

***Radula* (Radulaceae, Marchantiophyta) in India with three new additions from Arunachal Pradesh in Eastern Himalaya**

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Abstract – Three East and South-east Asian species of the genus *Radula* Dumort., viz. *R. chinensis* Steph., *R. kojana* Steph. and *R. sumatrana* Steph. are newly reported for the Indian bryoflora, from Arunachal Pradesh in Eastern Himalaya. Asexual reproduction through caducous leaves is described for the first time in *R. sumatrana*. Descriptions and illustrations of the three species based on Indian material are presented. A key to the Indian species of *Radula* is provided.

Liverworts / New record / *Radula chinensis* / *Radula kojana* / *Radula sumatrana*

INTRODUCTION

Radula Dumort. is one of the largest genera of liverworts with considerable diversity in the tropical and subtropical regions (Frey & Stech, 2009; Promma & Chantanaorrapint, 2015). It is represented in India by 22 species distributed mostly in the Western Ghats and the Eastern Himalaya, including the North-eastern states. These are *R. acuminata* Steph., *R. acuta* Mitt., *R. assamica* Steph., *R. auriculata* Steph., *R. complanata* (L.) Dumort., *R. formosa* (C.F.W.Meissn. ex Spreng.) Nees, *R. fulvifolia* (Hook.f. & Taylor) Gottsche *et al.*, *R. grandifolia* Steph., *R. japonica* Gottsche ex Steph., *R. javanica* Gottsche, *R. kurzii* Steph., *R. lindbergiana* Gottsche ex C. Hartm., *R. madagascariensis* Gottsche, *R. nilgiriensis* Udar & Dh. Kumar, *R. obscura* Mitt., *R. onraedtii* K.Yamada, *R. pandei* Udar & Dh.Kumar, *R. perrottetii* Gottsche ex Steph., *R. protensa* Lindenb., *R. retroflexa* Taylor, *R. tabularis* Steph., *R. tjobodensis* K.I.Goebel (Yamada, 1979; Manju *et al.*, 2005; Daniels, 2010; Majumdar *et al.*, 2012; Kariyappa & Daniels, 2013; Singh *et al.*, 2015). Of these, *R. nilgiriensis* and *R. pandei* are endemic to India. The reported occurrence of another two species, viz. *R. anceps* Sande Lac. and *R. campanigera* Mont. (Stephani, 1909-1912; Yamada, 1979; Kariyappa & Daniels, 2013) in Indian bryoflora has not been confirmed.

During the course of present study on liverworts and hornworts of Eastern Himalaya, we came across another three species of the genus, viz. *R. chinensis* Steph., *R. kojana* Steph. and *R. sumatrana* Steph. These species, earlier known from

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other East and South-east Asian countries, are described and illustrated for the first time in Indian bryoflora. With these additions, the number of species of the genus *Radula* in India increases to 25, while the East Himalayan bryogeographical region, with 18 species, harbours the maximum diversity.

KEY TO INDIAN SPECIES OF *RADULA*

1. Leaf lobe apex acute-apiculate2
1. Leaf lobe apex rounded3
 2. Leaf lobes ovate-falcate-ovate; cells without trigones; discoid gemmae present on leaf lobe margin*R. kojana*
 2. Leaf lobes ovate; cells with minute to indistinct trigones; gemmae absent*R. acuta*
3. Lobule base auriculate; lobule insertion transverse4
3. Lobule base not auriculate; lobule insertion longitudinal6
 4. Plants with minute, microphyllous secondary and tertiary branches; stem of main shoot 18-23 cells across diameter in cross section; leaf lobule large, orbicular, base strongly auriculate*R. chinensis*
 4. Plants without microphyllous secondary and tertiary branches; stem of main shoot 8-13 cells across diameter in cross section; leaf lobule smaller, base weakly auriculate5
5. Leaf lobules ovate-subquadrate, oblique to stem, apex obtuse*R. auriculata*
5. Leaf lobules ovate-triangular, nearly parallel to stem, apex narrowly obtuse
.....*R. perrottetii*
6. Plants with amentulose branches*R. formosa*
6. Plants without amentulose branches7
7. Leaf lobules with apex abruptly turning away from stem8
7. Leaf lobules with apex not abruptly turning away from stem9
 8. Leaf lobe median cells with indistinct trigones, intermediate thickenings absent; gemmae discoid on ventral surface of leaf lobe; rhizoids numerous*R. protensa*
 8. Leaf lobe median cells with long triradiate trigones and long-subnodulose intermediate thickening; gemmae and rhizoids absent*R. retroflexa*
9. Plants gemmiparous10
9. Plants not gemmiparous16
 10. Perianth inflated, long trumpet-shaped, stem perigynium present11
 10. Perianth usually flat-cylindric, stem perigynium absent13
11. Leaf lobules 1/3 length of leaf lobe, carinal region strongly inflated, rhizoid initial area strongly convex, apex usually truncate*R. tjobodensis*
11. Leaf lobules 1/2 length of leaf lobe, carinal region weakly inflated, rhizoidal initial area weakly convex, apex not truncate12
 12. Leaf lobules obliquely quadrate, apex acuminate; gemmae occurring on ventral surface of leaf lobes*R. acuminata*
 12. Leaf lobules narrowly subtriangular-ligulate or subrhombic, apex subacute; gemmae occurring along ventral margin of leaf lobes*R. assamica*
13. Plants monoicous, small (less than 1 cm long)*R. complanata*
13. Plants dioicous, large (more than 1 cm long)14

