

Anatomical Insights into Orchid Roots: Adaptive Mechanisms in *Polystachya concreta*, *Liparis viridiflora*, & *Coelogyne nervosa*

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Abstract— Orchids exhibit remarkable anatomical adaptations in their roots, enabling them to thrive in diverse ecological conditions. This study investigates the root anatomical features of three orchid species: *Polystachya concreta*, *Liparis viridiflora*, and *Coelogyne nervosa*. Specimens were collected from the Eunoia Orchid Garden, Ambalavayal, and analyzed using histological techniques. Observations revealed significant variations in root structures, including velamen layers, cortical organization, vascular bundle arrangements, and pith characteristics.

Polystachya concreta exhibited a three-layered velamen with hexagonal cortical cells and eight vascular bundles. *Liparis viridiflora* demonstrated a four-layered velamen, twelve vascular bundles, and pronounced protoxylem. *Coelogyne nervosa* displayed a six-layered velamen, over eighteen vascular bundles, and a well-developed parenchymatous pith. These anatomical features underscore the adaptive strategies of orchids to different environmental conditions, enhancing water retention, nutrient absorption, and resilience against abiotic stressors.

This comparative analysis highlights the morphological diversity among orchid species and provides insights into their ecological adaptations. The findings contribute to the understanding of orchid biology and support conservation efforts by identifying key anatomical traits essential for survival in varied habitats.

Keywords— *Orchidaceae*, *Root anatomy*, *Velamen structure*, *Polystachya concreta*, *Liparis viridiflora*, *Coelogyne nervosa*, *Vascular bundles*, *Adaptations*, *Histological analysis*, *Conservation biology*.

I. INTRODUCTION

Orchids, belonging to the family Orchidaceae, represent one of the largest and most diverse groups in the plant kingdom, with over 25,000 species and numerous hybrids distributed across the globe. Renowned for their unique morphology, ecological adaptations, and intricate relationships with pollinators, orchids are a focal point of botanical research. They are found in diverse habitats ranging from tropical rainforests to arid regions, displaying remarkable structural and functional adaptations that contribute to their ecological success. Among these, root anatomy plays a pivotal role in nutrient absorption, water retention, and plant stability, particularly for epiphytic and terrestrial orchids that encounter a wide range of environmental challenges.

The Western Ghats, a UNESCO World Heritage site and one of the world's eight "hottest hotspots" of biodiversity, harbors a rich array of orchid species. This region, known for its unique climatic conditions and varied topography, provides an ideal habitat for both epiphytic and terrestrial orchids. However, habitat loss, deforestation, and climate change pose significant

threats to the survival of many orchid species. The conservation and understanding of these orchids, particularly their anatomical and physiological features, are essential for their survival and ecological role.

Roots are among the most critical structures in orchids, especially in epiphytic species, which rely on them not only for water and nutrient uptake but also for anchorage on host plants. The velamen, a specialized tissue layer unique to orchid roots, serves as an efficient water absorption system while protecting the plant from desiccation. Anatomical studies of orchid roots provide insights into their adaptations to various habitats, shedding light on their survival strategies in nutrient-poor environments. Such studies are particularly valuable for conservation biology and offer guidance for sustainable cultivation practices.

This study focuses on the anatomical features of the roots of selected orchid species: *Polystachya concreta*, *Liparis viridiflora*, and *Coelogyne nervosa*. These species, representative of the diverse morphological and ecological adaptations within Orchidaceae, were selected for their varying habitats and root structures. *Polystachya concreta* is a rare species known for its sympodial growth habit and unique velamen anatomy. *Liparis viridiflora*, on the other hand, is a common species with distinct vascular bundles and cortical structures, while *Coelogyne nervosa* exhibits adaptations typical of epiphytic orchids thriving in the cooler climates of the Himalayan foothills and Southeast Asia.

The roots of orchids are highly specialized structures, featuring multiple layers of velamen, parenchymatous cortex, and well-defined vascular bundles. These structures are not only essential for water absorption but also facilitate gas exchange and provide mechanical support. The endodermis, pericycle, and pith further contribute to the functionality of orchid roots, enabling them to thrive in a range of ecological niches. The adaptations observed in these root structures highlight the evolutionary ingenuity of orchids, allowing them to establish themselves in diverse environments.

In this study, specimens were collected from the Eunoia Orchid Garden in Ambalavayal, Kerala, and analyzed for their root anatomical features. The species selected represent both epiphytic and terrestrial growth forms, offering a comprehensive understanding of the anatomical variations across different orchid habitats. The roots were processed and studied using standard anatomical techniques, and detailed observations were made regarding the structure and function of the velamen, cortex, vascular bundles, and associated tissues.

