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Phytoliths of Indian grasses and their potential use in identification

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Phytoliths are amorphous silicon dioxide ($SiO_2.nH_2O$) inclusions abundant in leaves, internodes and glumes in members of Poaceae. They may occur as inclusions filling the entire lumen of the silica cells, bulliform cells and trichomes or may be part of the outer epidermal cell walls. Since phytoliths are resistant to fungal or animal digestive juices, a large quantity of phytoliths accumulate in the soil where grasses grow. Compared with the pollen grains of grasses which tend to be uniform, phytoliths vary in size and morphology and can be of value in identification at different taxonomic levels and in the dating of past vegetation. The size and shape of phytoliths of about 100 species of grasses from Tamil Nadu, India, have been determined. Silica bodies were observed either after isolation or in cleared leaf blades. Size and shape of phytoliths were determined under a microscope or from micrographs of the specimens. Size and shape can be used to assign the phytoliths to their respective subfamilies and to distinguish some of the grasses at the generic level. Drawings of silica cells and an identification key are provided for 80 species.

ADDITIONAL KEY WORDS:—leaf – Poaceae – silica – epidermis – taxonomy.

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INTRODUCTION

Phytoliths are siliceous remains of plants. A large number of plants absorb monosilicic acid which is deposited as amorphous silica ($SiO_2.nH_2O$). Plant silica is opaline in nature and may be found in internal tissue but occur more often in the epidermis. The nature of plant silica and the distribution of silica bodies in different plant families are well documented (Geis, 1973; Simpson & Volcani, 1981; Ollendorf, Mulholland & Rapp, 1988; Ball, Brotherson & Gardner, 1993; Whang, Kim & Hess, 1998). Dayanandan (1983) and Dayanandan, Kaufman & Franklin (1983) evaluated methods used in the study of silica bodies and described three different staining techniques for microscopic localization of plant silica.

Phytoliths have been isolated from atmospheric dust, soil, ancient sediments and deep sea cores (Baker, 1959, 1960; Smithson, 1958; Twiss, Suess & Smith, 1969). Jones (1964) reported the occurrence of opal phytoliths in Cenozoic sedimentary rocks. Since phytoliths from different taxa tend to possess characteristic morphological features, several investigators have attempted to identify the plants from which the phytoliths might have been derived. Phytoliths of grasses are of particular interest in this respect. All members of Poaceae accumulate large quantities of silica. Grass phytoliths are abundant and can provide information about the composition of past grass flora, both wild and cultivated (Blackman, 1971; Mulholland, 1989). Grass phytoliths have been used to determine past ecological conditions (Rovner, 1971), soil genesis (Twiss *et al.*, 1969) and identify plants used by people in ancient and prehistoric periods (Rovner, 1983).

A classification of grass phytoliths is a prerequisite for effective use of silica bodies in palaeoecological and archaeological studies. Several authors have attempted to classify grass phytoliths based on their shape and size (Baker, 1959; Metcalfe, 1960; Twiss *et al.*, 1969; Brown, 1984; Watson & Dallwitz, 1988). No single comprehensive classification is yet available for all grass taxa to be of value in identifying phytoliths from all parts of the world. This paper provides information on Indian grasses thus adding to the growing world literature on phytoliths of grasses (Palmer & Gerbeth, 1988; Dunham, 1988).

MATERIAL AND METHODS

Grasses collected from the plains of Tamil Nadu, India, were identified by keying and comparing with grass herbarium specimens maintained in the laboratory. Leaf blades used in this investigation were mostly collected from the field and some were obtained from dry herbarium specimens.

Fresh leaves were cut into segments and immersed in 3:1 solution of lactic acid and chloralhydrate. Segements of dried leaves were first softened in water before transferring to the clearing solution. Segments of leaves were incubated in the clearing solution in an oven at 70°C for several days. Cleared segments were mounted in fresh solution and examined with a microscope. Cleared segments as well as fresh segments immersed in alcohol to remove chlorophyll were also stained. Methyl red (MR) or crystal violet lactone (CVL) was used for staining silica bodies according to Dayanandan *et al.* (1983).

Fresh leaf segments were also boiled in concentrated phenol solution with safranin and mounted in phenol for microscopic observation.

Individual silica bodies were isolated by prolonged treatment in a mixture of H_2SO_4 and HNO_3. After complete digestion of the cells and after diluting in water several times, the silica bodies were recovered in abundance by centrifugation.

