physiological role of silicon: Due to its presence in large quantities in many plants, silicon was believed to be an essential element for a long time. Later, however, it was claimed that successful growth of corn (Knop, 1861–62; Sachs, 1887) and oats (Kreuzhage and Wolff. 1884) could be obtained in nutrient solutions lacking silicon. The effect of silicon on phosphorous nutrition of plants has also been reported (Kreuzhage and Wolf, 1884: Sreenivasan, 1934).

Lipman (1938) reviewed the nutritional role of silicon and considered it as an essential element at least to plants like *Beta vulgaris*. Absence of silicon does not influence oats and rice in the seedling stage but affects grown up plants (Sommer, 1940). The silicon deficient plants develop roots normally but show poor tillering capacity. The leaves also exhibit abnormality of twisting and yellowing. A lack of stiffness is noticed in the entire body of the plant. Warming (1881) believed that the heavy deposition of silica in plants of Podostemaceae (which grow in swift flowing rivers) protects the plants against the shearing action of violent currents of water. Haberlandt (1914) concluded that silicated tissues might behave like other physiologically valueless structures which become secondarily adapted for ecological purposes.

Nampoothiri *et al* (1968) have reported that total silicon contents in the lower inter-node in rice has no influence on nature of lodging in that crop.

According to Ponnaiya (1960) the heavy deposition of silica in the endodermal layer of the root may be one of the factors giving drought resistance to this crop.

Ponnaiya and Rathnaswamy (1962) working on the Italian millet (*Setaria italica* Beauv.) have found that drought resistant varieties in this crop have well packed silica threads in the exodermal layers of the roots. It forms a cylinder which acts as a protective covering around the stele and may be one of the factors bringing about drought resistance in this millet.

Silica and resistance to insect and fungal pests: Palladin (1927) was the first to assign a role to silicon in protecting plants against attack from various parasites. He recorded that wheat and rye grown in nutrient solutions without silicon suffered very severely from rust. Similarly, silicon deficient *Lithospermum arvense* is badly attacked by plant lice. Germar (1934) reported that leaves of cereals well supplied with silica are more resistant to infection by the mildew *Erysiphe graminis*. McColloch and Salmon (1923) indicated that the resistance of certain varieties of maize to *Mayetiola destructor* might be due to the presence of large quantities of silica in them. In *Oryza sativa* L. the combination of silica with one or more components of the cell wall to form a complex has been postulated to build resistance to the blast disease caused by *Piricularia oryzae* Cav. (Volk *et al.*, 1958). Ponnaiya (1951) observed that sorghum varieties resistant to the fly pest *Atherigona indica* M. exhibit an earlier formation of silica particles at the site of attack and considered this to be the basic factor of resistance.

Blum (1968) confirms the findings of Ponnaiya (1960) but is of the view that the resistant variety possesses a much greater density of silica bodies (dumb-bell shaped, intercostal and silicified prickle hairs) as compared to susceptible ones.

Miller *et al.* (1960) have indicated that the presence of silica deposition on wheat plant tissue may be one of the factors related to resistance of certain varieties of the crop to hessian fly attck.

Silica deposition and taxonomy: Recent studies have revealed that certain types of silicated cells in the epidermis are characteristic of genera, tribes or even larger groups of Gramineae (de Wet, 1956).

Prat (1932) combined the evidence presented by Grob (1896) and Avdulov (1931) with his own earlier observations and recognized three types of epidermis viz., festucoid, panicoid and eragrostoid according to the shape of silica cells over the veins. The festucoid type of epidermis is met in the tribes Festuceae, Aveneae, Hordeae, Agrosteae and Phalarideae where these silica cells are mostly rounded or elongated. The hairs are either bicellular or absent. The panicoid type has linear bicellular hairs and silicious cells may be dumb-bell or cross shaped. This type of epidermis is commonly found in the genera belonging to the tribes Arundinelleae, Paniceae, Andropogoneae and Maydeae. The eragrostoid type is recognized by double headed, hatchet or saddle shaped silica cells. The hairs are either club shaped or spherical and bicellular in nature. The tribes that have this character are Eragosteae, Chlorideae, Zoysiae and Sporoboleae.

Studying the leaf epidermis of the tribe Danthoneae, de Wet (1956) pointed out that its systematic classification could be bettered by a study of the shape of silica cells.

