BIODIVERSITAS
Volume 27, Number 4, April 2026
Pages: 12

ISSN: 1412-033X
E-ISSN: 2085-4722
https://doi.org/10.13057/biodiv/d270429

Ecology and qualitative phytochemical profiles of wild orchids in Palolo Education Forest, Central Sulawesi, Indonesia

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Manuscript received: 22 February 2026. Revision accepted: 19 April 2026.

Abstract. *Nasrun MS, Gailea R, Buamona AFJ. 2026. Ecology and qualitative phytochemical profiles of wild orchids in Palolo Education Forest, Central Sulawesi, Indonesia. Biodiversitas 27 (4): d270429. https://doi.org/10.13057/biodiv/d270429.* Orchid diversity, community structure, and qualitative phytochemical profiles were investigated in KHDTK-HPUM, an education forest in Palolo Sub-district, Sigi District, Central Sulawesi, Indonesia. Orchids were recorded along three transects (1,500 m x 10 m each; 4.5 ha searched corridor) across forest edge, riverside, and forest interior habitats using a searched-corridor encounter survey. A total of 15 orchid species belonging to 10 genera were recorded, comprising 91 clump-based individuals; 14 species (93.33%) were epiphytic, and one was terrestrial. Species richness index (*Da*) ranged from 1.44 to 3.17, and Shannon diversity index (*H'*) from 0.66 to 1.08, indicating low to moderate diversity. *Liparis latifolia* (IVI = 41.76%, n = 25) and *Liparis pallida* (IVI = 39.56%, n = 23) were the ecologically dominant species. *Appendicula celebica*, an orchid endemic to Sulawesi, was also recorded (IVI = 21.32%), highlighting the biogeographic significance of the study area within the Wallacea biodiversity hotspot. Qualitative phytochemical screening of six species at Pharmacy Laboratory, Universitas Tadulako, detected alkaloids, flavonoids, saponins, tannins, steroids, and triterpenoids, with compound-class profiles varying notably between plant parts. *Dendrobium crumenatum* showed the most complete profile across stem and leaf tissues. An exploratory dual-criteria framework identified three species as Priority I for further cultivation-oriented research: *L. latifolia* and *Cymbidium finlaysonianum* (Priority I-A) and *D. crumenatum* (Priority I-B). These findings provide a first descriptive baseline of orchid ecology and qualitative phytochemical profiles for KHDTK-HPUM. All comparisons and priority rankings are preliminary and should be interpreted within the constraints of the exploratory sampling design.

Keywords: Importance Value Index, KHDTK, non-timber forest products, Orchidaceae, phytochemical screening

INTRODUCTION

Non-timber forest products (NTFPs) are essential components of sustainable forest management, encompassing biological materials from forests other than timber, including medicinal plants and ornamental species (Shackleton and Pandey 2014). In Indonesia, approximately 60 million people depend on forest resources for their livelihoods (Pasaribu et al. 2021), making NTFP management a critical strategy for balancing conservation objectives with community economic needs.

Among NTFPs, orchids of the family Orchidaceae represent a particularly valuable group combining ornamental and medicinal economic potential. As ornamental plants, wild-collected orchids contribute significantly to horticulture markets both locally and internationally (Hinsley et al. 2018). As medicinal resources, orchids are widely used in traditional Asian medicine for treating respiratory ailments, stomach complaints, inflammation, and skin conditions (Hossain 2011; Teoh 2019). Phytochemical research has confirmed the presence of diverse compound classes, including alkaloids, flavonoids, saponins, tannins, steroids, and triterpenoids across orchid genera (Chen et al. 2021; Xu et al. 2022). In addition to their economic value, epiphytic orchids function as ecological indicators sensitive to microclimate changes, host tree characteristics, and canopy structure, making them useful monitors of forest condition and disturbance (Adhikari et al. 2012; Zotz 2016).

Although advanced chromatographic techniques (HPLC, LC-MS) provide quantitative metabolite data, qualitative colorimetric screening remains a scientifically justified first-step approach for baseline phytochemical documentation in previously uncharacterized taxa and sites, enabling efficient identification of compound-class presence before committing resources to targeted quantitative profiling (Harborne 1998).

Indonesia harbors approximately 5,000 orchid species, representing about 18% of the estimated 28,000 species worldwide (Comber 2001; Christenhusz and Byng 2016). Sulawesi, as part of the Wallacea biodiversity hotspot, has received increasing attention in orchid research. Recent inventories have documented substantial regional diversity: 51 species in Polewali Mandar, West Sulawesi, Indonesia (Puspitaningtyas 2019), 60 species in Bantimurung-Bulusaraung National Park, South Sulawesi (Puspitaningtyas 2017), and 40 species across elevational zones in Lore Lindu National Park, Central Sulawesi (Nasrun et al. 2024). These studies have advanced the understanding of orchid distribution patterns across Sulawesi considerably.

However, KHDTK-HPUM (*Kawasan Hutan dengan Tujuan Khusus-Hutan Pendidikan* Universitas Muhammadiyah Palu/Special Purpose Forest Area-Educational Forest of Universitas Muhammadiyah Palu) differs ecologically from these national parks in that it comprises lowland cacao agroforestry at approximately 600 m asl with active anthropogenic disturbance, rather than the intact montane forests typical of national park inventories.

Despite these advances, existing Indonesian orchid research has focused predominantly on taxonomic inventories and ecological descriptions, without integrating assessments of phytochemical screening. Nasrun et al. (2024) examined orchid-host tree interactions in Lore Lindu but did not conduct phytochemical analyses. Similarly, Puspitaningtyas (2017, 2019) produced valuable species lists without compound-class profile data. This gap is particularly significant because integrated ecological-phytochemical assessments are a prerequisite for evidence-based NTFP management decisions, yet no such assessment exists for any education forest (KHDTK) in Indonesia.

The present study addresses this scientific gap at KHDTK-HPUM, designated under Ministerial Decree No. 260/Menhut-II/2011, which spans approximately 5,100 ha of tropical lowland forest in Palolo Sub-district, Sigi District, Central Sulawesi. Documentation of orchid communities at this site is particularly timely given increasing pressures from adjacent agricultural expansion in Palolo Valley and the complete absence of baseline biodiversity data for management planning. Understanding which species are ecologically dominant and which contain phytochemical compound classes is essential for designing evidence-based NTFP programs within the KHDTK management framework. No prior study has combined ecological community analysis with qualitative phytochemical screening at KHDTK-HPUM. The specific objectives of this study are: (i) to conduct a descriptive orchid species inventory and evaluate ecological status through quantitative indices across three habitat types, (ii) to screen selected dominant species for the presence of major compound classes using qualitative phytochemical methods, and (iii) to formulate species priority recommendations using an exploratory dual-criteria framework integrating ecological and phytochemical screening data to support NTFP management planning at KHDTK-HPUM.

