ISSN: 2287-688X

Annals of
Plant Sciences

Volume 15, Issue 07 (2026) pp. 26-36

Research Article

# Taxonomic Evaluation of Selected Moss Species Using Morphological Traits and Cluster Analysis

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## Abstract

Bryophytes are non-vascular land plants known for their diverse morphology and ecological adaptability. The objective of the present work is to study the micromorphological characteristics of four moss species, including *Philonotis revoluta*, *Philonotis mollis*, *Fissidens diversifolius*, and *Fissidens geminiflorus*, collected from different localities of Mount Abu, Rajasthan, India. Specimens were studied using stereomicroscopy and light microscopy. The species exhibited marked variation in growth form, leaf arrangement, costa, and cell structure. *Philonotis* species exhibited erect, tufted growth with spirally arranged leaves and were associated with moist rock surfaces exposed to running water. In contrast, *Fissidens* species showed flattened growth with a characteristic distichous leaf arrangement and were found on shaded, moisture-retentive walls. The presence of a vaginant lamina in *Fissidens* and differences in cell ornamentation, such as papillose and mammillose cells in *Philonotis*, served as key diagnostic features. These changes demonstrated adaptation to certain microhabitats and underscore the significance of micromorphological characteristics in species identification and taxonomy. The present study provides a platform for further ecological and chemotaxonomic research

**Keywords:** *Taxonomic evaluation, Mosses, Morphological traits, Cluster analysis, Dendrograms.*

## Introduction

Bryophytes are the earliest terrestrial plants and play an important role in plant evolution (Goffinet & Shaw, 2009; Singh, 2010). They are small, non-vascular plants that include mosses, liverworts, and hornworts and lack true roots, stems, and vascular tissues (Vashishta et al., 2010). Due to these structural limitations, bryophytes are mostly found in moist, shaded environments with consistently high humidity.

Among bryophytes, mosses are the most prominent group recognized by their upright shoots with spirally arranged leaf-like structures, whereas liverworts generally show a flattened or leafy thallus (Goffinet & Shaw, 2009). Based on their growth pattern and the position of the sporophyte, mosses are broadly divided into acrocarpous forms, which are erect with terminal sporophytes, and pleurocarpous forms, which grow in a creeping manner with laterally branched sporophytes. Of these, the pleurocarpous mosses are more widespread and usually develop in dense, carpet-like mats in humid habitats.

Despite their small size, bryophytes play significant roles in ecosystem functioning. They help retain moisture, influence the local microclimate, prevent soil erosion, and support seed germination by providing a suitable microhabitat (Glime, 2007). In addition, bryophytes are widely recognized as effective bioindicators of environmental conditions, including air and water pollution, soil pH, and nutrient status, because they can directly absorb and accumulate substances from their surroundings (Glime, 2007; Asakawa, 2007). Their ability to produce bioactive compounds has also attracted growing interest for potential applications in pharmaceutical research (Asakawa, 2007). The presence of five mosses, including *Tortula muralis*, *Gymnostomiella reronicosa*, *Hyophila involuta*, *Semibarbula orientalis*, and *Fissidens flaccidus*, was studied in the Indian Thar Desert,

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DOI: 10.5281/zenodo.21406606

Rajasthan (Deora and Deora, 2017). Various researchers have made significant contributions to the field, including Deora and Chaudhary (1997) and Deora and Guhil (2014).

The morphology of the moss gametophyte plays an important role in both taxonomy and ecological interpretation. Features such as leaf arrangement, costa structure, laminal cell pattern, and specialized features such as the vaginant lamina in *Fissidens* are commonly used for species identification. These traits are also influenced by environmental factors, reflecting adaptation to specific microhabitats.

In this context, the present study aims to examine the micromorphological characteristics of selected moss species from Mount Abu, Rajasthan, and to understand their correlation with ecological adaptations.

## Materials and Methods

### Study Area and Sample Collection

For the study, bryophyte specimens were collected from various localities of Mount Abu (Sirohi District, Rajasthan), a hill station located in the Aravalli range. Field surveys were conducted across different localities to document and collect moss specimens. Although several sites were explored, only a limited number of target species were encountered. A total of four moss species belonging to the genera *Philonotis* and *Fissidens* were collected. Sampling was carried out during the rainy season, which provides optimal conditions for moss growth and visibility. For each collection site, habitat characteristics, location details, and collection period were recorded.

### Specimen Identification

Preliminary identification of the collected specimens was carried out in the field using regional floras and standard taxonomic keys. A hand lens (10× magnification) was used to observe diagnostic characters, including leaf arrangement, costa development, and growth habit. Final identification was confirmed in the laboratory using standard bryological literature such as the Moss Flora of Rajasthan (Chaudhary and Deora, 1993) and other monographs. Finally, the identification was verified and authenticated with the help of the experts in the subject.