Ponnaiya (1960) found that sorghum roots both wild and cultivated have a heavy deposition of silica in the endodermal layer. In mature roots the deposition was so heavy that a complete cylinder of silica is formed at this zone. The location of the silica deposition was traced to the inner tangential wall of the endodermal cells. Each cell had a "silica knob" giving the silica cylinder a papillate appearance. The presence of "Silica Knobs" was found restricted only to sorghum and the other grasses belonging to the tribe Andropogoneae giving a clue that this character might be of taxonomic importance.

External factors affecting silica deposition in plants: Although the deposition of silicon in tissues is found to be limited to certain species of plants (Richardson, 1923) and that the silica pattern is constant for a particular species (de Wet, 1956), it is, nevertheless, recognized that environment in which the plant grows exerts a great influence on the quantum of its deposition.

The type of soil has a varied influence on the absorption of silica by plants. Wherry (1932) found that *Phlox subulata* contained more silicon on "low silicon serpentine barren soil" than on "sandy coastal plain woods soil". The same type of soil is reported to have an adverse effect of silicon absorption by *Silax rotundifolia*. Thus, it could be seen that a soil favourable to one species may be unfavourable for another.

Studying the relation between concentration of silicon in the nutrient solution and its deposition in plant parts, Whittenberger (1945) recorded the greatest absorption of silicon with highest concentration of the element in the solution (450 p. p. m.). He also found that differences in age, season, nutrient solution and substrata do not alter this relationship. It is interesting to note that silicon is not apparently toxic even when furnished in high concentrations, as much as 450 p. p. m.

The hydrogen-ion concentration of the soil and its influence on silicon absorption were studied by Whittenberger (1945) with *Secale cereale* L. and *Helianthus annus* L., which have normally heavy deposits of silica in their tissues. Maximum absorption of soluble silicon has been found to be favoured in both the plants approximately at neutral pH (7.1) although appreciable quantities are absorbed at relatively lower pH levels (3.6). Maximum absorption is independent of plant vigour and linked up with hydrogen-ion concentration whether the plants grow well or not at a particular pH. Hydrogen-ion concentration of soils is regarded as a variable character which could be modified extensively by cultural practices or climatic conditions.

The silica deposition in leaves also varies directly with the rate of transpiration (Germar, 1934). Because of its direct bearing on transpiration, sunlight has also been noted to influence silica deposition (Miller, 1938). Ponnaiya (1951) found that intense sunlight has a positive influence on the deposition of silica in *Sorghum*.

Chemistry of silicon in plants: The chemistry of silicon in plants was not determined for a long time. The author during his stay in the U. S. A. in 1957–1958 had the opportunity to study this aspect in collaboration with Dr. F. C. Lanning, the Silica Chemist and Dr. C. F. Crumpton the Geologist at the Kansas College, Manhatten. Using the petrographic microscope and

X-ray diffraction techniques, it was found that the silica depositions in sorghum, wheat, bamboo, corn and sunflower are characteristically opal while those from *Lantana* are both opal and a quartz. (Lanning *et al.*, 1958.)

REFERENCES

Arber, A. 1934. *The Gramineae.* A study of cereal Bamboo and Grass. Univ. Press, Cambridge. 480.

Artschwager, E. 1925. Anatomy of the vegetative organs of sugarcane. *J. agric. Res.*, 30: 197–221.

———. 1948. Anatomy and morphology of the vegetative organs of *Sorghum vulgare Bull. U.S. Dep. Agric.*, 957.

Avdulov, N. P. 1931. Karyo systematische Unter-suchung der Familie Grammeen. *Bull appl. Bot. Pl. Breed.*, 44: 1–428.

Blum, A. 1968. Anatomical phenomena in seedlings of Sorghum varieties resistant to the shoot fly *(Atherigona varia soccata) Crop Sci.*, 8: 388-91.

de Wet, J. M. J. 1954. The genus *Danthonia* in grass phylogeny. *Amer. J. Bot.*, 41: 204–11.

———. 1956. Leaf anatomy and Phylogeny in the tribe Danthoniae. *Amer. J. Bot.*, 43: 175.

Esau, K. 1953. *Plant Anatomy.* Chapman and Hall Ltd. London.

Frey-Wyssling, A. 1930 a. Uber die Ausscheidung der Kieseleaure in der pflanze. *Ber bot. Ges.*, 48: 179-83.

———. 1930 b. Vergleich zwischen der Ausscheidung von Kieselsaare und Kalzium-salzen in der *Pflanze, Ber. bot. Ges.*, 48: 184–91.

Germar, B. 1934. Some functions of silicic acid in cereals with special reference to resistance to mildew *Pflanzenernahr Dung. u Bodenk.* A. 35: 102–15.

