Geophytology 37(2008) : 75-80

# Studies in the morpho–anatomy of some Indian species of *Selaginella* Pal. Beauv.

Radhanath Mukhopadhyay*, Gautam Ganguly* and Panchanan De**

* *UGC Centre for Advanced Study, Department of Botany, University of Burdwan-713104, India*
** *Department of Botany, Uluberia College, Uluberia, Howrah-711 315, India*

Mukhopadhyay R, Ganguly G & De P, 2008. Studies in the morpho – anatomy of some Indian species of *Selaginella* Pal. Beauv. *Geophytology* **37** : 75-80.

Morpho-anatomical circumscriptions of three Indian species of *Selaginella* are presented here along with a key. The species studied are *S. delicatula* (Desv.ex Poir.) Alston, *S. miniatospora* (Dalz.) Baker and *S. pentagona* Spring. *S. miniatospora* is endemic to India. All these species are heterophyllous. *S. delicatula* and *S. pentagona* belong to the subgenus Stachygynandrum, while *S. miniatospora* belongs to the subgenus Heterostachys. It is found that the nature of vegetative leaves and sporophylls, stelar anatomy, distribution of micro – and megasporangia in the strobili and exospore sculptures of spores serve as important parameters in delineating taxa.

**Key-words**—Morphology-anatomy, Indian species, *Selaginella*.

## INTRODUCTION

*SELAGINELLA*, the only terrestrial extant heterosporous lycopsid, which is represented by about 700 species throughout the world (Jermy, 1990), grows mainly in the tropical and subtropical regions. In British India, Alston (1945) enumerated 58 species of *Selaginella*. Panigrahi and Dixit (1966, 1967, 1968) gave an account of the external morphologies of some 30 species of *Selaginella*. Dixit (1992) gave a morphological account of Indian members of *Selaginella*.

Contributions toward anatomical knowledge came from the works of Harvey-Gibson (1894, 1896, 1897, 1902), Mitchell (1910), Worsdell (1910), Uphof (1920), Majumdar (1931, 1942), Duerden (1934), Mital (1969), Webster and Steeves (1963, 1964, 1967), Mickel and Hellwig (1969), Ogura (1972), Mukhopadhyay and Sen (1986) and Gopalakrishnan and Ravi (1990). Detailed circumscription of individual Indian members of this taxon is, however, very scanty. So far, anatomical investigations have been made of about fifteen Indian species of *Selaginella* by different workers (Chowdhury, 1957, 1959; Mukhopadhyay, 1991-1992, 2002; Mukhopadhyay & Goswami, 1996; Mukhopadhyay & Das, 2004). Thus, this work was undertaken to circumscribe the morphological and anatomical details of three Indian species of *Selaginella* along with a key for their identification.

## MATERIAL AND METHODS

The source of the specimens examined are given below-

*Selaginella delicatula* (Desv. ex Poir) Alston, Watt 1119 (BSI, CAL); Rama Rao 698 (BSI, CAL); Das SN (Kalyani University); Ramamurthy 48478 (BSI, CAL).

*Selaginella pentagona* Spring, Panigrahi 35584 (BSI, Shillong); Burkill 36291 (BSI, CAL); Mukherjee K 53 (Kalyani University).

*Selaginella miniatospora* (Dalz.) Baker, Sen K48 (Kalyani University).

Epidermal studies were made from cleared leaf materials. Clearings were made with 1% to 2% NaOH solution, washed in distilled water and bleached in 2% Sodium hypochlorite (NaOCl) solution. Cleared materials were stained with 1% aqueous Safranin for observation. For anatomical studies materials were fixed in formalin-acetic acid-alcohol (FAA) and the customary method of paraffin sectioning was followed (Johansen, 1940). Sections were stained in Safranin & Orange G. Light microscopic study of spore morphology was based on acetolysed preparation following Erdtman (1952). Measurements mentioned are from unactolysed spores.