### Micromorphological Analysis

For the morphological study, hand sections of moss leaves were prepared. The collected plant material was thoroughly washed in tap water to remove soil particles, debris, and adhering plant fragments. Intact leaves were carefully separated and placed on clean glass slides in such a way that the entire lamina and costa were visible. The sections were mounted in diluted glycerin to prevent shrinkage and enhance clarity during microscopic observation. The temporary slides were prepared for all collected samples.

### Stereomicroscopic Observation

General morphological features of the specimens were examined using a stereomicroscope (LEICA EZ4E). Observations included growth form, leaf arrangement, and overall plant structure.

### Light Microscopic Observation

Microscopic observations were carried out using a compound light microscope at different magnifications (4×, 10×, 40×, and 100× objectives). Morphological features, including leaf shape, margin, apex, costa structure, and laminal cell characteristics, were recorded. Microphotographs were captured using a digital camera attached to the light microscope (ZEISS Primostar 3 and Cilika BT-E).

### Imaging and Measurement

Measurements of leaf length, width, and cell dimensions were made using an ocular micrometer, which had been calibrated with a stage micrometer. Multiple measurements were recorded for each specimen to ensure accuracy and reliability. All measurements were expressed in micrometers (µm) and millimeters (mm).

### Parameters Recorded:

The diagnostic characters recorded during microscopic examinations were leaf arrangement and shape, cell size, shape, and cell wall thickness; surface ornamentation (papillae and projections); presence and characteristics of the costa (midrib); and rhizoid type and arrangement

### 2.4 Data Recording and Analysis

All observations were systematically recorded and compared with standard descriptions in bryophyte floras and taxonomic monographs to identify species and assess morphological variation. For hierarchical cluster analysis,

morphological traits were examined to assess the taxonomic relationship between all selected moss species. The numerical data were analyzed using UPGMA clustering in PAST software to determine how similar or unlike these species are to one another

## Results

Descriptions of observed micromorphological features for each species are as follows:

***1. Philonotis revoluta***

Plants are tufted, yellowish-green, erect, and tomentose at the base. Shoots are brownish-red at the base and yellowish-green towards the apex, branched with subfloral innovations, reaching up to 4 cm in height. Numerous brown, multicellular, branched rhizoids with an oblique septum form a dense tomentum at the basal portion of the stem. Leaves are erect and spreading when moist, becoming appressed when dry; they are lanceolate, measuring 2.2–2.4 mm long and approximately 0.4–0.5 mm in width. The apex is sharply acuminate, with margins revolute in the lower region and denticulate towards the apex. The costa is well-developed and extends to the apex (percurrent). Upper laminal cells are papillose, thin-walled, and elongated, measuring approximately 7 × 50 µm. Basal cells are rectangular, becoming narrower and elongated towards the leaf margins. Plants were observed to be sterile.

***2. Philonotis mollis***

Plants form loose tufts, greenish-yellow and delicate with soft, branched stems, and measure approximately 4 to 5 cm long. Rhizoids are brown, multicellular, and sparsely to moderately developed at the base of the stem. Leaves are more densely packed towards the lower part of the stem, not closely overlapping above, and spread out in the upper region, remaining erect and patent when moist but shrinking and standing erect when dry. The leaves are lanceolate and narrow, measuring 1.5–2.0 mm long and about 0.3-0.5 mm wide. The base is decurrent, and the apex gradually tapers into a filiform point. Leaf margins are entire in the lower regions and serrate toward the apex, with paired tooth-like projections. The costa is strong and excurrent, extending beyond the leaf apex. Upper laminal cells are narrow and elongated, roughly 8 × 52 µm, while median cells are mammillose, and basal cells are smooth, rectangular, and larger. The plants observed were sterile.

***3. Fissidens diversifolius***

Plants are green, form delicate tufts, are flexuous, simple, and branched, and measure approximately 2-3 cm in length and up to 1.2 mm in width. Shoots are distinctly distichous. Rhizoids are brown, multicellular, and arise from the basal portion of the stem. Leaves are laxly arranged on the shoot, 10-14 pairs, each leaf measuring about 1.5-1.7 mm in length and 0.4-0.5 mm in width, oval-lanceolate, spreading when moist and curled when dry. Leaves are crowded towards the apex and are more distinct below. Margin entire, slightly denticulate towards the apex; the apex is broadly acute and symmetrical. The dorsal lamina narrows downward and terminates near the base of the costa. The sheathing lamina (vaginant lamina) encloses approximately one-half to three-fourths of the dorsal lamina, which is a characteristic feature of the genus. Leaves are broader near the base and gradually narrow towards the apex. The costa is well developed, light brown in color, and terminates 2–3 cells below the leaf apex (sub-percurrent). Upper and middle laminal cells are hexagonal, thin-walled, and measure approximately 9-11 µm. Basal cells near the costa are larger, while marginal cells are elongated, and basal cells are also hexagonal. Plants were observed to be sterile.