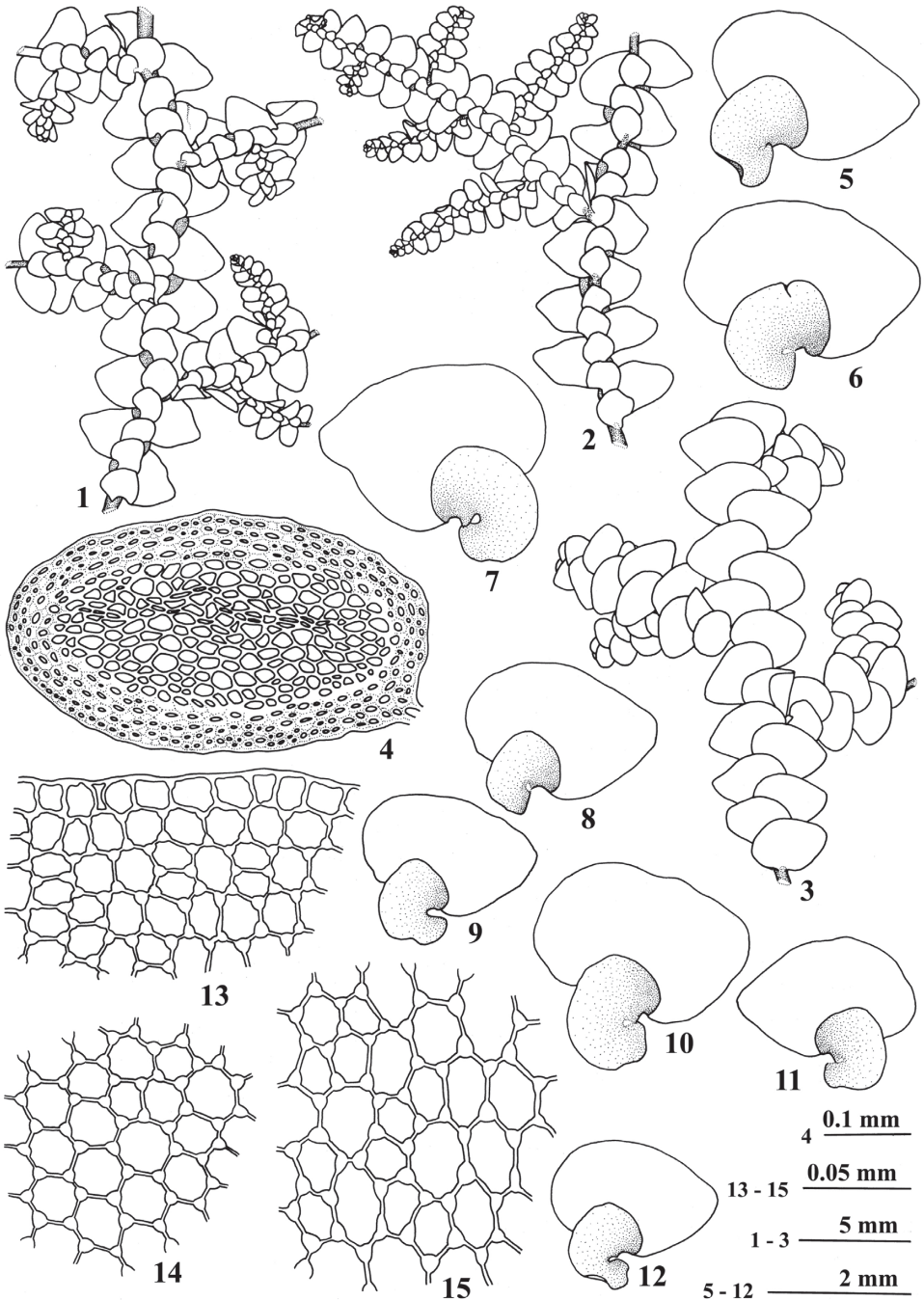
14. Stem in cross section with large trigones; leaf lobe cells with triangular, medium to large trigones; adaxial margin of leaf lobules undulate
.....*R. grandifolia*
14. Stem in cross section with minute trigones; leaf lobe cells with minute trigones; adaxial margin of leaf lobules straight15
15. Stem 5 cells across diameter; leaf lobule rectangulate; inner capsule wall with semiannular thickening bands.....*R. nilgiriensis*
15. Stem 8-9 cells across diameter; leaf lobule quadrate; inner capsule wall without semiannular thickening bands..... *R. lindbergiana*
16. Cortical cells smaller than medullary cells in cross section of stem.....17
16. Cortical cells equal to medullary cells in cross section of stem19
17. Adaxial margin of leaf lobule straight-undulate, widely arched with gibbous base; both cortical and medullary cells thin-walled*R. sumatrana*
17. Adaxial margin of leaf lobule not undulate, slightly arched without gibbous base; both cortical and medullary cells thick-walled.....18
18. Leaf lobes oblong-ovate, usually not incurved along ventral margin, trigones minute-medium, triangular; leaf lobules 1/3 leaf lobe length.....*R. javanica*
18. Leaf lobes widely ovate, strongly incurved along ventral margin, trigones large, confluent; leaf lobules about 1/2 leaf lobe length.....*R. kurzii*
19. Stem 14-15 cells across diameter in transverse section; perianth campanulate
.....*R. pandei*
19. Stem less than 8 cells across diameter in transverse section; perianth cylindrical.....20
20. Leaf lobe trigones minute; leaf lobules small, quadrate-subquadrate or subrhombic.....21
20. Leaf lobe trigones large; leaf lobules large, rectangulate24
21. Leaf lobes persistent (not fragile or caducous).....*R. japonica*
21. Leaf lobes fragile-caducous22
22. Stem cortical cells with large trigones; leaf lobules with obtuse apex
.....*R. obscura*
22. Stem cortical cells with minute trigones; leaf lobules with subacute apex23
23. Plants small, 3-5 mm long; leaf lobules subquadrate, c. 1/2 leaf lobe length
.....*R. onraedtii*
23. Plants medium sized, 20-30 mm long; leaf lobules subrhombic, c. 1/3 leaf lobe length
..... *R. fulvifolia*
24. Plants small, 1-7 mm long; leaf lobe surface minutely verrucose; leaf lobule c. 2/3 leaf lobe length.....*R. madagascariensis*
24. Plants medium sized, 20-30 mm long; leaf lobe surface smooth; leaf lobule c. 1/2 leaf lobe length..... *R. tabularis*

DESCRIPTION AND DISCUSSION

Radula chinensis Steph., *Sp. Hepat.* 4: 164. 1910

Figs 1-15, 54-59

Plants greenish-brown in herbarium, closely appressed to substratum, plumose; shoot 30-60 (-80) mm long, 2.8-4.0 mm wide including leaves, bipinnately-occasionally tripinnately branched. **Branches** present throughout; primary branches



Figs 1-15. *Radula chinensis* Steph. 1, 2. Portions of plant in ventral view showing bipinnate branching (rhizoids not drawn). 3. The same in dorsal view. 4. Transverse section of the main stem. 5-12. Leaves from main shoot. 13. Apical leaf lobe cells. 14. Median leaf lobe cells. 15. Basal leaf lobe cells. All figures drawn by S. Majumdar from D.K. Singh 170/4D/1985 (ASSAM).