Measurements of silica cells were made from surface view as seen on epidermal preparations. Direct measurements under a microscope and measurements on enlarged photographs were compared to arrive at accurate values. A minimum of 15 measurements were made for each species. The average value is presented in Table 1. Fractions were rounded up to the nearest value for constructing the key. All observations were made and photographs taken with a 'Nikon Labophot' microscope fitted with an automatic exposure system. 'Konica' and 'Kodak' colour negative films (100 ASA) were used to photograph the silica and bulliform cells and isolated phytoliths.

RESULTS

In cleared leaves and in isolated samples a variety of silica bodies could be identified (Fig. 1). The bulliform cells that occur on the adaxial surface of the epidermis are often filled with silica. Bulliform silica are the largest among grass phytoliths. Occasionally the lumen of a long epidermal cell can be fully silicified. Such epidermal silica bodies occur on both surfaces. Both the abaxial and adaxial surfaces of grass leaves possess trichomes of various shapes and sizes. Invariably at least a portion of the trichomes is silicified by the incrustation of silica in their walls. The epidermal system of grasses is made up of short and long cells (Metcalfe, 1960; Kaufman *et al.*, 1981). The short cells are usually differentiated into cork-silica cell pairs. By far the most useful silica body for the identification of grasses is the silica cell.

The key presented in this paper was constructed using size and shape differences of silica cells. Although silica bodies fill the silica cells, in the epidermal preparations used in this study the silica cell outlines were clearly delineated. When isolated the contents of silica cells are recovered as silica bodies. Silica bodies are three dimensional structures, and isolated bodies, depending upon how they lie, exhibit different shapes. In this study, in order to obtain repeatable results, only the surface view of silica cells in peels were taken into consideration.

Silica cells usually occur in 1–3 rows above the veins on both surfaces of grass leaf blades. Occasionally they occur in the intercostal regions. Silica cells vary in shape and size. The shape of a silica cell is determined by length–width dimensions and the presence and length of constriction in the middle. Nine different shapes were recognized in this study and used in the preparation of the key. They are illustrated in Figs 2, 3–82. The length of silica cells varies between 3 and 41 μm and the width varies from 3 to 18 μm (see Table 1).

TABLE 1. Dimensions and shape of silica cells. *Key: D, dumbbell; OM, omega; B, butterfly; OS, oblong sinuous; O, oblong; OE, oblong elliptic; SO, sub-orbicular; Q, quadrate; R, rectangular