## OBSERVATIONS

Key to the investigated species of *Selaginella* -

A. Sporophylls uniform and without any laminal flap:

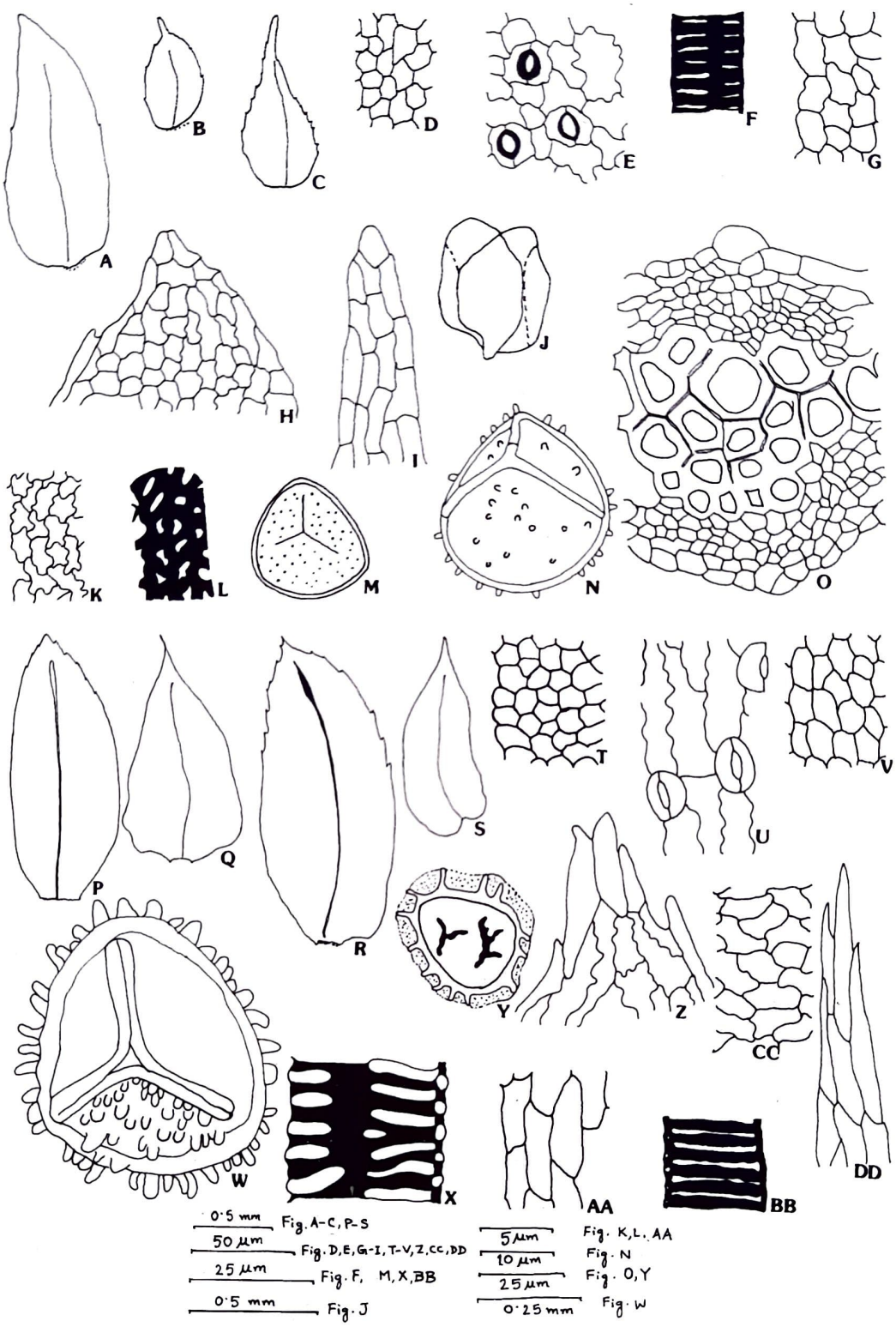
B. Stem with a single vascular cylinder .....2. *S. pentagona*

BB. Stem with more than one vascular cylinder ...1. *S. delicatula*

AA. Sporophylls dimorphic and the larger sporophylls bear laminar flap on the adaxial surface .....3. *S. miniatospora*

1. *Selaginella delicatula* (Desv. ex Poir.) Alston, Journ. Bot. **70**: 282. 1932.