5-24 mm long, 1.5-2.5 mm wide including leaves; secondary branches 5-17 mm long, 1.2-2.2 mm wide including leaves; tertiary branches minute, microphyllous, 0.5-7.0 mm long, 0.3-1.2 mm wide including leaves. **Stem** of main shoot oval-elliptical in outline in transverse section, $400-500 \times 200-280 \mu\text{m}$, 18-23 cells across diameter; strongly differentiated, cortical cells 3-4 (-5)-layered, subquadrate-rectangulate, $2.5-22.5 \times 2.5-10.0 \mu\text{m}$, strongly thick-walled, reddish brown, highly pigmented with very prominent middle lamella; medullary cells subquadrate-rectangulate or polygonal, $7.5-35.0 \times 2.5-22.5 \mu\text{m}$, thin-walled, hyaline, with indistinct trigones; primary branch stem oval-elliptical in outline in transverse section, 12-17 cells across diameter, cortical cells 2-4-layered; secondary branch stem oval-elliptical in outline in transverse section, 10-15 cells across diameter, cortical cells 2-3-layered; tertiary branches 7-11 cells across diameter, cortical cells 1-2-layered. **Leaves** of main shoot mostly imbricate-contiguous, but remote in older portion of stem, widely spreading, often fragile. **Leaf lobe** broadly triangular-ovate, 1.7-2.5 mm long, 1.6-2.0 mm wide, apex broadly obtuse, margin more or less undulate, dorsal margin arched, base rounded-auriculate, extending much beyond farther edge of stem, apical leaf lobe cells subquadrate-rectangulate, $10.0-27.5 \times (5.0-7.5-25.0 \mu\text{m})$; median leaf lobe cells oval-polygonal, $15.0-35.0 \times 12.5-27.5 \mu\text{m}$; basal leaf lobe cells, elongated, polygonal, $17-40 \times 15-25 \mu\text{m}$; cells thin-walled, with large nodulose trigones, intermediate thickenings absent; dorsal base of leaf lobe on primary, secondary and tertiary branches extending much beyond farther edge of stem; cuticle striolate; oil-bodies not seen. **Leaf lobules** of main shoot transversely attached, imbricate in apical region, imbricate-contiguous in middle and gradually remote in older portion, flat, large, $1/3-1/2$ of leaf lobe length, more or less orbicular, $0.6-1.3 \times 0.7-1.6 \text{ mm}$, extending much beyond further edge of stem, margin entire, undulated, sometimes incurved, base strongly appendiculate, auriculate, line of insertion short, carinal region not inflated; keel short, arched, smooth, extending at angles of $50-60^\circ$ with main shoot; hyaline papilla 1, at apex of main shoot leaf lobule; rhizoid initial area not developed; leaf lobules of primary and secondary branches orbicular-broadly subquadrate, $1/3-1/2$ of leaf lobe length, extending much beyond farther edge of stem; leaf lobules on tertiary branches rectangular, covering $1/2-2/3$ of stem width, or extending just beyond other edge of stem. **Rhizoids** lacking on lobules of main shoot, but occasionally present on those of subsequent level branches, brownish. **Gemmae** absent. **Androecia** and **gynoecia** not seen.

Habitat. Lignicolous, growing on decaying logs in moist and shady places in temperate forests in association with *Blepharostoma trichophyllum* (L.) Dumort., *Plagiochila cuspidata* Steph., *P. parvifolia* Lindenb., *Ptychanthus striatus* (Lehm. & Lindenb.) Nees, *Scapania ferruginea* (Lehm. & Lindenb.) Gottsche and mosses.

Distribution. Bhutan (Long & Grolle 1990); China (Zhu, 2006; Wang *et al.*, 2011); India [Eastern Himalaya (Arunachal Pradesh – present study)], Japan (Yamada & Iwatsuki, 2006).

Specimen examined. India: Eastern Himalaya, Arunachal Pradesh, Anjaw district, on way to Melinza from Dichhu, ca 2000 m, $28^\circ17'03'' \text{ N}$, $97^\circ00'56'' \text{ E}$, 31 Oct.1985, D.K. Singh 170/4D/1985 (ASSAM); on way to Simbi from Melinza, ca 2500 m, $28^\circ12' \text{ N}$, $97^\circ21' \text{ E}$, 31 Oct.1985, D.K. Singh 171/2C/1985 (ASSAM).

Radula chinensis is characterized by plants having plumose and bipinnate to occasionally tripinnate branching, with relatively small, nearly microphyllous, secondary or tertiary branches (Figs 1-3, 54-56); robust stem on main shoots, 18-23 cells across in diameter, with differentiated cortical layer of 3-4(-5) tiers of small, thick-walled and brown-pigmented cortical cells (Figs 4, 57); broadly triangulate

