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Review Article

A Comprehensive Documentation of Orchid Species in Kedah, Malaysia

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ABSTRACT

The documentation of orchid species in Kedah, Malaysia, highlights a remarkable biodiversity characterized by 130 species spread across five subfamilies and 61 genera. Significant ecological areas like Gunung Jerai, Ulu Muda Forest Reserve, and Langkawi UNESCO Global Geopark serve as critical habitats, hosting rare and endemic species such as Paphiopedilum exul and Spathoglottis hardingiana. Advanced methodologies, including DNA barcoding and micromorphological analysis, have been utilized to enhance taxonomic precision and elucidate evolutionary relationships among these orchids. Despite these advances, orchid diversity in Kedah faces serious threats from habitat loss due to deforestation, climate change, and illegal poaching. These anthropogenic pressures underline the pressing need for effective conservation strategies. The study identifies limestone hills and montane forests as biodiversity hotspots that require urgent protection. By promoting sustainable practices and addressing habitat degradation, this research underscores the vital importance of integrated conservation strategies to safeguard the unique orchid flora of Kedah for future generations. Furthermore, it advocates for increased awareness, community involvement, and the establishment of a centralized database to facilitate ongoing research and conservation efforts. Ultimately, this documentation serves as a foundational resource for future taxonomic studies, ecological assessments, and biodiversity conservation initiatives, contributing to policy recommendations aimed at preserving and restoring Kedah's rich orchid heritage.

Keywords: Conservation, DNA barcoding, endemic species, habitat loss, limestone hills, orchid diversity

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INTRODUCTION

Orchids (family Orchidaceae) are among the most diverse and widely distributed plant families, with approximately between 30,000 and 35,000 species globally (Choudhary et al., 2023; Mirioba et al., 2024). In Malaysia, orchid diversity is well-documented, with over 1,000 recorded species in Peninsular Malaysia and up to 3,000 species across Sabah and Sarawak including both terrestrial and epiphytic varieties (Bakar et al., 2023). Their ecological significance, aesthetic value, and economic importance in horticulture have made orchids a subject of extensive research. However, despite numerous studies documenting Malaysia's orchid flora, existing research has primarily focused on broad national-scale assessments or specific biodiversity hotspots like Sabah and Sarawak (Bakar et al., 2023; Besi et al., 2023b). The orchid diversity of Kedah, a state rich in ecological variation, remains understudied and lacks a comprehensive scientific review.

Historically, orchid documentation in Malaysia dates back to colonial botanical expeditions, where species descriptions were scattered across multiple publications and herbarium records (McCormack, 2018). Although subsequent studies have improved species identification and classification, Kedah's orchid diversity has received limited attention, with records often confined to local botanical surveys or unpublished field notes. Research and conservation initiatives in states such as Selangor, Sarawak, and Perlis have led to significant publications on orchid biodiversity, particularly in specific habitats like limestone hills and ecotourism sites, Kedah has not yet received similar attention (Go et al., 2020). The state's diverse landscapes including lowland dipterocarp forests, mangrove swamps, highland forests, and unique limestone formations suggest that Kedah hosts a significant yet underexplored variety of orchid species (Besi et al., 2019; Mirioba et al., 2024).

Moreover, anthropogenic threats such as deforestation, land conversion for agriculture, and illegal orchid collection pose increasing risks to native orchid populations in Kedah (Jaafar et al., 2020; Bakar et al., 2023). Conservation initiatives are hindered by the lack of a centralized database and insufficient documentation of species distribution and status. Without proper records, prioritizing conservation efforts and understanding species vulnerability remains challenging. Thus, this review aims to provide a systematic overview of species diversity, distribution patterns, and conservation challenges of orchids in Kedah. By examining existing records and synthesizing relevant findings, this study seeks to highlight the richness of orchid flora in Kedah, identify knowledge gaps, and assess potential conservation priorities. Given the increasing environmental pressures on orchid habitats, this documentation will serve as a foundation for future taxonomic research, ecological assessments, and biodiversity conservation efforts. Additionally, the insights gained from this review may contribute to policy recommendations, habitat restoration strategies, and sustainable orchid conservation initiatives in Malaysia.

RESULTS AND DISCUSSION

Taxonomic Distribution of Orchid Species

Major research on Malaysian orchids has focused on ecosystems such as limestone forests, peat swamp forests, hill forests, lowland forests, montane forests, coastal heath forests, and logged forests (Besi et al., 2022). Previous study in Gunung Jerai, Kedah, documented 74 orchid species across 40 genera, including 11 new records for Kedah and two new records for Malaysia. Orchid diversity in Gunung Jerai was categorized into four main subfamilies which are Apostasioideae, Cypripedioideae, Epidendroideae, and Orchidoideae. The orchid species found in this area was in the summit region's hill heath forest ecosystem, which is characterized by high humidity and cooler temperatures at elevations above 700 meters. This unique habitat, formed by granite and quartzite geology, supports a diverse range of orchids, with the study identifying 74 species across all five subfamilies of Orchidaceae despite covering only 0.34% of the area. The specific ecological conditions of this isolated mountainous environment are crucial for the growth and reproduction of these orchids, highlighting the need for further research to understand their habitat preferences and conservation requirements (Auyob et al., 2016).