The findings from this research contribute to the understanding of orchid root biology, emphasizing their ecological adaptations and anatomical diversity. By analyzing the root anatomy of these species, the study provides valuable insights into the structural-functional relationships in orchids, which are crucial for their conservation and sustainable management. This research highlights the need for continued investigation into the unique adaptations of orchids, particularly in biodiversity hotspots such as the Western Ghats, to ensure their survival in the face of environmental challenges.

II. METHODOLOGY

The present study investigates the root anatomical features of selected members of the Orchidaceae family to understand their structural adaptations and ecological significance. Specimen collection was conducted on April 8, 2021, at the Eunoia Orchids Garden in Ambalavayal, Wayanad, with the support of Mr. Sabu V. U. The specimens collected included roots from *Liparis viridiflora* (Blume) Lindl., *Polystachya concreta* (Jacq.) Garay, and *Coelogyne nervosa* A. Rich. Photographs of the plants were captured using a Canon EOS 200D camera for documentation.

Among the collected specimens, the best samples were selected for anatomical studies, ensuring that they were in optimal condition for microscopic examination. Fresh materials were processed in the MSc. Botany lab at St. Mary's College.

2.1 Sample Preparation:

The roots were sectioned manually using a sharp blade, ensuring the slices were as thin as possible to enhance visibility under a microscope. Sufficient water was applied to the blade edge to prevent air bubble entrapment in the sections. The cut sections were immediately transferred to a watch glass containing distilled water using a fine brush.

2.2 Staining and Mounting:

The sections were stained with 1% safranin for enhanced tissue contrast. Microslides were prepared by carefully transferring the stained sections using a brush. A drop of glycerine was applied to each slide as a mounting medium. Coverslips were gently placed over the sections with a needle to avoid trapping air bubbles. Excess glycerine was removed with tissue paper.

2.3 Microscopic Analysis:

The prepared slides were observed under a research microscope to analyze and document the anatomical features. Special attention was paid to tissue layers such as the epi-velamen, velamen, cortex, endodermis, pericycle, and vascular bundles.

III. IMPORTANCE OF THE SPECIES

The study focuses on the anatomical adaptations of roots in three selected members of the Orchidaceae family: *Polystachya concreta*, *Liparis viridiflora*, and *Coelogyne nervosa*. These orchids represent a diverse range of growth forms, including epiphytic, lithophytic, and terrestrial habits. Understanding their root anatomy is vital to comprehending their ecological success, survival strategies, and potential applications in conservation and biodiversity preservation.

3.1 Species Overview and Ecological Significance:

3.1.1 Polystachya concreta:

This species is a sympodial epiphyte with occasional lithophytic and terrestrial growth forms. Widely distributed in pantropical regions, including Asia, Africa, and the Americas, *P. concreta* is noted for its ecological flexibility. Anatomical studies revealed its uniseriate epi-velamen, three-layered velamen, and a relatively thick cortex with parenchymatous cells. The arrangement of vascular bundles, with exarch xylem and multiple phloem patches, highlights its efficient nutrient and water transport system. These features enable it to adapt to nutrient-poor soils and varying water availability. Despite its adaptability, this species is classified as rare, emphasizing the importance of its conservation.

3.1.2 Liparis viridiflora:

Commonly known as the Green-Flowered Liparis, this species thrives in terrestrial environments, particularly in the forests and hilly regions of South and Southeast Asia. It is widely distributed in India, including in Kerala, where it is frequently observed in the Western Ghats. Anatomical observations show its four-layered velamen, rounded cortical cells, and radial polyarch vascular bundles. These adaptations allow *L. viridiflora* to withstand varying moisture levels and support efficient water and nutrient transport. As a common species, its ecological role includes stabilizing soil in its native habitats and contributing to local biodiversity.

3.1.3 Coelogyne nervosa:

This primarily epiphytic orchid is distributed across the Himalayan region and Southeast Asia. It is recognized for its striking floral display and adaptability to cool climates. Anatomically, *C. nervosa* features a six-layered velamen, a thick cortex, and a large pith region. The numerous vascular bundles (more than 18) and polyarch arrangement indicate a robust system for nutrient storage and transport, critical for its survival in nutrient-poor epiphytic habitats. This species' ecological importance extends to its role in supporting pollinators and maintaining forest biodiversity.

3.2 Importance of the Study:

The anatomical analysis of these orchids provides insights into their survival strategies, particularly their root adaptations to varying environmental conditions. The velamen, a critical feature, aids in water absorption and storage, enabling orchids to survive in epiphytic and terrestrial habitats. The vascular bundle arrangements reveal their efficiency in nutrient transport and resilience to environmental stressors.

This study underscores the importance of conserving these species, as they play crucial roles in maintaining ecological balance. By understanding their structural and ecological attributes, the findings contribute to conservation strategies aimed at protecting orchids and the fragile ecosystems they inhabit, particularly in biodiversity hotspots like the Western Ghats.