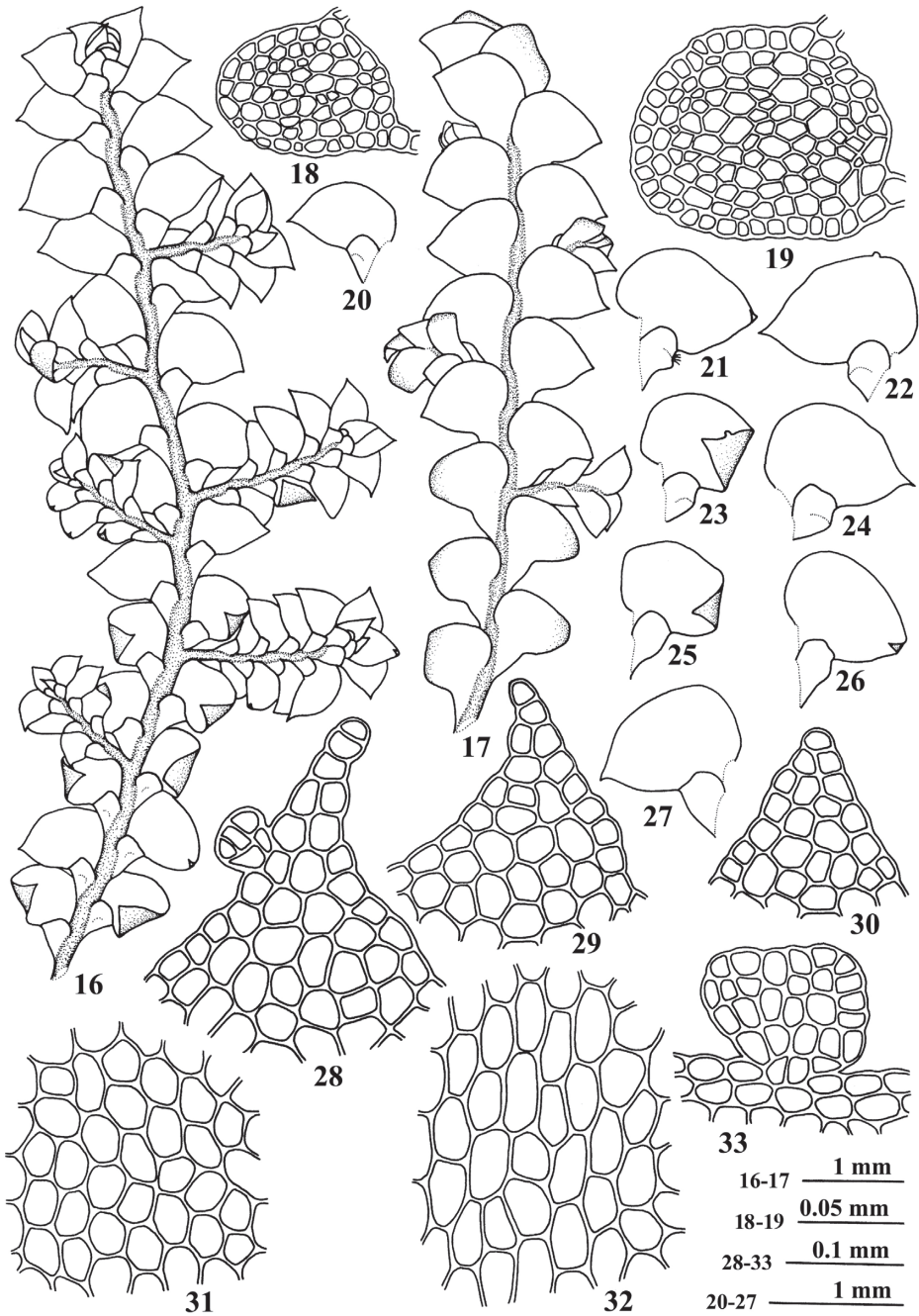
leaf lobe (Figs 5-12, 58); leaf lobule large, extending far beyond the farther edge of stem on main shoot (Figs 1, 2, 5-12, 54, 55, 58). The Indian plants of *R. chinensis* are more robust with the stem 18-23 cells thick in cross-section as compared to just 10-11 cells thick reported by Yamada (1979). As the stem thickness in Indian plants of the species varies in shoots of different level, it is very likely that Yamada's (1979) report pertains to secondary branches and not the main shoot. The Indian plants of *R. chinensis* occasionally show tripinnate branching (Figs 54, 56). The leaf lobules from different levels of shoot also exhibit interesting variation. The lobules on main shoot and primary and secondary branches are more or less orbicular to broadly subquadrate and extend much beyond the farther edge of the stem (Fig. 55). Whereas, those on the tertiary branches are comparatively larger, in relation to the leaf lobe, rectangular in shape and usually cover just 1/2-2/3 of the stem width (Fig. 56). Recently, Renner *et al.* (2013a) reported diversity in leaf lobule morphology in some members of the subgenus *Cladoradula* Spruce depending upon the duration of growth as well as the level of the shoot it is associated with. Our observations on Indian specimens of *R. chinensis*, also a member of the subgenus *Cladoradula*, further support their views.

Among the Indian species *R. chinensis* resembles *R. auriculata* and *R. perrottetii* in having a differentiated stem cortical layer, auriculate leaf lobule base, ovate-triangular leaf lobe with large nodulose trigones and smooth leaf surface. *R. chinensis*, however, can be easily distinguished from *R. auriculata* which has slender plants, 1.8-2.0 mm wide including leaves, regularly pinnately branched, ovate leaves and ovate-subquadrate leaf lobule. Whereas, it differs from *R. perrottetii* as the latter has leaf lobules which are nearly parallel to the stem. The bipinnate branching is very common in *R. chinensis* and it is one of the defining characters for its easy identification among Indian species.

Radula kojana Steph., *Bull. Herb. Boissier* 5: 105. 1897

Figs 16-33, 60-64

Plants brownish in herbarium; shoot 12-30 mm long, 1.4-2.3 mm wide including leaves, pinnately branched. **Branches** present throughout, 1.2-2.0 mm long, 0.7-1.3 mm wide including leaves. **Stem** of main shoot more or less circular to broadly elliptic in outline in transverse section, 150.0-222.5 × 115-180 μm, 8-12 cells across diameter, undifferentiated; outer epidermal cells subquadrate-rectangular or polygonal, 10.0-17.5 × 7.5-25.0 μm, thin-walled, yellowish; inner cells subquadrate-rectangular or polygonal, 7.5-22.5 × 7.5-25.0(-32.5) μm, thin-walled, hyaline, trigones indistinct; stem of primary branches 5-7 cells across diameter. **Leaves** mostly contiguous-imbricate, remote in older portion of stem, widely spreading. **Leaf lobe** broadly triangulate-ovate, falcate, dorsal margin arched, 0.8-1.2 mm long, 0.5-0.8 mm wide, apex apiculate-acute or subacute, incurved, margin entire, dorsal base of leaf lobe on main shoot covering 2/3-entire stem width near apex, 1/2-3/4 in middle region and 2/5-3/5 towards base, apical leaf lobe cells subquadrate-rectangular or polygonal, 10.0-22.5 × 10.0-18.2 μm; median leaf lobe cells subquadrate-polygonal, 15.0-29.3 × 13.0-19.2 μm; basal leaf lobe cells elongated, polygonal, 21.0-42.5 × 11.0-22.5 μm; cells thin-walled, with indistinct trigones, intermediate thickenings absent; cuticle smooth; oil-bodies not seen. **Leaf lobules** imbricate-contiguous in apical region, gradually becoming remote in older portion, subquadrate, inflated, 1/3-2/5 of leaf lobe length, 0.40-0.48 mm long, 0.20-0.33 mm wide, apex obtuse, covering 1/5-1/3 of stem width on main shoot, abaxial margin slightly curved, adaxial margin entire, carinal region inflated; keel very short, straight-slightly arched, smooth, extending at 45°-60° angle with stem, rhizoid initial area slightly convex, hyaline papilla 3, one at apex of leaf lobule, two