Orchids are an important group in biodiversity conservation due to their inherent characteristics and human influence. They are well-known for their complex life histories, distinctive floral structures, and specialized pollination syndromes (Zhang et al., 2022). However, the classification of orchid species is often complicated by their high genetic variability, hybridization, and diverse ecological adaptations, leading to ongoing taxonomic revisions and new species discoveries. A total of 61 unique genera, including *Apostasia*, *Paphiopedilum*, and *Acheirostylis*, have been documented, indicating substantial biodiversity. The total number of species stands at 130, with classifications for variations and subspecies, underscoring the impressive diversity of orchid flora (Table 1).

According to Table 1 author's found that, the diversity of orchids in Kedah is considerable, including five subfamilies including Apostasioideae, Cypripedioideae, Epidendroideae, Orchidoideae, and Vanilloideae. While map of orchid distribution in Kedah by species count (Figure 1) illustrates the distribution of orchid species in Kedah based on the number of species recorded at each location. In Kedah, orchid species are primarily found in important ecological areas, including as Gunung Jerai (previously Kedah Peak), the Ulu Muda Forest Reserve, and the Langkawi UNESCO Global Geopark. Gunung Jerai, a prominent limestone massif, harbours a unique montane ecosystem characterized by high humidity, well-drained soils, and cooler temperatures, making it an ideal habitat for epiphytic and lithophytic orchids. A study documented 74 orchid species from 40 genera on Gunung Jerai's summit, including 11 new records for Kedah and two new records for Malaysia, indicating the area's rich orchid diversity (Auyob et al., 2016). The Ulu Muda Forest Reserve, an extensive lowland dipterocarp forest, is known for its rich biodiversity, stable microclimate, and high canopy cover, which provide optimal conditions for terrestrial and epiphytic orchid species. The forest supports a variety of wildlife, including large mammals such as elephants and tapirs, and has been identified as a hotspot for orchid diversity, with species like *Bulbophyllum meson* being recorded (Bakar et al., 2023).

Meanwhile, Langkawi's habitat offers a unique environment for orchid species, particularly those adapted to limestone ecosystems, such as *Spathoglottis hardingiana*. Once thought to be restricted to the limestone vegetation of Pulau Langkawi, this species has now been recorded on the mainland, where individuals are significantly larger almost two to three times the size of those found on the island. The limestone formations of Langkawi, part of the Machinchang Formation, share geological similarities with the limestone outcrops of the Baling-Pengkalan Hulu complex in Kedah. Both formations originated over 500 million years ago, creating specialized karst habitats that support diverse orchid species. The floristic similarities between Langkawi, Perlis, and southern Thailand suggest a shared species composition across these regions due to their common geological history. The discovery of *S. hardingiana* in both Langkawi and Baling highlights the adaptability of orchids to ancient limestone substrates, which are characterized by high calcium carbonate content, fluctuating moisture levels, and microclimatic conditions that influence species distribution and growth patterns (Bakar et al., 2023). A comprehensive study by Ong and Nordin (2017) provided an updated description of *S. hardingiana* in Peninsular Malaysia, enhancing understanding of its morphological characteristics and aiding in accurate identification for conservation purposes.

