



УДК 582.382+581.96(513.21)

Selaginella submonospora (Selaginellaceae), a new species from Yunnan

A. P. Shalimov^{1,2}, X.-C. Zhang^{2,3*}

¹ Altai State University, Lenina Pr., 61, Barnaul, 656049, Russian Federation. ORCID iD: <https://orcid.org/0000-0002-8806-5217>

² State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany, Chinese Academy of Sciences (CAS), Beijing, 100093, China

³ E-mail: zhangxc@ibcas.ac.cn; ORCID iD: <https://orcid.org/0000-0003-3425-1011>

* Corresponding author

Keywords: China, Lycopodiophyta, new species, *Selaginella submonospora*, Selaginellaceae, taxonomy.

Summary. *Selaginella submonospora* is described as a new species from western Yunnan (China) based on morphological and molecular evidence. It is morphologically similar to *S. subdiaphana* (Wall. ex Hook. et Grev.) Spring, *S. monospora* Spring, and *S. hezhangensis* P. S. Wang et X. Y. Wang. *Selaginella submonospora* can be distinguished by its leaves with short denticulate-ciliolate margins, dorsal leaves obliquely subcordate at base, short acuminate at apices, and ventral leaf oblique at base. Furthermore, the phylogenetic analysis based on the concatenated chloroplast genes *rbcL*, *atpI*, and *psbA* supported that *S. submonospora* is a distinct species and closely related to *S. monospora*.

Selaginella submonospora (Selaginellaceae) – новый вид из Юньнани

А. П. Шалимов^{1,2}, С.-Ч. Чжан²

¹ Алтайский государственный университет, просп. Ленина, д. 61, г. Барнаул, 656049, Россия

² Лаборатория систематики и эволюционной ботаники, Институт ботаники Китайской Академии наук, г. Пекин, 100093, Китай

Ключевые слова: Китай, новый вид, таксономия, Lycopodiophyta, *Selaginella submonospora*, Selaginellaceae.

Аннотация. На основе морфологических и молекулярных данных представлено описание нового вида *Selaginella submonospora*, найденного на западе провинции Юньнань (Китай). *Selaginella submonospora* морфологически близок к *S. subdiaphana* (Wall. ex Hook. et Grev.) Spring, *S. monospora* Spring и *S. hezhangensis* P. S. Wang et X. Y. Wang, от которых отличается коротко реснитчато-зубчатым краем листьев, кососердцевидными в основании и коротко заостренными дорзальными листьями, а также косыми в основании вентральными листьями. Кроме того, филогенетический анализ, основанный на объединении хлоропластных генов *rbcL*, *atpI* и *psbA* подтверждает, что *S. submonospora* – это самостоятельный вид, который близко родственен *S. monospora*.

Introduction

Selaginella P. Beauv. (Selaginellaceae Willk.) is the largest genus of lycophytes, with ca. 750 species (Jermy, 1986). Species of *Selaginella* are distributed all over the world and diversified mainly in tropical and subtropical humid habitats.

Himalaya is one of the biodiversity centers of the world. In previous studies, 58–62 *Selaginella* species have been recorded in India (Alston, 1945; Dixit, 1992). Recently, Shalimov et al. (2019) revised the *Selaginella* of Nepal and recognized 25 species. When we prepared the treatment of Selaginellaceae for the “Flora of Pan-Himalaya”,

we examined the materials of *S. subdiaphana* (Wall. ex Hook. et Grev.) Spring from Yunnan, which represented a new record for China (Zhang, 2018). These reports were based on two collections, Xian-Chun Zhang et al. 8110 and Xian-Chun Zhang et al. 8111 (both – PE), the latter being morphologically different from the former. We also found out several earlier collections of *S. subdiaphana* from China, which were identified as *S. heterostachys* Baker, *S. chrysocaulos* (Hook. et Grev.) Spring, *S. leptophylla* Baker, or *S. kurzii* Baker, highlighting the difficulty in identification. Here, we tried to integrate evidences from morphological characters and molecular data to study those collections and delimitate *S. subdiaphana* and related species.

Material and methods

Specimens for morphological studies were obtained from our original collections and the herbaria E, K, KUN, KYO, L, PE, PYU, SABG, TI, and US (acronyms follow Thiers, 2022), as well as high resolution scanned images from the websites of GBIF (<https://www.gbif.org/>).

All morphological characters were observed and photographed with a Nikon DXM 1200F camera connected to a stereomicroscope (Nikon SMZ 1000) and computer, measurements were done by D 3.10 (<http://www.nikoninstruments.com>). Spore surfaces were observed using scanning electron microscopy (SEM). The spores were taken from mature sporangia and mounted on double-sided sticky tape, and sputter-coated with gold palladium. Spores were photographed and measured under different magnifications using a Hitachi S-4800 at 10–20 kV.

Phylogenetic analyses

For molecular analyses, a total of 72 individuals were included, representing 31 anisosporophyllous species. Outgroups were chosen based on the framework of Weststrand and Korall (2016) including *S. laxistrobila*, *S. nipponica*, *S. delicatula*, *S. remotifolia* and *S. kraussiana*. Detailed voucher information and GenBank accession numbers were listed in Appendix.

Total genomic DNA was isolated from silica-dried material using the Plant Genomic DNA Kit (Tiangen Biotech, Beijing, China) following the manufacturer's protocol, and the primers and PCR condition of three chloroplast genes (*rbcL*, *atpI*, and *psbA*) and phylogenetic methods in this study were performed as those described in Shalimov et al. (2019). Maximum likelihood (ML) and Bayesian inference (BI) methods were used to reconstruct the

phylogenetic trees. ML analyses were performed using RAxML v.7.2.6 (Stamatakis, 2014), and BI analyses were carried out using MrBayes v.3.2.6 (Ronquist et al., 2012).

Results and discussion

Taxonomic treatment

Selaginella submonospora Shalimov et X.-C. Zhang, **sp. nov.** (Fig. 1).

Diagnosis. *Selaginella submonospora* is similar to *S. subdiaphana* but differs in the acroscopic base of ventral leaf strongly oblique and slightly overlapping the branch (vs. enlarged, broader, strongly overlapping the branch); basiscopic margin denticulate-ciliolate from base to top and acute at apex (vs. entire and acuminate at apex); dorsal leaves broadly ovate (vs. ovate), base oblique subcordate or obtuse (vs. obtuse or slightly subcordate), margin denticulate-ciliolate (vs. ciliolate), and short-acuminate (vs. short-aristate) at apex; axillary leaves elliptic (vs. ovate to broadly ovate) and denticulate at margin (vs. ciliolate).

Holotype: “China, Yunnan, Gongshan, Dulongjiang, alt. 1300–1400 m. 23 I 2017. Xian-Chun Zhang et al. 8111” (PE!).