The plants are suberect, about 60cm long, pale green but become strameneous on drying. Branches are lax and copiously arise from the base of the stem. The leaves are dimorphic throughout the plant, pale green, membranaceous and are distantly placed on the mainstem but are contiguous on the branches. The lateral leaves are oblique, oblong, acute and minutely denticulate towards the distant margin (Text-Fig. 1 R,




Text-Fig.1

A–O: *Selaginella pentagona* Spring

A. A lateral leaf. B. A median leaf. C. A sporophyll D. Adaxial epidermal cells of a lateral leaf. E. Abaxial epidermal cells and stomata of a lateral leaf. F. Part of a scalariform tracheid. G. Adaxial epidermal cells of a median leaf. H. Distal part of a lateral leaf. I. Distal part of a median leaf. J. A microsporangium after dehiscence. K. Cells of a microsporangial surface. L. Cells of a megasporangial surface. M. A microspore. N. Proximal surface of a megaspore. O. Part of a cauline stele in transaction.

P–DD: *Selaginella delicatula* (Desv. ex Poir) Alston

P. An axillary leaf. Q. A sporophyll. R. A lateral leaf. S. A median leaf. T. Abaxial epidermal cells of a median leaf. U. Abaxial epidermal cells of a lateral leaf. V. Adaxial epidermal cells of a lateral leaf. W. Proximal surface of a megaspore. X. Part of a scalariform tracheid. Y. A microspore. Z. Distal part of a lateral leaf. AA. Cells of microsporangial surface. BB. Part of a scalariform tracheid. CC. Cells of a megasporangial surface DD. Distal part of a median leaf.

Z). The abaxial epidermal cells are long and sinuous (Text-Fig.1 U) whereas those of the adaxial surface are short with straight walls (Text-Fig. 1 V). Marginal cells of the lateral leaves bear warty thickenings. The unbranched midrib is narrow at the base but widens at the distal part (Text-Fig. 1 R). The median leaves are unequal, entire, ascending, elliptic and aristate (Text-Figs1S, DD). The epidermal cells of the abaxial surface are small in comparison to those of the adaxial surface (Text-Fig. 1 T). The median and lateral leaves are hypostomatic. The axillary leaves are symmetrical and resemble the lateral leaves (Text-Fig. 1 P).

The stem is glabrous and sulcate bearing three meristeles, the middle one being the largest. Each meristele is suspended within lacuna and is traversed by three or four celled trabecular filaments. The meristeles are laterally flattened and with exarch xylem. Metaxylem tracheids are scalariformly thickened (Text-Fig. 1 X, BB).

Strobili are 10 to 15 mm long, 1 to 2 mm in diameter and consist of uniform sporophylls; sporophylls are ovate, acuminate, entire (Text-Fig. 1 Q) and hypostomatic. Sporangia are bivalved. The micro- and megasporangia have no regular sequence of distribution within a strobilus. The cells of mega- and microsporangia are thin and straight (Text-Figs 1 AA, CC).

There are four megaspores within a megasporangium. Megaspores are dull brown, trilete, baculate and are about 380 μm in diameter (Text-Fig. 1. W). Microspores many, trilete, perisporate, 30 μm to 35 μm in size and long baculate (Text-Fig. 1 Y). Roots are long and originate in a manner like the stilt roots. All the aerial roots are confined to a few basal angle meristems.

*Distribution and Ecology*–This species is found in many states of India (Andaman & Nicobar Islands, Assam, Goa, Karnataka, Kerala, Maharashtra, Sikkim, Tamilnadu and Tripura). Plants are shade loving and grow mainly in the tropical and subtropical areas.

2. *Selaginella pentagona* Spring, Mem. Acad. Sci. Belg. **24**(2), 150, 1850.