MATERIALS AND METHODS

Study site

The study was conducted at KHDTK-HPUM, located at 120.091°-120.094°E and 1.103°-1.117°S (WGS 1984), covering 5,100 ha in Palolo Sub-district, Sigi District, Central Sulawesi, Indonesia (Figure 1). The site was designated as an education forest by Ministerial Decree No. 260/Menhut-II/2011 dated 12 May 2011, and encompasses two villages: Berdikari and Rezeki, at an elevation of approximately 600 m asl. According to Schmidt and Ferguson's climate classification, the area receives mean annual rainfall of 1,700-2,000 mm (Type A climate), with temperatures ranging from 22-34°C, relative humidity of 98%, and average wind speed of 3.6 km/h, based on long-term climate records from the BMKG Meteorological Station, Palu (BMKG 2025). The dominant land use within the study area is cacao (*Theobroma cacao* L.) agroforestry, which extends across the majority of accessible terrain along all three transects and serves as the primary phorophyte for epiphytic orchid species recorded in this study. Natural forest canopy species are interspersed within the agroforestry matrix, particularly along the riverside and forest interior transects.

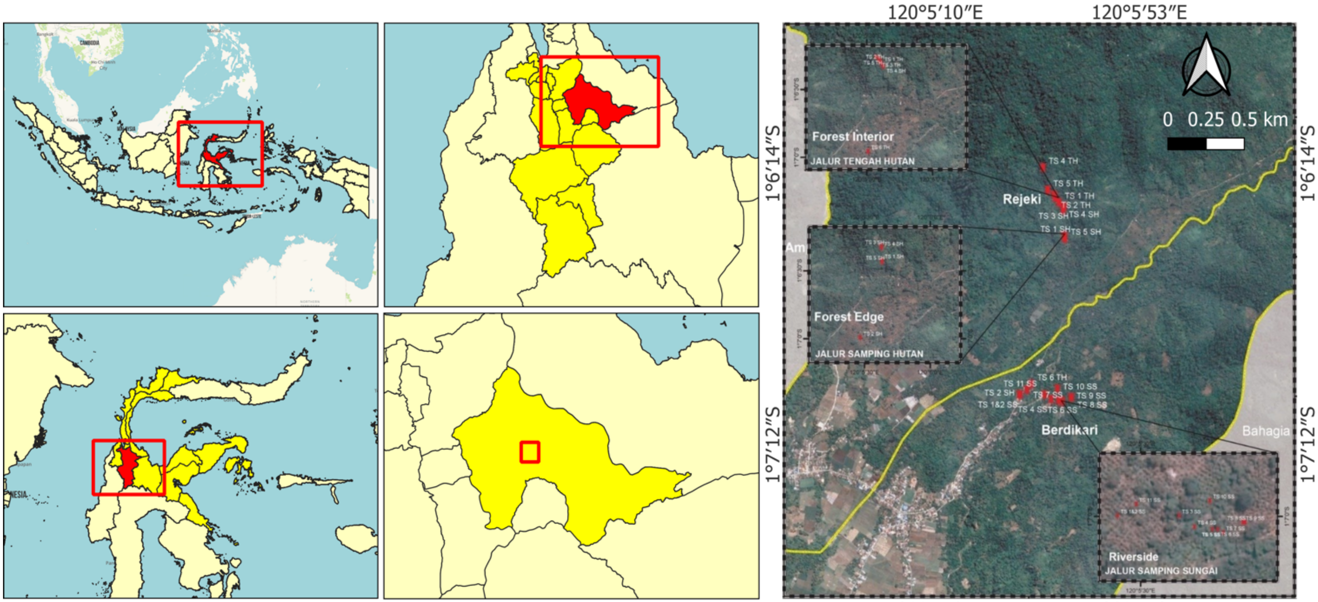

Figure 1. Location of study site and sampling transects at KHDTK-HPUM, Palolo Sub-district, Sigi District, Central Sulawesi, Indonesia

Data collection

Field surveys were carried out during August and September 2024 with expeditions along several transects using explorative methods. In this, the local guidelines for epiphytic orchid inventories were closely followed (Puspitaningtyas 2019). Based on landscape features, three transects were set up to serve as microhabitats representing major microhabitat types within the study site (Figure 1). The first transect, or the Forest Interior, was deep in the forest where there was a very dense canopy and almost no direct sunlight could penetrate. The Forest Edge Transect was at the perimeter of the forest, and medium light penetration was characterized by the presence of secondary vegetation and edge effects. The Riverside Transect was a few steps from the flowing water of a stream; therefore, it was humid, and the vegetation was typical of a riparian environment.

Each transect was 1,500 m long and 10 m wide (5 m on each side of the transect line), so that an area of 1.5 ha was covered for every transect. The overall sampling area of 4.5 hectares represented merely 0.09% of the total KHDTK area. The 1,500 m × 10 m transect dimensions defined the search corridor within which observers walked. Actual orchid records were made at encounter points where orchids were observed within this corridor, rather than as continuous belt-transect enumeration across the full 4.5 ha area. The search corridor extended 5 m on each side of the central transect line.

The sampling approach used in this study is best described as a searched-corridor encounter survey, not a continuous belt-transect census. Orchid records were made exclusively at encounter points within the corridor where orchids were visually detected. The 4.5 ha figure represents the nominal area of the searched corridor, not an area that was systematically enumerated. Ecological indices (RD, RF, IVI), therefore, reflect relative encounter frequency within the sampled corridor and should not be interpreted as density estimates per unit area.

Sampling points were determined along the transects where orchid individuals were observed, resulting in 22 georeferenced sampling points distributed among the three habitat types: 6 points in forest interior, 5 points in forest edge, and 11 points in riverside (Figure 1). The unequal distribution of encounter points reflects actual field conditions rather than predetermined allocation: the riverside corridor offered continuous phorophyte availability and accessible terrain along the stream margin, yielding more encounter opportunities, whereas steep slopes and dense undergrowth in the forest interior and edge transects limited both accessibility and orchid detectability. This encounter-driven point allocation is inherent to the searched-corridor survey design, in which sampling intensity is constrained by orchid occurrence rather than imposed by the observer.

Orchid recording followed an encounter-based approach, in which individuals were documented at points where orchids were observed along each transect, rather than through continuous line-intercept recording. Individual counting followed a physically separated clump criterion: a group of orchid shoots or pseudobulbs growing together from a single attachment point, regardless of the number of pseudobulbs or rosettes within it, was recorded as one individual. A second clump, visibly separated from the first by a gap in the substrate with no observable rhizome connection, was recorded as a separate individual. For vegetatively spreading taxa such as *Liparis* spp. and *Appendicula celebica*, which produce multiple pseudobulbs from a single rhizome system, the entire contiguous clump was counted as one individual; abundance estimates for these species therefore reflect the number of physically distinct clump units rather than the number of ramets. This clump-based counting convention follows established protocols for epiphytic orchid censuses, where individual ramet enumeration is impractical due to cryptic rhizome connections beneath the substrate (Adhikari et al. 2012; Zotz 2016).