***4.Fissidens geminiflorus***

Plants are brownish-green, slender, simple, and branched, measuring approximately 3-4 cm in length. The shoots are distichous. Rhizoids are brown, multicellular, and arise from the basal portion of the stem. Leaves 10-18 pairs, curled when dry and spreading when moist, measuring up to 1.5-2 mm in length and approximately 0.4-0.7 mm in

width, oblong-lanceolate with an acute apex, leaf margins entire. The sheathing lamina (vaginant lamina) covers about three-fourths of the dorsal lamina and occasionally extends slightly beyond it. The dorsal lamina is narrower with a decurrent base. The costa (nerve) is stout and terminates 2-3 cells below the apex (supercurrent). Upper, median, and basal cells are hexagonal, measuring approximately 7-14 µm; basal cells are slightly thickened. Plants were observed to be sterile.

**Dendrogram Analysis**

The dendrogram represented the studied species in two main clusters, the Bartramiaceae and Fissidenaceae families. Further analysis formed two clusters, one cluster of *Philonotis revoluta* and *Philonotis mollis*, and the other cluster of *Fissidens diversifolius* and *Fissidens geminiflorus*, indicating greater similarities within the genera than between genera. This trend shows that selected morphological characteristics effectively define the studied taxa and reflect their taxonomic affinity.

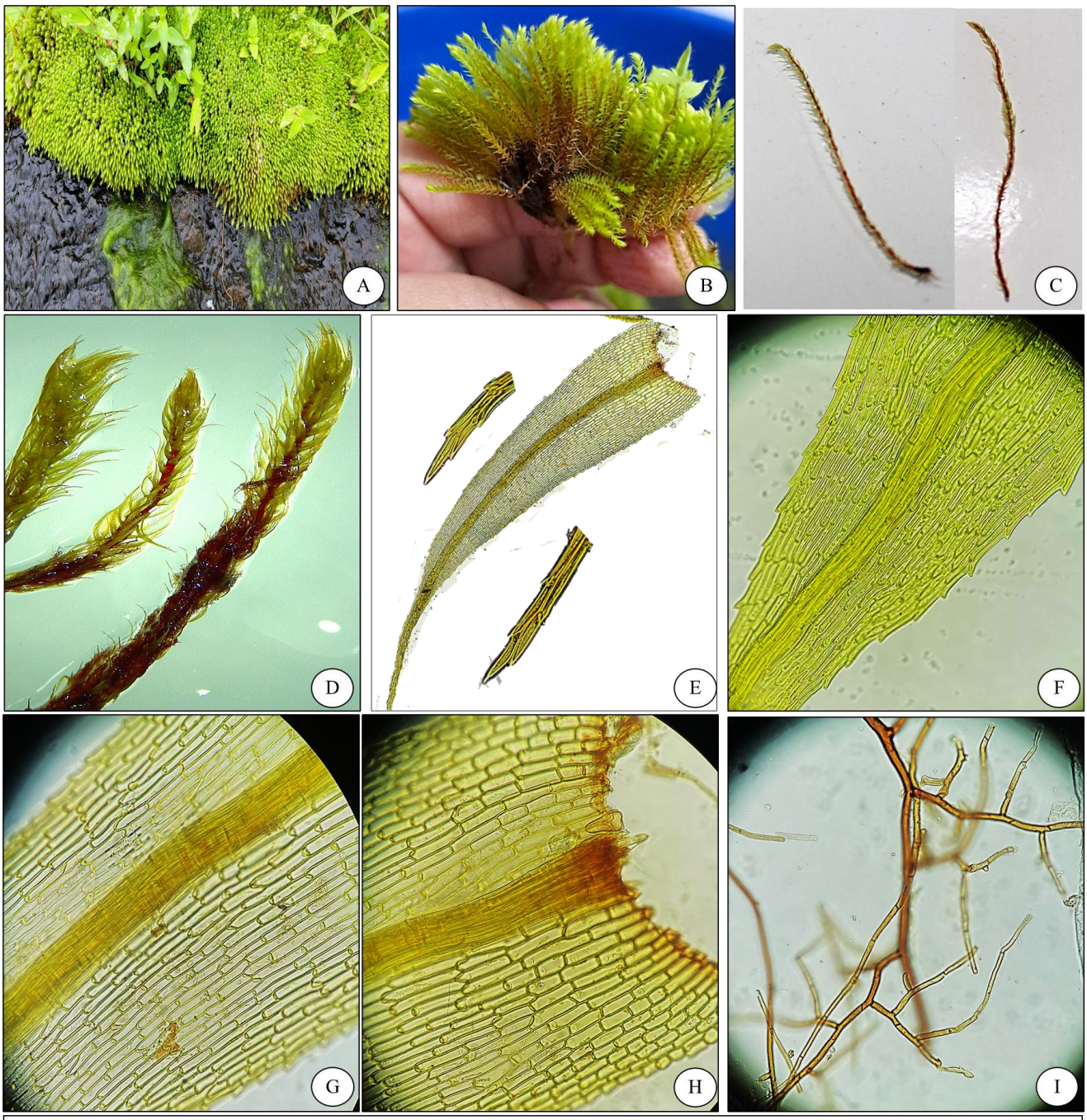
**Table 1: The study sites of selected moss species**

