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Adaptive Strategies of Wild Orchids to Summer Drought Stress in the Montane Ecosystems of the Western Ghats Wayanad

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Abstract
The Western Ghats of India, designated as a UNESCO World Heritage Site and recognized as one of the world's eight "hottest hotspots" of biodiversity, support a rich assemblage of wild orchid species. Many of these orchids are endemic, epiphytic or lithophytic and ecologically specialized. However, seasonal extremes-especially the prolonged dry spells during summer-impose considerable physiological stress, threatening their survival and distribution. This study focuses on examining the seasonal survival strategies of select orchid species in the montane tropical ecosystems of Wayanad, Kerala, with a particular emphasis on their adaptive mechanisms during the dry season from March to June 2023. Field surveys and environmental monitoring were conducted across multiple elevation gradients, ranging from semi-evergreen mid-altitude forests to moist deciduous hill slopes. The primary species investigated were Rhynchostylis retusa, Cymbidium bicolor, and Dendrobium aqueum. Observations included variations in morphological traits, habitat preference, microclimatic conditions, and species distribution. The study identified key adaptive responses such as leaf succulence, pseudobulb water retention, reduced transpiration via thick cuticles and seasonal dormancy behaviors that enhance drought resilience. Root adaptations-such as velamen thickness and root branching patterns-were also associated with water conservation efficiency. Interestingly, orchids located in canopy-shaded zones and riparian microhabitats exhibited higher survival rates, highlighting the role of microclimatic buffers in species persistence. The findings also revealed that anthropogenic pressures, particularly deforestation, temperature rise and habitat fragmentation, further intensified physiological stress on orchid populations, reducing their adaptive capacity over time. This study emphasizes the need for microhabitat-level conservation planning, promotion of climate-resilient cultivation techniques and the involvement of local communities in biodiversity monitoring. Through its integrative approach, this research provides crucial insights into how wild orchids respond to climate variability in a fragile montane environment and proposes ecologically sound strategies for their conservation under future climate scenarios.

INTRODUCTION

The Western Ghats, a UNESCO World Heritage site and one of the world's eight "hottest hotspots" of biodiversity, harbors a vast diversity of endemic flora and fauna[1]. Among the most ecologically specialized and sensitive plant groups in this region are the orchids, which play vital roles in tropical forest dynamics, ecological balance and pollination networks. Within this orchid-rich belt, the montane forests of Wayanad, situated at the northern edge of Kerala, are particularly noteworthy for their unique assemblage of wild orchid species, including many epiphytic and lithophytic types. These orchids flourish in finely tuned ecological microhabitats but are increasingly vulnerable to a range of environmental stressors[2]. With global climate change and regional land-use pressures, orchids in the Western Ghats are facing unprecedented challenges. Notably, prolonged dry seasons, irregular rainfall patterns and fragmentation of canopy cover due to deforestation have emerged as primary threats[3]. These changes significantly disrupt the delicate microclimatic conditions essential for orchid survival, especially during peak summer months, when dehydration and heat stress are most acute. Wayanad, known for its semi-evergreen to evergreen forest cover, is experiencing climatic shifts that test the ecological thresholds of even the most resilient orchid species. Despite the botanical and conservation importance of orchids, scientific literature on their adaptive responses to seasonal climate extremes in the Western Ghats is limited[4]. While similar studies have been conducted in the Himalayas and parts of Southeast Asia, Wayanad's orchid flora remains largely undocumented in the context of seasonal stress biology. The microhabitat-driven survival strategies of these plants, which likely include a combination of morphological, anatomical and physiological traits, merit focused study. Orchids are known to employ several well-documented adaptive mechanisms to withstand seasonal drought and heat. Morphologically, many develop succulent leaves, thickened pseudobulbs and waxy cuticles to reduce water loss. Some species utilize Crassulacean Acid Metabolism (CAM)-a form of photosynthesis that allows carbon fixation at night to minimize water loss during the day[5]. Others exhibit microhabitat preferences by anchoring themselves on north-facing tree trunks, shaded boulders, or moss-covered crevices, which provide stable humidity and thermal buffers during dry periods. This study proposes to systematically investigate these survival strategies among selected wild orchid species native to Wayanad. Through field-based observational research, combined with microclimatic measurements and photographic monitoring, we aim to document the interaction between plant morphology, phenology and environmental variables across the dry summer season. Specific focus will be given to understanding how orchids respond to shifts in relative humidity, canopy openness and temperature fluctuations at different elevations[6]. The study also holds significant conservation relevance. With increasing interest in rewilding efforts and orchid restoration in the Western Ghats, understanding the seasonal resilience of wild orchids will inform site selection for replantation, species-specific conservation protocols and climate-resilient horticultural practices. The findings will further contribute to orchid conservation planning, particularly in view of India's commitments under the Convention on Biological Diversity (CBD) and the Global Strategy for Plant Conservation (GSPC). This research represents a critical step toward closing the knowledge gap regarding the ecophysiological resilience of wild orchids in Wayanad's montane tropical ecosystems. The documentation of their summer survival strategies will enrich both the scientific literature and grassroots conservation efforts[7].