Description. *Plants terrestrial*, evergreen, creeping, 10–20 cm. *Rhizophores* at intervals throughout length of creeping stem and branches, borne on ventral side in axils of branches. *Main stems* branched from near base or lower part upward, pinnately branched, stramineous, ca. 1 mm in diam. in lower part, terete, not sulcate; primary leafy branches 5–10 pairs, 2 or 3 times pinnately branched, adjacent primary branches on main stem 0.7–1.5 cm apart, leafy portion of main stem including leaves 6–8 mm wide at middle, ultimate branches 2–3 mm wide including leaves. *Axillary leaves* on branches symmetrical, elliptic, 1.1–2.3 × 0.4–1.1 mm, base obtuse, margin denticulate. *Dorsal leaves* asymmetrical, those on main stems slightly larger than those on branches; dorsal leaves on branches distant or approximate, broadly ovate, 0.8–1.7 × 0.6–1.3 mm, not carinate, base oblique subcordate or obtuse, not peltate, margin denticulate-ciliolate, apex shortly acuminate. *Ventral leaves* asymmetrical, those on main stem larger than those on branches, at an angle to top; ventral leaves on branches distant, slightly ascending or spreading, ovate or broadly ovate, 1.5–3.2 × 0.6–1.6 mm, margin denticulate-ciliolate, apex acute; acroscopic base oblique, slightly overlapping stems and branches, margin denticulate-ciliolate,

basiscopic margin denticulate-ciliolate at base, from base to top denticulate. *Strobili* solitary, terminal, compact, dorsiventrally complanate, $3.0\text{--}5.6 \times 1.2\text{--}2.3$ mm; sporophylls dimorphic, resupinate, not white-margined; *dorsal sporophylls* ovate-lanceolate, carinate, margin denticulate-ciliolate, apex acuminate, with sporophyll-ptyeryx complete and denticulate; *ventral sporophylls* ovate-lanceolate, carinate, margin denticulate-ciliolate; megasporophylls in basal portion on lower side of strobilus. Megasporangia in two ventral rows; megasporangia slightly pinkish, papillate on proximal

and distal faces, surface smooth and perforate, with echinate microsculpture, $257\text{--}369$ μm in diam. Microsporangia in two dorsal rows; microspores pale yellow, on proximal and distal faces with verrucate, with two flat-rounded zones on distal face, and with granulate microstructures, main surface with vermiculate microsculpture, $25\text{--}41$ μm in diam.

Etymology. The specific epithet '*submonospora*' refers to its close relation and morphological similarity with *S. monospora*.

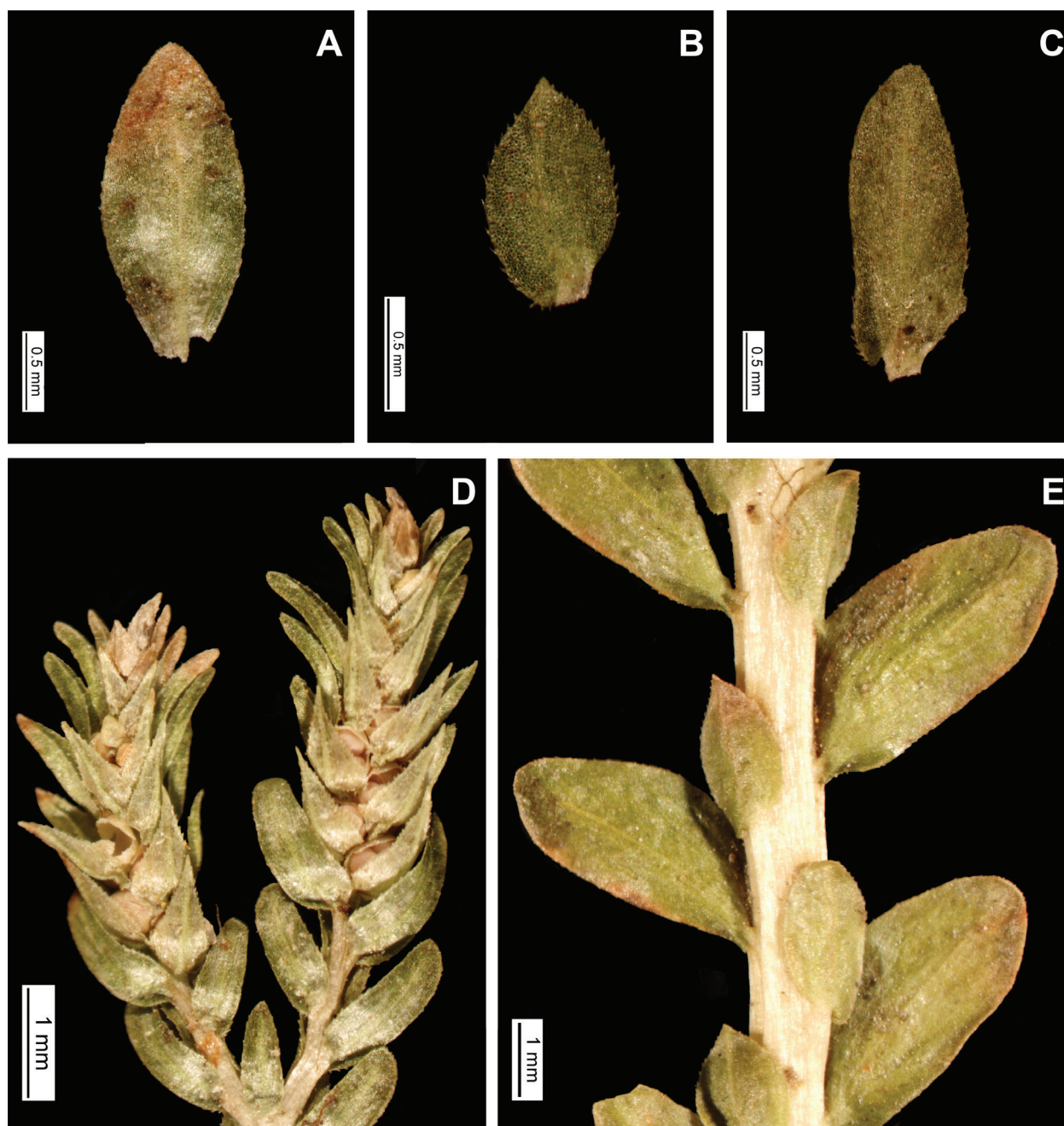


Fig. 1. *Selaginella submonospora* Shalimov et X.-C. Zhang: A – Axillary leaf; B. Dorsal leaf; C – Ventral leaf; D – Strobili; E – Dorsal side of main stem; C–H – from the holotype, Xian-Chun Zhang et al. 8111 (PE).

Distribution and habitat

Conservation status (VU). Known only from Gongshan County in NW Yunnan. Growing on shady rocks at ca. 1300–1800(–2000) m.

Specimens examined

Selaginella submonospora Shalimov et X.-C. Zhang: **CHINA. Yunnan.** “Yunnan, Taron-Täru Divide, Tangtehwang, alt. 1800 m, upon shady rocks. 27 VIII 1938. T. T. Yu 19985” (PE 00244924).

Selaginella hezhangensis P. S. Wang et X. Y. Wang: **CHINA. Gansu.** “Wenxian, Fanba, Yinchang village, 850 m. Y. P. Xu 1823” (PE); “Tianquan, 1600 m. 20 X 1953. X. L. Jiang 37602” (PE 00175951); *ibid.*, “1600 m. 20 X 1953. X. L. Jiang 37602” (PE 00175952); *ibid.*, Erlang Mt., 1650 m. 25 VII 1953. X. L. Jiang 35033” (PE 00175950; PE 00175949); *ibid.*, “Erlang Mt., Lianghekou. 26 VII 1953. X. L. Jiang 35065” (PE); “Luding, 2500 m. 18 IX 1938. T. P. Wang 9777” (PE 00175947); *ibid.*, “Pei 8151” (PE 00175948); “Panzhihua, Daheishan, 2200 m. 2002. X. C. Zhang s. n.” (PE).