The plants are terrestrial, trailing, 30 to 50cm long, decumbent at base and erect above. They are stramineous brown when dry; unbranched in basal regions but branched above. The branches are distant and decompound.

The leaves are ligulate, microphyllous and strongly dimorphic. At the base of the main stem, size difference of the leaves is not pronounced. Lateral leaves are distant on the mainstem but contiguous on the branches. All leaves are ascending, oblique, ovate, subacute, bright green, moderately firm in texture and with serrulate margins (Text-Figs 1 A, H). Foliar epidermal cells of the adaxial surface are very small, quadrangular to hexagonal in surface view and smooth (Text-Fig. 1 D), while abaxial cells are sinuous, long and having conical thickenings (Text-Fig. 1 E). Stomata are anomocytic and occur in 4 to 5 rows along the surface of the midrib on the abaxial surface. The inner wall of the guard cells surrounding the stomatal pore is considerably thick-walled (Text-Fig. 1 E).

The axillary leaves are ovate, symmetrical and denticulate. Stomata are like those of lateral leaves. The median leaves are small, ovate, margin slightly dentate with small aristate tips. The adaxial epidermal cells of the median leaves are small quadrangular to hexagonal with slightly sinuous margin (Text-Figs 1 B, G, I).

Stem is glabrous. In transaction the epidermis shows one layered thick-walled cells. Cortex is divisible into two zones. Cells of the outer cortex are two to three layered and are moderately thick-walled. Cells of the inner cortex are wavy to sinuous in outline, thin-walled and a few cells deep. The stem is monostelic and the vascular cylinder is laterally flattened (Text-Fig.1 O). The protoxylem elements lie at two peripheral extreme points of the flattened xylem mass and at midway between these points. Metaxylem tracheids are scalariformly thickened (Text-Fig 1 F); protoxylem elements are helically thickened. Protoxylem tracheids with two helically bands running in opposite direction are also found. Two to three layers of conjunctive parenchyma are also present between xylem and phloem layers. Parenchymatous pericycle two layers thick. Stele is suspended in the lacuna and is connected with the inner cortex by a few trabecular filaments.

The strobili are quadrangular, 6 to 7 mm in length 1 to 2 mm in diameter. The sporophylls are uniform (monomorphic), ovate, acute and dentate (Text-Fig. 1 C). Strobili are bisporangiate. Megasporangia occur at the proximal regions of the strobilus, while the microsporangia occupy the distal position.