Grass species	Length (l) (μm)	Width (w) (μm)	Ratio (w/l)	Shape*
SUBFAMILY: ARUNDINOIDEAE				
Aristida adscensionis L.	19.50	8.00	0.410	D
Aristida hystrix L.f.	41.25	9.87	0.239	D
Aristida setacea Retz.	25.25	7.87	0.312	D
Arundo donax L.	21.87	13.00	0.594	D
SUBFAMILY: BAMBUSOIDEAE				
Bambusa arundinacea (Retz.) Willd.	8.75	13.75	1.571	R
Dendrocalamus strictus (Roxb.) Nees	10.75	18.12	1.686	R
SUBFAMILY: ORYZOIDEAE				
Leersia hexandra Swartz	8.75	8.12	0.928	B
Oryza sativa L.	10.00	13.75	1.375	D
SUBFAMILY: CHLORIDOIDEAE				
Aeluropus lagopoides (L.) Trin.ex Thw.	13.87	6.25	0.451	D
Chloris dolichostachya Lagasca	9.50	14.50	1.526	R
Chloris gayana Kunth ex Stapf	11.75	12.80	1.089	O
Chloris inflata Link	10.00	13.87	1.387	O
Chloris montana Roxb.	11.75	11.87	1.010	SO
Coelachyrum lagopoides (Burm.f.) Senaratna	15.87	10.62	0.669	D
Cynodon arcuatus J.S. ex C.B.	13.12	11.50	0.877	SO
Cynodon barberi Rang. & Tad.	10.62	11.87	1.118	SO
Cynodon dactylon (L.) Pers.	6.62	8.00	1.208	SO
Cynodon plectostachyus (K. Schum. ex Engl.) Pilger	12.75	11.30	0.886	SO
Dacyloctenium aegyptium (L.) Willd.	9.00	15.12	1.680	O
Desmostachya bipinnata (L.) Stapf	7.87	14.00	1.779	O
Eleusine indica (L.) Gaertn.	9.00	8.62	0.958	SO
Eragrostiella bifaria (Vahl) Bor	8.75	13.12	1.499	R
Eragrostiella brachyphylla (Stapf) Bor	15.87	13.00	0.819	D
Eragrostis ciliaris (L.) R.Br.	8.25	6.75	0.818	SO
Eragrostis japonica (Thunb.) Trin.	8.75	7.37	0.842	SO
Eragrostis viscosa (Retz.) Trin.	8.87	8.25	0.930	OM
Leptochloa chinensis (L.) Nees	18.12	9.00	0.497	D
Microchloa indica (L.f.) P.Beauv.	8.37	9.62	1.149	R
Oropetium thomaeum (L.f.) Trin.	10.50	15.00	1.429	R
Perotis indica (L.) O.Ktze.	16.37	7.12	0.435	D
Pommereulla cornucopiae L.f.	14.87	2.00	0.134	OS
Sprobolus tremulus (Willd.) Kunth	7.18	7.25	1.010	SO
Sporobolus virginicus (L.) Kunth	3.12	6.62	2.122	OE
Tragus roxburghii Panigr.	9.37	10.25	1.094	SO
SUBFAMILY: PANICOIDEAE				
Alloteropsis cimicina (L.) Stapf	33.12	9.12	0.275	D
Andropogon pumilus Roxb.	23.25	13.12	0.564	D
Apluda mutica L.	49.00	6.37	0.130	D
Arthraxon castratus (Griff.) Narayanasw. Ex Bor	12.50	11.30	0.940	D
Axonopus compressus (Swartz) P.Beauv.	17.37	9.12	0.525	D
Bothriochloa pertusa (L.) A.Camus	21.20	10.00	0.456	D
Brachiaria distachya (L.) Stapf	17.50	12.00	0.686	D
Brachiaria miliiformis (J.S. ex C.B.Presl) A.chase	24.12	11.00	0.430	D
Brachiaria mutica (Forssk.) Stapf	22.62	11.62	0.514	D
Cenchrus ciliaris L.	16.37	7.37	0.450	D
Cenchrus glaucus Mudaliar & Sundararaj	21.30	13.50	0.634	D
Cenchrus setigerus Vahl	20.30	3.12	0.154	D
Chrysopogon aciculatus (Retz.) Trin.	9.00	6.50	0.722	D
Cymbopogon flexuosus (Nees ex Steud.) Wats.	16.10	12.25	0.761	D
Dichanthium annulatum (Forssk.) Stapf	23.80	12.00	0.504	D
Dichanthium caricosum (L.) A.Camus	22.10	18.50	0.837	D

continued

TABLE 1. *continued*

Grass species	Length (l) (μm)	Width (w) (μm)	Ratio (w/l)	Shape*
Dichanthium foveolatum (Del.) Roberty	15.10	8.80	0.583	D
Digitaria logiflora (Retz.)	13.30	10.10	0.759	D
Echinochloa colona (L.) Link	23.40	12.00	0.512	D
Eremochloa muricata (Retz.) Hack.	24.50	14.75	0.602	D
Eriochloa procera (Retz.) C.E.Hubb.	16.25	7.37	0.454	D
Hemarthria compressa (L.f.)R.Br.	16.80	12.50	0.744	D
Heteropogon contortus (L.) P.Beauv.	24.70	12.30	0.498	D
Iseilema laxum Hack.	25.00	10.10	0.404	D
Manisuris myuros L.	15.10	8.25	0.546	D
Mnesithea granularis (L.) Koning & Sosef	19.80	13.30	0.672	D
Oplismenus burmannii (Retz.) P. Beauv.	24.30	7.37	0.303	D
Panicum maximum Jacq.	16.87	8.12	0.481	D
Panicum psilopodium Trin.	13.75	9.43	0.686	D
Panicum repens L.	16.25	9.00	0.554	D
Panicum trypheron Schult.	16.00	10.00	0.625	D
Paspalidium flavidum (Retz.) A.Camus	22.12	9.30	0.420	D
Paspalidium geminatum (Forssk.) Stapf	12.75	9.68	0.759	D
Paspalum paspalodes (Michx.) Scribner	14.25	5.87	0.412	D
Pennisetum purpureum Schumach.	13.80	7.37	0.534	D
Pogonatherum crinitum (Thunb.) Kunth	6.25	6.25	1.000	Q
Rhynchelytrum repens (Willd.) C.E. Hubb.	19.37	10.12	0.522	D
Rottboellia cochinchinensis (Lour.) W.D.Clayton	27.10	12.50	0.461	D
Sacciolepis interrupta (Willd.) Stapf	21.00	10.75	0.511	D
Sehima nervosum (Rottl.) Stapf	20.75	11.25	0.542	D
Setaria pumila (Poir.) P. & S.	16.00	9.87	0.617	D
Setaria verticillata (L.) P.Beauv.	17.50	6.25	0.357	D
Stenotaphrum dimidiatum (L.) Brongn.	24.30	10.12	0.416	D
Trachys muricata (L.) Pers. ex Trin.	15.37	7.81	0.508	D
Urochloa mosambicensis (Hack.) Dandy	14.50	11.50	0.793	D
Zea mays L.	17.60	12.80	0.727	D
SUBFAMILY: POOIDEAE		NIL		