Selaginella monospora Spring: **INDIA. Sikkim.** “E Sikkim District. Above and S of Penlang Bazaar, below and on way up to Namphung Peak of the Tinjure ridge, W of Tashi viewpoint, across valley to the north of Gangtok. Just below crest on N side of densely mixed-forest ridge. 29 IX 1998. C. R. Fraser-Jenkins 27054 (FN 3031)” (L.4328985); **C NEPAL. Dolakha.** “Jiri, ca. 2200 m. 4 X 1988. T. Nakaike 3076” (PE); **E NEPAL. Ilam.** “Mai Majuwa-Mai Pokhari-Dhara Pani, 1500–1600 m. 4 XII 1963. H. Hara, H. Kanai, S. Kurasawa, G. Murata, M. Togashi, T. Tuyama s. n.” (KUN 0801546; L.3498103; KYO); **BHUTAN.** “Bootan, W. Griffith 391” (K001067478); “Yuto La, between Bumthang and Trongsa, 8500 ft, Shady banks in deciduous forest. 4 VIII 1949. F. Ludlow, G. Sherriff, J. H. Hicks 17023” (KYO; L.4328981); **CHINA. Yunnan.** “Fudong, Yapping, yapping road 16 km, SW facing 30–60-degree slope, Marble, 27°09′23.1″N, 98°48′21.1″E. On rock hill slope shady place, 2181 m. 7 V 2004. Gaoligong Shan Biodiversity Survey 20365” (KUN 1407314); *ibid.*, “Yaping, Lodging station, E facing 30–60-degree slope. Granite, 27°09′47.9″N, 98°46′57.5″E. Subtropical evergreen broadleaved forest, in forest on rock. 2485 m. 2 V 2004. Gaoligong Shan Biodiversity Survey 20013” (KUN 1407271); *ibid.*, “Lumadeng, ca. 2.8 direct km SSW of the Yaping bridge, on the W side of the Nujiang, ca. 22.5 direct km N of Fugong city, 27°06′28″N, 98°52′11″E, growing in thicket,

moist, near stream in forest shade area, 1255 m. 28 IV 2004. Gaoligong Shan Biodiversity Survey 19963” (E); “Baoshan, Nankang botany garden (Lihuipo), Broadleaved evergreen natural secondary-forest, in forest, 2150 m. 19 XI 2000. H. Li, Z. L. Dao, L. W. Yin 13235” (KUN 1407267); “Tengchong, Dahetou Town, 1914 m. 14 V 2016. Z. D. Fang et al. DJDC-653” (SABG 000034); “Dayao, 2400 m. 1965. W. M. Chu and Y. M. Feng 02280” (PYU); “Heqing, Songgui to Chamugou, Ma'ershan, 2100–2400 m. 1963. NW Yunnan Jinshajiang Team 4675” (PE); *ibid.*, “NW Yunnan. Jinshajiang Team 4668” (PE). **MYANMAR. Kachin.** “Kachin state, 27°31′56.4″N, 96°08′51.1″E, alt. 2393 m. 18 X 2016. T. Y. Nwe et al. Tyn380” (PE); “Kachin state, 27°30′55.2″N, 96°78′03.2″E, alt. 3033 m. 20 X 2016. T. Y. Nwe et al. Tyn410” (PE).

Selaginella subdiaphana (Wall. ex Hook. et Grev.) Spring: **INDIA.** “Dehra Dun, X 1892” (E00823911); “Kumaon, Kali valley, 2–3000 ft, 1984. J. F. Duthie 3726” (E00823913); “Mussoorie, Deosari, 6–7000 ft. 2 IX 1944. R. R. Stewart 21269” (US01393317); **W NEPAL. Dang.** “Between Kurpani and Ghorai, 4000 ft, growing on damp sheltered earth banks. 4 IX 1952. O. Polunin, W. R. Sykes, L. H. J. Williams 1331” (KYO; E00823900; US01393317). **C NEPAL. Myagdi.** “Near Takumsibang, 5000 ft, open slopes among rocks, 30 VIII 1954. Stainton, Sykes, Williams 4077” (E00823901); **Rasuwa.** “Langtang, between Ramche and Betrawati, 800–1800 m. 9 IX 1986. T. Nakaike 1427” (PE); **Kaski.** “en route from Huenda to Naudanda, 1100–1300 m. 21 IX 1976. Y. Suehiro 190” (KYO); **Lalitpur.** “W side of Phulchowki Mt., above and E of Godavari, SE of Kathmandu. Steep slope in light forest above road zig-zags. 2000 m. 30 VI 1996. C. R. Fraser-Jenkins, K. Neupane, J. Bahadur Pariyar, G. (R.) Pariyar, R. Boruwal, R. Pariyar (FN 29)” (US01393313); **Syangja.** “en route from Hyenda to Naudanda, 1100–1300 m, 21 X 1976. Y. Suehiro 204” (TI); **Kathmandu.** “Kathmandu, 1350 m. 3 IX 1954. A. Zimmermann 1005” (KYO); **Makawanpur.** “Balephi Khola, 27°50′N, 85°46′E, alt. 1000 m. 22 VIII 1971. J. F. Dobremez DBR NEP 829” (E00670681); **Nuwakot.** “Betrawati [Betrawati], 850 m. 15 IX 1972. A. Maire AMA 450” (E00670578); **Parbat.** “Kusma, on shady banks, 2500 ft. 5 IX 1954. Stainton, Sykes, Williams 7065” (E00823898). **E NEPAL. Taplejung.** “Shewaden (2600 m) – Mewa Khola (2100 m) – Papung (2000 m), ca. 2400 m. 29 VI 1972. H. Kanai et al. 725350B [873274]” (KYO); **Sankhuwasabha.** “Telok, 27°22′N, 87°50′E, alt. 1200 m.

J. F. Dobremez DBR NEP 1323” (E00754785); **Sun-sari**. “Dharan (400 m)-Sanguri Bhanjyang (1300 m). 2 VI 1972. H. Kanai, H. Ohashi, K. Iwatsuki, H. Ohba, Z. Iwatsuki, P. R. Shakya 725032 [872266]” (E00670676; KYO); “Dharan, 26°49’N, 87°18’E, alt. 800 m. 4 IX 1971. J. F. Dobremez DBR NEP 1779” (E00670604); **Morang**. “Chisapini, 26°50’N, 87°55’E, alt. 500 m. 26 IX 1971. J. F. Dobremez DBR NEP 1170” (E00670677); **CHINA. Xizang**. “Nyalam, Zhangmu, 27°34’217”N, 88°55’021”E, 2000 m. 26 X 2008. X. C. Zhang 5298” (PE); **Yunnan**. “Gongshan, 1400 m. 14 VIII 1982. Qinghai-Tibet Team 9336” (PE 00175040; PE 00175041; PE 00175042); *ibid.* “Cangnan watershed, 2300–2500 m. 29 X 1940. Feng 7087” (PE 00175964);

ibid., “Champutung, 2000 m. X 1935. C. W. Wang 66910” (PE); *ibid.* “Binzhongluo, Along the Niwa river gorge N or Bingzhongluo and Shimenguan (Stone Gate) on the W side of the Nu Jiang. E side of Gaoligong Shan. N facing 30–60-degree slope. 28°2’33”N, 98°34’45”E. Mature subtropical evergreen broadleaf forest. Growing on rock face among moss in moist areas. 1750 m. 8 X 2002. Gaoligongshan Biodiversity Survey 17076” (KUN 1407307; KUN 1407305; KUN 1407306); *ibid.* “Cikai, E side of Gaoligong Shan, in Dangdan park above Gongshang. 27°44’23”N, 98°39’33”E. *Pinus yunnanensis* plantation on dryer slopes with remnant broad-leaved evergreen forest in wet draws and moist slopes. Growing on rocks on a steep moist slope.