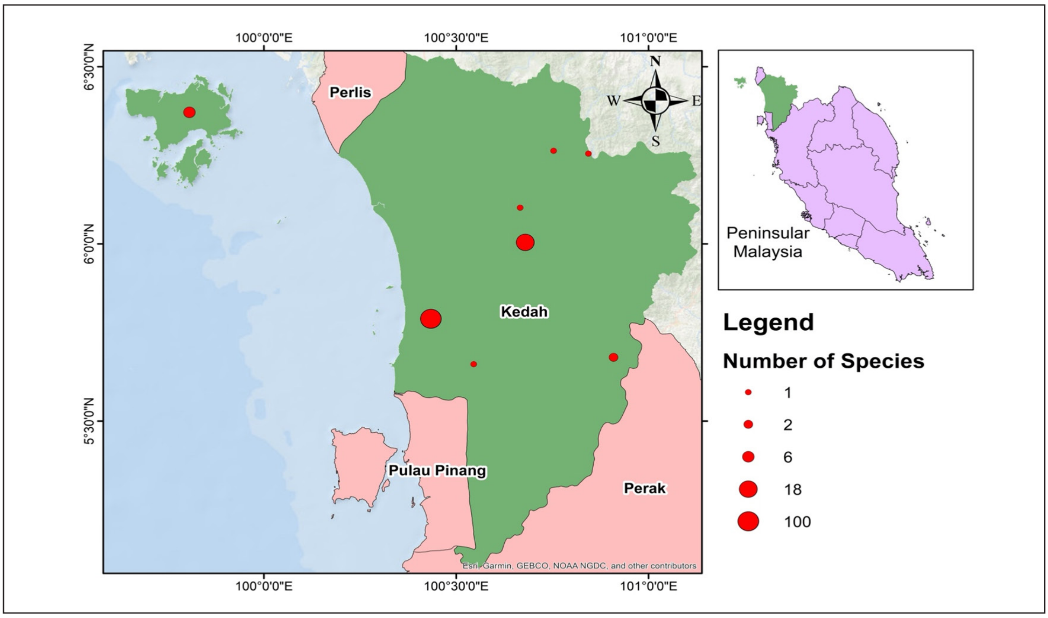

Figure 1. Map of orchid distribution in Kedah by species count

Table 1
Orchids documented in Kedah, Malaysia

Subfamilies	Genera	Species	Location	References
Apostasioideae	*Apostasia*	*Apostasia nuda* R.Br.	Gunung Jerai	1, 4
Cypripedioideae	*Paphiopedilum*	*Paphiopedilum callosum* var. *sublaeve* (Rchb.*f.*) P.J.Cribb *Paphiopedilum exul* *Paphiopedilum niveum* (Rchb.*f.*) Stein*	Bukit Pedu, Gunung Jerai	1, 4, 7, 10
Epidendroideae	*Acheirostylis*	*Acheirostylis goldschmidtiana* Schltr.	Gunung Baling, Gunung Pong,	4
	Acriopsis	*Acriopsis liliifolia* (J.Koenig) Ormerod*	Widespread in Peninsular	4
	Aerides	*Aerides krabiensis* Seidenf. *Aerides odorata* Lour.*	Gunung Baling	4
	Agrostophyllum	*Agrostophyllum majus* Hook.*f.* *Agrostophyllum stipulatum* (Griff.) Schltr. subsp. *Stipulatum** *Agrostophyllum stipulatum* subsp. *bicuspidatum* (J.J.Sm.) Schuit.*	Gunung Jerai	1, 4, 5
	Ania	*Ania penangiana* (Hook.*f.*) Summerh.*	Kedah	4, 5
	Appendicula	*Appendicula anceps* Blume *Appendicula cornuta* Blume *Appendicula reflexa* Blume	Gunung Jerai	1, 3
	Arundina	*Arundina graminifolia* (D.Don) Hochr.	Gunung Jerai	1
	Ascidiiera	*Ascidiiera longifolia* (Hook.*f.*) Seidenf.	Gunung Jerai	1
	Bromheadia	*Bromheadia finlaysoniana* (Lindl.) Miq. *Bromheadia rupestris* Ridl.	Gunung Jerai	1, 3
	Bryobium	*Bryobium hyacinthoides* (Blume) Y.P.Ng & P.J.Cribb	Gunung Jerai	1
	Bulbophyllum	*Bulbophyllum apodum* Hook.*f.* *Bulbophyllum bakhuizenii* Steenis *Bulbophyllum brevipes* Ridl. *Bulbophyllum cheiropetalum* Ridl. *Bulbophyllum cleistogamum* Ridl., J. Linn. Soc.* *Bulbophyllum dayanum* Rchb.*f.* *Bulbophyllum farinulentum* J.J.Sm.	Gunung Jerai; Gunung Fakir Terbang	1, 4, 5

Table 1 *(continue)*

Subfamilies	Genera	Species	Location	References
		Bulbophyllum gibbosum (Blume) Lindl.		
		Bulbophyllum inunctum J.J.Sm		
		Bulbophyllum lilacinum Ridl.		
		Bulbophyllum linearifolium King & Prantl.		
		Bulbophyllum medusae (Lindl.) Rchb.*f.**		
		Bulbophyllum meson J.J.Verm., Schuit. & de Vogel		
		Bulbophyllum planibulbe (Ridl.) Ridl.*		
		Bulbophyllum purpurascens Teijsm. & Binn. *Bulbophyllum sigaldiae* Guillaumin		
		Bulbophyllum uniflorum (Blume) Hassk.		
	Callostylis	*Callostylis pulchella* (Lindl.) S.C.Chen & Z.H.Tsi	Gunung Jerai	1, 5
		Callostylis rigida Blume, Bijdr. Fl. Ned.*		
	Campanulorchis	*Campanulorchis pecilis* (Rchb.*f.* ex Hook.*f.*) Y.P.Ng & P.J.Cribb	Gunung Jerai	1
	Cephalantheropsis	*Cephalantheropsis obcordata* (Lindl.) Ormerod	Gunung Jerai	1
	Ceratostylis	*Ceratostylis subulata* Blume	Gunung Baling, Gunung Jerai,	1, 4
		Cleisostoma sp.		
	Claderia	*Claderia viridiflora* Hook.*f.*	Gunung Jerai	1
	Cleisomeria	*Cleisomeria lanata* (Lindl.) Lindl. ex G.Don*	Kedah	4
	Coelogyne	*Coelogyne asperata**	Gunung Jerai; Pulau Langkawi	1, 2, 4
		Coelogyne cummingii Lindl.		
		Coelogyne foerstermannii Rchb.*f.*		
		Coelogyne prasina Ridl.		
		Coelogyne rochussenii de Vriese		
		Coelogyne swaniana Rolfe		
		Coelogyne trinervis Lindl		
	Corymborkis	*Corymborkis veratrifolia* (Reinw.) Blume*	Widespread in Peninsular	4
	Crepidium	*Crepidium calophyllum* (Rchb.*f.*) Szlach*	Kedah	3, 5
	Cylindrolobus	*Cylindrolobus biflorus* (Griff.) Rauschert*	Kedah	5
	Cymbidium	*Cymbidium haematodes* Lindl.	Kedah	2, 4
		Cymbidium testaceum (Lindl.) Hook.*		

