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Wild epiphytic orchid diversity and phorophyte preference along micro-environmental gradients in north-eastern protected forest areas of Bangladesh

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Abstract

Understanding epiphytic orchid diversity and their ecological associations with phorophytes is critical for effective forest conservation. This study assessed species richness, diversity, and orchid-phorophyte interactions along eight micro-environmental habitat variables (phorophyte height, BDH, bark thickness, phorophyte crown height, orchid attachment height, nearest forest edge distance, canopy coverage & elevation) across four protected forest areas in northeastern Bangladesh: Rema-Kalenga Wildlife Sanctuary (RKWS), Lawachara National Park (LNP), Satchari National Park (SNP), and Khadimnagar National Park (KNP). A total of 21 wild epiphytic orchid species within 12 genera were recorded, hosted by 74 tree species across 31 families. RKWS and LNP exhibited the highest species richness (20 species each), with RKWS also having the highest Shannon Diversity Index (2.84) and evenness (0.95), indicating a balanced and diverse orchid community. KNP demonstrated the lowest diversity ($H' = 1.945$) and species richness (9 sp.), indicating a fragmented ecosystem. Rank-abundance curves identified the most abundant orchid species, including *Cymbidium finalaysonianum* in RKWS and *Dendrobium lindleyi* in LNP. phorophyte specificity analysis revealed *Aerides* and *Cymbidium* as generalists occurring on 26 phorophyte species, while *Camarotis* and *Phalaenopsis* were specialists, found on only 3 phorophyte species. *Artocarpus* emerged as the most supportive host, associating with 11 orchid species. Micro-environmental factors such as phorophyte height, crown height, bark thickness, and orchid attachment height showed significant positive correlations with orchid abundance. PCA and Mantel tests indicated that environmental gradients, particularly edge distance and altitude along with variables like- canopy coverage and phorophyte diameter, influenced orchid distribution patterns. These findings depicted that both phorophyte diversity and habitat microclimatic conditions play vital roles in the colonization and sustainability of wild epiphytic orchid populations. Conservation strategies should prioritize maintaining phorophyte diversity and favorable microhabitat conditions to ensure the persistence of these epiphytic orchid species under environmental change scenario.



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Keywords Epiphytic orchids, Orchid diversity, Orchid-photophyte preference, Micro-environmental gradient, Orchid distribution patterns

1 Introduction

Epiphytic orchids comprise approximately 75% of the orchid family (Orchidaceae) which is one of the most diverse angiosperm families in the world, with approximately 25,000 known species [13, 18]. They are generally terrestrial, epiphytes, or lithophytes and occur most abundantly in tropical and subtropical forests. Epiphytic orchids are widely considered important ecological indicators and bioindicators due to their high sensitivity to environmental changes. They respond quickly to air pollution, climate variability, and moisture stress. Their presence, abundance, and diversity reflect the overall health and stability of forest ecosystems. [8, 12, 19, 29, 37]. However, wild epiphytic orchids are increasingly threatened by anthropogenic activities, including ornamental plant trade, pollution, and climate change [15, 18, 32]. In Bangladesh, orchid species are rapidly losing suitable niches due to forest degradation, illegal collection, habitat fragmentation, agricultural encroachment, invasive species, and the expansion of monoculture plantations [51, 66]. They face severe risks of illegal collection, habitat fragmentation, and agricultural encroachment [31]. Additionally, invasive species and the expansion of monoculture plantations further threaten their natural habitats [48]. It has been reported that, during peak season, a single orchid flower vendor earns 2,450 USD from wild orchid trading in Nepal [59]. In different parts of the world, many different cultures use orchids in their cultural norms [55, 64]. Epiphytic orchids contribute significantly to forest biodiversity, nutrient cycling, and canopy water retention, while providing habitat and food resources for canopy-dwelling fauna. Their interactions with host trees, mycorrhizal fungi, and pollinators form complex ecological relationships, making epiphytic orchids sensitive indicators of habitat quality and environmental change [11, 16, 33]. Recent surveys in northeastern Bangladesh report indiscriminate harvesting of rare epiphytic orchids. [7, 26]. Given their ecological importance, conserving these species has become a priority in tropical conservation efforts [70], but efforts are hindered by limited understanding of the habitat requirements and drivers of epiphytic orchid occurrence in natural forest ecosystems of Bangladesh.

Huda, [23] compiled a checklist comprising 160 species within 63 genera of the family Orchidaceae in Bangladesh, of which 106 were identified as epiphytic and 56 as terrestrial. Seventy-six different species were identified from the southeastern part of Bangladesh [28]. Many orchids are rare in nature despite this diversity and are on the edge of extinction. A study conducted by Rashid et al. [51]. revealed that 54 species from the checklist were not found in their previously recorded habitats, indicating significant habitat loss, while forests in Bangladesh are being destroyed at an annual rate of 2.6%, double the global annual rate of deforestation [61]. A total of 32 orchid species (epiphytic and terrestrial) have been recorded as extinct in Bangladesh, with many others across South and Southeast Asia and Sub-Saharan Africa facing severe threats due to forest destruction, habitat fragmentation, unplanned development, climate change impacts, and illegal collection [27, 39, 69].

Despite the abundant information on orchid species richness, phenology, and distribution, studies focused on orchids within forest-protected areas in Bangladesh remain

sparse [28, 31, 48, 51]. Epiphytic orchids are mostly understudied, though comprising a large part of forest canopy biodiversity [39]. Epiphytic orchids occur in various parts of Bangladesh on different phorophyte plant species, both in forests and outside [31]. Supplementary factors that are affecting epiphytic orchids are the phorophyte species and their characteristics (e.g., age, height, diameter, bark thickness), and some habitat attributes like canopy coverage, canopy height, and crown size [3, 17, 63], which collectively influence orchid colonization potential and survival in microclimatic conditions [28, 38]. Studies from tropical regions, particularly in Asia, have shown that orchid-phorophyte interactions are often non-random and influenced by specific phorophyte characteristics, which are important for the sustainability of orchid populations [36, 62]. The current fact of insufficient research on their phorophyte preferences confines our understanding of their complex interactions within ecosystems [28].

Epiphytic orchids are highly sensitive to microclimatic conditions and habitat disturbance, and changes in their diversity and distribution often reflect variation in forest structure and habitat quality [8, 12, 19, 29, 37]. Thus, recognizing the mechanisms that influence "where orchids occur and why" is crucial for evaluating the factors responsible for their diversity and distribution patterns. Realizing these dynamics can result in more efficient conservation efforts specific to the needs of orchid species in forest ecosystems [72]. However, it is evident that the findings available so far are scant, and several information gaps remain, either due to controversial reports or a lack of intensive data [51]. Diversity, status, and distribution of orchids have been evaluated for various regions of Bangladesh, but their status in forest-protected areas has not been fully examined [51]. An assessment of their diversity is necessary for the conservation of orchid species in forests, especially in protected areas that are vital biodiversity shelters.

Despite their significance, forests in Bangladesh, which harbor most terrestrial plants, have received little attention regarding orchid diversity. Previous research on epiphytic orchids in Bangladesh has focused on region-wise species richness [25, 31, 48], herbarium records and taxonomic verification [23, 51], country-wise conservation status [27], and medicinal and ethno-botanical values [21, 28, 56]. Despite their ecological importance, the specific roles of phorophyte characteristics and phorophyte-orchid interactions, particularly how phorophyte traits and associated microclimatic conditions influence orchid establishment, colonization, and their persistence remain insufficiently understood, limiting a comprehensive understanding of the mechanisms that enable epiphytic orchids to thrive. So, this study aims to reveal some of these unknown facts within four northeastern forest-protected areas of Bangladesh. The objectives of this study are twofold: (1) to assess wild epiphytic orchid diversity in all four forest-protected areas of northeastern Bangladesh; and (2) to evaluate orchid preferences for phorophyte characteristics and micro-environmental variables. Finally, this study provides a comprehensive monograph of the orchids in these vital forest-protected areas of Bangladesh, shedding light on the significant habitat and host-related gradients that influence their survival in the ecosystems.