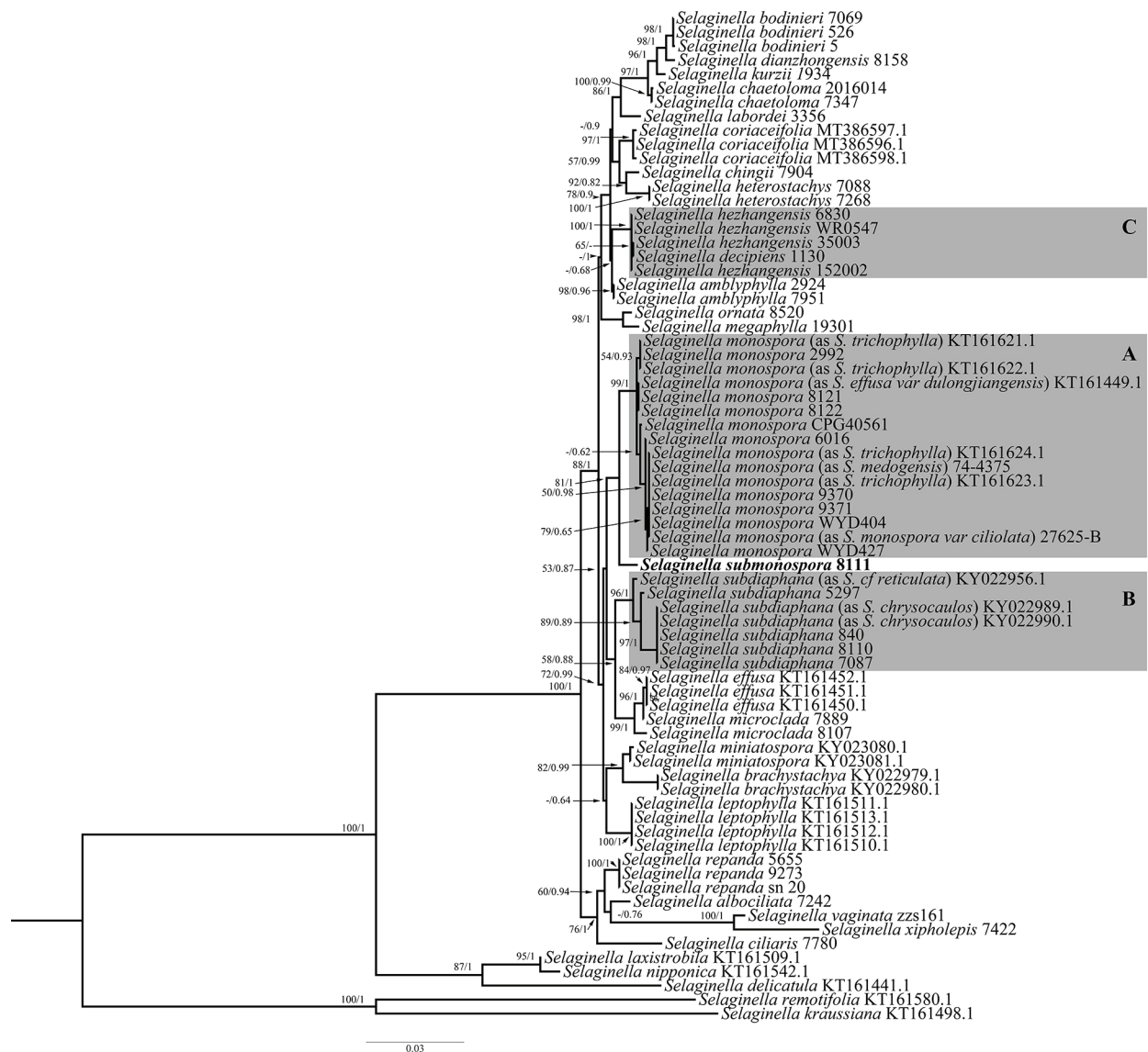


Fig. 2. The 50 % majority rule consensus tree derived from maximum likelihood showing the position of *Selaginella submonospora*. Support values (BS_{ML}/PP_{BI}) are shown above the main branches; the dash (–) indicates BS < 50 %. The three morphologically comparable species are shown in grey.

1600–1700 m. 29 VI 2000. L. Heng 11791” (KUN 1407308); “Fugong, Lumadeng, Yaping, S side of the N fork of Yamu He just above the confluence with the S fork Yamu He, E side of Gaoligong Shan. 27°7′47.4″N, 98°49′45.9″E. Limestone. Growing on wet cliff face above road. 1780 m. 11 VIII 2005. Gaoligongshan Biodiversity Survey 27010” (KUN 1407309); *ibid.*, “below old Shibali on the N side of S. fork of Yamu He, E side of Gaoligong Shan, 27°5′23″N, 98°49′45.9″E. Subtropical evergreen broadleaf forest. Secondary forest and thicket along road. Growing on cliff face above road, 2150 m. 21 VIII 2005. Gaoligongshan Biodiversity Survey 28756” (KUN 1407311); *ibid.*, “Maji, Laowuodong Qiao, 27°29′50″N, 98°49′9″E. Growing by a trail on a rock, 1388 m. 2004. Gaoligongshan Biodiversity Survey 19517” (E00268514).

Phylogenetic Analysis

The combined chloroplast DNA (*rbcL*, *atpI*, and *psbA*) matrix had 2020 characters, with 298 parsimony-informative sites. The topologies obtained from both ML and BI analyses are identical, hence the ML tree is shown in Fig. 2. In contrast to morphological results, the molecular phylogenetic results suggested that the new species is closely related to *Selaginella monospora* (Clade A) with strong support ($BS_{ML} = 81$; $PP_{BI} = 1.0$).

Several samples downloaded from GenBank were identified as *S. cf. reticulata* (Nepal, C. R. Fraser-Jenkins 1653, L), *S. pennata* (India, P. S. Sabharwal s. n., U), and *S. chrysocaulos* (China, Gaoligongshan Biodiversity Survey 27010, GH; H. Li 12202, GH) were grouped with our samples of