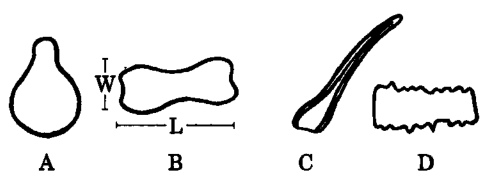


Figure 1. Diagram of different kinds of phytoliths found in grass leaf blade. A, bulliform cell; B, silica cell; C, silicified trichome; D, silicified epidermal cell; L, length; W, width.

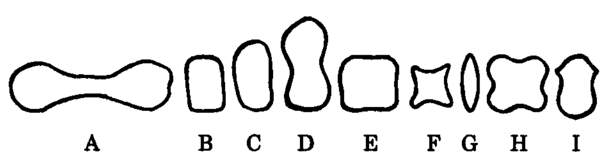


Figure 2. Diagram of shape of leaf blade silica cells. A, dumbbell. B, rectangular. C, oblong. D, oblong sinuous. E, sub-orbicular. F, quadrate. G, oblong elliptic. H, butterfly. I, Omega.

Key to species of Indian grasses based on the shape and size of silica phytoliths

1. Phytoliths dumbbell-shaped:
  2. Phytoliths short-shanked (1–3 μm long)
    3. Phytoliths once sinuous:
      4. Phytoliths with straight ends:
        5. Phytoliths 10 μm or less in width:
          6. Phytoliths *c.* 9 μm long ..... *Chrysopogon aciculatus*
          6. Phytoliths more than 10 μm long:
            7. Phytoliths 10–15 μm long:
              8. Phytoliths *c.* 15 μm long:
                9. Phytoliths *c.* 8 μm wide ..... *Manisuris myuros*
                9. Phytoliths *c.* 9 μm wide ..... *Dichanthium foveolatum*
              8. Phytoliths under 14 μm long:
                10. Phytoliths *c.* 6 μm wide ..... *Aeluropus lagopoides*
                10. Phytoliths more than 7 μm wide:
                  11. Phytoliths *c.* 7 μm wide ..... *Pennisetum purpureum*
                  11. Phytoliths *c.* 9 μm wide:
                    12. Phytoliths *c.* 13 μm long ..... *Paspalidium geminatum*
                    12. Phytoliths *c.* 14 μm long ..... *Panicum psilopodium*
            7. Phytoliths more than 15 μm long:
              13. Phytoliths *c.* 21 μm long ..... *Bothriochloa pertusa*
              13. Phytoliths 16–18 μm long:

Figures 3–28. Shape of silica cells in subfamily Chloridoideae. 3. *Aeluropus lagopoides*, 4. *Chloris inflata*, 5. *Chloris dolichostachya*, 6. *Chloris gayana*, 7. *Chloris montana*, 8. *Coelachyrum lagopoides*, 9. *Cynodon arcuatus*, 10. *Cynodon barberi*, 11. *Cynodon dactylon*, 12. *Cynodon plectostachyus*, 13. *Dactyloctenium aegyptium*, 14. *Desmostachya bipinnata*, 15. *Eleusine indica*, 16. *Eragrostiella bifaria*, 17. *Eragrostiella brachyphylla*, 18. *Eragrostis ciliaris*, 19. *Eragrostis japonica*, 20. *Eragrostis viscosa*, 21. *Leptochloa chinensis*, 22. *Microchloa indica*, 23. *Oropetium thomaeum*, 24. *Perotis indica*, 25. *Pommereulla cornucopiae*, 26. *Sporobolus tremulus*, 27. *Sporobolus virginicus*, 28. *Tragus roxburghii*.