Each orchid specimen found was recorded with the following data: species name, number of individuals counted as distinct clumps or rosettes, life form classified as epiphytic or terrestrial, and host tree species for epiphytes. Environmental conditions such as temperature, humidity, and light intensity at each sampling point were determined by portable instruments. Voucher specimens for all recorded species were deposited at Herbarium Celebense (CEB), Research Center for Plant Biodiversity of Wallacea, Universitas Tadulako, Palu, Central Sulawesi, Indonesia. Accession numbers for all 15 species are confirmed: *Liparis latifolia* Lindl. (CEB-016189), *Cymbidium finlaysonianum* Lindl. (CEB-015148), *Appendicula celebica* (Schltr.) Schltr. (CEB-015091), *Dendrobium crumenatum* Sw. (CEB-015096), *Dendrobium acinaciforme* Roxb. (CEB-015150), *Dendrobium reflexitepalum* J.J.Sm. (CEB-015157), *Coelogyne asperata* Lindl. (CEB-015092), *Dendrobium luteocilium* Rupp (CEB-015115), *Podochilus microphyllus* Lindl. (CEB-016177), *Dendrobium stratiotes* Rchb.f. (CEB-015140), *Spathoglottis plicata* Blume (CEB-015133), *Liparis pallida* (Blume) Lindl. (CEB-016398), *Arachnis flos-aeris* (L.) Rchb.f. (CEB-016399), *Dendrobium fimbriatum* Hook. (CEB-016400), and *Bulbophyllum biflorum* Teijsm. & Binn. (CEB-016401). Species identifications were based on authoritative taxonomic references, including Comber (1990; 2001), Schlechter (1925), and Handoyo and Prasetya (2012), and were verified by herbarium specialists at Herbarium Celebense (CEB), Universitas Tadulako.

Ecological data analysis

This study employed a descriptive-exploratory design. No inferential statistical comparisons were performed between habitat types. Ecological indices are presented as descriptive summaries of community structure within each transect. The two-parameter Importance Value Index (IVI = Relative Density + Relative Frequency, maximum 200%) was selected because dominance-based parameters such as basal area or canopy coverage are not meaningful metrics for epiphytic orchid communities, where individual size varies greatly, and canopy structure is determined by the phorophyte tree rather than the orchid itself.

Ecological parameters were determined from the data using the standard formulae of Magurran (2004); Odum and Barrett (2005). The Species Richness Index (*Da*) was calculated from the number of species (*S*) using Margalef's formula: $Da = (S-1)/\ln(N)$, where S is the total species number, and N is the total number of individuals. The classification corresponds to $Da < 2.5$ for low richness, $2.5 \leq Da < 4.0$ for moderate richness and $Da \geq 4.0$ for high richness. Shannon-Wiener Diversity Index (H') was calculated as: $H' = -\Sigma(pi \times \ln pi)$, where pi is the fraction of species i individuals in the total, $pi = ni/N$. The classification corresponds to $H' < 1$ for low diversity, $1 \leq H' < 3$ for moderate diversity and $H' \geq 3$ for high diversity.

Evenness Index (e) was determined from Pielou's equation: $e = H'/\ln(S)$. The classification is done through $e < 0.5$, which means uneven or low distribution, $0.5 \leq e < 0.75$ means moderate evenness, and $e \geq 0.75$ means high evenness or uniform distribution. Importance Value Index (IVI) was obtained by adding Relative Density and Relative Frequency: IVI = $RD + RF$ where $RD = (ni/N) \times 100\%$ and $RF = (Fi/\Sigma F) \times 100\%$, where Fi = number of georeferenced sampling points at which species i was recorded (out of 22 total points), and ΣF = sum of all Fi values across all species. By using only a two-parameter IVI, the maximum value is 200%. It should be noted that this two-parameter IVI is not directly comparable to the three-component IVI ($RD + RF$ + Relative Dominance, maximum 300%) conventionally used in tree ecology cross-study comparisons based on absolute IVI magnitude should therefore be avoided. Sørensen Similarity Index was computed as: $ISs = 2C/(A+B) \times 100\%$, whereby C is the number of species found in both locations, and A and B are the number of species at each location, respectively.

Phytochemical screening

The phytochemical tests were run on six of the 15 recorded species, selected based on population abundance ($n \geq 3$) and material accessibility. Species with $n \leq 2$ were excluded due to conservation constraints on destructive sampling. This selection approach introduces a bias toward numerically dominant species. The nine unscreened species remain phytochemically uncharacterized, which should be considered when interpreting the priority framework. The selected species were: *L. latifolia*, *C. finlaysonianum*, *D. crumenatum*, *D. stratiotes*, *D. luteocilium*, and *B. biflorum*. Fresh plant materials comprising leaves, stems, and roots, if available, were collected and taken to the lab within 24 hours. Samples were prepared for extraction by cleaning, sorting the plant parts and using methanol for extraction based on the standard protocol of Harborne (1998). Fresh plant materials were collected separately by organ (leaf, stem/pseudobulb, and root, where available) and dried to constant weight. For each organ, approximately 1 g dry weight was obtained in the field as bulk material. From this bulk, a 1 mg analytical subsample of dried, ground tissue was used for methanolic extraction. This small subsample was selected to minimize destructive sampling of wild orchid material. Each subsample was immersed in 3 mL methanol for 72 h with occasional stirring, then gently heated and filtered. The filtrate was evaporated to dryness under reduced pressure, and the crude extract was reconstituted in methanol to a final concentration of 0.33 mg/mL for each organ fraction.

Qualitative screening was carried out to identify six main bioactive compound classes by using the standard colorimetric and precipitation tests. Dragendorff and Mayer reagent tests were used for the identification of alkaloids, where the formation of a red-orange precipitate and cream-white precipitate, respectively, indicated positive results. The Mg-HCl reduction test (Shinoda test) was used to test for flavonoids, where pink to red coloration indicated positive results. The froth test was used to detect saponins, where positive results were confirmed by persistent foam formation after vigorous shaking. The $FeCl_3$ test was used for the detection of tannins, whereby blue-black or green-black coloration indicated positive results. The Liebermann-Burchard test was used for the identification of steroids, where green to blue coloration indicated positive results. The Salkowski test was used for the detection of terpenoids, where positive results were confirmed by reddish-brown coloration at the interface.

All phytochemical tests were repeated three times using independent aliquots drawn from the same crude extract per organ fraction to ensure consistency of results. For each replicate test, 1 mL of the crude methanol extract (0.33 mg/mL) was used per reaction. The three replicates, therefore, represent repeated analytical reactions from the same extraction batch rather than independent biological replicates from separate plant individuals, which was not feasible given conservation constraints on destructive sampling of wild orchid populations. Positive controls consisted of known reference standards (quinine sulfate for alkaloids, quercetin for flavonoids, saponin from soybean for saponins, tannic acid for tannins, cholesterol for steroids, and ursolic acid for triterpenoids). Negative controls consisted of pure methanol solvent. Positive results were scored as (+) when the expected color reaction or precipitate was clearly observed; the absence of reaction was scored as (−). Compound detection results were recorded separately for each plant part (stem/pseudobulb, leaf, and root, where available). Root samples were not collected for species with $n \leq 2$ due to conservation constraints on destructive sampling. In such cases, only the stem and leaf were analyzed.

Priority species assessment framework

Species of a priority nature in NTFP development were identified using an exploratory dual-criteria framework that combined ecological sustainability with bioactive potential. The scoring thresholds applied (ecological: IVI > 15% and $n > 10$, bioactive: ≥ 5 compound classes detected) are author-defined based on the internal data distribution of this study and have not been externally validated. This framework is therefore presented as an exploratory decision-support tool to guide future research prioritization, not as a validated management ranking system. An Ecological Score was given considering IVI values and the number of individuals of the populations: A High Score was allocated to species with IVI > 15% and $n > 10$, indicating relatively higher local abundance within the sampled area and greater potential for cultivation-based utilization. A Moderate Score was given to species with IVI 5-15% or n = 5-10 (limited cultivation potential), whereas a Low Score was assigned to species with IVI < 5% and n < 5 (conservation priority; wild utilization not recommended). Wild harvest of any orchid species requires regulatory permits and population viability assessment. This framework prioritizes cultivation and ex-situ propagation in compliance with CITES Appendix II regulations applicable to all Orchidaceae. A Bioactive Score was determined based on the number of compound classes found: A High Score was given to species with 5-6 compound classes detected, a Moderate Score for species with 3-4 compound classes detected, and a Low Score for species with 1-2 compound classes detected.