Table 1 *(continue)*

Subfamilies	Genera	Species	Location	References
	Dendrobium	*Dendrobium aloifolium* (Blume) Rchb.*f.** *Dendrobium angustifolium* (Blume) Lindl. *Dendrobium antennatum* *Dendrobium crumenatum* Sw. *Dendrobium derryi* Ridl.* *Dendrobium hughii* Rchb.*f.* *Dendrobium indragiriense* Schltr.* *Dendrobium leonis* (Lindl.) Rchb.*f.** *Dendrobium linguella* Rchb.*f.** *Dendrobium lobbii* Teijsm. & Binn.* *Dendrobium pachyphyllum* (Kuntze) Bakh.*f.** *Dendrobium pachyglossum* C.S.P.Parish & Rchb.*f. Dendrobium plicatile* Lindl.* *Dendrobium sanguinolentum* Lindl.	Gunung Jerai, Sungai Petani	1, 4, 5, 6
	Dendrochilum	*Dendrochilum gracile* (Hook.*f.*) J.J.Sm. *Dendrochilum simile* Blume	Gunung Jerai	1
	Dienia	*Dienia ophrydis* (J.Koenig) Seidenf.	Gunung Jerai	1
	Dilochia	*Dilochia wallichii* Lindl.	Gunung Jerai	1
	Dipodium	*Dipodium pictum* (Lindl.) Rchb.*f.*	Gunung Jerai	1
	Eria	*Eria diluta* Ridl. *Eria javanica* (Sw.) Blume* *Eria neglecta* Ridl. *Eria nutans* Lindl. *Eria pilifera* Ridl.	Gunung Jerai	1, 4
	Grosourdya	*Grosourdya appendiculata* (Blume) Rchb.*f.**	Kedah	4
	Ludisia	*Ludisia discolor* (Ker Gawl.) Blume*	Kedah	5
	Liparis	*Liparis elegans* Lindl *Liparis geophila* Schltr. *Liparis maingayi* (Hook.*f.*) Ridl.* *Malleola sylvestris* (Ridl.) Garay	Gunung Jerai	1, 3

Table 1 *(continue)*

Subfamilies	Genera	Species	Location	References
	Luisia	*Luisia brachystachys* (Lindl.) Blume* *Luisia zollingeri Rchb.f.*	Pulau Langkawi	4
	Malleola	*Malleola sylvestris* (Ridl.) Garay	Gunung Jerai	1
	Nephelaphyllum	*Nephelaphyllum tenuiflorum* Blume	Gunung Jerai	1
	Oberonia	*Oberonia sp.**	Kedah	4
	Oxystophyllum	*Oxystophyllum carnosum* Blume*	Kedah	4
	Phaius	*Phaius amboinensis* (Blume)*	Kedah	4
	Pholidota	*Pholidota imbricata* (Hook.)*	Kedah	4
	Pinalia	*Pinalia floribunda* (Lindl.) Kuntze *Pinalia tenuiflora* (Ridl.) J.J.Wood	Gunung Jerai	1, 4
	Plocoglottis	*Plocoglottis lowii* Rchb.*f.*	Gunung Jerai	1
	Podochilus	*Podochilus microphyllus* Lindl. *Podochilus muricatus* (Teijsm. & Binn.) Schltr. *Podochilus tenuis* (Blume) Lindl.	Gunung Jerai	1
	Porpax	*Porpax elwesii* (Rchb.*f.*) Rolfe	Gunung Jerai	1
	Prenanthera	*Prenanthera elongata* (Blume) Lindl.* *Renanthera histrionica* Rchb.*f.**	Kedah	4
	Sarcoglyphis	*Sarcoglyphis comberi* (J.J.Wood) J.J.Wood* *Spathoglottis hardingiana* C.S.P.Parish and Rchb.*f.*	Pulau Langkawi	4
	Spathoglottis	*Spathoglottis affinis* de Vriese *Spathoglottis aurea* Lindl. *Spathoglottis plicata* Blume	Gunung Jerai	1, 8, 11
	Taeniophyllum	*Taeniophyllum pusillum* (Willd.) Seidenf. & Ormerod*	Kedah	4
	Thrixspermum	*Thrixspermum centipeda* Lour.	Gunung Jerai	1
	Trichoglottis	*Trichoglottis lanceolaria* Blume	Gunung Jerai	1
	Trichotosia	*Trichotosia ferox* Blume *Trichotosia gracilis* (Hook.*f.*) Kraenzl. *Trichotosia pauciflora* Blume *Trichotosia poculata* (Ridl.) Kraenzl	Gunung Jerai	1, 4