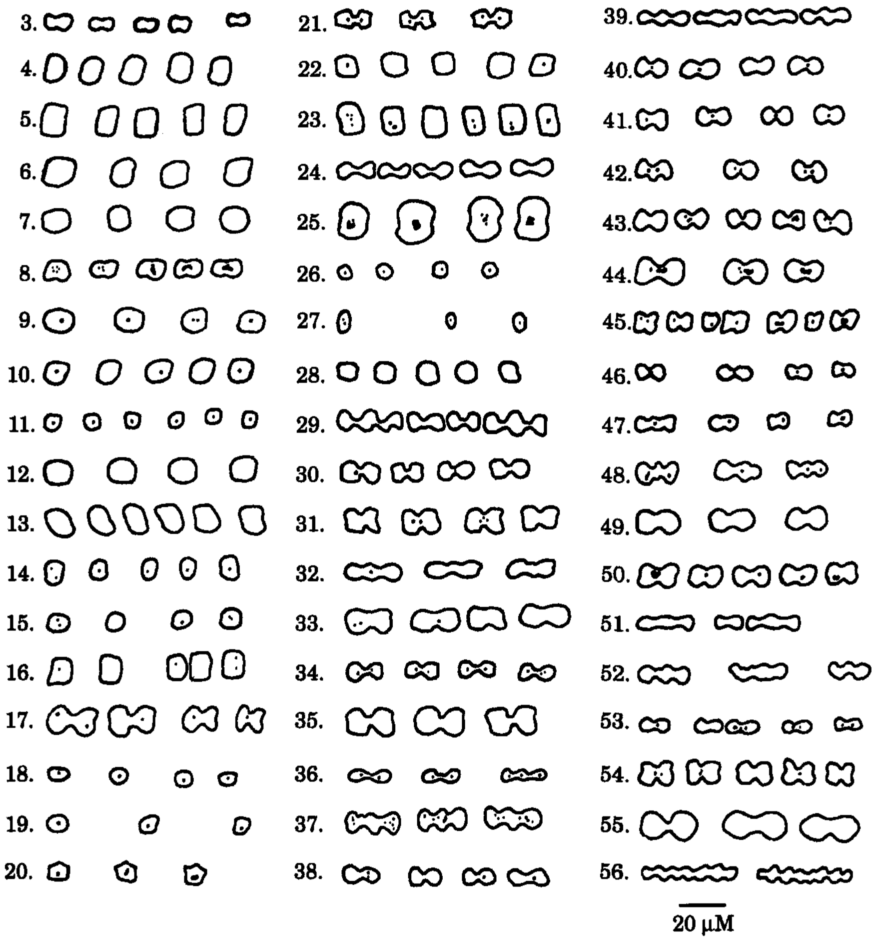
Figures 29–54. Shape of silica cells in subfamily Panicoideae, supertribe Panicanae. 29. *Alloteropsis cimicina*, 30. *Axonopus compressus*, 31. *Brachiaria distachya*, 32. *Brachiaria miliiformis*, 33. *Brachiaria mutica*, 34. *Cenchrus ciliaris*, 35. *Cenchrus glaucus*, 36. *Cenchrus setigerus*, 37. *Echinochloa colona*, 38. *Eriochloa procera*, 39. *Oplisminus burmannii*, 40. *Panicum maximum*, 41. *Panicum psilopodium*, 42. *Panicum repens*, 43. *Panicum trypheron*, 44. *Paspalidium flavidium*, 45. *Paspalidum geminatum*, 46. *Paspalum paspalodes*, 47. *Pannisetum purpureum*, 48. *Rhynchelytrum repens*, 49. *Sacciolepis interrupta*, 50. *Setaria pumila*, 51. *Setaria verticillata*, 52. *Stentaphrum dimidiatum*, 53. *Trachys muricata*, 54. *Urochloa mosambicensis*.

Figures 55–74. Shape of silica cells in subfamily Panicoideae, supertribe Andropogonanae. 55. *Andropogon pumilus*, 56. *Apluda mutica*, 57. *Arthroxon castratus*, 58. *Bothriochloa pertusa*, 59. *Chrysopogon aciculatus*, 60. *Cymbopogon flexuosus*, 61. *Dichanthium annulatum*, 62. *Dichantium caricosum*, 63. *Dichanthium foveolatum*, 64. *Digitaria longiflora*, 65. *Eremochloa muricata*, 66. *Hemarthria compressa*, 67. *Heteropogon contortus*, 68. *Iseilema laxum*, 69. *Manisuris myuros*, 70. *Mnesithea granularis*, 71. *Pogonatherum crinitum*, 72. *Rottboellia cochinchinensis*, 73. *Sehima nervosum*, 74. *Zea mays*.