Species were grouped according to priority levels using the following decision rules: Priority I-A for species with High Ecological AND High Bioactive scores (highest preliminary priority for cultivation-oriented research and further phytochemical investigation). Priority I-B for species with Moderate Ecological AND High Bioactive scores (putative phytochemical interest despite moderate population size) Priority II-Eco for species with High Ecological scores where bioactive data are unavailable (conservation with further screening recommended). Priority II-Bio for species with Low Ecological BUT High Bioactive scores (ex-situ conservation with priority for further phytochemical study). Priority III for species with Moderate Ecological scores where bioactive data are unavailable. Unranked for species with Low Ecological scores where bioactive data are also unavailable. Species not screened for bioactivity cannot be assigned bioactivity-based priority categories.

RESULTS AND DISCUSSION

Species composition and community structure

A total of 15 orchid species belonging to 10 genera were recorded at KHDTK-HPUM, comprising 91 individuals (Table 1). The orchid assemblage consisted of 14 epiphytic species representing 93.33% of species richness and 1 terrestrial species (*S. plicata*) representing 6.67%. This dominance of epiphytic orchids is characteristic of tropical forest ecosystems where abundant host trees provide suitable microhabitats for orchid colonization (Zotz 2016). The observed epiphyte to terrestrial ratio in this study is consistent with patterns reported from other tropical Asian forests, where epiphytic orchids typically comprise 70-90% of total orchid flora (Adhikari et al. 2012). Complete species composition and ecological parameters are presented in Table 1. All ecological indices (RD, RF, IVI, Da, H′, e) and similarity values were recomputed from the corrected dataset.

The genus *Dendrobium* was the most species-rich, with five species (*D. crumenatum*, *D. acinaciforme*, *D. luteocilium*, *D. reflexitepalum*, and *D. fimbriatum*) representing 33.33% of total species richness. This pattern matches the findings of a few other Indonesian forest places where *Dendrobium* has been found to be the most diverse orchid genus continuously (Puspitaningtyas 2019; Trimanto and Danarto 2020). The genus *Liparis* had two species, *L. latifolia* and *L. pallida*, which together numerically dominated the community with 48 individuals accounting for 52.75% of the total abundance.

Liparis latifolia showed the highest Importance Value Index (IVI = 41.76%), thus it is the ecologically dominant species in the orchid community. This species was recorded in all three habitat types, and the highest population was along the riverside transect. The dominance of *Liparis* species could result from their wide ecological tolerance, efficient vegetative reproduction by pseudobulbs and flexibility to vary light conditions (Pridgeon et al. 2005).

Liparis pallida came second in the importance ranking (IVI = 39.56%), after which *C. finlaysonianum* (IVI = 26.38%) followed. Collectively, these three species accounted for 64.83% of the total number of individuals (59 of 91), showing numerical dominance patterns typical of tropical orchid communities. The comparison of IVI for all species is available in Figure 2.

Table 1. Species composition and ecological parameters of orchids at KHDTK-HPUM, Central Sulawesi

Species	Life form	n	RD (%)	RF (%)	IVI (%)
Liparis latifolia Lindl.	Epiphytic	25	27.47	14.29	41.76
Liparis pallida (Blume) Lindl.	Epiphytic	23	25.27	14.29	39.56
Cymbidium finlaysonianum Lindl.	Epiphytic	11	12.09	14.29	26.38
Appendicula celebica (Schltr.) Schltr.	Epiphytic	9	9.89	11.43	21.32
Dendrobium crumenatum Sw.	Epiphytic	6	6.59	11.43	18.02
Dendrobium acinaciforme Roxb.	Epiphytic	3	3.30	8.57	11.87
Dendrobium reflexitepalum J.J.Sm.	Epiphytic	3	3.30	8.57	11.87
Coelogyne asperata Lindl.	Epiphytic	2	2.20	5.71	7.91
Dendrobium luteocilium Rupp	Epiphytic	2	2.20	5.71	7.91
Podochilus microphyllus Lindl.	Epiphytic	2	2.20	5.71	7.91
Arachnis flos-aeris (L.) Rchb.f.	Epiphytic	1	1.10	2.86	3.96
Bulbophyllum biflorum Teijsm. & Binn.	Epiphytic	1	1.10	2.86	3.96
Dendrobium fimbriatum Hook.	Epiphytic	1	1.10	2.86	3.96
Dendrobium stratiotes Rchb.f.	Epiphytic	1	1.10	2.86	3.96
Spathoglottis plicata Blume	Terrestrial	1	1.10	2.86	3.96
Total		91	100.00	100.00	200.00

Note: n: number of individuals, RD: Relative Density, RF: Relative Frequency ($F_i/\Sigma F \times 100\%$, where F_i = number of sampling points at which species was recorded out of 22 total points), IVI: Importance Value Index