| S. No. | Species | Family | Substrate | Locality | Coordinates |
|---|---|---|---|---|---|
| 1. | *Philonotis revoluta* Bosch & Lac. | **Bartramiaceae** | On vertical rock surfaces exposed to running water | Guru Shikhar Road, Mount Abu | 24.62684°N 72.74313°E |
| 2. | *Philonotis mollis* (Doz. & Molk.) Mitt. | **Bartramiaceae** | On the ground rock surface, intermittent running water | Sunset Point Road, Mount Abu | 24.59408°N 72.70194°E |
| 3. | *Fissidens diversifolius* Mitt. | **Fissidentaceae** | On an old, moist, shaded wall, with lime coating | Nakki Lake, Mount Abu | 24.594004°N 72.702608°E |
| 4. | *Fissidens geminiflorus* Bosch | **Fissidentaceae** | On a small, moist wall microhabitat | Goumukh Road, Mount Abu | 24.576051°N 72.713998°E |

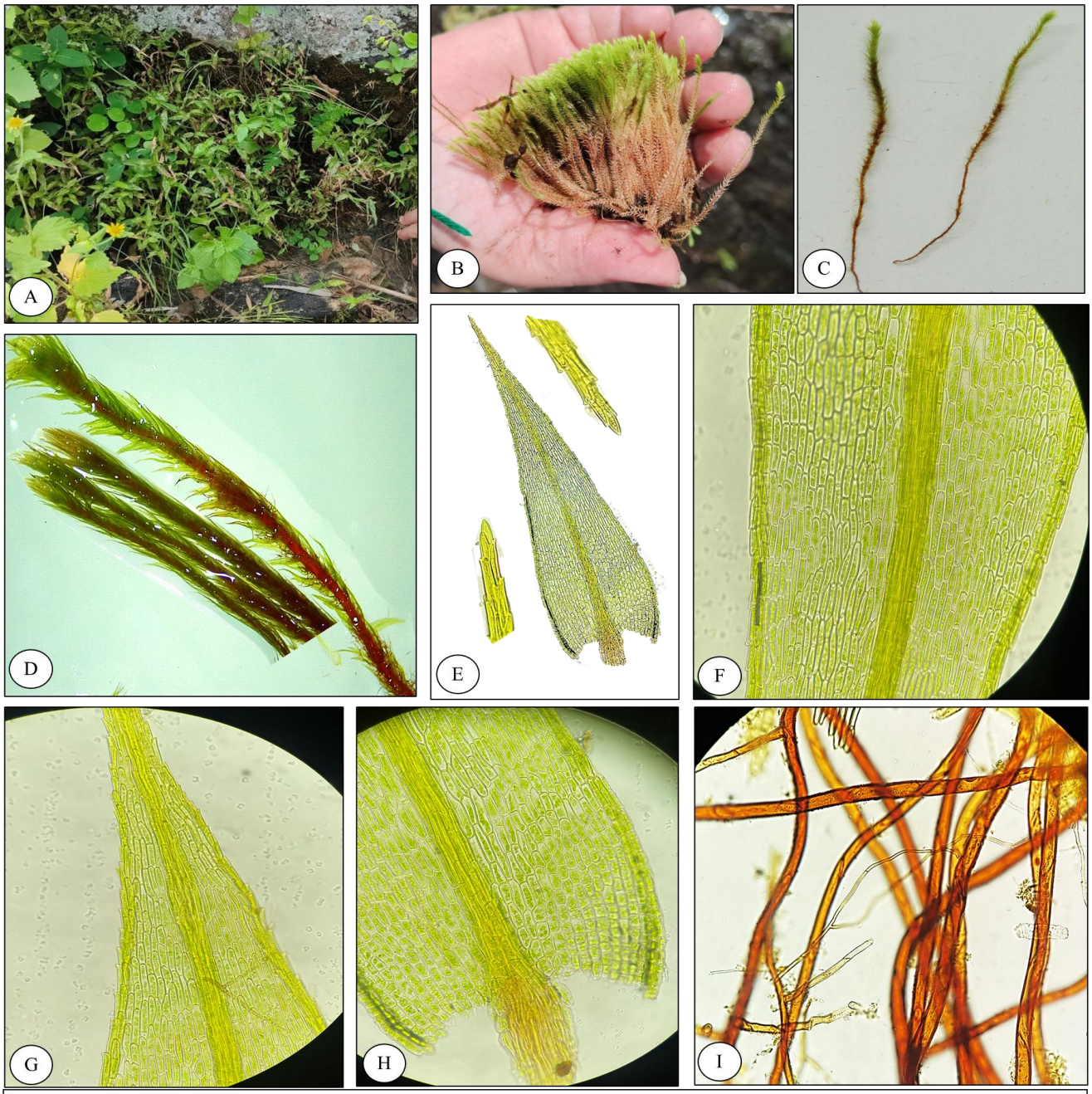
**Table 2: Comparison of morphological characters of the studied moss species**