Figures 75–78. Shape of silica cells in subfamily Arundinoideae. 75. *Aristida adscensionis*, 76. *Aristida hystrix*, 77. *Aristida setacea*, 78. *Arundo donax*.

Figures 79, 80. Shape of silica cells in subfamily Bambusoideae. 79. *Bambusa arundinacea*, 80. *Dendrocalamus strictus*.

Figures 81, 82. Shape of silica cells in subfamily Oryzoideae. 81. *Leersia hexandra*, 82. *Oryza sativa*.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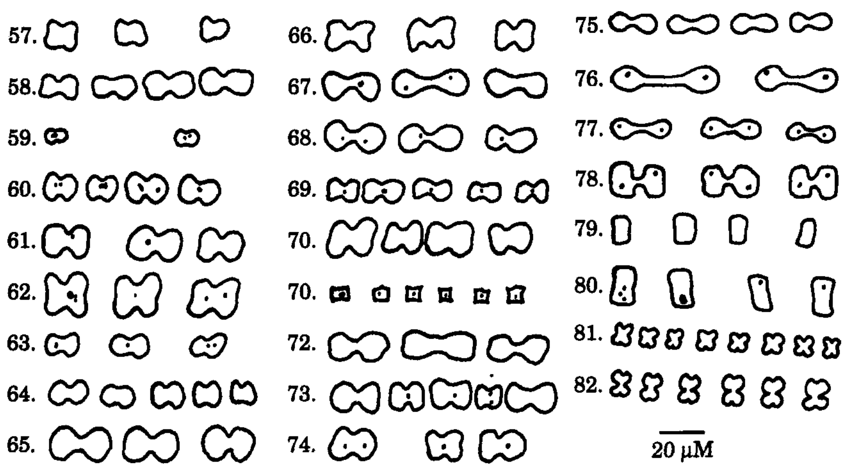
20 μM


57. 58. 59. 60. 61. 62. 63. 64. 65.
66. 67. 68. 69. 70. 70. 72. 73. 74.
75. 76. 77. 78. 79. 80. 81. 82.
20 μM

14. Phytoliths *c.* 17 μm long ..... *Axonopus compressus*
14. Phytoliths *c.* 16 μm long:
15. Phytoliths *c.* 7 μm wide ..... *Eriochloa procera*
15. Phytoliths *c.* 10 μm wide ..... *Setaria pumila*
5. Phytoliths 11 μm or more in width:
16. Phytoliths 12–18 μm long:
17. Phytoliths *c.* 18 μm long:
18. Phytoliths *c.* 12 μm wide ..... *Brachiaria distachya*
18. Phytoliths *c.* 13 μm wide ..... *Zea mays*
17. Phytoliths less than 17 μm long:
19. Phytoliths less than 15 μm long:
20. Phytoliths *c.* 13 μm long ..... *Arthraxon castratus*
20. Phytoliths *c.* 15 μm long ..... *Urochloa mosambicensis*
19. Phytoliths more than 15 μm long:
21. Phytoliths *c.* 16 μm long ..... *Eragrostiella brachyphylla*
21. Phytoliths *c.* 17 μm long ..... *Hemarthria compressa*
16. Phytoliths more than 18 μm long:
22. Phytoliths *c.* 18 μm wide ..... *Dichanthium caricosum*
22. Phytoliths less than 15 μm wide:
23. Phytoliths 11–12 μm wide:
24. Phytoliths *c.* 21 μm long ..... *Sehima nervosum*
24. Phytoliths more than 22 μm long:
25. Phytoliths *c.* 23 μm long ..... *Brachiaria mutica*
25. Phytoliths *c.* 24 μm long ..... *Dichanthium annulatum*
23. Phytoliths *c.* 13 μm wide:
26. Phytoliths *c.* 20 μm long ..... *Mnesithea granularis*
26. Phytoliths more than 21 μm long:
27. Phytoliths *c.* 21 μm long ..... *Cenchrus glacus*
27. Phytoliths *c.* 22 μm long ..... *Arundo donax*
4. Phytoliths with curved ends:
28. Phytoliths 5–11 μm wide:
29. Phytoliths 13–17 μm long:
30. Phytoliths less than 15 μm long:
31. Phytoliths *c.* 6 μm wide ..... *Paspalum paspalodes*
31. Phytoliths *c.* 10 μm wide ..... *Digitaria longiflora*
30. Phytoliths more than 15 μm long:
32. Phytoliths *c.* 11 μm wide ..... *Coelachyropsis lagopoides*
32. Phytoliths less than 10 μm wide:
33. Phytoliths *c.* 15 μm long ..... *Trachys muricata*
33. Phytoliths more than 16 μm long:
34. Phytoliths 8 μm wide:
35. Phytoliths *c.* 7 μm wide ..... *Perotis indica*
35. Phytoliths *c.* 8 μm wide ..... *Panicum maximum*
34. Phytoliths more than 9 μm wide:
36. Phytoliths *c.* 9 μm wide ..... *Panicum repens*
36. Phytoliths 10 μm wide ..... *Panicum trypheron*
29. Phytoliths more than 20 μm long:
37. Phytoliths *c.* 21 μm long ..... *Sacciolepis interrupta*
37. Phytoliths *c.* 22 μm long ..... *Paspalidium flavidum*