Figs 16-33. *Radula kojana* Steph. **16.** A portion of plant in ventral view showing pinnate branching (rhizoids not drawn). **17.** The same in dorsal view. **18, 19.** Transverse sections of the stem from main shoot. **20-27.** Leaves from main shoot. **28-30.** Apical leaf lobe cells. **31.** Median leaf lobe cells. **32.** Basal leaf lobe cells. **33.** Marginal gemmae. All figures drawn by S. Majumdar from D.K. Singh 110F/1985 (ASSAM).

at base; leaf lobule on primary branch 1/5-1/3 of leaf lobe length, covering 1/6-1/5 of stem width. **Rhizoids** occasionally present, few, hyaline. **Gemmae** present, usually restricted towards apex of leaf lobe, sometimes present at dorsal leaf lobe margin, discoid, $27.5-67.5 \times 30.0-81.0 \mu\text{m}$. **Androecia** and **gynoecia** not seen.

Habitat. Lignicolous, growing on decaying logs in moist and shady places in subtropical forests in association with *Lejeunea tuberculosa* Steph.

Distribution. China (Zhu & So, 2001; Zhu, 2006; Wang *et al.*, 2011); India [Eastern Himalaya (Arunachal Pradesh – present study)]; Japan (Yamada & Iwatsuki, 2006); Korea (Yamada & Choe, 1997); Philippines (Tan & Engel, 1986).

Specimen examined. India: Eastern Himalaya, Arunachal Pradesh, Anjaw district, on way to Yasong from Menzong, ca 1000 m, $27^{\circ}53'07''$ N, $96^{\circ}48'37''$ E, 26 Oct. 1985, D.K. Singh 110F/1985 (ASSAM).

Radula kojana is characterized by pinnate branching (Figs 16, 17, 60); falcate leaves with apiculate-acute apex of leaf lobes (Figs 20-27, 60, 63) and presence of marginal and apical gemmae on the leaf lobe (Figs 22, 23, 28, 33, 63). Except for the apical region of the stem on main shoot, where no dorsal leaf free strip is present, *R. kojana* exhibits both dorsal and ventral leaf free strip on its shoots.

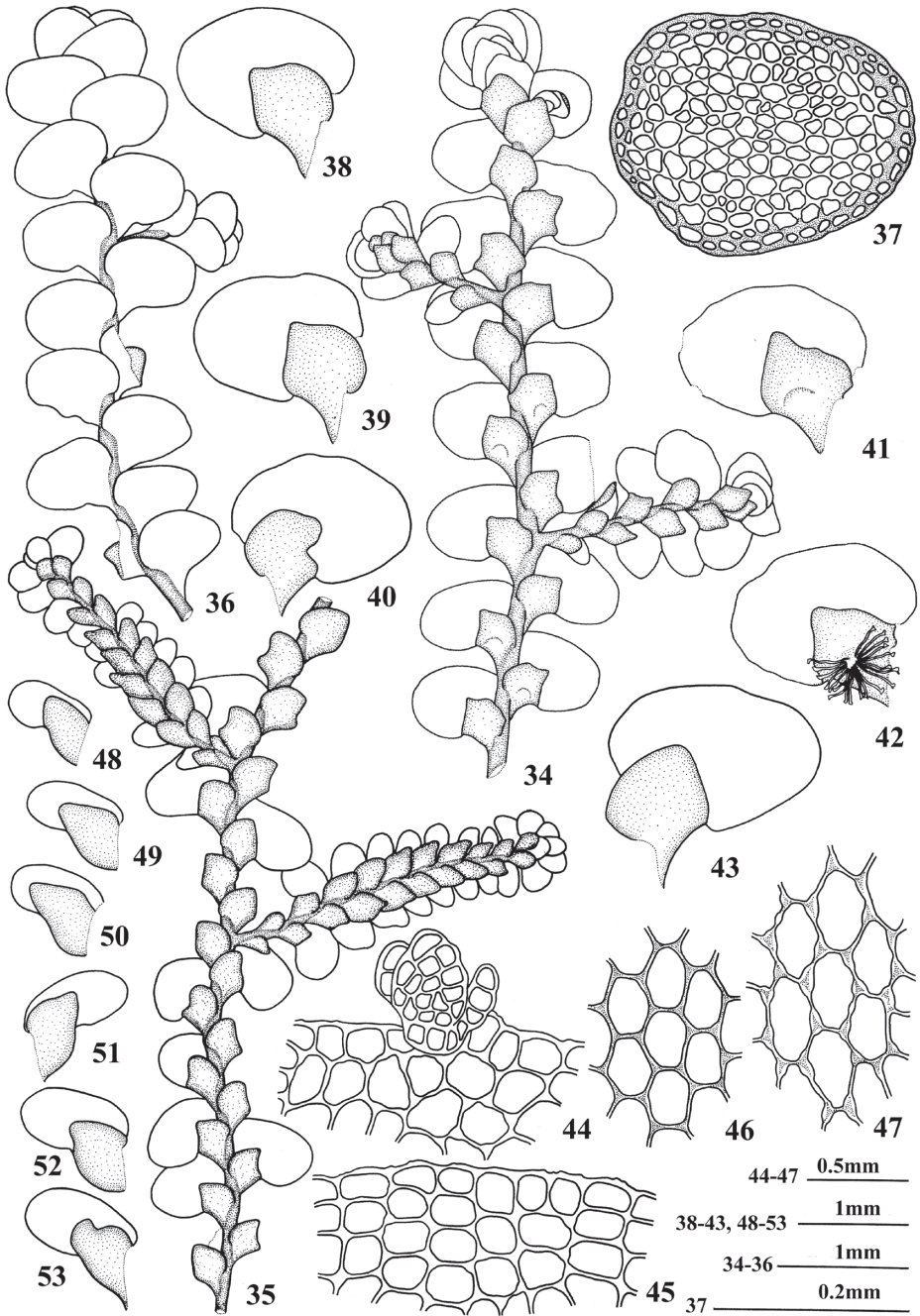
Among the Indian species, *R. kojana* resembles *R. acuta* Mitt., which also exhibits pinnately branched plants having slightly falcate leaves with acute-apiculate leaf lobe apex. But, *R. acuta* differs from *R. kojana* in strongly arched dorsal leaf lobe margin and total lack of apical and marginal gemmae.