Studies:

1. **Polystachya concreta:** Known for its single-layered epi-velamen and three-layered velamen, this species exhibits parenchymatous cortical cells and a radial arrangement of vascular bundles with exarch xylem.
2. **Liparis viridiflora:** Features a single-layered epi-velamen and four-layered velamen, with polyarch vascular bundles and well-defined endodermis and pith.
3. **Coelogyne nervosa:** Displays a six-layered velamen and more than eighteen vascular bundles. The cortex is thick and parenchymatous, with a prominent pith region.

These anatomical studies provide insights into the unique structural adaptations of terrestrial and epiphytic orchids, enabling them to thrive in diverse ecological niches. Observations of features such as velamen thickness, vascular organization, and cortical structure offer valuable data for understanding orchid ecology and aiding conservation efforts.

This methodology lays the foundation for future comparative studies on root anatomy and its role in the ecological success of Orchidaceae species in varying habitats.

IV. RESULTS

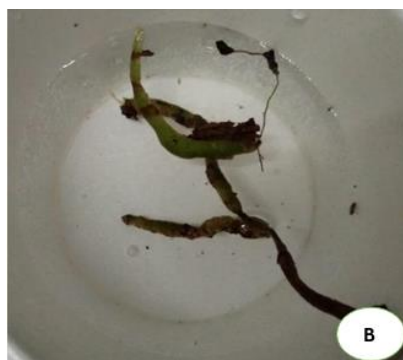
The anatomical study of the roots of three orchid species (*Polystachya concreta*, *Liparis viridiflora*, and *Coelogyne nervosa*) revealed significant structural adaptations supporting their survival and ecological function in diverse environments.

1. **Polystachya concreta** exhibited a uniseriate epi-velamen and a compactly arranged three-layered velamen, providing effective moisture absorption and retention. The cortex was parenchymatous with hexagonal cells containing chlorophyll, facilitating photosynthesis. The vascular bundle arrangement was exarch with eight radial bundles, with protoxylem located at the periphery and metaxylem at the center.
2. **Liparis viridiflora** displayed a four-layered velamen with thick-walled parenchymatous cortex cells. The vascular bundles were polyarch, with 12 distinct bundles organized radially. The xylem showed spiral and reticulate thickenings, optimizing water transport. A well-defined pith was composed of parenchymatous cells.
3. **Coelogyne nervosa** exhibited a six-layered velamen and a thick parenchymatous cortex with well-defined endodermis and pith. The vascular bundles, numbering more than 18, were exarch and polyarch. Protoxylem with spiral thickenings and metaxylem with annular thickenings enhanced water conduction efficiency.

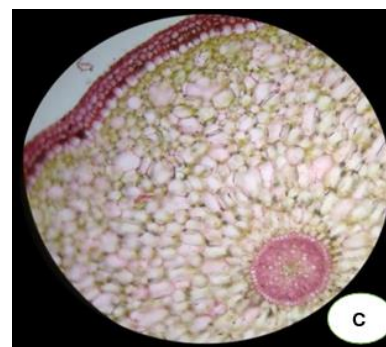
The observed variations in root anatomy demonstrate adaptations for moisture absorption, nutrient transport, and photosynthesis, underscoring the ecological diversity and survival strategies of these orchid species. These findings highlight the intricate relationship between structure and function in orchids' adaptation to their habitats.