2 Methodology

2.1 Study areas

The study was conducted in four forest protected areas (Fig. 1) in the north-eastern region of Bangladesh: Rema-Kalenga Wildlife Sanctuary (RKWS), Khadimnagar

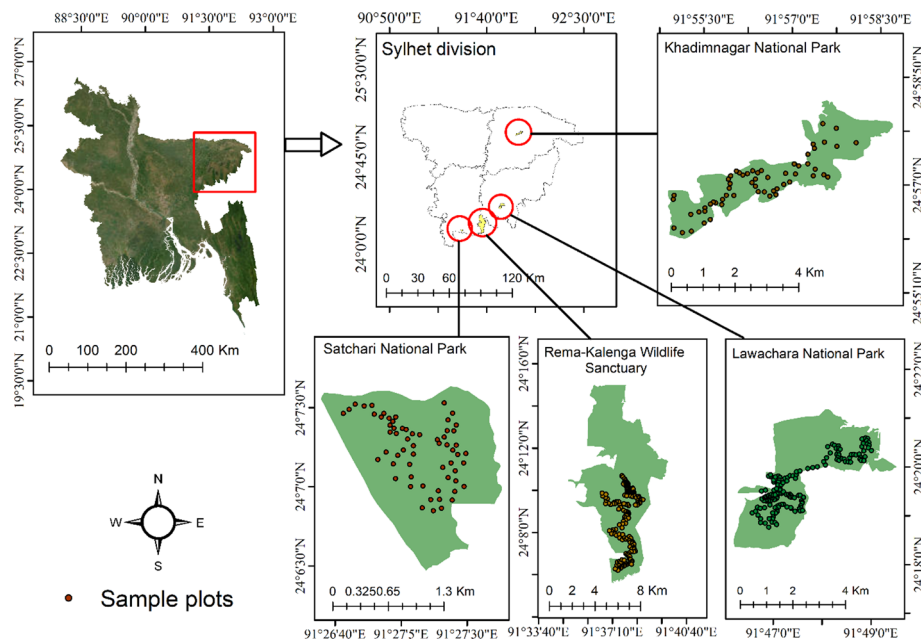


Fig. 1 Four studied areas of north eastern forest protected areas of Bangladesh

National Park (KNP), Lawachara National Park (LNP), Satchari National Park (SNP). These areas represent diverse tropical and subtropical forest ecosystems that provide critical habitats for wild epiphytic orchids and their phorophytes.

RKWS is located in Chunarughat Upazila of Habiganj district, between 24°06'–24°14' N latitude, 91°34'–91°41' E longitude and altitude 67 m approx. Established in 1982, the sanctuary now covers approximately 1,795.54 hectares. It is one of the largest semi-evergreen forests in Bangladesh, characterized by a mix of primary and secondary forests with a high diversity of flora and fauna. With a humid environment and mature tree stands it provides ideal conditions for epiphytic orchids.

LNP is part of the West Bhanugach Reserved Forest in Moulovibazar district. It spans 1,250 hectares and is located between 24°30'00"–24°32'00" N latitude and 91°37'00"–91°39'00" E longitude. Established in 1996, this semi-evergreen forest has dense canopy cover with scattered hillocks ranging altitude from 10 to 50 m from the mean sea level.

KNP, situated in Sylhet Sadar Upazila, was declared a protected area in 2006. It lies between 24°56'–24°58' N latitude and 91°55'–91°59' E longitude and covers 678.80 hectares of hilly terrain ranging from 28 to 50 m height from sea level. Surrounded by tea estates (Kalagool, Bhurjan, and Goolni), the park consists of secondary tropical forests that support various orchid species. The park's fragmented forest patches provide insights into how orchid diversity responds to human disturbances.

SNP is a protected area within the Raghunandan Hill Reserve Forest, located in Chunarughat Upazila of Habiganj district. It covers 243 hectares, lying between 24°5'–24°10' N latitude, 91°25'–91°30' E longitude and the elevation vary above 65 m from mean sea level. Declared as a national park in 2006. It features semi-evergreen and deciduous forest patches and dense tree cover, making it a crucial site for studying orchid diversity along micro-environmental gradients.

2.2 Data collection

Field data were collected using a modified arbitrary sampling method following Focho et al. (2010). Surveys were conducted periodically from mid-June 2023 to October 2024. Sampling intervals were maintained with deliberate temporal gaps to observe seasonal variability in epiphytic orchid occurrence and phorophyte associations along micro-environmental conditions. Each study area was surveyed using route-based walking paths along major forest trails, with survey routes at least 500 m (approx.) apart. Sampling plots were established at locations where epiphytic orchids were encountered. The number of trails varied depending on the size of the study area. Each of these transects has been walked and each epiphytic orchid (identified by Rabeya Khatun) has been recorded with its phorophyte traits detail [63]. Orchid was identified based on Banks (1999). In case of unidentified species, we have taken help from Bangladesh National Herbarium and Botanical Garden. Circular plots with a 5.461 m radius (100 m²) were established around each identified orchid, and data on orchid characteristics, phorophyte attributes, and associated micro-environmental variables were recorded, as described in Table 1.

Along with orchid bearing trees, other tree species without epiphytic orchids within sampling plots were recorded, to document host availability. However, analyses of orchid-phorophyte associations were limited to orchid-bearing trees to examine patterns of host association.

3 Statistical approaches

3.1 Diversity indices

The dataset was compiled based on field observations, where the presence and abundance of orchids were recorded in four study sites: RKWS, LNP, KNP, and SNP. Then to assess the diversity of orchid species across the study sites, various biodiversity indices were employed to quantify species composition, distribution, and dominance patterns. These indices were selected to represent complementary dimensions of diversity (richness, abundance structure and evenness) which are widely used in epiphytic orchid and phorophyte-association studies, allowing comparison with earlier regional studies. Species richness (S) quantified the total number of species in each site, while the Shannon Diversity Index (H') incorporated both species richness and relative abundance to reflect community heterogeneity. Evenness (E) further refined this by assessing how uniformly species are distributed. Beyond individual site diversity, Beta Diversity (β sor), using the Sørensen Dissimilarity Index, measured species turnover between sites, highlighting habitat differentiation along micro-environmental gradients. Gamma Diversity

Table 1 Measured variables with descriptions

SI	Variables	Details
1	Phorophyte height (m)	Total height of each tree
2	BDH (m)	Diameter at the breast height (1.3 m)
3	Bark thickness (cm)	Measured by inserting a fine needle into the bark until the underlying wood was reached, and the penetration depth was recorded
4	Phorophyte crown height (m)	Measured by subtracting crown length from total height
5	Orchid attachment height (m)	Height of attachment of each orchid
6	Nearest forest edge distance (m)	Distance of each sample plot from the nearest forest edge
7	Canopy coverage (%)	Canopy coverage as percentage by GRS densitometer
8	Elevation (m)	Elevation of each plot from mean sea level

(γ) represented the total species richness across all study sites, offering a regional perspective on species diversity. Additionally, Rank Abundance analysis was conducted to understand the relative dominance and distribution patterns of the orchids and their phorophyte species. Together, these indices provide a holistic and interpretable assessment of epiphytic orchid diversity and phorophyte composition across the study areas, consistent with the study objectives and comparable with existing literatures (Table 2).

3.2 Orchid-phorophyte association

To assess orchid-phorophyte associations, only phorophytes supporting more than one orchid species were considered. The analyses were restricted to phorophytes supporting multiple orchid species to avoid over-interpretation of incidental associations and to allow comparative evaluation of host preference. Phorophytes associated with a single orchid species were included in overall diversity and distribution analyses but excluded from this specific assessment. Orchid specificity was determined by counting the number of phorophyte species per orchid genus, while the specificity of phorophytes was assessed by the number of orchid species they supported. This approach identified generalist orchids with broad phorophyte ranges and specialist orchids with restricted associations, along with the key phorophytes that support orchid diversity (Table 3).

3.3 Orchid-phorophyte relationship along micro-environmental variables

A number of statistical tests were carried out to assess the correlation between orchid species composition and micro-environmental factors. Firstly, Pearson correlation analysis was conducted to measure the linear relationship between individual variables within the datasets. Following this, the Standard Mantel Test was applied using the Euclidean Distance method to evaluate the correlation between the two distance matrices, one representing species composition and the other representing microenvironmental variables. This method allowed for the quantification of ecological distance relationships, ensured that the patterns were statistically significant rather than random.