Table 1 *(continue)*

Subfamilies	Genera	Species	Location	References
	Tropidia	*Tropidia curculigoides* Lindl	Gunung Jerai	1, 4
	Vandopsis	*Vandopsis gigantea* (Lindl.) Pfitzer	Pulau Langkawi	4
Orchidoideae	*Anoectochilus*	*Anoectochilus albolineatus* C.S.P.Parish& Rchb.*f.* *Anoectochilus geniculatus* Ridl. *Anoectochilus sanguineus* P.T.Ong & P.O'Byrne*	Gunung Jerai	1, 4
	Corybas	*Corybas geminigibbus* J.J.Sm. *Corybas calopeplos* Dransfield & Smith*	Gunung Jerai	1, 9
	Cryptostylis	*Cryptostylis arachnites* (Blume) Hassk.	Gunung Jerai	1
	Goodyera	*Goodyera viridiflora* (Blume) Blume	Gunung Jerai	1, 3
	Habenaria	*Habenaria rhodocheila* Hance*	Kedah	3
	Peristylus	*Peristylus monticola* (Ridl.) Seidenf.*	Kedah	3
	Zeuxine	*Zeuxine affinis* (Lindl.) Benth. ex Hook.*f.* *Zeuxine gracilis* (Breda) Blume	Gunung Jerai	1, 3
Vanilloideae	*Lecanorchis*	*Lecanorchis malaccensis* Ridl.	Gunung Jerai	1

Note. 1- Auyob et al. (2016); 2- Yoh et al. (2022); 3- Nordin et al. (2021); 4- Bakar et al. (2023); 5- Besi et al. (2019); 6- Rahim and Mohd (2021); 7- Besi et al. (2022); 8- Nordin et al. (2022); 9- Go et al. (2015); 10- Besi et al. (2021); 11- Ginibun et al. (2018a). Symbols (*) indicate locations not specifically mentioned

Rare and Endemic Species

Besi et al. (2019) documented several notable orchid species in Kedah, highlighting the region's rich biodiversity. *Agrostophyllum stipulatum* (Griff.) Schltr. subsp. *stipulatum* and *Agrostophyllum glumaceum* Hook.*f.* are commonly found in lowland and montane forests, typically growing epiphytically on fallen trees. The subspecies *Agrostophyllum stipulatum* subsp. *bicuspidatum* (J.J.Sm.) Schuit. shares similar habitats and growth patterns. *Ania penangiana* (Hook.*f.*) Summerh., in contrast, is less common and thrives in grassy areas of hills and montane forests on dune-originated soils. *Trichoglottis lanceolaria* Blume and *Trichotosia gracilis* (Hook.*f.*) Kraenzl. are also frequently encountered in hill and montane forests, with epiphytic growth on fallen trees. The diversity of orchid species in Kedah is exemplified by *Spathoglottis hardingiana*, a species found in prominent locations such as Gunung Baling and Pulau Timun in Langkawi. Nordin et al. (2022) emphasize the ecological significance and unique floral characteristics of this species, along with others in the Dwarf *Spathoglottis* group. Through phylogenetic analysis, their research not only reinforces the classification of these orchids but also sheds light on their evolutionary relationships, offering valuable insights into the biodiversity of orchids in Kedah.

Nordin et al. (2021) conducted a study focusing on the orchid flora of Gunung Ledang, documenting a total of 122 species, including five endemic to Peninsular Malaysia and two hyper-endemic species unique to the region, thereby underscoring the mountain's exceptional biodiversity. Notably, 26 species (67%) corresponded with records by Ridley (1901), and 65 species (83%) aligned with Turner's (1995) checklist, illustrating both the persistence of certain species and shifts in their distribution over time. The study employed advanced methodologies, such as field and stereo microscopy, to enhance species identification while minimizing the collection of living specimens, demonstrating adherence to contemporary conservation practices. Furthermore, the identification of 30 new records for the locality highlights the ongoing potential for species discovery in under-explored regions. These findings not only enrich the understanding of orchid diversity in Gunung Ledang but also underscore the critical importance of conservation efforts in safeguarding its unique floristic heritage.