A. Habit

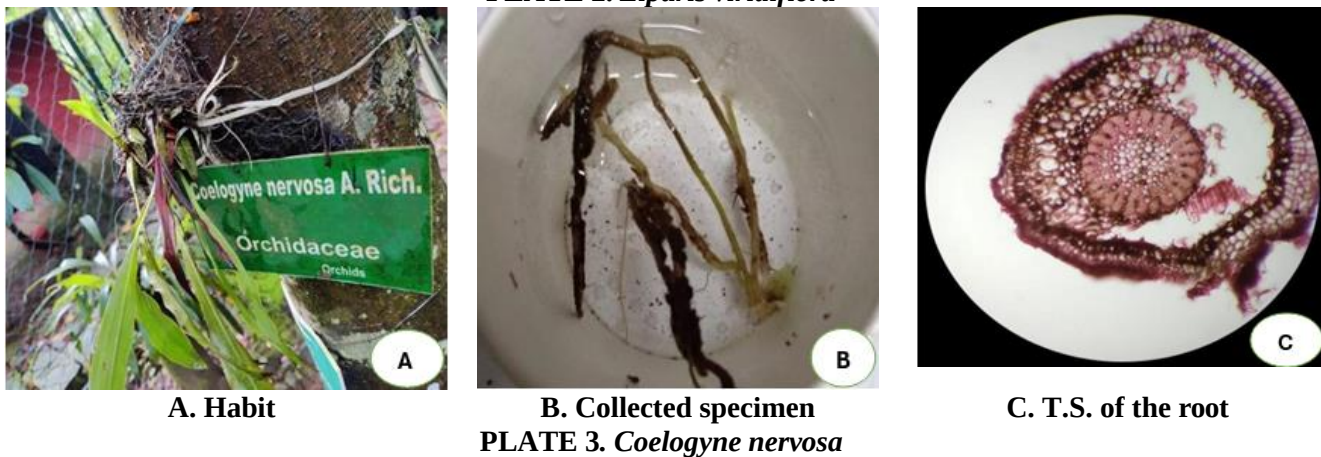


B. Collected specimen



C. T.S. of the root

PLATE 1. *Polystachya concreta*



V. DISCUSSION

The root anatomical study of *Polystachya concreta*, *Liparis viridiflora*, and *Coelogyne nervosa* highlights the unique structural adaptations that enable these orchids to thrive in diverse environments. These adaptations are vital for nutrient acquisition, water retention, and ecological resilience.

The presence of velamen in all three species, albeit with different layering, is a hallmark adaptation in orchids. The uniseriate epi-velamen followed by multiseriate velamen in *Polystachya concreta* (three layers), *Liparis viridiflora* (four layers), and *Coelogyne nervosa* (six layers) plays a critical role in water absorption and prevention of desiccation. This layered structure also facilitates the storage and slow release of moisture, which is particularly important for epiphytic orchids in fluctuating water conditions.

The cortex, composed of parenchymatous cells, varies in thickness and shape among the species, providing mechanical support and aiding in photosynthesis due to chlorophyll-containing cells. The specialized endodermis, distinct in all studied species, functions as a barrier regulating water and nutrient flow into the vascular tissues. Notably, the vascular bundle arrangement—polyarch and exarch with varying numbers—underscores the efficiency of these orchids in conducting water and nutrients. The presence of spiral and reticulate thickenings in protoxylem and metaxylem vessels, respectively, suggests structural adaptations to support mechanical stress and ensure optimal functionality.

These findings reveal the intricate anatomical adaptations that underpin the ecological success of terrestrial and epiphytic orchids. The comparative analysis of these root structures provides valuable insights into the evolutionary strategies of orchids, emphasizing the need for conservation efforts to protect these unique species in their natural habitats.

This table summarizes the key anatomical features observed in the root structures of the three orchid species.

TABLE 1
ANATOMICAL FEATURES IN THE ROOT STRUCTURES OF THE THREE ORCHID SPECIES

Species	Velamen	Cortex	Endodermis	Pericycle	Vascular Bundle	Xylem	Phloem	Pith
Polystachya concreta	Uniseriate epi-velamen, 3-layered velamen	Parenchymatous, hexagonal, chlorophyll-containing	Well-defined, innermost cortical layer	Narrow ring following endodermis	8 radial bundles, exarch, centripetal organization	Protoxylem at periphery, metaxylem at center	Phloem patches between xylem	Simple, parenchymatous
Liparis viridiflora	Single-layered epi-velamen, 4-layered velamen	Thick parenchymatous, rounded/oval cells	Thin-walled	Narrow ring, distinguishable	12 radial, polyarch bundles, exarch	Spiral thickening in protoxylem, reticulate thickening in metaxylem	Phloem patches between xylem	Well-defined, parenchymatous
Coelogyne nervosa	Uniseriate epi-velamen, 6-layered velamen	Thick parenchymatous, round cells	Narrow, well-defined	Absent	More than 18 radial, polyarch bundles, exarch	Spiral thickening in protoxylem, annular thickening in metaxylem	Phloem patches between xylem	Large, parenchymatous

VI. CONCLUSION

This study provides valuable insights into the root anatomy of three orchid species from the Western Ghats, namely *Polystachya concreta*, *Liparis viridiflora*, and *Coelogyne nervosa*. The anatomical features of these species reveal significant adaptations that contribute to their survival in diverse environmental conditions. The study found that the presence of specialized root structures, such as the velamen and epidermal layers, plays a crucial role in moisture retention and nutrient uptake, essential for orchids' growth in both terrestrial and epiphytic habitats. The varying structures of the vascular bundles and cortical layers further highlight the diversity of adaptation strategies within the orchid family.

The findings emphasize the importance of these root adaptations in ensuring the resilience of orchids to environmental stressors, particularly in regions like the Western Ghats, which are subject to varying climatic conditions. Understanding these anatomical features not only enhances our knowledge of orchid physiology but also informs conservation strategies. Given the increasing threats to orchid habitats, particularly through deforestation and climate change, preserving such species is vital for maintaining biodiversity in the region.

Further research on other orchid species and their root anatomical adaptations will contribute significantly to the conservation and management of these ecologically important plants, providing a sustainable approach to their preservation in natural ecosystems.

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