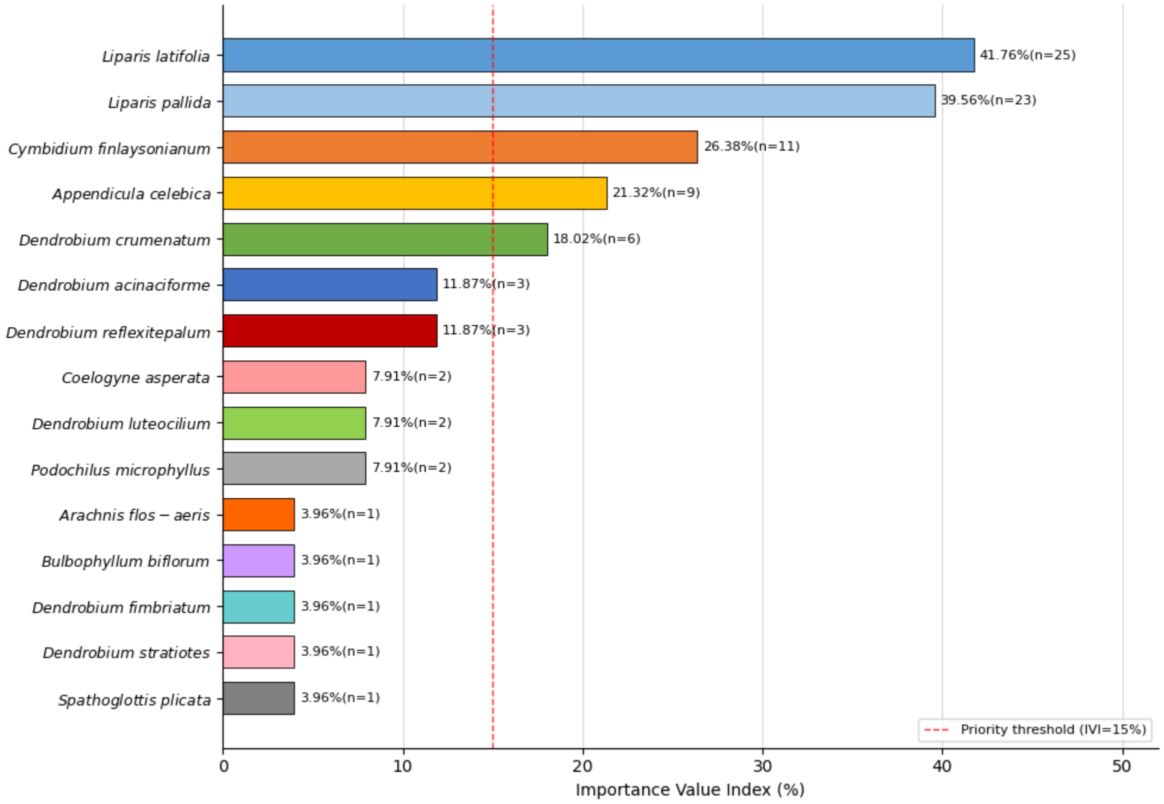

Figure 2. Importance Value Index (IVI) of 15 orchid species at KHDTK-HPUM

A notable finding was the presence of *A. celebica* (IVI = 21.32%), an orchid species endemic to Sulawesi (Schlechter 1925), documented here based on voucher specimens verified at Herbarium Celebense. The occurrence of this endemic species at KHDTK-HPUM is consistent with its known distribution in Central Sulawesi and highlights the biogeographic significance of the study area within the Wallacea biodiversity hotspot. The orchid distribution across habitat types is illustrated in Table 2.

Orchid distribution varied across habitat types (Table 2). The riverside transects recorded the highest individual abundance (42 individuals, 46.15%), with equal species richness to the forest edge (10 species each) but more individuals per species — a pattern tentatively consistent with the hypothesis that moisture availability along the stream may support higher local density. However, given the unequal number of sampling points across habitats (edge: 5, riverside: 11, interior: 6), this pattern should be treated as a preliminary observation rather than evidence of habitat preference.

The forest interior transects recorded the lowest species richness (6 species) but the second highest individual abundance (32 individuals, 35.16%), a pattern consistent with the hypothesis that closed-canopy conditions may favor a smaller subset of shade-tolerant species capable of reaching high local density, though this interpretation remains speculative given the exploratory sampling design. The distribution proportion of the individuals per habitat is illustrated in Figure 3.

Ecological indices and diversity patterns

Ecological indices calculated for each habitat type revealed moderate to low diversity levels across the study site (Table 3). Species Richness Index (*Da*) ranged from 1.44 to 3.17, with the forest edge transect showing the highest value (*Da* = 3.17) classified as moderate richness. Higher species richness at forest edges can be attributed to ecotone effects, where transitional zones between habitat types typically support greater species diversity due to species overlap from adjacent communities (Odum and Barrett 2005). The riverside transects showed low richness (*Da* = 2.41) while the forest interior exhibited the lowest value (*Da* = 1.44), which may reflect reduced species accumulation under closed-canopy conditions.

Shannon-Wiener Diversity Index (H′) recorded a fluctuation range of 0.66 to 1.08, labeling the biodiversity level as between low and moderate in line with Magurran (2004) category. The highest diversity value (*H′* = 1.08) was surprisingly recorded by the forest interior transect, which had the lowest number of species. However, the explanation for this seemingly contradictory forest interior comes from the Evenness Index (*e*), which varied between 0.29 and 0.60 in different habitats. The forest interior had a moderate evenness (*e* = 0.60), where individuals were more evenly distributed among species than in the forest edge (*e* = 0.41) and riverside (*e* = 0.29) habitats, which were numerically dominated by a few species, thus having a low diversity overall.

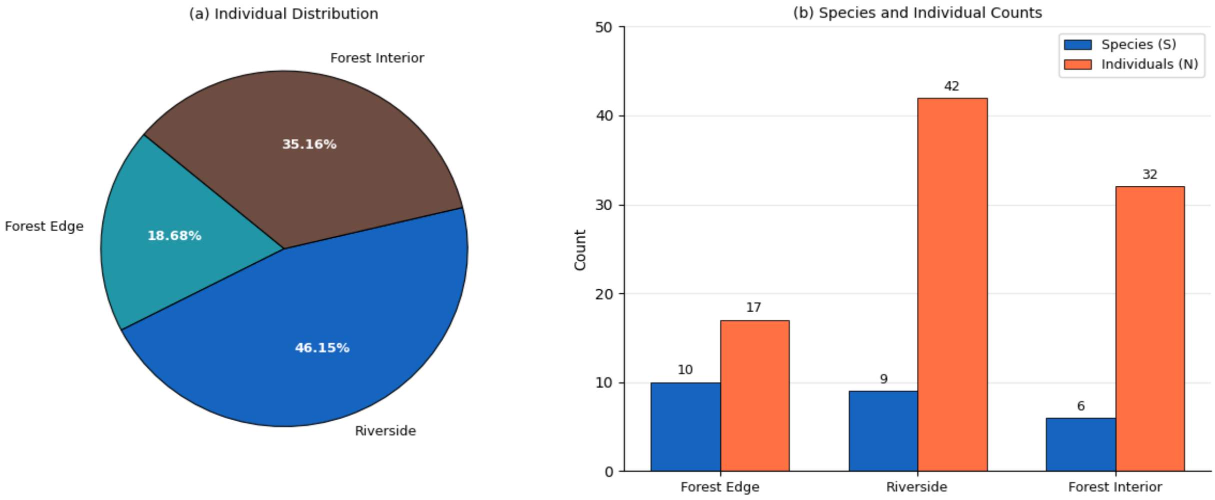

Figure 3. Distribution of orchid individuals by habitat type at KHDTK-HPUM

Table 2. Distribution of orchid species and individuals across three habitat types at KHDTK-HPUM, Central Sulawesi

Species	Forest edge (n)	Riverside (n)	Forest interior (n)	Total (n)
Liparis latifolia Lindl.	4	21	-	25
Liparis pallida (Blume) Lindl.	2	-	21	23
Cymbidium finlaysonianum Lindl.	1	9	1	11
Appendicula celebica (Schltr.) Schltr.	1	2	6	9
Dendrobium crumenatum Sw.	2	2	2	6
Dendrobium acinaciforme Roxb.	2	1	-	3
Dendrobium reflexitepalum J.J.Sm.	-	3	-	3
Coelogyne asperata Lindl.	1	1	-	2
Dendrobium luteocilium Rupp	2	-	-	2
Podochilus microphyllus Lindl.	1	1	-	2
Arachnis flos-aeris (L.) Rchb.f.	1	-	-	1
Bulbophyllum biflorum Teijsm. & Binn.	-	1	-	1
Dendrobium fimbriatum Hook.	-	-	1	1
Dendrobium stratiotes Rchb.f.	-	-	1	1
Spathoglottis plicata Blume	-	1	-	1
Total individuals	17	42	32	91
Total species	10	10	6	15*
% individuals	18.68%	46.15%	35.16%	100%

Note: n: number of individuals. (-): species absent in that habitat. *total unique species across all habitats; some species occur in multiple habitats. Abundance values reflect encounter frequency within the searched corridor and should not be interpreted as density estimates per unit area. Unequal sampling points across habitats (edge: 5, riverside: 11, interior: 6) may influence species detection rates.