Research on the limestone hills of Kedah showed a great diversity of orchids, with 56 species from 37 genera identified in five important locations: Gunung Fakir Terbang, Gunung Batu Putih, Gunung Pong, Gunung Baling, and Gunung Pulai. Twelve of these species were newly discovered in Kedah, while *Bulbophyllum meson* and *Luisia brachystachys* were discovered in Malaysia for the first time. Peninsular Malaysia is home to three species that have been identified as endemic: *Anoectochilus sanguineus*, *Cheirostylis goldschmidtiana*, and *Phalaenopsis appendiculata*. These environments are important ecologically, as evidenced by the rediscovery of *Cheirostylis goldschmidtiana* and the endangered *Paphiopedilum niveum*. Gunung Batu Putih, Gunung Baling, and

Gunung Fakir Terbang were found to be the most diversified sites (Bakar et al., 2023). The study's use of heat maps to identify geographical hotspots of orchid diversity, particularly at Gunung Fakir Terbang, provides valuable insights into species distribution that can guide future conservation efforts.

Besi et al. (2022) identify Bukit Pedu in Kedah as a critical habitat for orchid diversity, particularly highlighting the rare species *Paphiopedilum exul*, which thrives in the shaded, dry conditions of limestone hill forests. This finding underscores the ecological significance of Bukit Pedu in contributing to the rich biodiversity of orchids in northern Peninsular Malaysia. The presence of *P. exul* not only enriches the documented orchid flora of the region but also emphasizes the urgent need for conservation efforts in light of threats such as deforestation and land development. These findings reinforce the importance of safeguarding vulnerable habitats to ensure the preservation of unique orchid species. *P. exul* is a rare and endangered orchid species that requires targeted conservation efforts due to habitat loss and overcollection. Research by Imsomboon and Thammasiri (2017) examined the effects of pH and sucrose on the seed germination of *P. exul*, identifying optimal conditions that could enhance propagation efforts. Their findings are crucial for ex-situ conservation, particularly for seedling production in controlled environments. Furthering these efforts, Imsomboon and Thammasiri (2020) investigated cryopreservation techniques for *P. exul* seeds, providing strategies for long-term preservation. This method ensures genetic material is retained for future restoration initiatives, making cryopreservation a vital tool in safeguarding the species from extinction.

Corybas geminigibbus and *Corybas calopeplos*, two rare orchids of mossy montane forests, play significant ecological roles and require targeted conservation measures. These species are highly specialized, thriving in thick humus layers within montane ecosystems, which are characterized by cool temperatures, high humidity, and limited soil disturbance (Go et al., 2015). Their restricted distribution *C. geminigibbus* being confined to a single locality in Kedah and *C. calopeplos* found only in two locations in Kedah and Pahang highlights their vulnerability to environmental changes and habitat degradation. As part of the montane orchid flora, these species contribute to the stability of their ecosystems by forming intricate relationships with fungal symbionts necessary for seed germination and nutrient uptake (Swarts & Dixon, 2009). Additionally, their presence serves as an indicator of ecosystem health, as montane orchids are highly sensitive to climate fluctuations and habitat disturbances (Dixon et al., 2003). Given their limited range and specialized habitat requirements, urgent conservation efforts are needed to prevent further population declines. Protecting montane forest habitats from deforestation, land conversion, and climate change impacts is critical. Ex-situ conservation strategies, such as in-vitro propagation and mycorrhizal symbiont research, could enhance their survival prospects and facilitate potential reintroduction efforts (Rasmussen et al., 2015). Furthermore, integrating these species into conservation policies and raising awareness about their ecological importance among local communities can contribute to long-term protection initiatives. Without immediate conservation action, the survival of *C. geminigibbus* and *C. calopeplos* remains at risk, threatening the broader biodiversity of Malaysia's montane ecosystems.

Advanced Methodologies

Yoh et al. (2022) conducted an in-depth study on *Coelogyne* species in Peninsular Malaysia, yielding significant findings that advance understanding of this genus. The study identified two primary clades based on morphological and molecular analyses: the first comprising the sections *Longifoliae*, *Speciosae*, and *Fuliginosae*, and the second encompassing *Flaccidae*, *Coelogynae*, *Tomentosae*, and *Verrucosae*. These results highlight distinct evolutionary relationships among the groups. A morphological similarity of 61.9% among the examined species underscores the complexities in species delimitation due to substantial overlap in traits. Furthermore, the findings corroborate the taxonomic classifications proposed by Seidenfaden and Wood (1992), reinforcing their validity. The study underscores the necessity for continued morphological and molecular research to address unresolved taxonomic ambiguities and improve species delimitation within the genus.

DNA barcoding has significantly improved orchid taxonomy by enabling precise species identification, particularly for morphologically similar taxa. DNA barcoding has been widely recognised as an effective tool for the accurate identification of medicinal orchids, particularly when morphological features are indistinguishable in processed plant materials. Studies have demonstrated that genetic markers such as ITS, matK, rbcL, and trnH-psbA are reliable for distinguishing closely related orchid species, aiding in conservation and trade regulation. The establishment of a barcode library containing over 7,000 sequences has significantly improved the authentication of medicinal orchids in Asia (Raskoti & Ale, 2021). This technique has been instrumental in resolving taxonomic ambiguities, such as distinguishing cryptic species within genera like *Dendrobium* and *Bulbophyllum* (Xu et al., 2015).