Radula sumatrana Steph., *Sp. Hepat.* 4: 204. 1910

Figs 34-53, 65-79

Plants fragile, yellowish green-pale brown in herbarium; shoot 50-70 mm long, 2.0-3.5 mm wide including leaves, pinnately-occasionally bipinnately branched.

Branches irregular; primary branches often as long as main stem, distally producing secondary branches. **Stem** on main shoot more or less circular in outline in transverse section, $200-340 \times 250-310 \mu\text{m}$, 11-16 cells across diameter, weakly differentiated; cortical cells smaller, in a single layer, subquadrate-rectangulate or polygonal, $7.5-14.0 \times 11.0-30.0 \mu\text{m}$, thin-walled, brown pigmented; medullary cells, polygonal-rectangulate, $12.5-21.0 \times 10.0-31.0 \mu\text{m}$, thin-walled, yellowish brown with medium-large trigones; primary branches 8-11 cells across diameter in transverse section; secondary branches 7-10 cells across diameter in transverse section. **Leaves** caducous, contiguous, imbricate-slightly remote, obliquely spreading. **Leaf lobes** broadly ovate, sometimes concave, 1.2-1.7 mm long, 1.0-1.3 mm wide, apex broadly-narrowly rounded; margin entire, dorsal margin arched, covering 3/4-entire stem width on main shoot, extending beyond farther edge of stem near apical region, 1/2-entire stem width on primary branches, 1/3-3/4 stem width on secondary branches, ventral margin slightly arched-nearly straight; apical leaf lobe cells subquadrate-rectangulate, $11.0-19.0 \times 9.0-22.5 \mu\text{m}$; median leaf lobe cells polygonal, $20.0-31.0 \times 17.5-24.0 \mu\text{m}$; basal leaf lobe cells polygonal, $26.0-42.5 \times 14.0-20.0 \mu\text{m}$, thin-walled, with small trigones in apical and median region, nodulose trigones in basal region, intermediate thickenings usually absent, or occasionally present in basal cells; surface densely verrucose; oil-bodies not seen. **Leaf lobules** slightly inflated, closely imbricate in apical region, contiguous-remote in older portion, subrhombic-subquadrate; lobules on main shoot 2/5-3/5 of leaf lobe length, $0.9-1.1 \times 0.6-0.8$ mm, apex narrowly obtuse, occasionally subacute-more or less emarginated, abaxial margin straight, adaxial margin perpendicular to or tending away from stem, straight-undulate, widely arched, covering 1/2-entire width of stem; hyaline papilla 2, one at lobule apex, another at base of inner free margin of lobule, $30-55 \times 13-19 \mu\text{m}$;



Figs 34-53. *Radula sumatrana* Steph. 34. A portion of plant in ventral view. 35. A portion of male plant in ventral view. 36. A portion of plant in dorsal view. 37. Transverse section of the stem from main shoot. 38-43. Leaves from main shoot. 44. Regenerating shoot from leaf lobe margin. 45. Marginal leaf lobe cells. 46. Median leaf lobe cells. 47. Basal leaf lobe cells (surface ornamentation not drawn). 48-53. Male bracts. All figures drawn by S. Singh Deo from D.K. Singh 930A/1984 (ASSAM).

carinal region slightly inflated, keel nearly straight, smooth, extending at 40°-50° angle with stem; rhizoidal initial area weakly convex, seen only in older portion of shoot; lobules on primary and secondary branches 1/2-3/5 of leaf lobe length, covering 1/3-3/4 of stem width. **Rhizoids** brown. **Gemmae** absent; asexual reproduction by caducous leaf lobes in older portion of shoot, group of regenerating cells or shoot primordia forming irregular buds on leaf lobe margins or on dorsal surface of leaf lobe before fragmentation.

Dioicous (?). **Androecia** terminal, occasionally on secondary branches, becoming intercalary by continued vegetative growth of branch; bracts in 6-10 pairs, narrowly oblong-ovate, 0.8-1.1 × 0.4-0.5 mm, bract lobules 1/2-2/3 of bract lobe length. **Gynoecia** and mature sporophytes not seen.

Habitat. Terrestrial, growing on soil enriched with humus in subtropical forests in association with *Lejeunea tuberculosa* Steph., *Cheilolejeunea krakakammae* (Lindenb.) R.M.Schust. and mosses.