Table 3. Ecological indices of orchid communities across habitat types at KHDTK-HPUM

Habitat type	*S*	*N*	*Da*	*H'*	Category	*e*	Category
Forest edge	10	17	3.17	0.94	Low	0.41	Uneven
Riverside	10	42	2.41	0.66	Low	0.29	Uneven
Forest interior	6	32	1.44	1.08	Moderate	0.60	Moderate

Note: *S*: number of species, *N*: number of individuals, *Da*: Margalef Richness Index, *H'*: Shannon-Wiener Diversity Index, *e*: Pielou Evenness Index

The Sørensen Similarity Index revealed that there was a moderate compositional similarity among habitat types: forest edge and riverside showed high compositional similarity (*ISs* = 70.00%; *C* = 7 shared species), riverside and forest interior were 37.50% similar (*C* = 3), and forest edge and forest interior were 50.00% similar (*C* = 4). The high Edge-Riverside similarity reflects shared generalist species tolerant of both open and transitional conditions (e.g., *L. latifolia*, *C. finlaysonianum*, *A. celebica*). The lower Riverside-Interior similarity (37.50%) suggests that riverside species (e.g., *D. reflexitepalum*, *B. biflorum*) do not extend into closed-canopy interior conditions. These values should be interpreted as descriptive, as unequal sampling effort across habitats may influence species detection.

It should be noted that species richness estimates may be influenced by unequal sampling effort across transects (forest edge: 5 sampling points, riverside: 11 points, forest interior: 6 points). The higher species richness at forest edge (10 species) relative to forest interior (6 species) is consistent with ecotone theory, but should be interpreted cautiously given the exploratory design and unequal sampling intensity. Standardized rarefaction analysis was not performed due to small sample sizes per transect, which represents a limitation that future research should address through balanced sampling designs.

Additionally, the clump-based individual definition may slightly inflate abundance estimates for rhizomatous species such as *Liparis* spp. and *A. celebica*, which spread vegetatively, potentially influencing their RD and IVI values; solitary-growth species such as *Spathoglottis plicata* are unlikely to be affected by this counting convention.

For contextual reference only — noting that direct comparisons are constrained by substantial differences in sampling area, elevation range, sampling design, and survey effort among studies — KHDTK-HPUM recorded 15 species compared to Lore Lindu National Park (40 species) (Nasrun et al. 2024), Bantimurung-Bulusaraung National Park (60 species) (Puspitaningtyas 2017), and West Sulawesi forests (51 species) (Puspitaningtyas 2019). Shannon-Wiener diversity at KHDTK-HPUM (H' = 0.66-1.08) was lower than values reported for Mount Merapi (H' = 3.03, Kurniawan et al. 2020) and Curug Cibereum (H' = 2.54, Fitriana et al. 2022), sites that differ markedly in area, elevation, and sampling intensity.

The comparatively lower values at KHDTK-HPUM may be associated with the managed agroforestry-dominated landscape, lower elevation (600 m asl), and smaller sampled area of the study site, although direct comparison remains limited by differences in study design (Kindlmann et al. 2023). Low evenness values indicate numerical dominance by Liparis species.

Direct comparisons of diversity indices across studies should be interpreted with caution, as the referenced studies differ substantially in sampling area, elevation range, sampling design, and survey effort; the values reported here are descriptive summaries for KHDTK-HPUM under the current sampling conditions.

Bioactive compound profiles of selected species

A phytochemical screening of six diverse species showed that each species contained a variety of bioactive compound classes. All species tested positively for the groups of compounds screened; however, different plant parts and species gave variations in color intensity and strength of the reaction, suggesting that there could be qualitative differences in concentration of the compounds rather than identical chemical composition. The data are based on the combined observations of leaf, stem, and root extracts and, thus, the figures represent overall detection of compounds rather than quantitative abundance. Repeating tests to verify results has shown the consistency of the compounds, and these are most probably really present. At the same time, the variation in the intensities of the reactions suggests that future work should quantify the precise concentration of the compounds using chromatographic techniques.

Phytochemical profiles varied notably between plant parts within each species (Table 4), demonstrating that organ-specific sampling is essential in orchid phytochemical studies. In *L. latifolia*, stem and leaf tissues contained alkaloids, flavonoids, saponins, tannins, and triterpenoids, whereas roots yielded only saponins, suggesting that roots serve primarily as storage organs with limited secondary metabolite biosynthesis. In *C. finlaysonianum*, root tissue showed the richest profile with all six compound classes detected, contrasting with stem tissue, where only alkaloids were present. This pattern is consistent with the role of roots as the primary interface with the substrate, where chemical defense compounds may be concentrated. *D. crumenatum* exhibited the most consistent and complete profile, with all six compound classes detected in both stem and leaf tissues. *B. biflorum* showed a notable contrast between the stem (only saponin) and leaf (all six classes), indicating that leaves are the primary site of secondary metabolite accumulation in this species.

Table 4. Phytochemical screening results of selected orchid species from KHDTK-HPUM

Species	Plant part	ALK	FLV	SAP	TAN	STE	TER
Liparis latifolia Lindl.	Stem/pseudobulb	+	+	+	+	-	+
	Leaf	+	+	+	+	+	+
	Root	-	-	+	-	-	-
Dendrobium stratiotes Rchb.f.	Stem/pseudobulb	+	-	+	+	-	-
	Leaf	-	+	+	-	+	+
Cymbidium finlaysonianum Lindl.	Stem/pseudobulb	+	-	-	-	-	+
	Leaf	-	+	+	-	+	+
	Root	+	+	+	+	+	+
Bulbophyllum biflorum Teijsm. & Binn.	Stem/pseudobulb	-	-	+	-	-	-
	Leaf	+	+	+	+	+	+
Dendrobium crumenatum Sw.	Stem/pseudobulb	+	+	+	+	+	+
	Leaf	+	+	+	+	+	+
Dendrobium luteocilium Rupp	Leaf Only	+	+	+	+	+	+

Note: ALK: Alkaloids, FLV: Flavonoids, SAP: Saponins, TAN: Tannins, STE: Steroids, TER: Triterpenoids. (+): detected, (−): not detected. All tests were performed in triplicate with positive and negative controls at the Pharmacy Laboratory, Universitas Tadulako

The presence of these compound classes is consistent with literature reports for the respective genera and suggests bioactive potential warranting further quantitative investigation. It must be emphasized that qualitative phytochemical screening detects only the presence or absence of broad compound classes, and does not quantify their concentration or confirm specific biological activity. Therefore, conclusions regarding pharmacological relevance from this study cannot be drawn, and validation through quantitative chemical profiling (HPLC/LC-MS) and standardized bioactivity assays is necessary before any therapeutic inferences can be made.

The following interpretation places the present phytochemical observations within the context of published genus-level literature. All habitat-related patterns should be regarded as preliminary observations reflecting encounter frequency within the searched corridor rather than as statistically validated habitat preferences. Similarly, phytochemical interpretations are limited to compound-class detection and do not imply quantified bioactivity or pharmacological relevance.