Molecular DNA barcoding, combined with botanical taxonomy, serves as a crucial tool for the identification and conservation of orchids. This approach is particularly valuable in distinguishing species that are morphologically similar, supporting both biodiversity assessments and conservation efforts. A modified CTAB protocol is commonly used for DNA extraction, followed by the amplification of key barcoding regions such as ITS, matK, rbcL, and trnH-psbA, which enhance species classification accuracy. DNA sequencing data are typically analysed using bioinformatics tools, such as BioEdit software for sequence assembly and the BLAST algorithm on the NCBI database for species identification. Studies have demonstrated that molecular barcoding data align closely with traditional taxonomic classifications, reinforcing its reliability as a species identification method. Additionally, research suggests that the combination of ITS and matK provides greater precision in differentiating orchid species compared to other genetic markers. Beyond identification, DNA barcoding contributes to conservation efforts by enabling the creation of species reference databases, which can be used to track genetic diversity and monitor species distribution (Tsaballa et al., 2023). As habitat loss and illegal trade continue to threaten global orchid diversity, the integration of DNA barcoding with conservation strategies is essential for long-term species protection and ecological sustainability.

According to Karbarz et al. (2024), DNA barcoding is an effective tool for determining the genetic identity of endangered *Paphiopedilum* orchids. Their study evaluated five loci (matK, rbcL, ITS2, atpF-atpH, and trnH-psbA) as potential molecular markers. Among single-locus barcodes, matK was the most effective, correctly identifying 64% of species. However, matK + ITS2, matK + rbcL, and matK + trnH-psbA were recommended as complementary tools alongside morphological data for species identification. Given the threats of overexploitation and illegal trade, precise genetic identification is essential for conservation. The findings emphasize the need for broader testing and barcode selection based on species representation within the genus. According to Lal et al. (2025), DNA barcoding is an effective technique for molecular-level identification in plants, particularly orchids, which exhibit high genetic variability despite morphological similarities. Their study assessed the effectiveness of universal chloroplast gene markers (matK and rbcL) for identifying *Aerides multiflora* and *Rhynchostylis retusa* at the species level. Phylogenetic analysis revealed 99.4% sequence alignment for matK in A. multiflora and 99.87% alignment for matK in *R. retusa*, while the rbcL region showed 100% identity with *R. retusa*, *C. peduncularis*, and *A. praemorsa*. These findings confirm the reliability of matK and rbcL as DNA barcodes for authenticating these orchid species.

DNA barcoding is a powerful tool for species identification and phylogenetic studies, particularly in plants with closely related species that exhibit high morphological similarity. While universal barcode markers such as rbcL and matK are widely used, their effectiveness in distinguishing species within the same genus can be limited. Recent research has shown that alternative genetic loci, such as nuclear ribosomal DNA (nrDNA) markers, may provide higher resolution for phylogenetic classification. By analysing multiple genetic regions, scientists can improve species identification, address phylogenetic incongruences, and enhance the accuracy of evolutionary studies in plant biology (Chattopadhyay et al., 2017). Another importance of DNA barcoding is in identifying plant species with high morphological similarity, such as *Cymbidium* orchids, which have significant ornamental and commercial value. Research comparing multiple genetic loci, including plastid (matK, rbcL, psbA-trnH, atpF-atpH) and nuclear (ITS) markers, has shown that ITS provides the highest resolution for distinguishing *Cymbidium* species. This marker exhibits greater genetic divergence, a well-defined barcoding gap, and a high success rate in species identification. Additionally, ITS-based phylogenetic analysis aligns with traditional morphological classification, making it a reliable tool for both species authentication and evolutionary studies in *Cymbidium* orchids (Chen et al., 2024).

Additionally, Rajaram et al. (2019) demonstrated the effectiveness of DNA barcoding in identifying endangered *Paphiopedilum* species from Peninsular Malaysia. Their study evaluated four DNA markers (rbcL, matK, ITS, and trnH-psbA) and found matK to be the most reliable, exhibiting 100% sequence quality, BLASTn accuracy, and species resolution in phylogenetic analysis. While ITS and trnH-psbA showed moderate effectiveness, rbcL had limited variation. The study suggests that a combination of these markers can aid in preliminary species identification, with matK offering the highest accuracy for definitive classification. This highlights the value of DNA barcoding in conservation and taxonomy of *Paphiopedilum* orchids. Ginibun et al. (2018b) explored the use of DNA barcoding for species identification in *Spathoglottis*, a terrestrial orchid with landscaping and commercial value. Due to the morphological diversity of orchids, traditional identification methods are often insufficient. The study examined four chloroplast coding regions (matK, rbcL-a, rpoB, and rpoC1) to assess genetic variation and identified eight haplotype groups for DNA barcoding. A combination of rbcL-a, rpoB, and rpoC1 provided the highest resolution for distinguishing species. Phylogenetic analysis revealed that five Malaysian native species formed a similar group, with *S. plicata* being distinct from *S. microchilina*, *S. affinis*, *S. aurea*, and *S. gracilis*. These findings highlight the usefulness of chloroplast DNA markers in the phylogenetic classification of *Spathoglottis*.