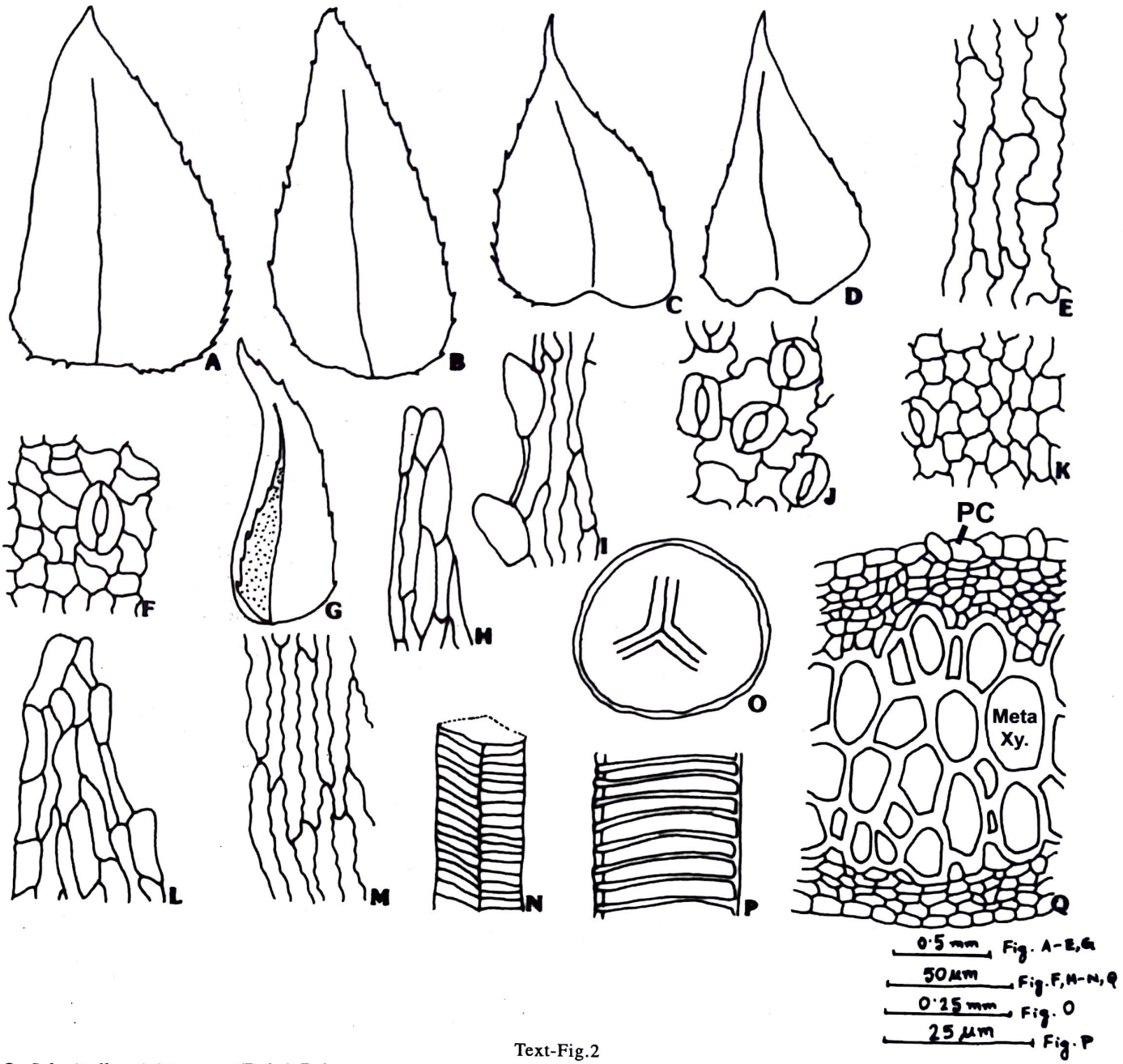
Microsporangia are bivalved (Text-Fig. 1 J) and the cells composing the microsporangial wall are thin and sinuous (Text-Fig. 1 K). Cells of the megasporangial wall are thick-walled (Text-Fig. 1 L). There are four megaspores in a megasporangium. Megaspores whitish, baculate, 250 μm to 300 μm in diameter (Text-Fig. 1 N). Microspores many, orange red in colour, trilete, verrucoid and 30 μm to 35 μm in diameter (Text-Fig. 1 M).

Roots are confined at the basal part of the plant.

*Distribution and Ecology*: This species is confined in the Eastern India (Arunachal Pradesh, Meghalaya). Grows on moist laterite soil, under shade on hill slopes.

3. *Selaginella miniatospora* (Dalz.) Baker, Jour. Bot. **23**: 249. 1885.

The plants are erect; 10 to 20 cm long, copiously branched from the base. The branches are compound. The leaves are dimorphic throughout, bright green and membranaceous. Lateral leaves are oblique, ovate-oblong, subacute and have dentate margins (Text-Figs 2 A, L). The epidermal cells of the adaxial surface are smaller than those of the abaxial surface (Text-Figs 2 J, K). Lateral leaves are amphistomatic. Marginal cells are thick-walled and bear warty thickenings on the




Text-Fig.2

A–Q, *Selaginella miniatospora* (Dalz.) Baker

A. A lateral leaf. B. An axillary leaf. C. A median leaf. D. A smaller sporophyll E. Adaxial epidermal cells of a median leaf. F. Abaxial epidermal cells of a median leaf. G. A larger sporophyll with laminal flap. H. Distal part of a smaller sporophyll. I. Margin of a larger sporophyll. J. Abaxial epidermal cells of a lateral leaf with stomata. K. Adaxial epidermal cells of a lateral leaf. L. Distal part of a lateral leaf. M. Abaxial epidermal cells of a smaller sporophyll. N. Tracheid with scalariform thickenings. O. A megaspore in proximal view. P. Tracheid with scalariform thickenings. Q. Part of a flattened cauline vascular cylinder.

surface. The midrib is composed of tracheids with helical bands and a few narrow, elongated, thin-walled parenchymatous cells.