The detection of alkaloids and flavonoids in both *Liparis* species is consistent with published phytochemical reports for this genus. Liang et al. (2019) reviewed nearly 200 compounds isolated from *Liparis* species worldwide, including nervogenic acid derivatives, phenanthrenes, bibenzyl derivatives, flavonoids, and pyrrolizidine alkaloids. Chen et al. (2025) similarly reported that phenolic acids, flavonoids, and alkaloids are major chemical constituents of the genus *Liparis*, with documented haemostatic, antitumor, and anti-inflammatory activities in other studied taxa. Chen et al. (2019) demonstrated anticancer activity of pyrrolizidine alkaloids from *Liparis nervosa* against HCT116 cells. However, whether analogous compounds occur at biologically relevant concentrations in the KHDTK-HPUM *Liparis* populations cannot be determined from qualitative screening alone. Quantitative profiling and standardized bioassays would be required before any such inference can be made.

The qualitative phytochemical profile of *C. finlaysonianum* is consistent with published reports on this species. Lertnitikul et al. (2020) isolated a new dihydrophenanthrene along with eight phenanthrene derivatives from *C. finlaysonianum*, some of which showed cytotoxic activity against NCI-H187 cells in that study. Jimoh et al. (2022) similarly reported dihydrophenanthrene and bibenzyl compounds from related *Cymbidium* species. The detection of steroids and triterpenoids in root extracts in the present study is consistent with the genus-level literature, but does not confirm any specific bioactivity in the KHDTK-HPUM population. Standardized assays remain necessary for validation.

The detection of all six compound classes in three *Dendrobium* species (*D. crumenatum*, *D. stratiotes*, *D. luteocilium*) is consistent with the well-documented phytochemical richness of this genus. Chen et al. (2021) reviewed more than 120 bioactive compounds from *Dendrobium* species, including polysaccharides, bibenzyls, flavonoids, alkaloids, and phenanthrenes. *D. crumenatum* is traditionally used for treating earaches, fever, and skin infections in Southeast Asian communities (da Silva et al. 2015). The present qualitative detection is consistent with these genus-level reports, but does not confirm that these compound classes are present at pharmacologically relevant concentrations in the KHDTK-HPUM populations.

The qualitative phytochemical profile of *B. biflorum*, showing all six compound classes in leaf tissue, is consistent with published genus-level reports. Sharifi-Rad et al. (2022) reported a range of compound classes in *Bulbophyllum* species with documented bioactivities in those studied taxa. Targu et al. (2023) confirmed that phenols, flavonoids, alkaloids, and triterpenoids are commonly present in the genus. Chen et al. (2008) extracted phenanthrenes and bibenzyls from *Bulbophyllum odoratissimum* with reported antitumor activity. The compound-class profile detected in *B. biflorum* at KHDTK-HPUM is consistent with this literature but requires quantitative validation before bioactivity can be inferred for the present population.

Priority species for NTFP development

Using a dual-criteria framework integrating ecological sustainability and bioactive potential, 15 orchid species were ranked across four priority tiers (Table 5). Three species were designated as highest priority (I-A and I-B): *L. latifolia* and *C. finlaysonianum* (Priority I-A: high ecological + high bioactive) for cultivation-oriented research and further phytochemical investigation, and *D. crumenatum* (Priority I-B: moderate ecological + high bioactive) as a preliminary phytochemical priority due to its complete qualitative metabolite profile. *L. pallida*, despite its high ecological dominance (IVI = 39.56%, n = 23), was placed in Priority II-Eco rather than Priority I because phytochemical screening data were unavailable; this should be prioritized in future research. These species showed relatively higher encounter frequency and IVI values within the sampled corridor and were found to contain multiple compound classes in qualitative screening; they are therefore identified as preliminary candidates for further cultivation research and quantitative phytochemical investigation. Management decisions based on this exploratory ranking require demographic validation through multi-seasonal monitoring, population viability assessment, and quantitative chemical profiling before implementation.

Liparis latifolia (Figure 4.A) is a notable candidate for further investigation in NTFP research development due to its high ecological dominance (IVI = 41.76%, n = 25) and broad qualitative phytochemical profile. The species had the largest population size of all orchids recorded, suggesting potential for cultivation-based utilization, subject to population-level validation and regulatory compliance. Various compound classes were detected in qualitative screening, consistent with the broad phytochemical richness reported for Liparis in the literature. Quantitative validation is required before pharmacological relevance can be established. Cultivation trials on this species should emphasize vegetative propagation by pseudobulb division since this is the natural reproductive mode in *Liparis* species, which is most commonly observed.

Table 5. Priority ranking of all 15 orchid species at KHDTK-HPUM based on ecological and bioactive criteria

Priority	Species	IVI (%)	Ecological score	Bioactive score	Recommendation
I-A	*Liparis latifolia* Lindl.	41.76	High	High (5-6 classes)	Cultivation-oriented research + further phytochemical study
I-A	*Cymbidium finlaysonianum* Lindl.	26.38	High	High (6 classes)	Cultivation-oriented research + further phytochemical study
I-B	*Dendrobium crumenatum* Sw.	18.02	Moderate	High (6 classes)	Priority for quantitative chemical profiling
II-Eco	*Liparis pallida* (Blume) Lindl.	39.56	High	N/A	Cultivation + further screening
II-Eco	*Appendicula celebica* (Schltr.) Schltr.	21.32	Moderate	N/A	Conservation + research
II-Bio	*Dendrobium luteocilium* Rupp	7.91	Moderate	High (6 classes)	Ex-situ conservation + future phytochemical screening
II-Bio	*Bulbophyllum biflorum* Teijsm. & Binn.	3.96	Low	High (6 classes)	Ex-situ conservation
II-Bio	*Dendrobium stratiotes* Rchb.f.	3.96	Low	High (5 classes)	Ex-situ conservation
III	*Dendrobium acinaciforme* Roxb.	11.87	Moderate	N/A	Conservation monitoring
III	*Dendrobium reflexitepalum* J.J.Sm.	11.87	Moderate	N/A	Conservation monitoring
III	*Coelogyne asperata* Lindl.	7.91	Moderate	N/A	Conservation monitoring
III	*Podochilus microphyllus* Lindl.	7.91	Moderate	N/A	Conservation monitoring
-	*Arachnis flos-aeris* (L.) Rchb.f.	3.96	Low	N/A	Population monitoring
-	*Dendrobium fimbriatum* Hook.	3.96	Low	N/A	Population monitoring
-	*Spathoglottis plicata* Blume	3.96	Low	N/A	Population monitoring

Note: Priority I-A: High Ecological + High Bioactive; I-B: Moderate Ecological + High Bioactive, II-Eco: High Ecological, bioactive data unavailable. II-Bio: Low/Moderate Ecological + High Bioactive, III: Moderate Ecological, bioactive data unavailable, Low Ecological, bioactive data unavailable. N/A: not screened. All rankings are exploratory and based on author-defined thresholds derived from the internal data distribution of this study; they have not been externally validated and should not be used for management decisions without further demographic and quantitative phytochemical validation

Figure 4. Priority orchid species at KHDTK-HPUM. A. *Liparis latifolia*, B. *Liparis pallida*, C. *Cymbidium finlaysonianum,* D. *Dendrobium crumenatum*, E. *Appendicula celebica*, F. *Dendrobium stratiotes*

Liparis pallida (Figure 4.B) is the second most important by the criteria of its high ecological abundance, and it is found in a variety of habitat types. This species appears locally abundant in the present survey and may be suitable for future cultivation research, pending further population assessment. *L. pallida* was not subjected to phytochemical screening in this study due to the shortage of material in the field, but its position in the taxonomic tree relative to *L. latifolia* and the fact that it shares a similar ecological niche adaptability make it a candidate for detection of compound classes in related *Liparis* taxa, suggesting this species warrants laboratory investigation in the future.