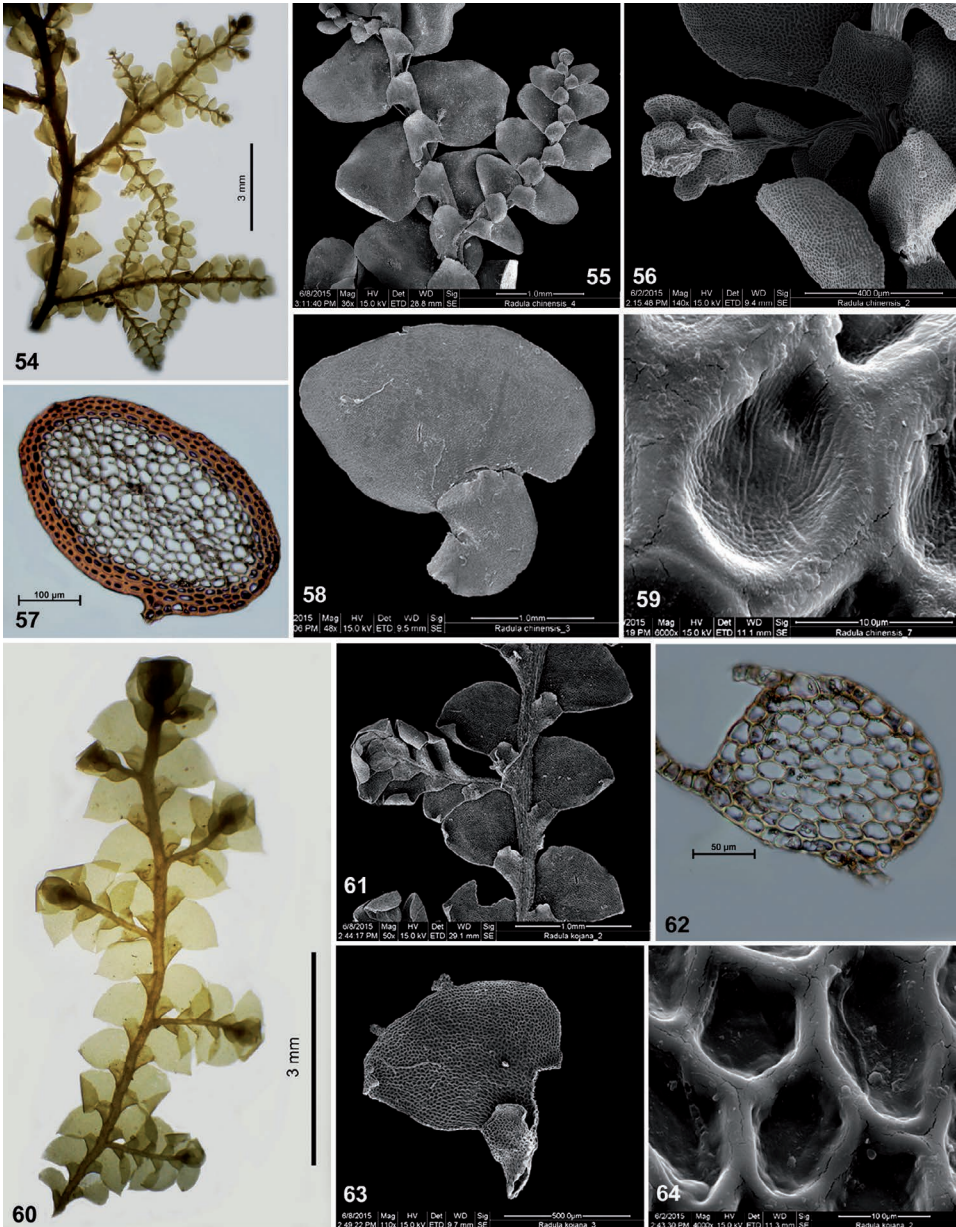
Distribution. China (Zhu, 2006); India [Eastern Himalaya (Arunachal Pradesh – present study)]; Indonesia (Yamada, 1979; Söderström *et al.*, 2010); Malaysia (Chuah-Petiot, 2011); Thailand (Lai *et al.*, 2008).

Specimens examined. India: Eastern Himalaya, Arunachal Pradesh, West Siang District, on way to Naying from Yapik, ca 750 m, 28°31'49" N, 94°22'31" E, 28 Dec.1984, D.K. Singh 930A/1984 (ASSAM).

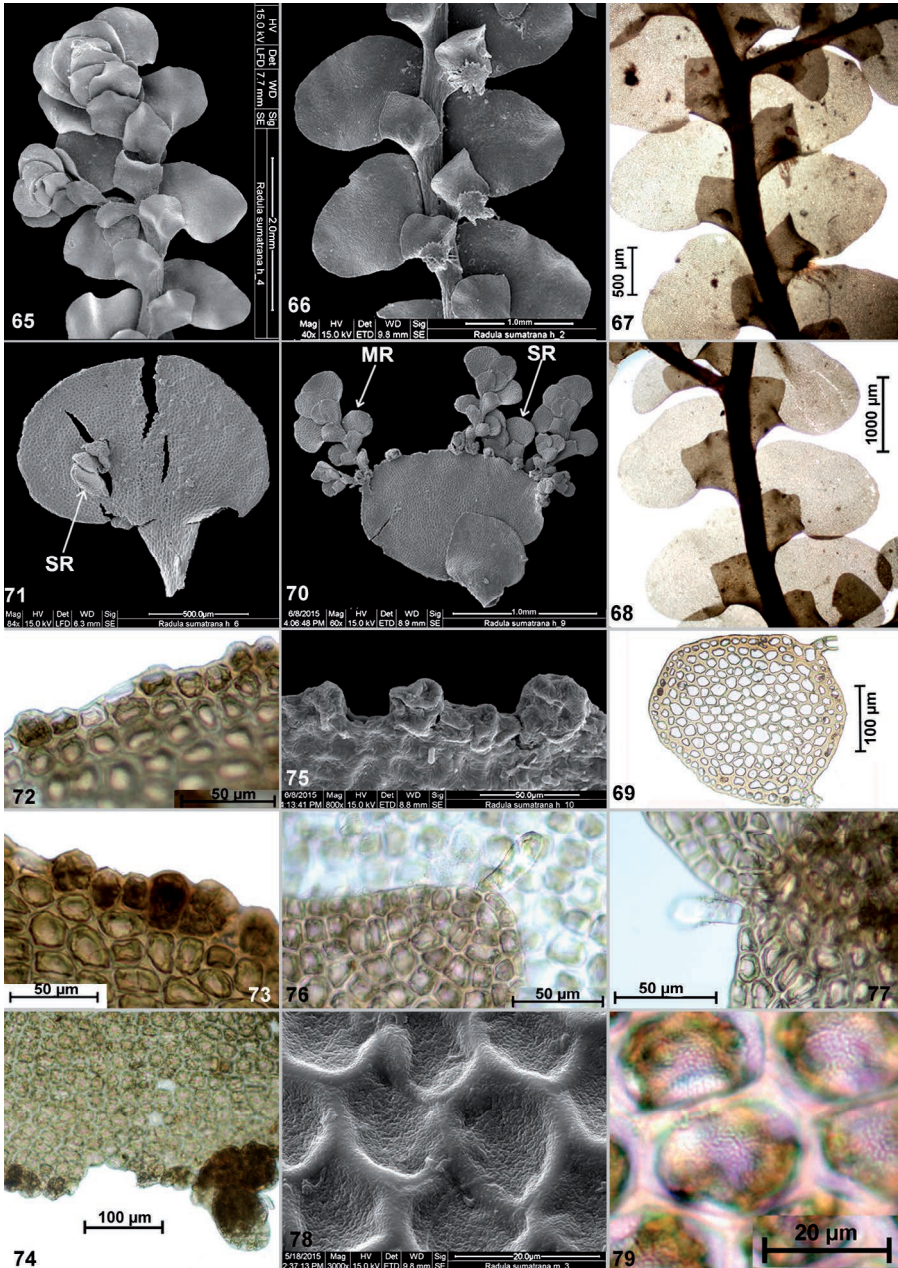
Radula sumatrana is characterized by the stem more or less circular in outline in transverse section, 11-16 cells across diameter, with brown pigmented, 1-layered cortical cells smaller than medullary cells (Figs 37, 69); broadly ovate leaf lobes with obtuse apex (Figs 38-43, 70, 71); leaf lobe cells thin-walled with usually small to medium trigones (Figs 44-47); densely verrucose leaf surface (Figs 78-79) and subrhombic-subquadrate leaf lobules on main shoot, 2/5-3/5 of leaf lobe length (Figs 38-43), with straight-undulate or arched adaxial margin covering half to entire width of the stem (Figs 34, 35, 65-68).