Afterwards, Principal Component Analysis (PCA) was conducted to reduce dimensionality and identify dominant patterns within the multivariate dataset. The Mantel Test results were further validated using permutation testing to assess the robustness of

Table 2 Diversity indices with formula and description

Index	Formula	Description
Species richness (S)	$S = \sum I (n_i > 0)$	$I (n_i > 0)$, an indicator function that equals 1 when the species is present and 0 when absent
Shannon diversity index (H')	$H' = -\sum p_i \ln p_i$	$p_i = \frac{n_i}{N}$, relative abundance of the species i n_i abundance of the species i N , total abundance of all the species
Evenness (E)	$E = \frac{H'}{\ln S}$	S , species richness An E value close to 1 indicated an even species distribution, while lower values suggested dominance by a few species
Beta diversity (β_{sor})	$\beta_{sor} = \frac{2B}{2B+A}$	A , Number of species shared between two sites B , Number of species unique to one of the sites $\beta_{sor} = 0$ indicates identical species composition, while $\beta_{sor} = 1$ means completely different species compositions
Gamma diversity (γ)	$\gamma = \sum I (n_i > 0)$ [For all sites]	$I (n_i > 0)$, an indicator function that equals 1 when the species is present and 0 when absent
Rank abundance	Log relative rank abundance = $\log (\frac{n_i}{N})$	N , the total abundance of all species of a given site

Table 3 Summary of orchid-microenvironmental variables correlation

Correlation test	Variables	r-value	P value	Significance	PCA covariances
Pearson	HH	0.20	< 0.001	***	
	BT	0.13	< 0.01	**	
	CH	0.19	< 0.001	***	
	ATH	0.13	< 0.01	**	
Mantel test	DBH	0.121	0.023	*	
	CC	0.067	< 0.01	**	
	ALT	0.060	0.032	*	
PCA	PCA1				99.7% variance
	PCA2				0.2% variance
	ED (PCA1)				0.99996 (loading)
	ALT (PCA2)				0.96797 (loading)

HH-phorophyte Height; BT-Bark Thickness; CH-Crown Height; ATH-Attachment Height; DBH-Diameter at Breast Height; CC-Canopy Cover; ALT-Altitude; ED-Distance of nearest forest Edge
*Significant; **strongly significant; ***very strongly significant

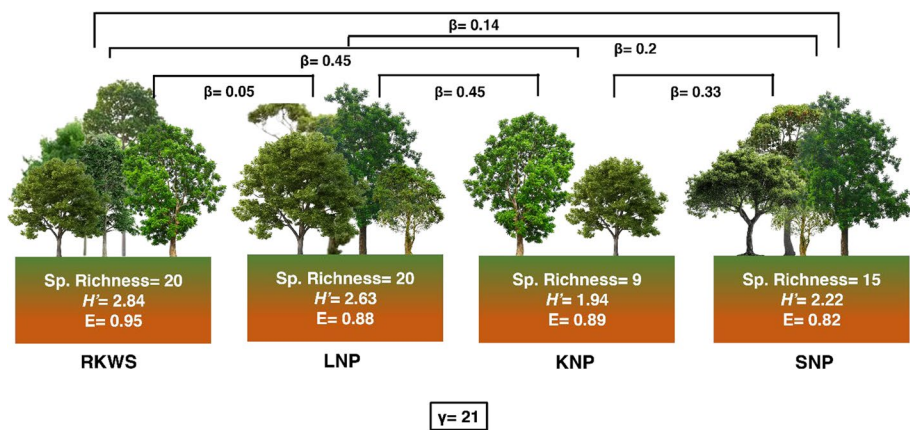


Fig. 2 Diversity indices of epiphytic orchids in the four studied areas. RKWS: Rema Kalenga Wildlife Sanctuary; LNP: Lawachara National Park; KNP: Khadim Nagar Park; SNP: Satchari National Park

the observed correlations. Collectively, these statistical approaches provided a comprehensive framework for understanding the orchid-phorophyte relationship by integrating direct variable correlations, distance-based association tests, and multivariate pattern recognition.

4 Results

4.1 Orchid species diversity and abundance

RKWS is found to have the highest species richness (20 species), which aligns with its high Shannon Diversity Index and evenness (Fig. 2). Similar species richness (20 species) is also seen in LNP. SNP has 15 species, which is lower than RKWS and LNP but still indicates a reasonably diverse ecosystem (Fig. 2). KNP showed the lowest species richness (9 species) (Fig. 2), which explains its low Shannon Diversity Index (1.94) (Fig. 2). This suggests that KNP has fewer species compared to the other locations.

The Shannon Diversity Index (H') generally ranges from 0 to >3.5 where values >3 reflect high diversity with well-distributed species. In the present study RKWS has the highest Shannon Diversity Index (2.84) among the four locations, placing it at the upper end of the moderate diversity range and close to the high diversity threshold, indicating

that it is the most diverse in terms of species richness and evenness (Fig. 2). This suggests that RKWS is a thriving ecosystem with a balanced distribution of species. LNP follows closely behind RKWS with a Shannon Index of 2.63 indicating a rich biodiversity of orchid species here (Fig. 2). However, its slightly lower Shannon Index suggests that the distribution of species is not as even as in RKWS. SNP has a Shannon Index of 2.22, indicating moderate but comparatively lower diversity, suggesting a less even distribution of orchid species. KNP has the lowest Shannon Index ($H' = 1.94$), which, although still within the moderate diversity category, indicating reduced species richness or higher dominance by a few species (Fig. 2).

Pielou's Evenness Index (J') ranges from 0 to 1, where values close to 1 indicate a more even distribution of individuals among species. In this study, RKWS shows the highest evenness ($J' = 0.95$), suggesting that orchid individuals are relatively evenly distributed across species compared to other sites (Fig. 2). LNP has an evenness of $J' = 0.88$, which is slightly lower than RKWS but still indicates a fairly even distribution of species (Fig. 2). KNP has an evenness of $J' = 0.89$ (Fig. 2), which is almost similar to LNP. Despite having the lowest Shannon Index, the species in KNP are relatively evenly distributed. SNP has the lowest evenness ($J' = 0.82$), suggesting that some species dominate the ecosystem more than others (Fig. 2).

Sørensen beta diversity values range from 0 to 1, where values close to 0 indicate high similarity in species composition. RKWS and LNP have a very low beta diversity (0.05), meaning they share a high proportion of species similarity, suggesting ecologically comparable habitat conditions between these two locations (Fig. 2). LNP and SNP have a beta diversity of 0.20, reflecting low to moderate dissimilarity, with a substantial proportion of shared orchid species (Fig. 2). RKWS and SNP also displayed low beta diversity ($\beta = 0.14$), indicating a relatively similar species composition.

In contrast, LNP–KNP and RKWS–KNP both recorded higher beta diversity values ($\beta = 0.45$), which fall within the moderate dissimilarity range, suggesting noticeable differences in orchid assemblages despite some shared species (Fig. 2). KNP and SNP have a beta diversity of 0.33, suggesting moderate dissimilarity (Fig. 2). They share some species but also have distinct differences.

All four locations combined presented 21 different species (Fig. 2) under 12 distinct genera (Fig. 3) of epiphytic orchids hosting on a broad range of diversified tree species (68) under 31 families in Northeastern region of Bangladesh.

4.2 Rank abundance

RKWS showed the highest orchid abundance, with a peak rank value of 1.362 (Fig. 4a) by the species *Cymbidium finlaysonianum* followed by LNP at 1.415 with the species *Dendrobium lindleyi*. Both sites exhibited a gradual decline in abundance, suggesting high species richness with a few numerically dominant species. SNP showed slightly lower diversity, with a peak value of 1.322 (*Aerides odorata*) and a steeper decline in abundance (Fig. 4a). KNP had the lowest diversity, with a peak value of 1.230 (*Rhynchosstylis retusa*) and a sharp drop in abundance (Fig. 4a). These variations highlight differences in habitat conditions and ecological factors influencing orchid species distribution in these protected areas.