Cymbidium finlaysonianum (Figure 4.C) is already recognized as an ornamental species with established horticultural value and as candidate for further phytochemical investigation. The species in question recorded a very high ecological importance (IVI = 26.38%) and a full qualitative bioactive profile, supporting its inclusion as a candidate for cultivation-oriented NTFP research, pending quantitative phytochemical validation. Propagation of *C. finlaysonianum* via tissue culture techniques has been reported in previous studies (Puspitaningtyas and Handini 2020), suggesting potential for scaled propagation, although feasibility under local conditions at KHDTK-HPUM requires further evaluation.

Dendrobium crumenatum (Figure 4.D) merits further phytochemical investigation, given the well-documented phytochemical richness of the genus *Dendrobium*. Locally, the orchid has been traditionally used for healing earaches, fever, and skin infections in the various communities of Southeast Asia. Published phytochemical studies have reported alkaloids, flavonoids, and phenanthrene derivatives in *Dendrobium* species (Chen et al. 2021). Whether these compound classes occur at biologically relevant concentrations in the *D. crumenatum* population studied here cannot be determined from qualitative screening alone.

Appendicula celebica (Figure 4.E) was given a Priority II category as a call for conservation-oriented management because of its endemic distribution limited only to Sulawesi. Even though no phytochemical data were recorded for the species, its unique biogeographic value brings out the educational forest's conservation emphasis within the Wallacea biodiversity hotspot.

Dendrobium stratiotes (Figure 4.F), which showed almost all the different qualitatively bioactive compounds, was decided to be mainly used for ex-situ conservation programs because of its extremely small population size (only 1 individual) at the study area. A wild harvest of rare species should be absolutely avoided to prevent the decline of the local population. Thus, propagation of the species should be directed at creating safe ex-situ collections and tissue-culture-based multiplication before any use.

Management implications for education forest NTFP development

The results certainly suggest a number of points for merging orchid NTFP management with KHDTK-HPUM's educational mandate. To begin with, the fact that the diversity is only moderate and the species showed varied distribution patterns across habitat types suggests that maintaining microhabitat heterogeneity is important for orchid diversity conservation. Greater species richness at forest edges and a higher number of individuals along streams indicate that ecotones and riparian areas may warrant priority attention in future in situ conservation planning. Management should also refrain from uniform canopy manipulation, which is likely to reduce microhabitat diversity.

Secondly, the detection of multiple compound classes in each of the six screened species is consistent with the hypothesis that local orchid flora may harbor phytochemical diversity warranting further quantitative investigation, although medicinal application cannot be inferred from qualitative screening alone. On the other hand, most species have small population sizes (10 out of 15 species have $n \leq 3$), which means that harvesting from the wild is not a viable method for the majority of the community. NTFP development should primarily emphasize cultivation and ex situ propagation rather than wild extraction.

All Orchidaceae are listed under CITES Appendix II, requiring documentation of legal acquisition for any commercial trade. Any specimen collection from KHDTK-HPUM requires prior authorization from the management authority (Ministerial Decree No. 260/Menhut-II/2011). Conservation strategies should therefore explicitly prioritize non-destructive approaches, including habitat protection, in-situ monitoring, and community-based propagation programs. Voucher specimens for this study were collected under research permits as part of the institutional research program of Universitas Muhammadiyah Palu. The educational mandate is an excellent setting for linking propagation training to conservation education.

Thirdly, focusing on endemic species as well as species with a high potential for producing bioactive substances but which are rare implies that management approaches need to be tailored to the specific needs of each species. The orchid garden in a place like KHDTK-HPUM can cover various aspects of management: it is for conservation of the germplasm through living collections, propagation training, demonstration of sustainable cultivation, and also for public education. The feasibility of such a facility as a potential income source would require dedicated feasibility studies beyond the scope of this baseline survey.

It is important to distinguish between conservation-oriented management recommendations, which can be implemented immediately based on the present baseline data, and commercial NTFP development, which requires additional population viability assessments, quantitative phytochemical profiling, market feasibility studies, and regulatory compliance evaluation before any practical implementation.

Fourth, KHDTK-HPUM holds only a portion of the regional orchid diversity, which is reason enough to include it in broader protected education forest networks. Collaborating with Lore Lindu and Bantimurung-Bulusaraung National Parks could create complementary conservation networks that could support the protection of different forest management categories. Through its educational directive, the forest offers opportunities for joint research and student participation in monitoring programs.

This study has several limitations: (i) sampling was conducted during a single season (August-September 2024), which may not capture temporal variation in orchid abundance; (ii) phytochemical screening was qualitative only and limited to six of 15 species; (iii) the exploratory sampling design with unequal effort across habitats precludes formal statistical habitat comparisons; and (iv) priority ranking for unscreened species is based on ecological data only. Future research should prioritize quantitative chemical profiling and in vitro bioactivity assays for priority species, seasonal monitoring to capture full orchid phenology, and balanced sampling designs to enable rigorous habitat comparisons.

In conclusion, this research documents 15 orchid species belonging to 10 genera comprising 91 individuals across three habitat types at KHDTK-HPUM, Central Sulawesi, Indonesia. Of these, 14 species (93.33%) were epiphytic, and 1 species (6.67%) was terrestrial. *L. latifolia* (IVI = 41.76%, n = 25) and *L. pallida* (IVI = 39.56%, n = 23) were the ecologically dominant species, while *A. celebica* (IVI = 21.32%) represents a notable finding as an orchid endemic to Sulawesi. Riverside habitat supported the highest individual abundance (42 individuals, 46.15%), while Forest Edge showed the highest species richness (10 species). Shannon's diversity index was highest in Forest Interior ($H' = 1.08$), indicating more even species distribution under closed-canopy conditions. Qualitative phytochemical screening of six species revealed compound class profiles that varied significantly by plant part. *D. crumenatum* showed the most complete profile (all six classes in both stem and leaf), while *C. finlaysonianum* showed the richest profile in root tissue. Using an integrated dual-criteria priority framework, three species were identified as Priority I: *L. latifolia* and *C. finlaysonianum* (Priority I-A) and *D. crumenatum* (Priority I-B). This study provides a first descriptive baseline of orchid ecology and qualitative phytochemical profiles for orchid conservation and NTFP management at KHDTK-HPUM, and offers a preliminary framework that may be adapted for similar descriptive assessments in other Indonesian education forests.

ACKNOWLEDGEMENTS

The authors are grateful to the management of KHDTK-HPUM for granting research permits and field access, and to the staff of the Pharmacy Laboratory, Universitas Tadulako, Indonesia, for their assistance in phytochemical analysis. We also thank Herbarium Celebense (CEB), Universitas Tadulako, for specimen verification. This study was financially supported by the Faculty of Agriculture, Universitas Muhammadiyah Palu, Indonesia, and the authors acknowledge the institutional support of Universitas Muhammadiyah Palu.

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