| Characters | ***Philonotis revoluta*** Bosch & Lac. | ***Philonotis mollis*** (Doz. & Molk.) Mitt. | ***Fissidens diversifolius*** Mitt. | ***Fissidens geminiflorus*** Bosch |
|---|---|---|---|---|
| **Habitat** | Ground-level moist rock (intermittent flow) | Vertical rock with running water | Moist shaded wall (lime-coated) | Moist wall microhabitat |
| **Growth form** | Erect, tufted | Erect, tufted | Creeping, flattened | Creeping, flattened |
| **Main shoots** | Branched | Branched | Branched | Rarely Branched |
| **Leaf arrangement** | Spiral | Spiral | Distichous | Distichous |
| **Leaf shape** | Lanceolate | Lanceolate | Oval-lanceolate | Oblong-lanceolate |
| **Apex** | Sharply Acuminate | Filiform, Acute–acuminate | Broadly Acute | Acute |
| **Margin** | Revolute below, denticulate above | Entire below, Serrate above | Entire, slightly denticulate | Entire/slightly serrulate, Entire |
| **Costa** | Present, Double, Strong, Percurrent | Present, Double, Strong, Excurrent | Present, Double, Strong, Subpercurrent | Present, Double, Strong, Subpercurrent |
| **Laminal cell** | Elongated | Elongated | Rectangular/Hexagonal | Rectangular |
| **Upper cells** | Papillose, Elongated | Narrow, Elongated | Hexagonal | Hexagonal |
| **Median cells** | Elongated | Mammillose | Hexagonal | Hexagonal |
| **Basal cells** | Rectangular | Rectangular, smooth | Larger, hexagonal | Hexagonal |
| **Cell wall** | Thin-walled | Thin-walled | Thin-walled | Thin-walled |
| **Alar cells** | Present | Present (inflated) | Distinct | Distinct |
| **Rhizoids** | Dense, Multicellular, Branched, Oblique Septa, Brown, Basal (Tomentose) | Multicellular, Branched, Oblique Septa, Brown, Sparse to moderate, Basal | Multicellular, Branched, Oblique Septa, Brown, Basal | Multicellular, Branched, Oblique Septa, Brown, Basal |

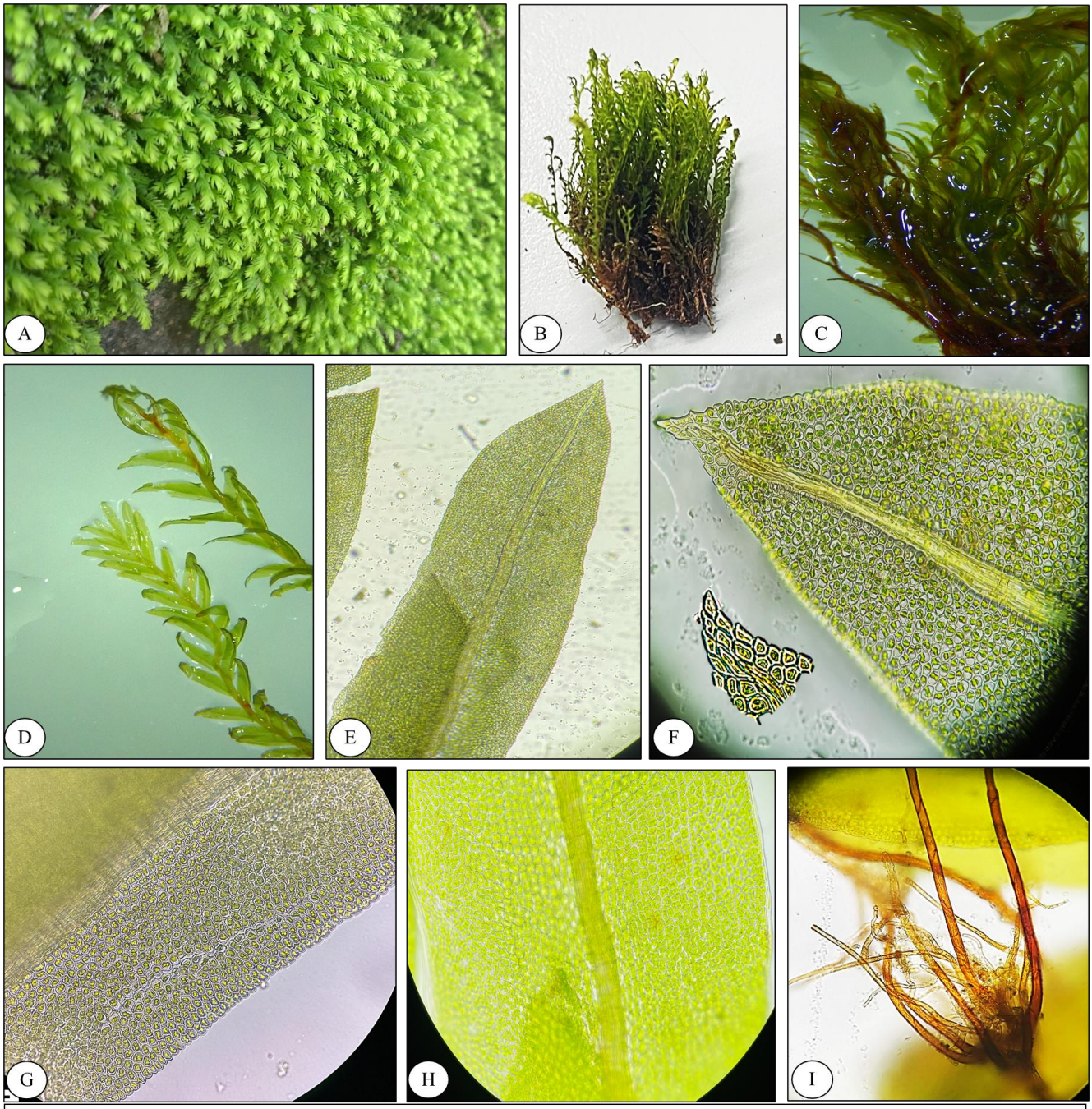
| **Special feature** | Papillose upper cells | Mammillose median cells | Vaginant lamina | Vaginant lamina |
|---|---|---|---|---|



