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Frullania bolanderi Austin (Marchantiophyta: Jubulaceae), a rare, disjunct liverwort in the Himalaya

Genus *Frullania* is represented in India with 72 taxa, including 63 from the Eastern Himalayan localities[1], thus constituting an important part of the Indian bryoflora. During a recent exploration in Tawang district, Arunachal Pradesh, India, few plants of *Frullania* were identified as *Frullania bolanderi* Austin. This species has its main distribution in boreal North America[2–5] and Europe[6], while in Asia it has been reported from a few localities in Japan[6,7] and Russia[8–13]. The species thus shows a transoceanic disjunct distribution between North America and Europe[5]. A report of the species from Caucasus indicated that it may have further southward distribution[14]. Thus the present study from the Himalaya extends its range of distribution further southeastwards, possibly attributed to long-range dispersal mechanism as suggested by Frahm[15]. While discussing the disjunctive distribution of some North American species in Europe, Frahm[16] speculated *Frullania oakesiana* and *F. bolanderi* as possibly holarctic species rather than circumpolar. The current global distribution and the present study from the Himalaya confirm its holarctic distribution as speculated by Frahm[16].

An interesting aspect about *F. bolanderi* disjunction is that sexual reproduction in this species remains unknown, while asexual reproduction usually takes place through unique modified caducous leaves producing leaf gemmae and their *in situ* germination. Long-range dispersal is generally achieved best by spores, whereas vegetative dispersal places the vegetative reproducing structures or diaspores like vegetative propagules, gemmae, etc. close to the parent plant, generally in the same environment[17]. Studlar *et al*.[18] have concluded that some diaspores, including plant fragments, could travel with the help of wind into the atmosphere. Yet the living vegetative propagules, active fragments, gemmae, etc. may or may not be dormant and are least adopted to the conditions of the stratosphere. Pohjamo *et al*.[19] concluded that gemmae, at least the size of spores, can contribute to long-range dispersal. However, it is unclear whether a modified leaf gemmae, as reported in the case of *F. bolanderi*[20] (Figure 1 *e–g*), much larger than the size of spores, can withstand the conditions of long-range dispersal by wind. Further, in Indian plants, frequent *in situ* germination from leaf lobes and leaf lobules has been observed; a condition unsuitable for long-range dispersal through wind. Hence these factors make this case interesting for further studies to understand whether the disjunction of *F. bolanderi* should be attributed to long-range dispersal by wind or some other reason. One possible scenario could be the role of migratory birds. It is well known that migratory birds help in the long-range dispersal of higher plants through epi- or endo-zoochory; however, their role in the long-range dispersal of bryophytes was barely considered till recently, when Lewis *et al*.[21] for the first time provided evidence on the role of epi-zoochory by migrating birds in the long-range dispersal of bryophyte diaspores. Boch *et al*.[22] reported that bryophyte spores and vegetative reproductive structures can withstand ingestion by slugs, hence supporting the endo-zoochory theory. Similarly, endo-zoochory of large bryophyte fragments by water birds has been reported recently[23]. Every year, India hosts a large number of migratory birds from various parts of the globe. A number of birds have been reported to migrate from Europe and Russia to India through the Central Asian flyway. The Siberian crane is an excellent example of a migratory bird which travels annually from Russia to India. In the light of these findings, the dispersal of asexual gemmae of *F. bolanderi* from Europe or Russia to India through migratory birds, though not observed directly in the present study, seems more appropriate than purely by wind. Further studies may provide a new angle to the Himalayan disjunction of bryophytes.

Taxonomic enumeration.

Frullania bolanderi Austin, *Proc. Acad. Nat. Sci. Philadelphia* 21: 226. 1869 (Figure 1).

Plants form reddish-black patches, growing prostrate and closely appressed on bark with some apical, upright flagelliform branches with caducous leaves, small to medium sized, up to 13 mm long, 0.6 mm wide, branching 1–2-pinnate. Stem differentiated into cortex and medulla. Leaves imbricate, incubous, ovate, dorsal lobe 0.19–0.42×0.24–0.56 mm in size, dorsal margin arched, crossing and growing beyond the stem width. Leaf cells thick-walled,

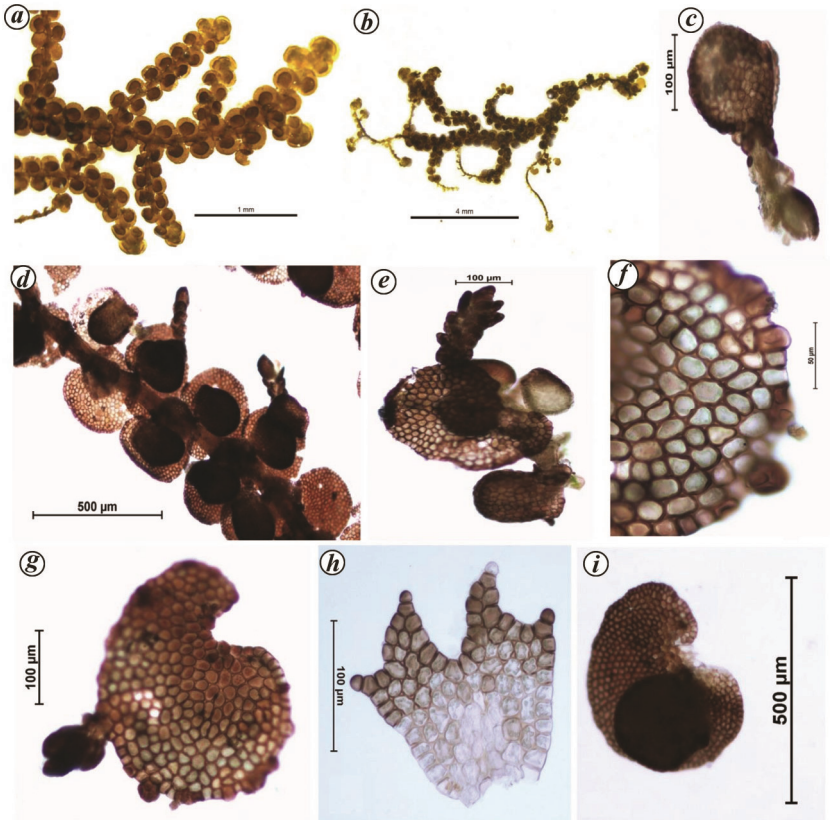

Figure 1. *Frullania bolanderi* Austin. ***a***, A portion of the plant, ventral view. ***b***, A portion of the plant showing apical denuded branches. ***c***, Regeneration from lobule mouth. ***d***, *In situ* regeneration. ***e–g***, Caducous leaf gemmae with propagules. ***h***, Underleaf, ***i***, Normal leaf.

trigonous, marginal cells 12–16 × 8–16 µm, median cells 12–24 × 12–20 µm, basal cells 12–32 × 16–28 µm in size; lobule galeate (helmet-shaped), large, one-third to half of the lobe size, 0.16–0.29 × 0.11–0.24 mm in size. Underleaves 0.14–0.24 × 0.14–0.24 mm in size, bilobed with an additional tooth on both margins. Asexual reproduction through caducous leaves, behaving as modified gemmae borne on specialized, upright positioned apical branches. Frequent *in situ* germination was observed from the marginal cells of leaf lobes as well as cells near the beak of leaf lobules. Sexual reproductive structures not observed.

Specimen examined: India, Arunachal Pradesh, Tawang, near Tawang monastery, on bark, 27°35′6.5″N, 91°51′27.7″E, c. 2966 m, 16.06. 2015, K.K. Rawat 300243C (LWG).

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