The median leaves are ovate, acuminate and have dentate margins (Text-Fig. 2 C). Epidermal cells of the abaxial surface are small, rectangular and and have straight to minutely wavy walls (Text-Fig. 2 F). Epidermal cells of the adaxial surface are, however, long and have sinuous walls (Text-Fig. 2 E). Marginal cells of the epidermis are warty and thick-walled. Median leaves are hypostomatic and stomata occur throughout their lamina. The axillary leaves are symmetrical, ovate, acuminate and bear dentae at their margins (Text-Fig. 2 B). Marginal cells bear conical warty thickenings. Axillary leaves are hypostomatic and stomata are distributed along the midrib in 5 to 6 rows. Epidermal cells are like those of the lateral leaves.

The stem is very slender, terete and glabrous. Epidermis unilayered and is composed of small thick-walled cells. Outer

cortex is parenchymatous and consists of hexagonal cells with moderately thick walls. The cells of the inner cortex are thin-walled. The single cauline vascular strand is laterally flattened with exarch xylem (Text-Fig. 2 Q) . Phloem is separated from the xylem mass by 2 to 3 layers of conjunctive parenchyma. Pericycle is made up of 2 to 3 layers of parenchymatous cells. Tracheids of metaxylem (Text-Fig. 2 N, P) are scalariformly thickened.

The strobili are copious, short and resupinate. Strobili are about 6 mm long and 2 mm in diameter. The sporophylls are dimorphic. The smaller sporophylls are broadly ovate, acuminate (Text-Fig. 2 H), dentate (Text-Fig. 2 I) and hypostomatic, while the larger sporophylls are broadly ovate, acuminate, rhomboid, acute and dentate (Text-Figs 2 D, G). The abaxial epidermal cells of the smaller sporophylls are elongated and sinuous (Text-Fig. 2 M). A laminal flap is borne on the adaxial surface of the larger sporophylls, which are amphistomatic (Text-Fig. 2 G). Strobili bisporangiate; megasporangia are borne on a few proximal sporophylls of the strobilus. Usually four megaspores develop within a megasporangium out of which two are distinctly smaller in size. Megaspores are about 200 μm in diameter, trilete, dull yellow in colour, perisporate and have apparently smooth exine (exospore) (Text-Fig. 2 O). Microspores many, trilete, deep yellow, 20 μm to 30 μm in diameter and verrucate.

Roots develop from a few basal angle meristems.

*Distribution and Ecology*–The species is endemic to India and is mainly found in Goa and Maharashtra. The plants grow in subtropical forest and are shade loving.