The rank abundance analysis of phorophyte species followed similar trends. RKWS had the highest diversity, with a peak rank abundance of 1.633, followed closely by LNP at 1.643, both with the species *Artocarpus chaplasha*, showing a gradual decline in abundance (Fig. 4b). SNP exhibited lower diversity, with a peak value of 1.041 and a sharper decline, while KNP had the lowest diversity, with a peak value of 1.079 (Fig. 4b) and a steep drop in abundance both

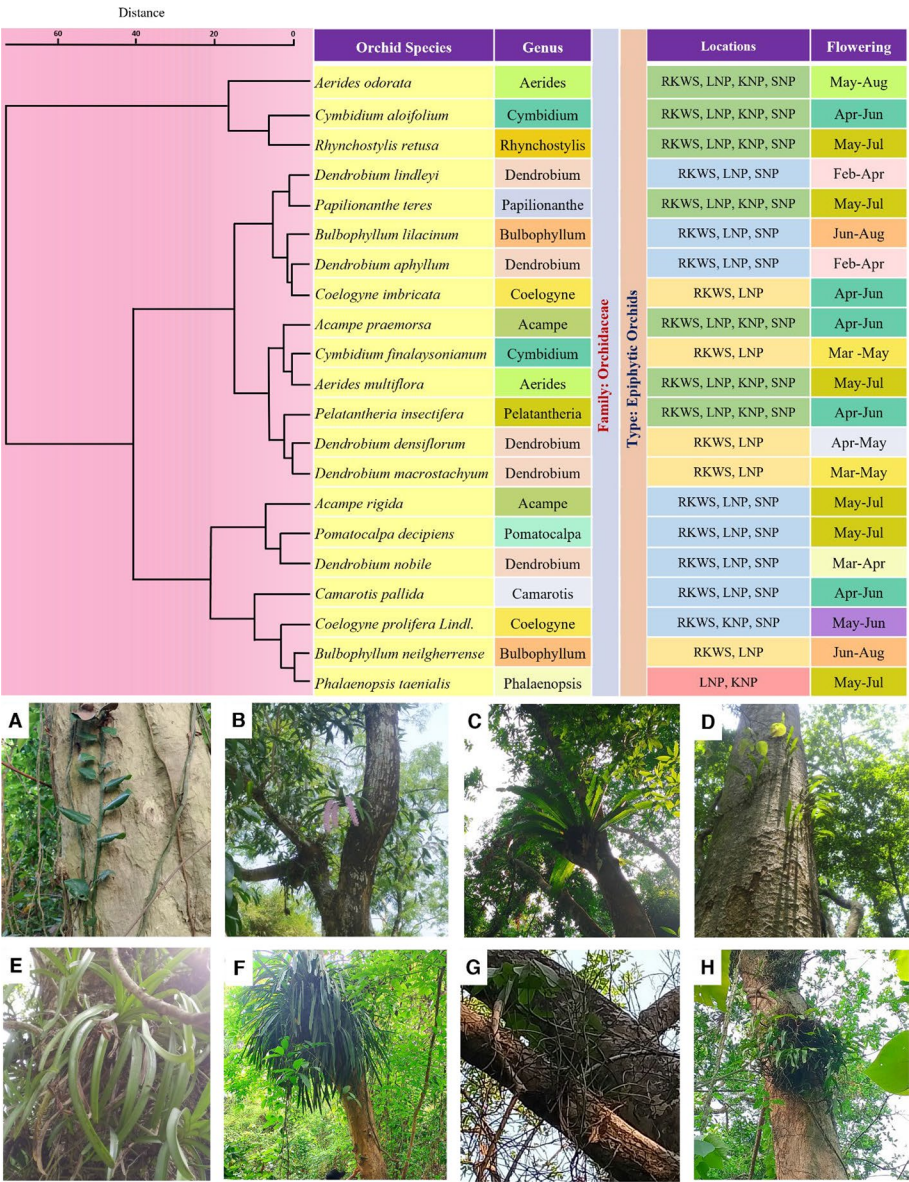


Fig. 3 Dendrogram illustration of the clusters of orchid species based on their number of individuals across four protected areas: Rema Kalenga Wildlife Sanctuary (RKWS), Lawachara National Park (LNP), Khadimnagar National Park (KNP), and Satchari National Park (SNP). The branching patterns reflect the similarity in abundance and distribution of orchid species, highlighting their ecological preferences in different habitats. **A** (*Dendrobium densiflorum*); **B** (*Aerides multiflora*); **C** (*Coelogyne imbricata*); **D** (*Bulbophyllum neilgherrense*); **E** (*Acampe praemorsa*); **F** (*Cymbidium aloifolium*); **G** (*Papilionanthe teres*); **H** (*Coelogyne prolifera*). Flowering time sources [22, 24, 35, 48, 51, 54]

ranked with the species *Chukrassia tabularis*. The sharp decline in abundance values in SNP and KNP indicates a more fragmented phorophyte community, which may impact orchid species richness and distribution in these protected areas.

4.3 Orchid-phorophyte association

Among all the orchid genera, *Aerides* and *Cymbidium* exhibited the broadest phorophyte range, occurring on 26 different phorophyte species (Fig. 5). This indicates a high degree of ecological adaptability and generalist behavior in these orchids, allowing them to thrive across a wide variety of phorophytes. *Dendrobium* and *Rhynchostylis* also

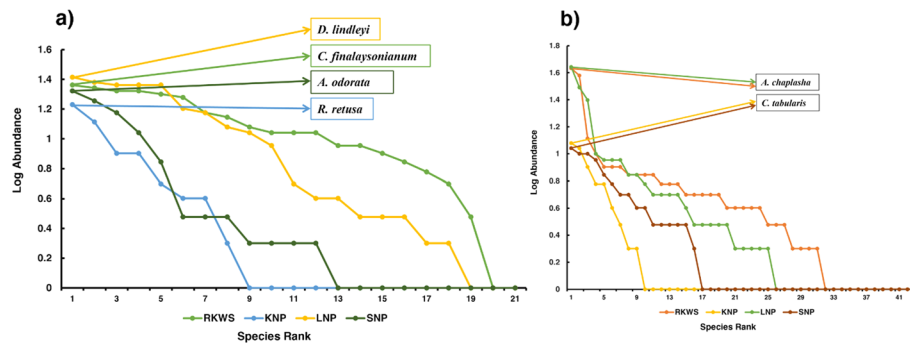


Fig. 4 Species Rank Abundance of both Epiphytic orchids and phorophyte species (**a** Orchid species; **b** phorophyte species). RKWS-Rema-Kalenga Wildlife Sanctuary; KNP-Khadimnagar National Park; LNP-Lawachara National Park; SNP-Satchari National Park

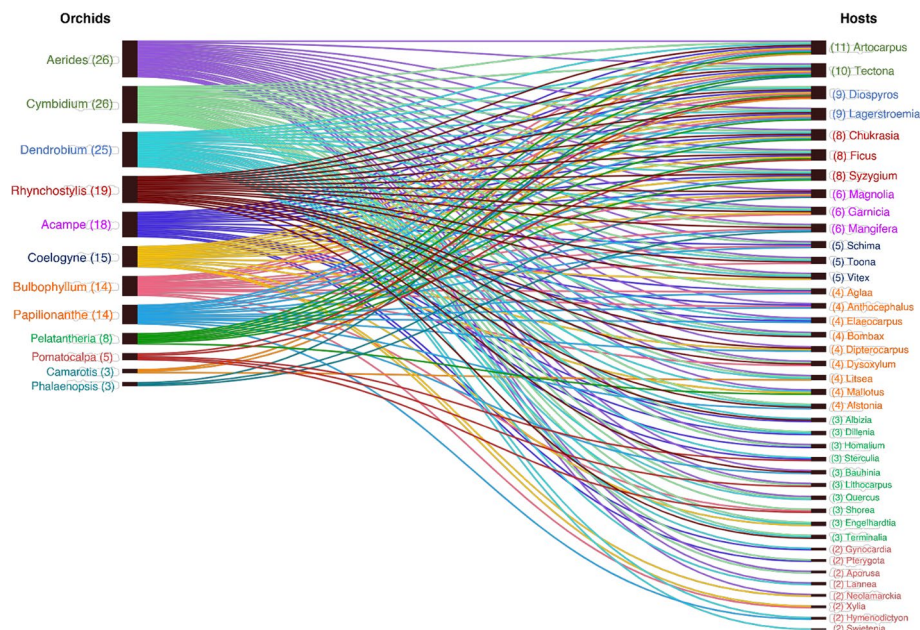


Fig. 5 Alluvial diagram illustrating orchid-phorophyte associations, with connection widths representing frequency of occurrence and highlighting generalist and specialist relationships

demonstrated a relatively wide phorophyte range, occurring on 25 and 19 phorophyte species, respectively.