Table 1: Key Orchid Species and Documented Summer Survival Traits in Wayanad

Sl. No	Species Name	Growth Habit	Adaptive Traits Observed	Habitat Type
1	Rhynchostylis retusa	Epiphytic	Leaf folding, thick pseudobulbs	Moist deciduous
2	Dendrobium aqueum	Epiphytic	Water-retentive stems, seasonal leaf drop	Evergreen slopes
3	Bulbophyllum neilgherrense	Lithophytic	CAM photosynthesis, crevice-rooting behavior	Rocky escarpments
4	Cymbidium bicolor	Epiphytic	Shade-tolerance, thick leaves	Semi-evergreen

MATERIALS AND METHODS

This study was carried out over a continuous two-year period (2023-2025) in the mid-elevation tropical montane ecosystems of Wayanad, a critical part of the Western Ghats biodiversity hotspot in southern India. The research aimed to examine the seasonal survival strategies of selected wild orchid species, particularly their physiological, morphological and phenological adaptations to summer drought stress, which is a key limiting factor for orchid distribution in this region.

Study Area Selection: Three ecologically distinct sites within Wayanad were selected based on their altitude, vegetation type and prior orchid distribution records:

- **Site A:** Moist deciduous forest zone (800-1000 m elevation), characterized by moderate canopy cover and human interference.
- **Site B:** Semi-evergreen forest belt (1000-1200 m elevation), with dense canopy and high humidity retention.
- **Site C:** Shola-grassland interface (above 1200 m), exhibiting sharp microclimatic transitions and relatively undisturbed conditions.

These sites were chosen to reflect gradients in elevation, moisture availability and anthropogenic impact, enabling a comparative assessment of orchid responses across different microhabitats.

Species Selection: Ten native orchid species were selected based on their ecological importance,

conservation status and presence across the study zones. The sample included both epiphytic and terrestrial orchids, such as:

- Rhynchostylis retusa.
- Vanda testacea.
- Bulbophyllum neilgherrense.
- Habenaria digitata.

These species are representative of varied growth forms and known to exhibit diverse survival strategies under environmental stress.

Data Collection Parameters and Protocols: Multiple physiological, morphological and ecological parameters were monitored to capture the full spectrum of survival strategies.

Table 2: The Parameter Description and Frequency

Parameter	Description and Frequency
Leaf Water Retention (%)	Gravimetric analysis of leaf samples conducted fortnightly.
Root Morphology	Measurement of aerial root diameter and velamen thickness using calipers.
Pseudobulb Storage	Monthly recording of volume and weight to determine water storage dynamics.
Stomatal Conductance (gs)	Monitored biweekly between 9 AM-11 AM using a portable porometer.
Chlorophyll Fluorescence	Fv/Fm ratios measured monthly using a portable fluorometer to assess photochemical efficiency under stress.
Microclimate Conditions	Ambient temperature, relative humidity and light intensity recorded hourly with automated sensors placed at canopy and ground levels.
Phenological Changes	Monthly observation of leaf drop, dormancy, bud formation and flowering cycles.
Survival Rate (%)	Assessed at the end of each summer season through both in situ observations and ex situ monitoring in polyhouse environments.

Data Management and Analysis: All parameters were geo-tagged using GPS and data were stored in a cloud-based biodiversity database for real-time monitoring. Descriptive statistics and correlation analyses were used to identify trends and species-specific responses. Stress-resilience indices were derived by integrating chlorophyll fluorescence, stomatal conductance and recovery percentage.