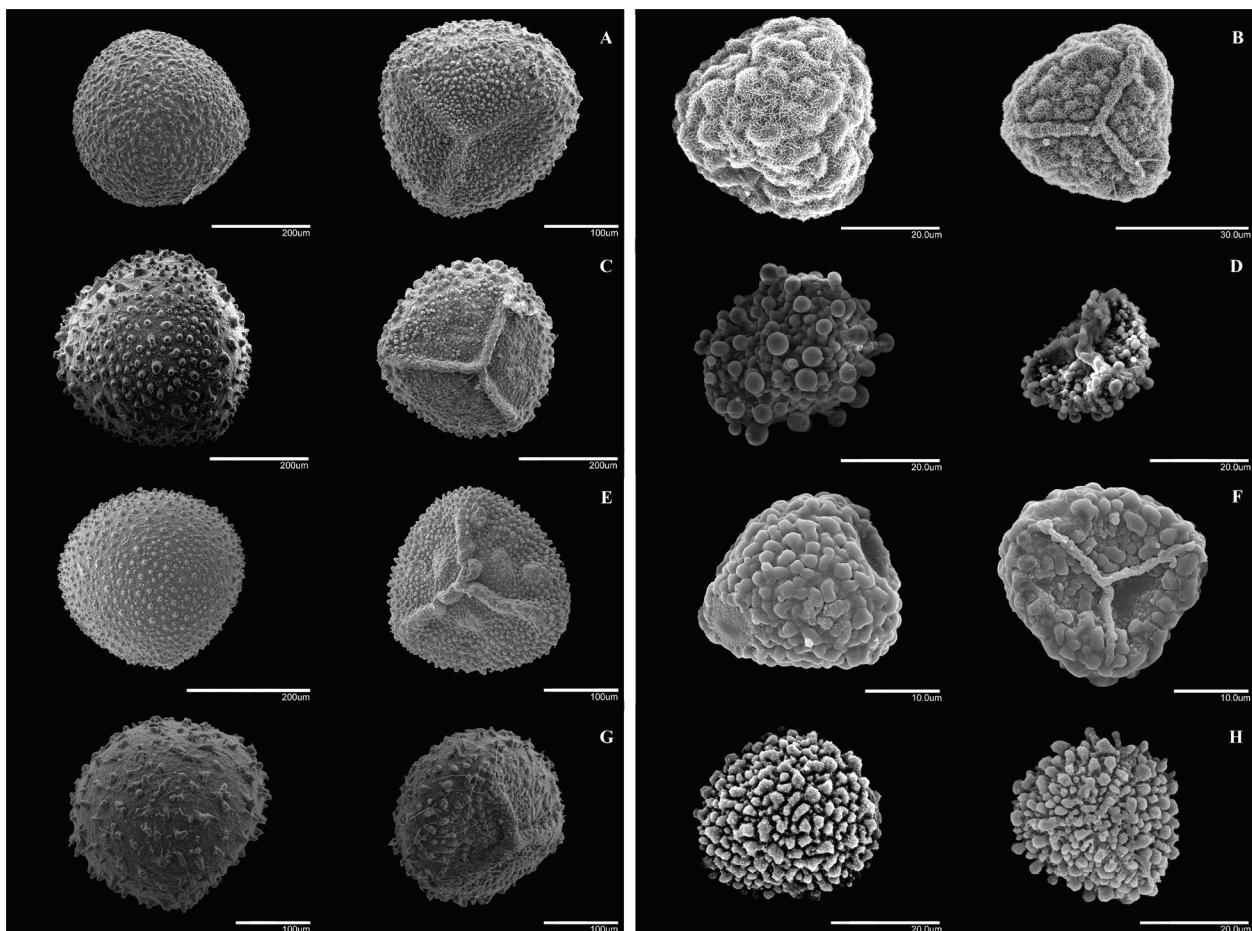


Fig. 3. Spore morphology: **A** – Megaspores of *Selaginella hezhangensis* from X. C. Zhang s. n. (PE); **B** – Microspores of *S. hezhangensis* from X. C. Zhang s. n. (PE); **C** – Megaspores of the paratype of *S. monospora* var. *ciliolata* from Lu & Zhang 27625–B (PE); **D** – Microspores of the paratype of *S. monospora* var. *ciliolata* from Lu & Zhang 27625–B (PE); **E** – Megaspores of the type of *S. submonospora* from Xian-Chun Zhang et al. 8111 (PE); **F** – Microspores of the type of *S. submonospora* from Xian-Chun Zhang et al. 8111 (PE); **G** – *S. subdiaphana* megaspores from Feng 7087 (PE); **H** – *S. subdiaphana* microspores from Feng 7087 (PE).

S. subdiaphana and formed a well-supported clade ($BS_{ML} = 96$; $PP_{BI} = 1.0$). We checked again housed collections based on digital images, taking into ac-

count habitus and gross morphology, and came to the conclusion that they are all of *S. subdiaphana*.

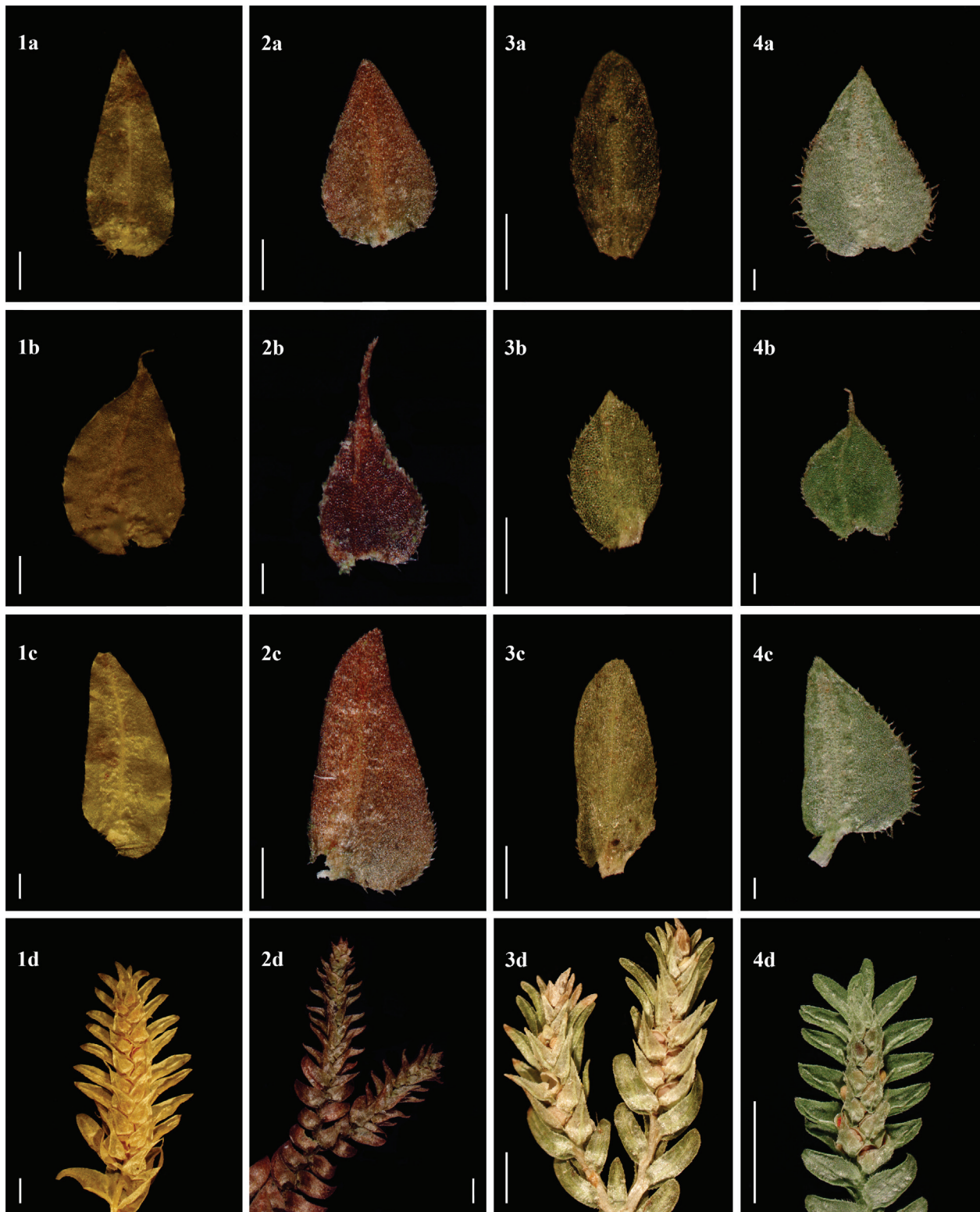


Fig. 4. Differences in leaves and strobilus: **1A–D** – *Selaginella hezhangensis* (X. L. Jiang 35033, PE 00175949); **2A–D** – *S. monospora* (CPG Expedition CPG40561 (Y. J. Lai, Q. Zhang); PE); **3A–D** – *S. submonospora* (Xian-Chun Zhang et al. 8111, PE); **4A–D** – *S. subdiaphana* (Zhang 5, PE). **A** – Axillary leaves; **B** – Dorsal leaves; **C** – Ventral leaves; **D** – Strobili. Scale bars = 0.5 mm (**1A–1C**, **2A**, **2C**, **3A–3C**), 0.2 mm (**2B**, **4A–4C**), 1 mm (**1D**, **2D**, **3D**) and 2 mm (**4D**).

Additionally, *S. submonospora* is also similar to *S. hezhangensis*, especially in the shape of dorsal leaves, however, they are placed in different subclades in the subg. *Stachygynandrum* (Fig. 2, Clade C).