## DISCUSSION

Out of these three studied species, two species, viz., *S. delicatula* and *S. pentagona* belong to the subgenus Stachygynandrum due to the presence of heteromorphic leaves and uniform (monomorphic) sporophylls. While the other species, *S. miniatospora* belongs to the subgenus Heterostachys due to its resupinate strobilus bearing dimorphic sporophylls (Baker, 1887; Walton & Alston, 1938). It is interesting to note that the larger sporophylls of *S. miniatospora* bear laminal flap. Laminal flap is a vertical extension of laminar tissue on the adaxial surface of the larger sporophyll attached along the midrib. The implications of the presence of laminal flap in species of *Selaginella* having dimorphic sporophylls are not only to provide nourishment to the developing megagametophytes by increasing the photosynthetic area but also it acts as a contrivance for capturing the microspores by its marginal hairs so that germination of the microspores at close vicinity of the megaspores is possible (Mukhopadhyay & Sen, 1981). Most Indian species of *Selaginella* are monostelic and at the very young stage the vascular strand is always single. That derivation of multistranded vascular cylinder from monostelic condition takes place through schizogenous splitting of the vascular strand has been explained in *S. fulcrata* (Mukhopadhyay & Sen, 1986). Thus, multistranded vascular cylinder which is found in *S. delicatula* may be considered as an advanced condition over the monostelic stems of *S. pentagona* and *S. miniatospora*. Arrangements of micro- and megasporangia in the strobili of different species of *Selaginella* have been studied in detail by Horner (1961, 1962) and Horner and Arnott (1963) and Mukhopadhyay (1997). Horner and Arnott (1963) classified four patterns (Type I to Type IV) of arrangements of micro- and megasporangia in the strobili of *Selaginella*. Type I represents strobilus with a few basal megasporangia followed by distal microsporangia. Type II represents strobilus with two vertical tiers of megasporangia and two tiers of microsporangia. Type III denotes entirely megasporangiate or microsporangiate strobili and Type IV represents strobili with haphazard arrangement of micro- and megasporangia. Type I is considered as the basic type of arrangement as it is present in members of all the four subgenera of *Selaginella* and probably has given rise to other types of arrangements (Mukhopadhyay, 1997). *S. pentagona* and *S. miniatospora* are having Type I mode of arrangement of sporangia and may be considered as primitive than *S. delicatula* possessing Type IV sporangial arrangement.

## REFERENCES


Alston AHG, 1945. An enumeration of the Indian species of *Selaginella*. *Proc. Nat. Sci. India* **11**(3): 211–235.

Baker JG, 1887. *Handbook of Fern Allies*. George Bell and Sons, London.

Chowdhury NP, 1957. Observation on the structure and ecology of a xerophytic *Selaginella* from India, Burma and Ceylon (*S. wightii* Hieron.). *Bull. Bot. Soc. Bengal.* **11**: 41–48.

Chowdhury NP, 1959. Observation on the structure and ecology of a xerophytic *Selaginella* from India I. *Selaginella bryopteris* (L.) Baker. *Jap. Jour. Bot. Tokyo* **17**: 101–119.

Dixit RD, 1992. *Selaginellaceae of India.* Bishen Singh Mahendra Pal Singh, Dehra Dun.

Duerden H, 1934. On the occurrence of vessels in *Selaginella*. *Ann. Bot.* **48**: 459–465.

Erdtman G, 1952. *Pollen Morphology and Plant Taxonomy*. Chronica Bot. Co. Waltham Mass. USA.

Gopalakrishnan V & Ravi S, 1990. Comparative anatomy of some species of *Selaginella* P. Beauv. *Indian Fern J.* **7**: 94–99.

Harvey-Gibson RJ, 1894. Contribution toward a knowledge of genus *Selaginella* Spr. The Stem. *Ann. Bot.* **8**: 133–206.

Harvey-Gibson RJ, 1896. Contribution toward a knowledge of genus *Selaginella* Spr. The ligule. *Ann. Bot.* (Lond.) **10**: 77–78.

Harvey-Gibson RJ, 1897. Contribution toward a knowledge of genus *Selaginella* Spr. The leaf. *Ann. Bot.* (Lond.) **11**: 123–155.

Harvey-Gibson RJ, 1902. Contribution toward a knowledge of genus *Selaginella* Spr. The root. *Ann. Bot.* **16**: 446–449.

Horner HT Jr, 1961. Sporangial arrangement in two species of *Selaginella*. *Amer. J. Bot.* **48**: 534.

Horner HT Jr, 1962. Pattern of sporangial arrangement in North American species of *Selaginella*. *Amer. J. Bot.* **49**: 660.

Horner HT Jr & Arnott HJ, 1963. Sporangial arrangement in North American species of *Selaginella*. *Bot. Gaz.* **124** (5): 371–383.

Jermy AC, 1990. Selaginellaceae. In: Kramer KU & Green PS (Eds). *The Families and Genera of Vascular Plants*, pp. 39–45. Springer- Verlag, Berlin.