28. Phytoliths 12–14 µm wide:
    38. Phytoliths less than 18 µm long:
        39. Phytoliths *c.* 10 µm long ..... *Oryza sativa*
        39. Phytoliths 16 µm long ..... *Cymbopogon flexuosus*
    38. Phytoliths more than 20 µm long:
        40. Phytoliths *c.* 13 µm wide ..... *Andropogon pumilus*
        40. Phytoliths *c.* 15 µm wide ..... *Eremochloa muricata*

3. Phytoliths two or more times sinuous:
  41. Phytoliths twice sinuous:
    42. Phytoliths less than 20 µm long:
        43. Phytoliths *c.* 6 µm wide ..... *Setaria verticillata*
        43. Phytoliths *c.* 10 µm wide ..... *Rhynchelytrum repens*
    42. Phytoliths more than 23 µm long:
        44. Phytoliths more than 30 µm long ..... *Alloteropsis cimicina*
        44. Phytoliths less than 25 µm long:
            45. Phytoliths less than 8 µm wide ..... *Oplisminus burmannii*
            45. Phytoliths more than 9 µm wide:
                46. Phytoliths 10 µm wide:
                    47. Phytoliths *c.* 10 µm wide ..... *Stenotaphrum dimidiatum*
                    47. Phytoliths 11 µm wide ..... *Brachiaria miliiformis*
                46. Phytoliths *c.* 12 µm wide ..... *Echinochloa colona*
  41. Phytoliths three or more times sinuous ..... *Apluda mutica*

2. Phytoliths long-shanked (4–20 µm long):
  48. Phytoliths with curved ends:
    49. Phytoliths 16–21 µm long:
        50. Phytoliths less than 4 µm wide ..... *Cenchrus setigerus*
        50. Phytoliths more than 6 µm wide:
            51. Phytoliths *c.* 16 µm long ..... *Cenchrus ciliaris*
            51. Phytoliths *c.* 20 µm long ..... *Aristida adscensionis*
    49. Phytoliths more than 24 µm long:
        52. Phytoliths *c.* 41 µm long ..... *Aristida hystrix*
        52. Phytoliths less than 30 µm long:
            53. Phytoliths *c.* 12 µm wide ..... *Heteropogon contortus*
            53. Phytoliths less than 11 µm wide:
                54. Phytoliths *c.* 10 µm wide ..... *Iseilema laxum*
                54. Phytoliths *c.* 8 µm wide ..... *Aristida setacea*
  48. Phytoliths with straight or angular ends:
    55. Phytoliths with straight ends ..... *Rottboellia cochinchinensis*
    55. Phytophils with angular ends ..... *Leptochloa chinensis*

1. Phytoliths other than dumbbell-shaped:
  56. Phytoliths sub-orbicular:
    57. Phytoliths less than 9 µm wide:
        58. Phytoliths 8–9 µm long:
            59. Phytoliths *c.* 9 µm wide ..... *Eleusine indica*
            59. Phytoliths 6–8 µm wide:
                60. Phytoliths *c.* 8 µm long ..... *Eragrostis ciliaris*
                60. Phytoliths *c.* 9 µm long ..... *Eragrostis japonica*
        58. Phytoliths 6–7 µm long:
            61. Phytoliths *c.* 7 µm wide ..... *Sporobolus tremulus*