Morphological observations

Spore morphology

The micromorphology of spores of *Selaginella hezhangensis*, *S. monospora*, *S. submonospora*, and *S. subdiaphana* were observed (Fig. 3; Table 1). Megaspores of *S. submonospora* are sub-smooth with slightly perforated surface and with papillate ornamentation and echinate micro-sculptures (Fig. 3E), which is different from the megaspores of *S. hezhangensis* (Fig. 3A), *S. monospora* (Fig. 3C), and *S. subdiaphana* (Fig. 3G). Proximal surface of

megaspores of *S. hezhangensis* is irregularly sized and densely spaced verrucae and the distal side with densely located or interconnected verrucae, covered with vermiculate micro-sculptures. The megaspore morphology of *S. monospora* and *S. subdiaphana* is similar, their megaspore surfaces are covered with verrucae. The microspores of these four species are quite different. The microspores of *S. submonospora* are verrucate, with two flat-rounded zones on distal face, and with granulate micro-structures, surface with vermiculate micro-sculptures (Fig. 3F). Micro-sculptures microspores of *S. hezhangensis* are represented by blunt spinules (Fig. 3B). The microspores of *S. monospora* are covered with verrucate/spherulate ornamentation and with fine reticulate micro-sculptures (Fig. 3F). The microspores of *S. subdiaphana* are covered with irregularly sized verrucae and with reticulate micro-sculptures (Fig. 3H).

Table 1

Morphological characters mega- and microspores of *Selaginella hezhangensis*, *S. monospora*, *S. submonospora*, and *S. subdiaphana*

Characters	<i>S. hezhangensis</i>	<i>S. monospora</i>	<i>S. submonospora</i>	<i>S. subdiaphana</i>
Megaspores				
Megaspores: proximal and distal surfaces	irregularly sized and densely spaced verrucate/densely located or interconnected verrucate	verrucate and/or papillate	papillate	irregularly sized verrucate
Megaspores: microsculptures	vermiculate	vermiculate and densely spinulose	echinate	vermiculate, with spinules
Microspores				
Microspores: proximal and distal surfaces	irregularly sized verrucate	verrucate/spherulate	irregularly sized verrucate with two flat-rounded zones without verrucae	irregularly sized verrucate
Microspores: microsculptures	blunt spinules	fine reticulate	vermiculate	reticulate

Leaf morphology

Selaginella submonospora is morphologically similar to *S. hezhangensis*, *S. subdiaphana*, and *S. monospora*. However, several leaf features, such as ventral leaves ovate or broadly-ovate, apices acute, acroscopic base oblique and not or slightly overlapping the stem; dorsal leaves broadly ovate, margins denticulate-ciliolate, inner margin at bases oblique subcordate or obtuse, and apices shortly acuminate, differentiate the new species from the other three (Table 2; Fig. 4).

Key to *S. submonospora* and related species

1. Plants long creeping, sporophylls slightly dimorphic (sometimes appearing uniform), dorsal leaves ovate-lanceolate or elliptic, obtuse at base, margin denticulate, apex acuminate or shortly aristate ***S. microclada***
- + Plants long creeping or suberect, sporophylls strongly dimorphic, dorsal leaves obliquely ovate-elliptic, broadly ovate-elliptic, or ovate, ciliolate, denticulate or denticulate to ciliolate at margin, apex shortly acuminate, or aristate to cuspidate 2

2. Ventral leaves strongly overlapping branches, acroscopic base denticulate or ciliolate to denticulate at margin 3
 + Ventral leaves not overlapping branches, acroscopic base short denticulate-ciliolate at margin ***S. submonospora***
3. Plants creeping or suberect, 13–25 cm long, vegetative leaves tender, dorsal leaves broadly ovate, obtuse or oblique subcordate at base, margin ciliolate, apex short cuspidate ***S. hezhangensis***
 + Plants erect, creeping, suberect or ascending from decumbent base, dorsal leaves ovate or/to broadly ovate, or obliquely ovate-elliptic, margin denticulate or ciliolate to denticulate, apex aristate or/to cuspidate 4
4. Axillary leaves ovate, ovate-triangular, or ovate-elliptic, ventral leaves oblong or oblong-ovate, acroscopic base enlarged, broader, strongly overlapping branches, margin denticulate ***S. effusa***
 + Axillary leaves ovate or/to broadly ovate, ventral leaves ovate-triangular, oblong or oblong-ovate, margin ciliolate to denticulate 5
5. Ventral leaves ovate-triangular, margin ciliolate, dorsal leaves ovate, base subcordate margin ciliolate, apex aristate to cuspidate ***S. monospora***
 + Ventral leaves ovate to ovate-lanceolate, angled upward, acroscopic base ciliate-dentate, dorsal leaves ovate, base obtuse or slightly subcordate, margin ciliolate to denticulate, apex short aristate ..
 ***S. subdiaphana***

Table 2

Morphological characters of *Selaginella hezhangensis*, *S. monospora*, *S. submonospora* and *S. subdiaphana*

Characters/Species	<i>S. hezhangensis</i>	<i>S. monospora</i>	<i>S. submonospora</i>	<i>S. subdiaphana</i>
<i>Habit</i>	Stems creeping or suberect, 13–25 cm long	Stems creeping, 30–50 cm long	Stems creeping, 10–20 cm long	Stems creeping or suberect, 15–25 cm long
<i>Axillary leaves</i>	Ovate or narrowly ovate, 0.9–2.5 × 0.4–1.7 mm, apex acuminate	Ovate, 1.2–2.5 × 1–2 mm, apex acuminate	Elliptic, 1.1–2.3 × 0.4–1.1 mm, apex obtuse	Ovate to broadly ovate, 1.4–2.7 × 0.6–1.7 mm, apex acuminate
<i>Base of axillary leaf</i>	Base obtuse, white-margined, short ciliolate	Base exauriculate, ciliolate	Base obtuse, denticulate	Base exauriculate, ciliolate
<i>Dorsal leaves</i>	Broadly ovate, 1.2–2 × 0.8–1.4 mm, carinate, apex cuspidate	Ovate, 1.2–1.9 × 0.5–1 mm, not carinate, apex aristate to cuspidate	Broadly ovate, 0.8–1.7 × 0.6–1.3 mm, not carinate, apex shortly acuminate	Ovate, 1.6–1.9 × 0.7–0.9 mm, apex short aristate
<i>Base of dorsal leaf</i>	Obtuse or obliquely subcordate, ciliolate, white-margined	Obtuse or subcordate, ciliolate	Obliquely subcordate or obtuse, denticulate	Obtuse or slightly subcordate, ciliolate
<i>Ventral leaves</i>	Ovate-oblong or oblong, 2.1–4.2 × 1.0–2.1 mm, acroscopic base enlarged, strongly overlapping branch, apex acute	Ovate-triangular, oblong or oblong-ovate, 2–3.2 × 0.8–1.6 mm, acroscopic base enlarged, overlapping branch apex acute	Ovate or broadly-ovate, 1.5–3.2 × 0.6–1.6 mm, acroscopic base oblique, slightly overlapping branch, apex acute	Ovate-triangular, 1.9–3.8 × 0.8–2.1 mm, acroscopic base enlarged, overlapping branch, apex acuminate
<i>Acroscopic margin of ventral leaves</i>	Shortly ciliolate to denticulate	Denticulate, ciliolate	Denticulate-ciliolate	Ciliolate to denticulate
<i>Basiscopic margin of ventral leaves</i>	Shortly ciliolate from base to top	Ciliolate at base, subentire from middle up to top	Denticulate-ciliolate from base to top	Entire
<i>Strobili</i>	4.3–16 × 2.7–4.6 mm	6.0–10 × 1.2–2.3 mm	3.0–5.6 × 1.2–2.3 mm	3.2–12 × 1.4–3.4 mm