On the other hand, *Camarotis* and *Phalaenopsis* were found to be the most specialized orchids, occurring on only 3 phorophyte species (Fig. 5). *Pelatantheria* and *Pomatochalpa* also displayed limited phorophyte ranges, occurring on 8 and 5 phorophyte species, respectively.

The phorophyte *Artocarpus* emerged as the most supportive host, harboring the highest number of orchid species (11 species) (Fig. 5). This indicates that *Artocarpus* provides a highly suitable habitat and ecological niche for a diverse range of orchids. Other phorophytes that supported a relatively high number of orchid species include *Chukrasia*, *Diospyros*, *Ficus*, *Lagerstroemia*, *Syzygium*, and *Tectona*, each hosting 8 to 10 orchid species (Fig. 5).

In contrast, the phorophyte *Gynocardia* was found to support the least number of orchids (2 species), with only *Acampe* and *Dendrobium* recorded as associates (Fig. 5).

Similarly, *Hymenodictyon* and *Swietenia* were also among the least supportive hosts, each hosting only two orchid species (Fig. 5). These results suggest that certain phorophytes may offer less favorable conditions or have limited ecological compatibility with orchids (Table 4).

4.4 Orchid-phorophyte relationship along micro-environmental variables

4.4.1 Pearson correlation

Pearson's correlation analysis revealed that four variables including phorophyte height, bark thickness, crown height, and orchid attachment height were positively associated with orchid abundance, although all correlations were weak in magnitude (Fig. 6). Phorophyte height showed a weak but statistically significant positive correlation with orchid abundance ($r=0.20$, $p<0.001$) (Fig. 6). In contrast, phorophyte DBH exhibited a weak, statistically insignificant correlation with orchid abundance ($r=0.07$, $p>0.05$) (Fig. 6). Although DBH significantly correlated with phorophyte height and weakly to moderately correlated with bark thickness and crown height Table 5 (Appendix). Bark thickness showed a weak but significant positive correlation with orchid abundance ($r=0.13$, $p<0.01$); Crown height demonstrated a weak positive correlation ($r=0.19$, $p<0.001$) (Fig. 6). Orchid attachment height showed a weak but significant positive correlation with orchid abundance ($r=0.13$, $p<0.01$) (Fig. 6).

A weak negative correlation was observed with the distance to the nearest forest edge ($r=-0.08$, $p>0.05$); while canopy coverage and elevation showed weak and statistically insignificant correlations with orchid abundance ($r=0.07$, $p>0.05$) (Fig. 6).

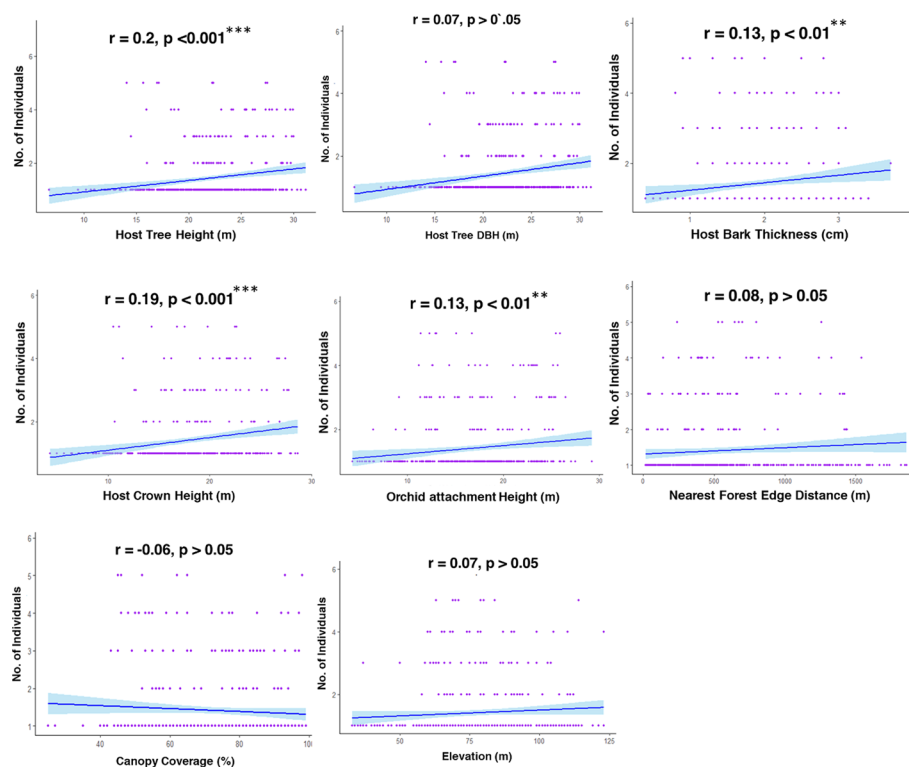


Fig. 6 Pearson correlation between orchid occurrence and phorophyte, micro-environmental variables. ($P<0.05$ *-significant; $P<0.01$ **--strongly significant; $P<0.001$ ***--very strongly significant)

4.4.2 Mantel test

Mantel test analysis revealed generally weak, but some strong associations between orchid species composition and microenvironmental variables (Fig. 7). Such as *Aerides* showed a weak but statistically significant positive correlation with canopy coverage ($r=0.067$, $p<0.01$) Table 6 (Appendix). Again, *Phalaenopsis* exhibited a weak, significant correlation with host tree DBH ($r=0.121$, $p=0.023$) Table 6 (Appendix). *Bulbophyllum* exhibited a weak, near-significant association with orchid attachment height ($r=0.037$, $p=0.090$) Table 6 (Appendix).

Other genera, including *Cymbidium*, *Rhynchostylis*, *Dendrobium*, *Papilionanthe*, *Coelogyne*, *Pelatantheria*, *Pomatocalpa*, and *Camarotis* showed no statistically significant correlations with the measured environmental variables, although weak trends were observed (Fig. 7).

4.4.3 Principal component analysis (PCA) of phorophyte & environmental variables

The Principal Component Analysis (PCA) revealed that the first two principal components (PCA1 and PCA2) together accounted for the majority of the variance in orchid distribution, with PCA1 explaining 99.7% of the variance (standard deviation = 429.38) and PCA2 contributing 0.2% (standard deviation = 18.08) (Fig. 8). PCA1 was dominated by Edge Distance (ED), with a loading value of 0.99996, while PCA2 was strongly influenced by Altitude (ALT), with a loading value of 0.96797 (Fig. 8).

Other PCA components demonstrated that canopy-related factors (CC, CH, and ATH) are the primary drivers of orchid distribution, while other variables such as bark thickness and tree diameter play secondary roles (Fig. 8).

5 Discussion

5.1 Diversity indices

The assessment of orchid diversity across the four forest protected areas revealed noticeable variations in species richness, evenness, and overall diversity. Rema-Kalenga Wildlife Sanctuary (RKWS) and Lawachara National Park (LNP) emerged as the most species-rich sites, indicating biologically diverse and ecologically stable habitats for epiphytic orchids. These areas also reflected a relatively even distribution of orchid species, suggesting favorable ecological

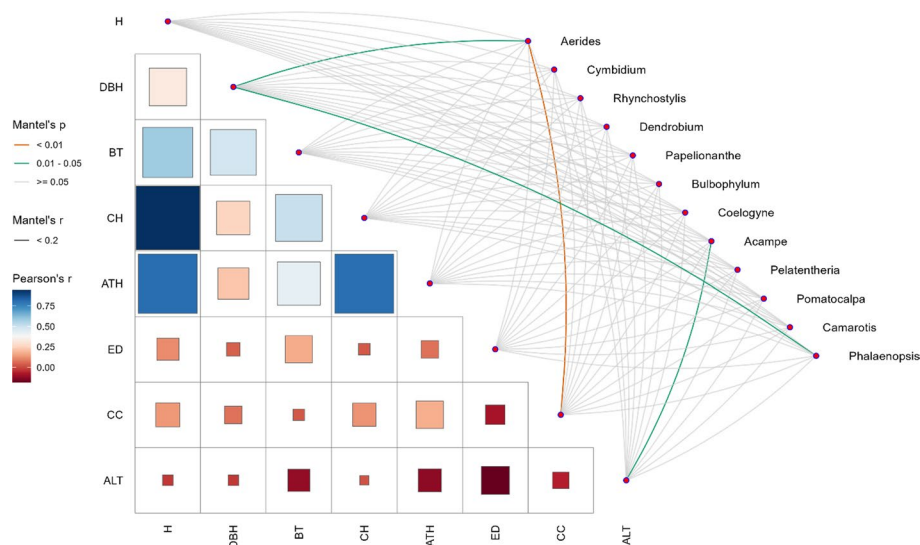


Fig. 7 Mantel test showing the correlation between orchid species and phorophyte, microenvironmental variables based on Euclidean distance