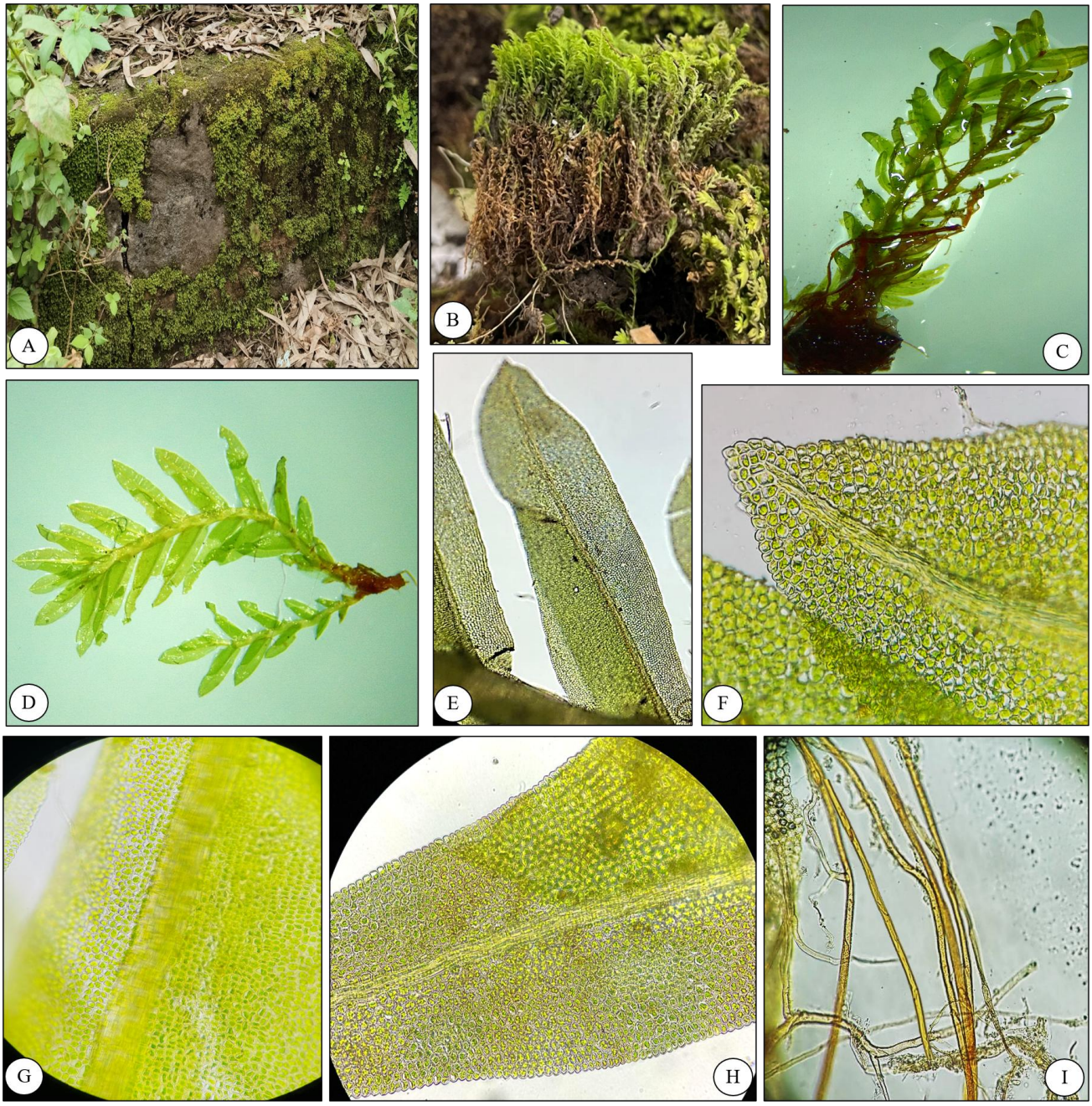

**Figures 1:-** ***Philonotis revoluta*** **A. Habitat, B. & C. Complete Plant, D. Plant under Stereo, E. Complete leaf with Apex, F. G. & H. Upper, Middle, and Basal part of leaf, I. Rhizoids**




**Figures 2:- *Philonotis mollis* A. Habitat, B. & C. Complete Plant, D. Plant under Stereo, E. Complete leaf with Apex, F. G. & H. Upper, Middle, and Basal part of leaf, I. Rhizoids**




**Figures 3:-** ***Fissidens diversifolious*** **A. Habitat, B. Complete Plant, C. & D. Plant under Stereo, E. Complete leaf, F. G. & H. Upper, Middle, and Basal part of leaf, I. Rhizoids**




**Figures 4:-** ***Fissidens geminiflorous*** **A. Habitat, B. Complete Plant, C. & D. Plant under Stereo, E. Complete leaf, F. G. & H. Upper, Middle, and Basal part of leaf, I. Rhizoids**