Table 2 (end)

Characters/Species	<i>S. hezhangensis</i>	<i>S. monospora</i>	<i>S. submonospora</i>	<i>S. subdiaphana</i>
<i>Dorsal sporophylls</i>	Ovate-lanceolate, carinate, margin ciliolate to denticulate, apex acuminate to acute	Ovate-lanceolate, carinate, margin denticulate, apex acuminate	Ovate-lanceolate, carinate, margin denticulate, apex acuminate	Ovate-lanceolate, margin denticulate, apex acuminate
<i>Ventral sporophylls</i>	Ovate-triangular, carinate, margin denticulate, apex acuminate	Ovate-lanceolate, carinate, margin denticulate	Ovate-lanceolate, carinate, margin denticulate	Broadly ovate, carinate, margin denticulate

Acknowledgements

We express our gratitude to all herbaria visited for making collections available to us; especially to the Royal Botanic Garden Edinburgh (E) for the loan of *Selaginella* collections; and also to GBIF, L, NY, P, US for providing high-resolution digitized

specimen images. The authors thank Meng-Hua Zhang for discussion, manuscript language checking, and help with experiments. The Chinese Academy of Sciences is acknowledged for the doctoral scholarship to the first author, which made it possible carrying out the present study.

REFERENCES

- Alston A. H. G.** 1945. An enumeration of the Indian species of *Selaginella*. *Proceedings of the National Institute of Sciences of India* 11: 211–235.
- Dixit R. D.** 1992. *Selaginellaceae of India*. Dehra Dun, Bishen Singh Mahendra Pal Singh. 196 pp.
- Jermy A. C.** 1986. Subgeneric names in *Selaginella*. *Fern Gazette* 13: 117–118.
- Ronquist F., Teslenko M., Van der Mark P., Ayres D. L., Darling A., Höhna S., Larget B., Liu L., Suchard M. A., Huelsenbeck J. P.** 2012. MrBayes 3.2: Efficient Bayesian phylogenetic inference and model choice across a large model space. *Systematic Biology* 61(3): 539–542. DOI: 10.1093/sysbio/sys029
- Shalimov A. P., Zhu Y.-M., Zhang M.-H., Zhang X.-C.** 2019. *Selaginella dianzhongensis* (Selaginellaceae), a new spikemoss from China. *PhytoKeys* 118: 75–87. DOI: 10.3897/phytokeys.118.30375
- Stamatakis A.** 2014. RAxML Version 8: A tool for phylogenetic analysis and post-analysis of large phylogenies. *Bioinformatics (Oxford, England)* 30(9): 1312–1313. DOI: 10.1093/bioinformatics/btu033
- Thiers B.** [2022]. *Index Herbariorum: A global directory of public herbaria and associated staff*. New York Botanical Garden's Virtual Herbarium. URL: <http://sweetgum.nybg.org/science/ih/> (Accessed 5 January 2022).
- Weststrand S., Korall P.** 2016. A subgeneric classification of *Selaginella* (Selaginellaceae). *American Journal of Botany* 103(12): 2160–2169. DOI: 10.3732/ajb.1600288
- Zhang X.-C.** 2018. Some new records of *Selaginella* from China. *Philippine Journal of Systematic Biology* 12(1): 22–23.

Appendix

Specimen information and GenBank accession numbers (* indicates new accession)

Taxon	Voucher	Country	rbcl	atpI	psbA
<i>Selaginella albociliata</i> P. S. Wang	Zhang X.-C. 7242 (PE)	Guizhou, China	MH814882	MH814826	MH814854
<i>Selaginella amblyphylla</i> Alston	Zhang X.-C. 2924 (PE)	Yunnan, China	MH814883	MH814827	MH814855
<i>Selaginella amblyphylla</i> Alston	Zhang X.-C. 7951 (PE)	Yunnan, China	MH814884	MH814828	MH814856
<i>Selaginella bodinieri</i> Hieron.	Zhang X.-C. 5 (PE)	Chongqing, China	MH814885	MH814829	MH814857
<i>Selaginella bodinieri</i> Hieron.	Zhang X.-C. 526 (PE)	Sichuan, China	MH814886	MH814830	MH814858
<i>Selaginella bodinieri</i> Hieron.	Zhang X.-C. 7069 (PE)	Guizhou, China	MH814887	MH814831	MH814859

Taxon	Voucher	Country	rbcL	atpI	psbA
<i>Selaginella brachystachya</i> (Hook. et Grev.) Spring	W. A. Sledge 913 (L)	Sri Lanka	KY022979	–	–
<i>Selaginella brachystachya</i> (Hook. et Grev.) Spring	J. Klackenberg 434 (S)	Sri Lanka	KY022980	–	–
<i>Selaginella</i> cf. <i>reticulata</i>	C. R. Fraser-Jenkins 1653 (L)	Nepal	KY022956.1	–	–
<i>Selaginella chaetoloma</i> Alston	Guo Z.-Y. 2016014 (PE)	Guizhou, China	MH814888	MH814832	MH814860
<i>Selaginella chaetoloma</i> Alston	Zhang X.-C. 7347 (PE)	Guizhou, China	MH814889	MH814833	MH814861
<i>Selaginella chingii</i> Alston	Zhang X.-C. 7904 (PE)	Guangxi, China	MH814890	MH814834	MH814862
<i>Selaginella chrysocaulos</i> (Hook. et Grev.) Spring	Gaoligong Shan Biodiversity Survey 27010 (GH)	China, Yunnan	KY022989	–	–
<i>Selaginella chrysocaulos</i> (Hook. et Grev.) Spring	H. Li 12202 (GH)	China, Yunnan	KY022990	–	–
<i>Selaginella ciliaris</i> (Retz.) Spring	Zhang X.-C. 7780 (PE)	Yunnan, China	MH814892	MH814836	MH814864
<i>Selaginella coriaceifolia</i> X. M. Zhou, N. T. Lu et Li Bing Zhang	L.-B. Zhang et al. 7307 (CDBI, MO, VNMN)	Quang Binh, Vietnam	MT386596	–	–
<i>Selaginella coriaceifolia</i> X. M. Zhou, N. T. Lu et Li Bing Zhang	L.-B. Zhang et al. 7347 (CDBI, MO)	Quang Binh, Vietnam	MT386597	–	–
<i>Selaginella coriaceifolia</i> X. M. Zhou, N. T. Lu et Li Bing Zhang	L.-B. Zhang et al. 7371 (CDBI, MO, VNMN)	Quang Binh, Vietnam	MT386598	–	–
<i>Selaginella decipiens</i> Warb.	Zhang X.-C. 1130 (PE)	Guangxi, China	MH814893	MH814837	MH814865
<i>Selaginella delicatula</i> Alston	Gao & al. HGX10734 (CDBI)	Sichuan, China	KT161441	–	–
<i>Selaginella dianzhongensis</i> X.-C. Zhang	Zhu Y.-M. 8158 (PE)	Yunnan, China	MH814909	MH814853	MH814881
<i>Selaginella effusa</i> Alston	Zhang 5438 (CDBI)	Guangxi, China	KT161450	–	–
<i>Selaginella effusa</i> Alston	Zhang 5442 (CDBI)	Guangxi, China	KT161451	–	–
<i>Selaginella effusa</i> Alston	Wang 20051 (CDBI)	Guizhou, China	KT161452	–	–
<i>Selaginella effusa</i> var. <i>dulongjiangensis</i> W. M. Chu	Chu & al. 31299 (PYU)	Yunnan, China	KT161449	–	–
<i>Selaginella heterostachys</i> Baker	Zhang X.-C. 7088 (PE)	Guizhou, China	MH814896	MH814840	MH814868
<i>Selaginella heterostachys</i> Baker	Zhang X.-C. 7268 (PE)	Guizhou, China	MH814897	MH814841	MH814869
<i>Selaginella hezhangensis</i> P. S. Wang et X. Y. Wang	FLPH Sichuan Expedition 152002	Sichuan, China	OM864654*	OM864639*	OM864647*
<i>Selaginella hezhangensis</i> P. S. Wang et X. Y. Wang	Jiang X.-L. 35003 (PE)	Sichuan, China	OM864655*	OM864640*	–