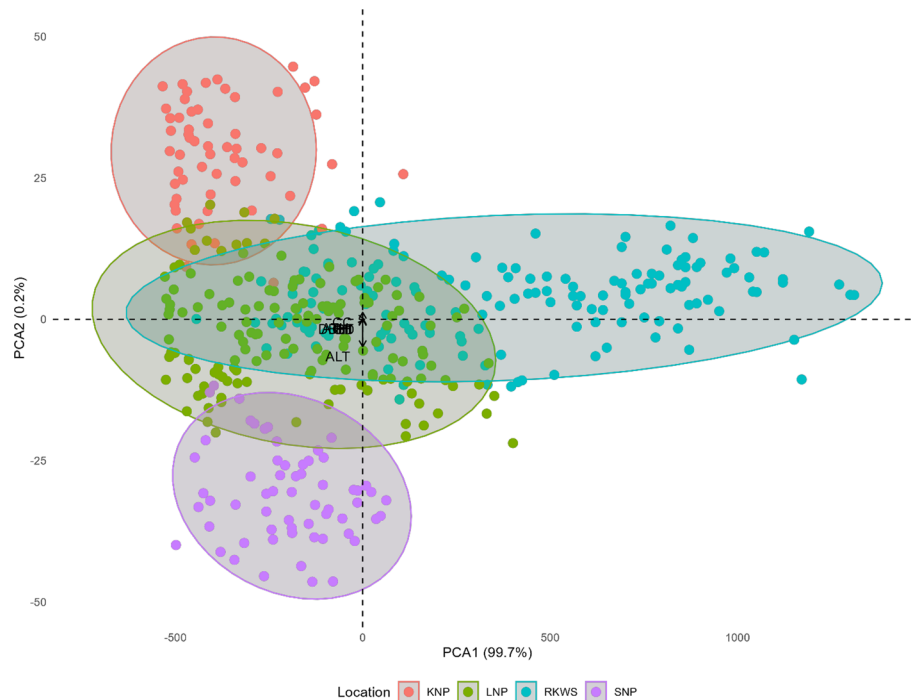


Fig. 8 Principal component analysis (PCA) showing major environmental gradients influencing orchid–phorophyte species composition

conditions that promote community evenness. The mature, stratified forest structure and stable microclimatic conditions in these sites likely provide suitable niches for a wide range of orchid species. Additionally, lower levels of anthropogenic disturbance and effective conservation management practices may enhance phorophyte availability and habitat integrity, further supporting orchid diversity.

In contrast, Khadimnagar National Park (KNP) exhibited the lowest orchid diversity, implying limited habitat heterogeneity, potential environmental stress, or anthropogenic disturbances [57]. Patterns in species evenness reinforced these differences, with more uniform population structures observed in the more diverse sites. Analysis of species turnover among sites also revealed a high degree of similarity between RKWS and LNP, reflecting shared ecological characteristics and possibly similar forest compositions. These findings align with prior research by Huda et al. [28] who reported higher orchid diversity in relatively undisturbed and structurally complex forests of northeastern Bangladesh compared to more degraded landscapes. Similarly, studies in Chunati and Madhupur forests have also shown that habitat fragmentation and human interference lead to noticeable declines in orchid diversity [7, 45, 49], reinforcing the patterns observed in KNP. Overall, the gamma diversity of the study region underscores the ecological importance of northeastern forest reserves, highlighting their role as vital reservoirs for epiphytic orchid conservation in Bangladesh [30, 67]

5.2 Orchid-phorophyte association

Phorophyte associations varied markedly among epiphytic orchid species, revealing a spectrum of ecological strategies ranging from generalist to specialist behaviors. Some species such as *Aerides* and *Cymbidium* displayed associations with a wide variety of phorophytes, indicating a high degree of ecological plasticity. This generalist strategy allows them to thrive across diverse forest structures and microclimatic conditions, a pattern similarly observed

by Pant & Raskoti [44] in tropical forest ecosystems. Likewise, species of *Dendrobium* and *Rhynchostylis* also demonstrated broad phorophyte adaptability, likely due to their efficient seed dispersal, high physiological flexibility, and less stringent microhabitat requirements. These findings align with previous studies that emphasize the success of generalist orchids in fragmented or heterogeneous forest landscapes [7, 9, 20, 41].

On the other hand, species such as *Camarotis* and *Phalaenopsis* exhibited strong phorophyte specificity, being associated with only a few tree species. This specialization suggests a narrow ecological niche and heightened sensitivity to phorophyte availability and associated environmental factors. Such orchid-phorophyte fidelity is consistent with research indicating that certain epiphytic orchids rely on specific bark textures, canopy conditions, or microclimatic features such as humidity and light levels [1, 20, 71]. The limited phorophyte range may also reflect co-evolutionary relationships or dependency on particular forest strata or successional stages [50, 52].

Among the phorophytes recorded, certain species like *Artocarpus*, *Chukrasia*, *Diospyros*, *Ficus*, and *Tectona* were found to support a notably diverse orchid community. These trees likely offer favorable attributes such as rough or moisture-retentive bark, extensive crown structure, and optimal microhabitat conditions for orchid attachment and growth. Similar trends have been reported in studies from Southeast Asia and the Neotropics, where trees with complex canopy architecture and stable microenvironments support richer epiphyte loads [14, 43, 58]. In contrast, tree species such as *Gynocardia*, *Hymenodictyon*, and *Swietenia* supported very few orchid species, possibly due to smooth bark texture, limited canopy structure, or microclimatic conditions less favorable to orchid establishment.

These patterns underscore the importance of both phorophyte traits and orchid-specific ecological strategies in shaping orchid-phorophyte associations and highlight the need for forest management practices that maintain tree diversity and structural complexity to support epiphytic orchid populations. Although patterns of orchid occurrence suggest non-random phorophyte associations, these patterns may partly reflect the relative abundance of tree species within the study areas [4, 47, 68] and therefore should not be interpreted as strict host for a specific epiphytic orchid.

5.3 Phorophyte and microenvironmental factors shaping orchid diversity

The relationship between orchid distribution and phorophyte characteristics or microenvironmental factors was statistically explored through Pearson correlation, Mantel tests, and Principal Component Analysis (PCA). Pearson correlation showed significant positive correlations between orchid abundance and phorophyte height, bark thickness, crown height, and attachment height, indicating that tall trees with thicker bark and extended crowns provide more suitable niches for orchid colonization [34]. Taller trees are more likely to intersect diverse light gradients and moisture conditions within the canopy, enhancing microhabitat heterogeneity favorable for epiphyte establishment [42]. Similarly, thicker bark may retain more moisture and phorophyte more mosses and lichens, which facilitate seed germination and root anchorage for orchids [65]. These findings are in line with those of Zotz & Vollrath, [73] and Tay et al. [60], who found that epiphytic orchids preferentially colonize phorophytes with complex architecture and textured bark. Interestingly, DBH did not correlate significantly with orchid abundance but had strong associations with other tree traits through this correlation test, indicating an indirect influence on orchid occupancy. This contrasts with some studies where DBH was considered a significant predictor of epiphyte load [10, 14],

suggesting that the role of DBH may be context-dependent and influenced by forest type and age structure.