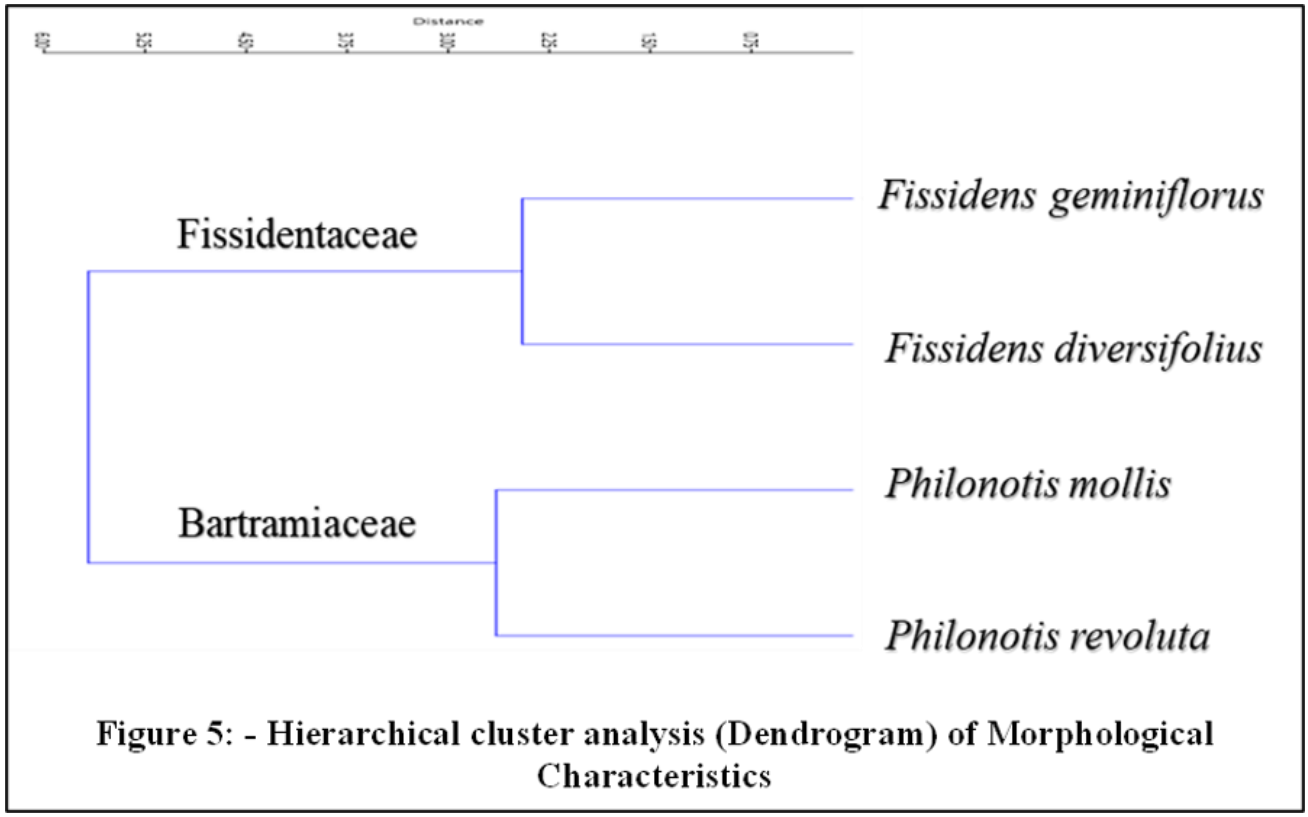



**Figure 5: - Hierarchical cluster analysis (Dendrogram) of Morphological Characteristics**

**Table 3:** Summary of the quantitative characters (measurements) of the studied species

| Characters | *Philonotis revoluta* (P1) Bosch & Lac. | *Philonotis mollis* (P2) (Doz. & Molk.) Mitt. | *Fissidens diversifolius* (F1) Mitt. | *Fissidens geminiflorus* (F2) Bosch |
|---|---|---|---|---|
| **Stem length** | 3.5-4 cm | 4-5 cm | 2-3 cm | 3-4 cm |
| **Leaf length** | 2.235 mm | 1.540 mm | 1.775 mm | 1.577 mm |
| **Leaf width** | 0.483 mm | 0.376 mm | 0.454 mm | 0.437 mm |
| **Laminal cells length** | 33-53 µm | 43-52 µm | 9-18 µm | 9-11 µm |
| **Laminal cells width** | 9-10 µm | 8-9 µm | 9-11 µm | 7-10 µm |
| **Costa width** | 49 µm | 35 µm | 44 µm | 35 µm |
| **Apex** | 27x9 µm | 35x11 µm | 22x8 µm | 13x8 µm |

## Discussion

The present study revealed morphological variation among the investigated moss species, particularly in growth form, leaf arrangement, and structural features, showing their ecological preferences. These findings are consistent with earlier bryological studies emphasizing the role of morphology in adaptation and taxonomy (Goffinet & Shaw, 2009).

The *Philonotis* species *P. mollis* and *P. revoluta* exhibited erect, tufted growth with spirally arranged leaves, typical of acrocarpous mosses. Their occurrence on rocks with running water indicates hydrophilous adaptation. Leaf features such as lanceolate shape, acute to acuminate apices, and serrate or revolute margins likely facilitate water drainage and reduce mechanical stress. The well-developed costa may provide structural support and aid in water conduction (Glime, 2007).

In contrast, *Fissidens diversifolius* and *F. geminiflorus* showed flattened growth with a characteristic distichous leaf arrangement. These species were found on moist, shaded walls, including lime-coated substrates, indicating

adaptation to stable humid microhabitats. The presence of a vaginant lamina, a key diagnostic feature, likely contributes to water retention and protection (Singh, 2010).