Taxon	Voucher	Country	rbcL	atpI	psbA
<i>Selaginella hezhangensis</i> P. S. Wang et X. Y. Wang	Zhang X.-C. 6830 (PE)	Guizhou, China	OM864656*	OM864641*	OM864648*
<i>Selaginella hezhangensis</i> P. S. Wang et X. Y. Wang	Wei R., Yang J. WRO547	Sichuan, China	OM864657*	OM864642*	OM864649*
<i>Selaginella kraussiana</i> (Kunze) A. Braun	Zhou 062 (CDBI)	Yunnan, China, Cult.	KT161498	–	–
<i>Selaginella kurzii</i> Baker	Zhang X.-C. 1934 (PE)	Yunnan, China	MH814898	MH814842	MH814870
<i>Selaginella labordei</i> Hieron. ex Christ	Zhang X.-C. 3356 (PE)	Hubei, China	MH814899	MH814843	MH814871
<i>Selaginella laxistrobila</i> K. H. Shing	Chu et al. 24449 (PYU)	Yunnan, China	KT161509	–	–
<i>Selaginella leptophylla</i> Baker	Zhang 5853 (CDBI)	Guizhou, China	KT161510	–	–
<i>Selaginella leptophylla</i> Baker	Zhang 5199 (CDBI)	Guangxi, China	KT161511	–	–
<i>Selaginella leptophylla</i> Baker	Zhou 011 (CDBI)	Sichuan, China	KT161512	–	–
<i>Selaginella leptophylla</i> Baker	Zhou & al. DJY05380 (CDBI)	Sichuan, China	KT161513	–	–
<i>Selaginella medogensis</i> Ching et S. K. Wu	Qinghai-Xizang Complex Exped. 74-4375 (PE)	Tibet, China	OK247696	–	–
<i>Selaginella megaphylla</i> Baker	Jin X.-H. 19301 (PE)	Tibet, China	MH814901	MH814845	MH814873
<i>Selaginella miniatospora</i> (Dalz.) Baker	C. van Hardeveld and H. H. van derWerff 120 (U)	Tamil Nadu, India	KY023080	–	–
<i>Selaginella miniatospora</i> (Dalz.) Baker	J. Klackenbergh and R. Lundin 567 (S)	Kerala, India	KY023081	–	–
<i>Selaginella microclada</i> Baker	Zhang X.-C. 7889 (PE)	Guangxi, China	MH814902	MH814846	MH814874
<i>Selaginella microclada</i> Baker	Zhang X.-C. et al. 8107 (PE)	Yunnan, China	OK247701	OK247684	OK247716
<i>Selaginella monospora</i> var. <i>ciliolata</i> W. M. Chu	Lu S. G., Zhang G. F. 27625-B (PE)	Yunnan, China	OK247710	OK247693	OK247723
<i>Selaginella monospora</i> Spring	Yan Y.-H. et al. WYD427 (PE)	Guangdong, China	OK247712	OK247695	OK247725
<i>Selaginella monospora</i> Spring	CPG Expedition CPG40561 (PE)	Meghalaya, India	OK247709	OK247692	OK247722.1
<i>Selaginella monospora</i> Spring	Zhang X.-C. et al. 8121 (PE)	Yunnan, China	OK247705	OK247688	OK247720
<i>Selaginella monospora</i> Spring	Zhang X.-C. et al. 8122 (PE)	Yunnan, China	OK247706	OK247689	OK247721
<i>Selaginella monospora</i> Spring	Zhang X.-C. 2992 (PE)	Yunnan, China	OK247703	OK247686	OK247718
<i>Selaginella monospora</i> Spring	Yan Y.-H. et al. WYD404 (PE)	Guangdong, China	OK247711	OK24769	OK247724
<i>Selaginella monospora</i> Spring	Zhang X.-C. 6016 (PE)	Guangxi, China	OK247704	OK247687	OK247719
<i>Selaginella monospora</i> Spring	Wang Y.-R. 9370 (PE)	Hainan, China	OK247707	OK247690	–

Taxon	Voucher	Country	rbcL	atpI	psbA
<i>Selaginella monospora</i> Spring	Wang Y.-R. 9371 (PE)	Hainan, China	OK247708	OK247691	–
<i>Selaginella nipponica</i> Franch. et Sav.	Zhou et al. DJY07479 (CDBI)	Sichuan, China	KT161542	–	–
<i>Selaginella ornate</i> (Hook. et Grev.) Spring	Zhang X.-C. 8520 (PE)	Yunnan, China	MH814903	MH814847	MH814875
<i>Selaginella remotifolia</i> Spring	Zhou 005 (PYU, CDBI)	Yunnan, China	KT161580	–	–
<i>Selaginella repanda</i> (Desv. ex Poir.) Spring	Zhang X.-C. 5655 (PE)	Yunnan, China	MH814904	MH814848	MH814876
<i>Selaginella repanda</i> (Desv. ex Poir.) Spring	Zhang X.-C. 9273 (PE)	Yunnan, China	MH814905	MH814849	MH814877
<i>Selaginella repanda</i> (Desv. ex Poir.) Spring	Li B.-G. sn_20 (PE)	Yunnan, China	MH814906	MH814850	MH814878
<i>Selaginella submonospora</i> Shalimov et X.-C. Zhang	Zhang X.-C. et al. 8111 (PE)	Yunnan, China	OM864660*	OM864646*	OM864653*
<i>Selaginella subdiaphana</i> (Wall. ex Hook. et Grev.) Spring	Zhang X.-C. 5297 (PE)	Tibet, China	OM864658*	OM864643*	OM864650*
<i>Selaginella subdiaphana</i> (Wall. ex Hook. et Grev.) Spring	Wu Y.D. 840 (PE)	Yunnan, China	OM864659*	OM864645*	OM864652*
<i>Selaginella subdiaphana</i> (Wall. ex Hook. et Grev.) Spring	Feng 7087 (PE)	Yunnan, China	–	OM864644*	–
<i>Selaginella subdiaphana</i> (Wall. ex Hook. et Grev.) Spring	Zhang X.-C. et al. 8110 (PE)	Yunnan, China	–	–	OM864651*
<i>Selaginella trichophylla</i> K. H. Shing	Zhang et al. 6784 (CDBI, MO, VNMN, PYU)	Cao Bang, Vietnam	KT161624	–	–
<i>Selaginella trichophylla</i> K. H. Shing	Chu et al. 31925 (PYU)	Yunnan, China	KT161621	–	–
<i>Selaginella trichophylla</i> K. H. Shing	Chu et al. 29310 (PYU)	Yunnan, China	KT161622	–	–
<i>Selaginella trichophylla</i> K. H. Shing	Jiang 318 (PYU, CDBI)	Hainan, China	KT161623	–	–
<i>Selaginella vaginata</i> Spring	Zhang Z.-S. 161 (PE)	Shaanxi, China	MH814907	MH814851	MH814879
<i>Selaginella xipholepis</i> Baker	Zhang X.-C. 7422 (PE)	Guizhou, China	MH814908	MH814852	MH814880