Renner *et al.* (2013b) noted that *R. sumatrana* usually has large leaf lobules which are imbricate and tend to cover the stem surface in ventral view. Whereas, Yamada (1979) reported 'usually contiguous' leaf lobules at upper portion of stem and 'slightly remote' at lower portion in the species. Our plants with leaf lobules closely imbricate in its apical region and contiguous-remote in the remaining portion (Figs 34, 35, 65-68) are, therefore, characteristically similar to *R. sumatrana* in this feature. Yamada (1979) noted considerable variability in the adaxial margin of the leaf lobules in *R. sumatrana* 'even in the same plant'. The variations in the form of adaxial margin of the leaf lobules observed in Indian plants of the species, ranging from straight to undulate to even curved or arched (Figs 34, 35, 66-68) fully exemplify this. Besides, the adaxial margin in the lobules on main shoot as well as the primary or the level one branches are either perpendicular to the stem or tend to turn away from it (Figs 34, 35, 65-68). Renner and Braggins (2004) underlined the taxonomic significance of position of hyaline/slime papillae on leaf lobules similar to those in many genera of Lejeuneaceae. In our plants (of *R. sumatrana*) two slime papillae can be seen, one at lobule apex (Fig. 76) and another at base of inner free margin of lobule (Fig. 77).

Yamada (1974, Fig. 5a) illustrated weakly convex rhizoid initial area in some lobules only, but did not observe any rhizoids in *R. sumatrana*. Later, he (Yamada, 1979) reported weakly convex rhizoid initial area with few brown rhizoids in this species. The Indian plants of the species exhibit weakly convex rhizoidal initial area on the lobules in older portion of main shoot and its branches, occasionally bearing brown rhizoids (Figs 66, 67).



Figs 54-64. *Radula chinensis* Steph. **54.** A portion of plant. **55.** The same showing primary and secondary branches under SEM. **56.** The same showing secondary and tertiary branches under SEM. **57.** Transverse section of stem of main shoot. **58.** A leaf from main shoot. **59.** A portion of the same under SEM showing striolate ornamentation of cuticle. *Radula kojana* Steph. **60.** A portion of plant. **61.** The same under SEM. **62.** Transverse section of stem of main shoot. **63.** A leaf from main shoot showing marginal gemmae. **64.** A portion of the same under SEM showing smooth cuticle. 54-59 from *D.K. Singh 170/4D/1985* (ASSAM), 60-64 from *D.K. Singh 110F/1985* (ASSAM).



Figs 65-79. *Radula sumatrana* Steph. 65-68. Portions of plant in ventral view. 69. Transverse section of stem of main shoot. 70. A leaf from main shoot in ventral view showing marginal regenerants (MR) and dorsal surface regenerants (SR). 71. The same in dorsal view showing a regenerating shoot (SR) from the dorsal surface. 72-75. Sectors of leaf lobe margin showing different stages of shoot primordia. 76. A portion of leaf lobule showing apical slime papilla. 77. A portion of the same showing basal slime papilla. 78. A portion of the leaf lobe under SEM showing verrucose ornamentation of cuticle. 79. The same under light microscope. All images from *D.K. Singh 930A/1984* (ASSAM).

The asexual reproduction mechanism of any kind has apparently been unknown so far in *R. sumatrana* (see also Castle, 1966; Yamada, 1979). The Indian plants of the species exhibit vegetative propagation by means of caducous leaf lobes usually in the older portion of the shoot. The proliferating cells on the leaf lobe margin copiously produce callus-like groups of cells ultimately developing into young regenerants (Figs 44, 70, 72-75). Such shoot primordia and the regenerants have been observed on the leaf lobes before their separation from the stem. Interestingly, the regenerants were also found arising on the dorsal surface of leaf lobes (Figs 70, 71).

Among the Indian species of the genus, *R. sumatrana* approaches *R. pandei* Udar & Dh.Kumar in stem thickness, shape of the leaves and leaf lobe apex, extent of leaf lobule base covering the stem and the absence of gemmae. The former, however, differs from the latter in having fragile plants with smaller, deeply pigmented cortical cells with the cells of both cortex and medulla uniformly thin-walled; caducous leaves with the apical and median leaf lobe cells having small, triradiate trigones, but basal lobe cells with large nodulose trigones and densely verrucose leaf cuticle, as compared to rigid plants with uniformly thick-walled cortical and medullary cells without any differentiation; leaves with the leaf lobe cells showing nodulose trigones throughout and smooth cuticle in the latter. *R. sumatrana* also resembles *R. grandifolia*, but the latter differs from it in the presence of smooth cuticle, large nodulose trigones in the leaf lobe cells and marginal gemmae on leaf lobes.

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