The Mantel test provided further resolution, showing species-specific environmental preferences: *Aerides* correlated positively with canopy coverage, *Phalaenopsis* with DBH, and *Acampe* with altitude. These associations reflect ecological niche specialization, where certain orchids preferentially occupy specific vertical strata or forest structures depending on their light and humidity requirements [20]. For instance, species like *Aerides* favor denser canopies due to their moisture-dependent physiology, while species like *Acampe* are adapted to higher elevations where cooler temperatures may reduce competition [2, 20]. Similar niche partitioning based on elevation and canopy characteristics has been observed in tropical forests of Southeast Asia and the Andes, highlighting the adaptability of different orchid taxa to distinct environmental gradients [2, 5, 46]

PCA revealed that edge distance and altitude were the dominant factors structuring orchid distribution, with canopy-related variables such as canopy cover, crown height, and attachment height also playing vital roles. Forest edges typically experience greater microclimatic fluctuations, which may limit orchid colonization, while forest interiors provide more stable conditions and phorophyte diversity [53]. Altitudinal gradients, on the other hand, influence orchid distribution through variations in temperature, light availability, and air moisture factors critical to orchid survival and reproduction [5, 8]. These findings are consistent with global studies highlighting the importance of forest structure and microclimatic stability in shaping epiphytic orchid diversity [7, 40]. Furthermore, they align with observations from Neotropical regions where orchid richness and abundance declined significantly near forest edges due to exposure-related stressors [46, 53]. The influence of forest edge proximity and elevation suggests that conservation strategies should prioritize maintaining habitat continuity and protecting forest interiors to sustain orchid diversity.

6 Conclusion

This study explored the richness and ecological patterns of wild epiphytic orchids and their phorophyte associations across four protected forest areas in northeastern Bangladesh. A total of 21 orchid species were recorded, exhibiting varying degrees of phorophyte specificity and distribution patterns shaped by micro-environmental gradients. Sites like Rema-Kalenga and Lawachara demonstrated higher orchid richness and diversity, while Khadimnagar showed signs of fragmentation and lower orchid abundance. Key factors influencing orchid distribution included phorophyte height, bark characteristics, attachment height, canopy cover, and environmental variables such as altitude and distance from forest edges. The identification of both specialist and generalist orchid species discloses the complex relationships between orchids and their phorophytes in tropical forest environments. These findings underline the necessity for conservation strategies that emphasize the protection of diverse phorophytes and the preservation of microhabitat conditions that are critical for orchid survival. The study offers crucial baseline data in order to facilitate long-term monitoring, habitat restoration, and successful biodiversity conservation in Bangladesh's forest reserves.

Appendix

See Tables 4, 5 and 6

Table 4 Summary of statistical methods used to analyze the correlation between orchid species composition and microenvironmental factors, including their purpose, input data, and output measures

Method	Purpose	Input data	Output	Formula	Symbols
Pearson Correlation	Measures linear relationship between two variables	Two continuous variables	Correlation coefficient (r) ranging from -1 to 1	$r = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2} \cdot \sqrt{\sum (Y_i - \bar{Y})^2}}$	X_i, Y_i : Observed values of variables X and Y for the i -th sample $\bar{X}, \bar{Y}$: Mean values of variables X and Y r : Pearson correlation coefficient
Mantel Test	Tests correlation between two distance/proximity matrices	Two distance matrices	Correlation coefficient (often with permutation-based p-value)	$D_X(i, j) = \sqrt{\sum_{k=1}^p (X_{ik} - X_{jk})^2};$ $D_Y(i, j) = \sqrt{\sum_{k=1}^q (Y_{ik} - Y_{jk})^2}$ $r_M = \frac{\sum_i \sum_j (D_X(i, j) - \bar{D}_X) (D_Y(i, j) - \bar{D}_Y)}{\sqrt{\sum_i \sum_j (D_X(i, j) - \bar{D}_X)^2} \cdot \sqrt{\sum_i \sum_j (D_Y(i, j) - \bar{D}_Y)^2}}$ $p = \frac{999 \text{ of times } r_M^* \geq r_M}{N}$	$D_X(i, j), D_Y(i, j)$: Distance between sites i and j in matrices X and Y X_{ik}, X_{jk} : Values of the k -th variable for sites i and j p, q : Number of variables in matrices X and Y $\bar{D}_X, \bar{D}_Y$: Mean distances of matrices X and Y r_M : Mantel correlation coefficient r_M^* : Correlation coefficient from permuted matrices N : Total number of permutations n : Standardized data matrix n : Number of observations C : Covariance matrix V : Matrix of eigenvectors A : Diagonal matrix of eigenvalues Y : Principal component score matrix T : Transpose of a matrix
PCA	Reduces dimensionality and identifies patterns in multivariate data	Multiple continuous variables	Principal components (uncorrelated linear combinations of original variables)	$C = \frac{1}{n-1} Z^T Z, C = V \Lambda V^T, Y = ZV$	

Table 5 Pearson correlation

	Total ind. in plot	Host height	Host tree DBH	Bark thickness	Crown height	Orchid attachme nt height	Nearest Forest edge distance	Canopy Coverage	Elevation
Total sp in plot		1.70E-05	0.12708	0.007909	4.81E-05	0.006018	0.08866	0.18448	0.12797
Host height	0.20487		3.50E-12	1.30E-40	4.73E-210	7.47E-103	0.017588	0.005324	0.59097
Host tree DBH	0.07335	0.32569		1.49E-27	4.67E-08	2.68E-06	0.38181	0.13803	0.59488
Bark thickness	0.12734	0.58144	0.48968		4.05E-30	3.44E-21	0.000382	0.53287	0.017103
Crown height	0.19382	0.94394	0.25852	0.51006		1.16E-101	0.52067	0.008518	0.67917
Orchid attachment height	0.13166	0.81151	0.22311	0.4323	0.80882		0.13846	0.000239	0.010395
Edge distance	0.081822	0.11392	0.042083	0.16976	0.030914	0.071232		0.067721	0.000133
Canopy coverage	-0.063822	0.13356	0.07131	0.030015	0.12614	0.17548	-0.08778		0.18518
Elevation	0.073178	-0.02587	-0.0256	-0.11441	0.019909	-0.12289	-0.18237	-0.06372	

Table 6 Mantel test

SI	Orchid genera	Variables	r	p	rd	pd
1	<i>Aerides</i>	H	0.0112189	0.325	<0.2	> =0.05
2	<i>Aerides</i>	DBH	0.0730582	0.036	<0.2	0.01 –0.05
3	<i>Aerides</i>	BT	0.039596	0.102	<0.2	> =0.05
4	<i>Aerides</i>	CH	–0.0089305	0.615	<0.2	> =0.05
5	<i>Aerides</i>	ATH	–0.0183162	0.731	<0.2	> =0.05
6	<i>Aerides</i>	ED	–0.0371783	0.908	<0.2	> =0.05
7	<i>Aerides</i>	CC	0.067141	0.007	<0.2	<0.01
8	<i>Aerides</i>	ALT	–0.0174517	0.73	<0.2	> =0.05
9	<i>Cymbidium</i>	H	0.0319465	0.128	<0.2	> =0.05
10	<i>Cymbidium</i>	DBH	–0.028059	0.764	<0.2	> =0.05
11	<i>Cymbidium</i>	BT	0.0269631	0.18	<0.2	> =0.05
12	<i>Cymbidium</i>	CH	0.0246889	0.201	<0.2	> =0.05
13	<i>Cymbidium</i>	ATH	–0.0089984	0.568	<0.2	> =0.05
14	<i>Cymbidium</i>	ED	–0.0139307	0.654	<0.2	> =0.05
15	<i>Cymbidium</i>	CC	0.004931	0.41	<0.2	> =0.05
16	<i>Cymbidium</i>	ALT	0.0054829	0.428	<0.2	> =0.05
17	<i>Rhynchostylis</i>	H	0.0060993	0.404	<0.2	> =0.05
18	<i>Rhynchostylis</i>	DBH	–0.0178395	0.66	<0.2	> =0.05
19	<i>Rhynchostylis</i>	BT	0.0236847	0.201	<0.2	> =0.05
20	<i>Rhynchostylis</i>	CH	0.0134207	0.29	<0.2	> =0.05
21	<i>Rhynchostylis</i>	ATH	0.0244241	0.179	<0.2	> =0.05
22	<i>Rhynchostylis</i>	ED	0.0092505	0.351	<0.2	> =0.05
23	<i>Rhynchostylis</i>	CC	0.0320624	0.099	<0.2	> =0.05
24	<i>Rhynchostylis</i>	ALT	0.007832	0.37	<0.2	> =0.05
25	<i>Dendrobium</i>	H	–0.0284358	0.827	<0.2	> =0.05
26	<i>Dendrobium</i>	DBH	–0.0241814	0.705	<0.2	> =0.05
27	<i>Dendrobium</i>	BT	–0.0278089	0.812	<0.2	> =0.05
28	<i>Dendrobium</i>	CH	–0.0399314	0.917	<0.2	> =0.05
29	<i>Dendrobium</i>	ATH	–0.0459102	0.941	<0.2	> =0.05
30	<i>Dendrobium</i>	ED	0.0054962	0.407	<0.2	> =0.05
31	<i>Dendrobium</i>	CC	–0.0215999	0.825	<0.2	> =0.05
32	<i>Dendrobium</i>	ALT	–0.0402411	0.928	<0.2	> =0.05
33	<i>Papilionanthe</i>	H	0.0167288	0.303	<0.2	> =0.05
34	<i>Papilionanthe</i>	DBH	–0.0021802	0.445	<0.2	> =0.05
35	<i>Papilionanthe</i>	BT	–0.0019613	0.495	<0.2	> =0.05
36	<i>Papilionanthe</i>	CH	0.0284159	0.189	<0.2	> =0.05
37	<i>Papilionanthe</i>	ATH	–0.0022913	0.516	<0.2	> =0.05
38	<i>Papilionanthe</i>	ED	–0.0314531	0.857	<0.2	> =0.05
39	<i>Papilionanthe</i>	CC	–0.0375528	0.954	<0.2	> =0.05
40	<i>Papilionanthe</i>	ALT	–0.0457956	0.956	<0.2	> =0.05
41	<i>Bulbophyllum</i>	H	–0.0161444	0.711	<0.2	> =0.05
42	<i>Bulbophyllum</i>	DBH	–0.0421433	0.867	<0.2	> =0.05
43	<i>Bulbophyllum</i>	BT	–0.0515796	0.966	<0.2	> =0.05