Johansen DA, 1940. *Plant Microtechnique*. Mc Graw Hill Book Co., NY and London.

Majumdar GP, 1931. On the origin of medullation in *Selaginella* Spr. and the stelar theory. *Proc. 18th Indian Sci. Congr.*, Nagpur : 268.

Majumdar GP, 1942. On the origin of siphonostele in three species of *Selaginella* Spr. *Proc. Nat. Acad. Sci. SG Indian Sci* (B). **15** (4): 172–176.

Mickel JT & Hellwig RL, 1969. Actino-Plectostely a complex newer pattern in *Selaginella*. *Amer. Fern. J.* **59** (3): 123.

Mital PL, 1969. Epidermal studies in the *Selaginella* Beauv. *Bull. Bot. Surv. India.* **11**: 150–160.

Mitchell G, 1910. Contribution toward a knowledge of the anatomy of *Selaginella*. Part V. The Strobilus. *Ann. Bot.* **24**: 19 – 33.

Mukhopadhyay R, 1991-92. Morphological and anatomical studies of Indian homophyllous members of *Selaginella* P. Beauv. *Burdwan Uni. Sci. J.* **6-7**: 98–107.

Mukhopadhyay R, 1997. Pattern of sporangial arrangement and their evolution in some Indian members of *Selaginella* Beauv. *Sci. & Cult.* **63** (11-12): 289-290.

Mukhopadhyay R, 2002. Morpho-anatomical observations on some Indian members of *Selaginella* Pal. Beauv., *In*: Trivedi PC. (Ed) *Advances in Pteridology*, pp 234-247, Pointer Publishers, Jaipur, India.

Mukhopadhyay R & Das Anupam, 2004. Morpho-anatomical studies on some Indian species of *Selaginella* Pal. Beauv. *Phytomorphology* **54** (1 & 2): 39-49.

Mukhopadhyay R & Goswami N, 1996. Cytotaxonomical observations on *Selaginella* P. Beauv. *Indian Fern J.* **13**: 22-29.

Mukhopadhyay R & Sen U, 1981. The occurrence of laminal flap in *Selaginella*. *Fern Gaz.* **12** (3):180-181.

Mukhopadhyay R & Sen U, 1986. On the anatomy and phylogeny of *Selaginella* Palisot de Beauvois. *Indian Fern J.* **3**: 60-69.

Ogura Y, 1972. *Comparative Anatomy of Vegetative Organs of Pteridophytes*. Gebruder Borntrager, Berlin

Panigrahi G & Dixit RD, 1966. Studies in the systematics of Indian *Selaginella*-III. *Proc. Nat. Acad. Sci. India* **36** (B) : 102-108.

Panigrahi G & Dixit RD, 1967. Studies in the systematics of Indian *Selaginella*-II. *J. Indian Bot. Soc.* Vol. **XLVI**, Nos (2-3) 222-233.

Panigrahi, G & Dixit, RD 1968. Studies in the systematics of Indian *Selaginella*-I. *Nat. Inst. Sci. India*. **34** (B) (4). 191-201

Uphof, JCT, 1920. Root of *Selaginella*. *Ann. Bot.* **34**: 493-517.

Walton J & Alston, AHG, 1938. Lycopodineae Selaginellaceae, *In*: Verdoon F & Nijhoff M (Ed.). *Manual of Pteridology*. pp. 503-504. The Hague.

Webster TR & Steeves TA, 1963. Morphology and development of root of *S. densa* Rydb. *Phytomorphology* **13**: 367-375.

Webster TR & Steeves TA, 1964. Developmental morphology of the root of *S. kraussiana* A. Br. and *S. wallacei* Hieron. *Can. J. Bot.* **42**: 1665-1676.

Webster TR & Steeves TA, 1967. Developmental morphology of the root of *S. martensii* Spr. *Can J. Bot*. **45**: 395-404.

Worsdell WC, 1910. The rhizophore of *Selaginella*. *New Phytol.* **9**: 242-252.