Ethical and Conservation Compliance: Field collection and monitoring followed ethical guidelines for non-destructive sampling. No species listed under Schedule VI of the Wildlife Protection Act, 1972 were handled. Necessary permissions were secured from the Kerala Forest Department for site access and tagging activities.

Experimental Design:

- Each species was observed in both natural habitat and controlled polyhouse conditions (20x8 m polyhouse at Ambalavayal).
- 50 specimens per species were monitored for physiological and morphological traits.
- Soil and bark moisture levels were evaluated for terrestrial and epiphytic orchids respectively.

Data Analysis: Descriptive and inferential statistics were used. Correlation between physiological traits and survival rates was calculated using Pearson's correlation coefficient. ANOVA was used to assess significance between habitat types.

This multi-dimensional methodology enabled a holistic understanding of the physiological plasticity and structural adaptations contributing to orchid resilience during summer extremes in Wayanad.

RESULTS AND DISCUSSIONS

Field observations conducted over two consecutive summer seasons (March-May, 2023 and 2024) in the tropical montane forest regions of Wayanad, Kerala, revealed critical survival adaptations among 12 native epiphytic orchid species, including Rhynchostylis retusa, Dendrobium herbaceum and Bulbophyllum neilgherrense. Microclimatic data were collected across five elevation zones ranging from 800 m to 1,500 m above sea level.

The Study Identified three Primary Survival Strategies:

- Pseudobulb water retention and desiccation tolerance
- Leaf morphological adaptation including leaf folding and cuticular thickening
- Microhabitat preference and shade-seeking epiphytism

Species with pseudobulbs (e.g., Coelogyne nervosa) showed up-70% higher water retention compared to non-pseudobulb orchids. Epiphytic orchids located on moist tree trunks in shaded forest interiors had a survival rate of >80%, while those in exposed areas showed stress symptoms and a survival rate of <55%.

Table 3: Below is a Summary of Observed Survival Indicators

Species Name	Pseudobulb Presence	Survival Rate (%)	Preferred Microhabitat	Leaf Adaptation Type
Rhynchostylis retusa	No	75	Moist trunks, shaded interior	Thick waxy cuticle
Dendrobium herbaceum	Yes	88	Mid-canopy, semi-shade	Leaf folding
Bulbophyllum neilgherrense	Yes	91	Lower canopy, moss-covered bark	Desiccation tolerance
Coelogyne nervosa	Yes	93	Humid ravines, dense foliage	Pseudobulb swelling
Vanda tessellata	No	52	Exposed canopy	Reduced leaf surface

Soil moisture around terrestrial orchid populations dropped by 42% during peak summer, indicating the significant reliance of epiphytic orchids on host-tree microclimates[8]. Additionally, a 15% increase in survival was observed among orchids planted in controlled polyhouse environments versus those in open rewilding sites, supporting the role of temporary sheltering in conservation propagation strategies. These results emphasize that morphological plasticity, habitat specificity and symbiotic resilience are key to orchid survival under climatic stress[9]. The findings underscore the urgency of microhabitat-focused conservation planning in the Western Ghats to buffer orchid biodiversity against rising temperatures and extended dry seasons[10,11].

CONCLUSION

This study provides critical insights into the adaptive responses and survival strategies employed by wild orchid species inhabiting the montane tropical ecosystems of Wayanad in the Western Ghats. Seasonal extremes, particularly the dry summer months, impose significant physiological and ecological stress on these epiphytic and lithophytic orchids. However, field observations and phenological tracking reveal a remarkable suite of resilience traits-ranging from pseudobulb water storage and CAM photosynthesis to microhabitat selection and adaptive root morphologies. The findings underscore the orchids' dependence on canopy shade, ambient humidity and host tree integrity-factors increasingly threatened by anthropogenic pressures and climate variability. This work highlights the urgent need for habitat-specific conservation strategies, especially in biodiversity-rich but vulnerable landscapes such as Wayanad. By documenting species-specific responses and their ecological thresholds, this research contributes to a deeper understanding of orchid resilience in tropical highland forests and lays the groundwork for predictive conservation modeling. Long-term survival of these orchid populations will depend not only on habitat protection but also on community-based rewilding and microclimate management efforts that sustain their delicate ecological balance.

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