Overall, the comparison highlights that *Philonotis* species are adapted to water-influenced rock habitats, whereas *Fissidens* species prefer shaded, moisture-retentive substrates. The observed traits, including leaf margin, costa, and cell structure, serve as reliable taxonomic characters and reflect ecological adaptation. These findings reinforce the importance of micromorphological features in bryophyte identification and ecological studies.

## Conclusion

The present study highlights significant micromorphological variation among the investigated moss species, particularly in growth form, leaf arrangement, costa development, and laminal cell structure. These characters proved to be useful for species identification and effectively distinguished the genera *Philonotis* and *Fissidens*. The observed differences also reflect ecological adaptations, with *Philonotis* species associated with water-influenced rock habitats and *Fissidens* species adapted to shaded, moisture-retentive substrates.
The findings emphasize the importance of micromorphological traits in bryophyte taxonomy and their role in understanding species-environment relationships. Furthermore, this study provides baseline data for future research on bryophyte diversity in the Mount Abu region.

Future studies may incorporate advanced techniques, such as scanning electron microscopy (SEM) and molecular approaches, to achieve more precise characterization and support taxonomic and phylogenetic interpretations.

**Acknowledgements**
The first author gratefully acknowledges the Council of Scientific and Industrial Research (CSIR), Government of India, for the award of a research fellowship (CSIR-JRF). The authors thank the Department of Botany and the RUSA-supported laboratory for providing laboratory facilities and technical support. Assistance received during fieldwork and sample collection is also gratefully acknowledged.

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**Source of support:** Nil;
**Conflict of interest:** The authors declare no conflict of interests.

## Cite this article as:

Parihar, S. Deora, G.S., Sarswati, Agrawal, J., and Shekhawat, M.K. "Taxonomic Evaluation of Selected Moss Species Using Morphological Traits and Cluster Analysis." *Annals of Plant Sciences.* 15.07 (2026): pp. 26-36.