61. Phytoliths *c.* 8 µm wide ..... *Cynodon dactylon*
57. Phytoliths more than 10 µm wide:
62. Phytoliths less than 10 µm long ..... *Tragus roxburghii*
62. Phytoliths more than 11 µm long:
63. Phytoliths *c.* 11 µm ..... *Cynodon barberi*
63. Phytoliths more than 12 µm long:
64. Phytoliths *c.* 13 µm long ..... *Cynodon arcuatus*
64 Phytoliths less than 13 µm long:
65. Phytoliths *c.* 12 µm long ..... *Chloris montana*
65. Phytoliths *c.* 13 µm long ..... *Cynodon plectostachyus*
56. Phytoliths other than sub-orbicular:
66. Phytoliths rectangular:
67. Phytoliths 8–10 µm long:
68. Phytoliths *c.* 10 µm wide ..... *Microchloa indica*
68. Phytoliths more than 12 µm wide:
69. Phytoliths *c.* 15 µm wide ..... *Chloris dolichostachya*
69. Phytoliths less than 14 µm wide:
70. Phytoliths *c.* 13 µm wide ..... *Eragrostiella bifaria*
70. Phytoliths *c.* 14 µm wide ..... *Bambusa arundinacea*
67. Phytoliths *c.* 11 µm long:
71. Phytoliths *c.* 15 µm wide ..... *Oropetium thomaeum*
71. Phytoliths *c.* 14 µm wide ..... *Dendrocalamus strictus*
66. Phytoliths other than rectangular:
72. Phytoliths oblong:
73. Phytoliths 7–9 µm long:
74. Phytoliths *c.* 8 µm long ..... *Desmostachya bipinnata*
74. Phytoliths *c.* 9 µm long ..... *Dactyloctenium aegyptium*
73. Phytoliths 10–12 µm long:
75. Phytoliths *c.* 10 µm long ..... *Chloris inflata*
75. Phytoliths *c.* 12 µm long ..... *Chloris gayana*
72. Phytoliths other than oblong:
76. Phytoliths quadrate ..... *Pogonatherum crinitum*
76. Phytoliths other than quadrate:
77. Phytoliths oblong sinuous ..... *Pommereulla cornucopiae*
77. Phytoliths other than oblong sinuous:
78. Phytoliths oblong–elliptic ..... *Sporobolus virginicus*
78. Phytoliths other than oblong–elliptic:
79. Phytoliths butterfly shaped ..... *Leersia hexandra*
79. Phytoliths omega shaped ..... *Eragrostis viscosa*

DISCUSSION

Silica cells of 80 species are described in this paper. These grasses represent five out of six subfamilies of grasses since no members of Pooideae occur on the plains of Tamil Nadu, India. The subfamily Arundinoideae is characterized by dumbbell-shaped silica cells. In Oryzoideae *Leersia hexandra* has butterfly-shaped silica cells, while *Oryza sativa* has dumbbell-shaped silica cells. In the subfamily Chloridoideae as many as eight different types of silica cells have been identified. In Panicoideae, except *Pogonatherum crinitum* which has quadrate silica cells, all other species possess dumbbell-shaped silica cells.

Based on the size and shape of silica cells in the 80 species an identification key has been prepared. This represents about 6% of the Indian grasses. Description of silica cells in more species and from other localities will help confirm the usefulness of this key. In particular, the grasses of higher altitudes should be studied since practically all Pooideae members found in India are confined to the temperate hills.

CONCLUSIONS

Silica is deposited within the lumen or over the cell walls of a variety of cell types in members of Poaceae. Among these, the silica cells occupy a predictable position on the leaf epidermis following characteristic patterns of differentiation (Kaufman *et al.*, 1981). This survey of about 100 species of Indian grasses has offered data sufficient for developing a key. Since the survey represents less than 10% of the Indian grasses there is a need to extend this study. The measurements reported here were made of the outlines of the silica cells as seen in surface views in cleared preparations. However, isolated silica bodies are three dimensional structures. More accurate schemes of classification can be developed when all dimensions are taken into consideration. Bromophenol flotation technique (Brown, 1984) can be used to isolate soil phytoliths. A study of phytoliths isolated from datable soil cores and their comparison with living grasses can help determine the ecological distribution and the time of origin of grasslands in India.

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