Table 6 (continued)

SI	Orchid genera	Variables	r	p	rd	pd
44	<i>Bulbophyllum</i>	CH	−0.0164291	0.704	<0.2	>=0.05
45	<i>Bulbophyllum</i>	ATH	0.0367283	0.09	<0.2	>=0.05
46	<i>Bulbophyllum</i>	ED	−0.0004711	0.512	<0.2	>=0.05
47	<i>Bulbophyllum</i>	CC	−0.015607	0.733	<0.2	>=0.05
48	<i>Bulbophyllum</i>	ALT	0.0120204	0.329	<0.2	>=0.05
49	<i>Coelogyne</i>	H	0.0006836	0.46	<0.2	>=0.05
50	<i>Coelogyne</i>	DBH	−0.0664082	0.993	<0.2	>=0.05
51	<i>Coelogyne</i>	BT	−0.014929	0.657	<0.2	>=0.05
52	<i>Coelogyne</i>	CH	0.0073184	0.351	<0.2	>=0.05
53	<i>Coelogyne</i>	ATH	−0.0032746	0.543	<0.2	>=0.05
54	<i>Coelogyne</i>	ED	0.0324188	0.124	<0.2	>=0.05
55	<i>Coelogyne</i>	CC	−0.0005231	0.489	<0.2	>=0.05
56	<i>Coelogyne</i>	ALT	−0.0578726	0.975	<0.2	>=0.05
57	<i>Acampe</i>	H	−0.0311628	0.862	<0.2	>=0.05
58	<i>Acampe</i>	DBH	−0.0294333	0.745	<0.2	>=0.05
59	<i>Acampe</i>	BT	−0.0256645	0.788	<0.2	>=0.05
60	<i>Acampe</i>	CH	−0.0540789	0.965	<0.2	>=0.05
61	<i>Acampe</i>	ATH	−0.0139101	0.673	<0.2	>=0.05
62	<i>Acampe</i>	ED	−0.0109674	0.623	<0.2	>=0.05
63	<i>Acampe</i>	CC	−0.0041798	0.584	<0.2	>=0.05
64	<i>Acampe</i>	ALT	0.0596454	0.032	<0.2	0.01–0.05
65	<i>Pelatentheria</i>	H	−0.0097557	0.601	<0.2	>=0.05
66	<i>Pelatentheria</i>	DBH	−0.034291	0.803	<0.2	>=0.05
67	<i>Pelatentheria</i>	BT	0.0054906	0.422	<0.2	>=0.05
68	<i>Pelatentheria</i>	CH	−0.0040268	0.514	<0.2	>=0.05
69	<i>Pelatentheria</i>	ATH	−0.0391652	0.914	<0.2	>=0.05
70	<i>Pelatentheria</i>	ED	0.0007969	0.465	<0.2	>=0.05
71	<i>Pelatentheria</i>	CC	0.0271282	0.14	<0.2	>=0.05
72	<i>Pelatentheria</i>	ALT	−0.0508361	0.961	<0.2	>=0.05
73	<i>Pomatocalpa</i>	H	0.0176277	0.292	<0.2	>=0.05
74	<i>Pomatocalpa</i>	DBH	0.0358938	0.177	<0.2	>=0.05
75	<i>Pomatocalpa</i>	BT	−0.013075	0.611	<0.2	>=0.05
76	<i>Pomatocalpa</i>	CH	0.0421399	0.112	<0.2	>=0.05
77	<i>Pomatocalpa</i>	ATH	0.0241086	0.222	<0.2	>=0.05
78	<i>Pomatocalpa</i>	ED	−0.0197051	0.707	<0.2	>=0.05
79	<i>Pomatocalpa</i>	CC	0.0136763	0.283	<0.2	>=0.05
80	<i>Pomatocalpa</i>	ALT	−0.0168354	0.701	<0.2	>=0.05
81	<i>Camarotis</i>	H	−0.0283126	0.809	<0.2	>=0.05
82	<i>Camarotis</i>	DBH	−0.0083358	0.401	<0.2	>=0.05
83	<i>Camarotis</i>	BT	−0.0438442	0.924	<0.2	>=0.05
84	<i>Camarotis</i>	CH	−0.0238948	0.742	<0.2	>=0.05
85	<i>Camarotis</i>	ATH	0.0073506	0.36	<0.2	>=0.05
86	<i>Camarotis</i>	ED	−0.0400013	0.916	<0.2	>=0.05
87	<i>Camarotis</i>	CC	−0.017539	0.736	<0.2	>=0.05
88	<i>Camarotis</i>	ALT	−0.0304054	0.827	<0.2	>=0.05
89	<i>Phalaenopsis</i>	H	0.0224767	0.235	<0.2	>=0.05
90	<i>Phalaenopsis</i>	DBH	0.1207651	0.023	<0.2	0.01–0.05
91	<i>Phalaenopsis</i>	BT	0.03015	0.188	<0.2	>=0.05
92	<i>Phalaenopsis</i>	CH	0.0426947	0.118	<0.2	>=0.05
93	<i>Phalaenopsis</i>	ATH	0.0025752	0.468	<0.2	>=0.05
94	<i>Phalaenopsis</i>	ED	0.003693	0.378	<0.2	>=0.05
95	<i>Phalaenopsis</i>	CC	0.0159762	0.252	<0.2	>=0.05
96	<i>Phalaenopsis</i>	ALT	−0.0349744	0.843	<0.2	>=0.05

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1007/s44415-026-00076-x>.

Supplementary file 1.

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Author contributions

Conceptualization and design were done by Kazi Mohammad Masum and Rabeya Khatun. The funding acquisition was performed by Kazi Mohammad Masum. Field work was performed by Rabeya Khatun, Md Mahbub Hasan and S M Rakib Bin Asghar. Writing of original draft was done by Rabeya Khatun. Final revision was done by all authors.

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Data availability

All data generated or analyzed during this study are included in this published article (and its supplementary information files).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Name of plant/plant part identifier

Species identification was carried out by the first author- Rabeya Khatun, co-operated by Md Mahbub Hasan and S M Rakib Bin Asghar

Permission statement

Permission to conduct field survey and collect data was obtained from the Bangladesh Forest Department.

Compliance with plant collection guidelines

This study was based on non-destructive field observations. No protected species were collected. The research complied with national forest and biodiversity conservation regulations.

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