Grob, A. 1896. Beitrage zur Anatomie der Epidermis der Gramineen blatter. *Bibl. bot. Stuttgart.* 7 (36) 1–122.

Haberlandt, G. 1914. *Physiological Plant Anatomy.* Macmillan Company, London.

Knop, W. 1861-62. Quantitative-analytische Arbeiten uber den Erhah-rungs-process der Pflanzen. *Landw. Versucks-Stat.*, 3. 295–324. 4: 173–85. (cited from Millet, 1938).

Kreuzhage, C. and E. Wolff. 1884. Beduetung der Kieselsaure fur die Entwicklung der Hafter-Pflanze, *Landw. Ver-Suchs-Stat.*, 30: 161–97. (cited from Miller, 1938).

Lanning, F. C., B. W. X. Ponnaiya and C. F. Crumpton. 1958. The chemical nature of silica in plants. *Plant Physiol.*, 33: 339–43.

Lipman, C. B. 1938. Importance of silicon, aluminium and chlorine for higher plants. *Soil Sci.*, 45: 189–98.

McColloch, J. W. and S. C. Salmon. 1923. Fly. A Progress Report *J. econ-Ent.*, 16: 293–8. The resistance of wheat to the Hessian.

Mettenius. 1864. Silica deposits. *Abh. sachs. Ges.* 7. Quoted from Haberiandt. 1914.

Miller, B. S, R. J. Robinson, J. A. Johnson, E. T. Jones and B. W. X. Ponnaiya. 1960. Studies on the relation between silica in wheat plants and resistance to Hessian Fly attack. *Jrl. Econ. Ent.*, 53: pp. 995–9.

Miller, E. C. 1938. *Plant Physiology*. McGraw Hill Book Company Inc. New York and London, 1201.

Mobius. 1908. Wiesner Festochrift, Vienna. Quoted from Haberlandt. (1914).

Nampoothiri, K. U. K., B. W. X. Ponnaiya and V. S. Raman. 1968. Studies on lodging in rice (*Oryza sativa* L.) *Indian J. agric.*, **38**: 360-7.

Palladin, V. I. 1927. *Plant Physiology*. Eng. trans. Livingston, B.E., Blakistons Son & Co. Philadelphia. 360.

Ponnaiya B. W. X. 1951. Studies in the genus *Sorghum*: II. The cause of resistan.e in Sorghum to the insect pest *Atherigona indica* M. *J. Madras Univ. B* **21**: 203-17.

———, 1960. Silica deposition in Sorghum roots and its possible roles. *Madras agric. J.*, **47**: 31-2.

———, and Charles Rathnaswamy. 1962. Silica and drought resistance in the Italian Millet (*Setaria italica* Beauv.) *Madras agric. J.*, **50**: 31-2.

Prat, H. 1932. L'Epiderme des Graminees Etude anatomique et systematique. *Ann. des. Sci. nat. Bot.*, **14**: 117-326.

———, 1936. La Systimatique der Graminees. Ann. Sci. nat. (a) *Botanique*, **10**: 18: 165.

Richardson, W. D 1920. The ash of dune plants. *Science*, **51**: 546-51.

Sachs, J. 1887. Lectures on the Physiology of plants. Eng. ed. Clarendon press (cited from Miller, 1938)

Sommer, A. L. 1940. Mineral nutrition of plants. *Annu. Rev. Bichem.*, **9**: 487-8.

Sprague, G. F. 1955. *Corn and Corn Improvements. Academic Press, Inc.* N.Y.

Sreenivasan, A. 1934. The role of silicon in plant nutrition. *Curr. Sci.*, **3**: 193-7.

Steele, C. C. 1934. *An Introduction to plant Biochemistry*. Bell & Sons. Ltd. London. 1934, pp. 356.

Volk, R. J., R. P. Kahn and R. L. Weintraub. 1958. Silicon content of the rice plant as a factor influencing its resistance to infection by the blast fungus. *Piricularia oryzae. Phytopathology*, **48**: 179-84.

Warming. 1881-8. E'tudes sur la famille des Podostemaces, Copenhagen. Quoted from Harberlandt. (1914)

Wherry, E T. 1932. Ecological studies of serpentine barren plants I. Ash composition. *Proc. Pa Acad. Sci.*, **6**: 32-8. (cited from Whitten bergen, 1945)

Whittenberger, R. T. 1945. Silicon absorption by rye and Sunflower. *Amer. J. Bot.*, **32**: 539-49.