In different research, detailed analyses of floral structures, such as those in *Paphiopedilum barbatum* and *P. callosum* var. *sublaeve*, play a crucial role in distinguishing closely related orchid species, particularly in regions like Kedah. The integration of DNA barcoding with morphological studies has proven effective in improving taxonomic clarity and addressing conservation challenges for endemic or endangered orchids. Employing advanced methodologies, including scanning electron microscopy, not only facilitates micromorphological examination but also aids in understanding ecological distributions. These insights are essential for developing targeted conservation strategies to combat the significant threats posed by habitat loss to orchid diversity in Kedah (Besi et al., 2021). Meanwhile research by Ginibun et al. (2018a) reveals that 78.5% of genetic variation exists within populations, highlighting the critical need to preserve genetic diversity for the survival of orchid species, particularly in Kedah, where similar environmental threats may endanger local populations. The study also underscores the detrimental effects of habitat loss driven by industrialization, a pressing issue faced by native orchids in the region. Findings on the distinct genetic structures among *Spathoglottis plicata* populations suggest that geographical factors play a significant role in genetic differentiation, a principle applicable to other orchid species in Kedah. Moreover, the application of Amplified Fragment Length

Polymorphism (AFLP) markers in this research offers a robust methodological framework for evaluating orchid diversity and conservation status.

Gostel and Kress (2022) highlight the pivotal role of DNA barcoding in species identification, ecological research, evolutionary studies, and conservation. By providing a rapid and accurate method for distinguishing species, especially those with high morphological similarity, DNA barcoding has revolutionized taxonomic classification. Its application extends to understanding species interactions, phylogenetic relationships, and biodiversity patterns, thereby contributing to ecological and evolutionary research. Furthermore, DNA barcoding aids in conservation efforts by facilitating the monitoring of endangered species, preventing illegal wildlife trade, and informing targeted conservation strategies. Advances in sequencing technology and computational tools have enabled large-scale, high-throughput barcoding applications, enhancing species classification and genetic data analysis. The continuous expansion of global DNA barcode databases further strengthens taxonomic frameworks, supports the discovery of new species, and refines existing classifications. As biodiversity faces increasing threats from habitat loss and environmental changes, DNA barcoding remains an indispensable tool for mitigating species extinction and preserving genetic diversity. While Mahadani et al. (2022) mentioned that traditional methods of species identification can be challenging due to morphological similarities, making molecular approaches such as DNA barcoding a reliable alternative. By utilizing genetic markers like ITS, matK, rbcL, and trnH-psbA, researchers can accurately distinguish between closely related species. Among these loci, ITS has been found to be the most efficient for species identification, although some species may require additional methods for precise differentiation. The integration of DNA barcoding with similarity-based and character-based approaches enhances species authentication, contributing to biodiversity conservation, sustainable resource management, and the protection of medicinal plant integrity. As more sequences are added to global databases, DNA barcoding continues to strengthen its role in botanical research, facilitating accurate species classification and supporting efforts in ecological and pharmaceutical studies.

Similarly, micromorphological analysis, particularly through scanning electron microscopy (SEM), has also provided deeper insights into orchid taxonomy. A study examining the labellum surfaces of 21 *Dendrobium* species identified distinct structural features that aid in species differentiation, refining classifications that were once solely based on floral morphology (Burzacka-Hinz et al., 2022). Additionally, seed micromorphology studies have clarified evolutionary relationships within the Orchidaceae family. For example, analysis of seed coat structures in Habenaria and related taxa has offered valuable data for delimiting species boundaries, supporting DNA-based phylogenies (Rewicz et al., 2022). By integrating DNA barcoding and micromorphological analyses, researchers have corrected historical taxonomic errors and uncovered new species, reinforcing the importance of combining molecular and morphological approaches for comprehensive orchid systematics.

Micromorphological analysis using light and SEM has revealed key epidermal structures that aid in orchid species identification and phylogenetic classification. Variations in labellum surface striations, secretory trichomes, and papillae contribute to distinguishing taxa. The presence of secretory cells and calcium oxalate crystals within the labellum suggests adaptations related to pollination strategies. For instance, in *Ophrys*, dense labellum hairs mimic insect morphology, potentially enhancing pollinator attraction. The invaginations of the labellum forming the spur, along with specific epidermal features, highlight morphological diversity across genera. Cluster analysis (UPGMA) has further refined species classification by evaluating micromorphological traits, reinforcing their significance in resolving taxonomic ambiguities and understanding evolutionary relationships (Şeker et al., 2016). While study by Aytar et al. (2024) highlights the significance of morphometric and FTIR chemical analyses in distinguishing orchid species and understanding their seed characteristics. Variations in seed size, embryo size, and cavity percentage contribute to taxonomic differentiation, with species of the same genus clustering together. FTIR spectral analysis confirms the familial classification of the examined species while revealing interspecific variations in absorbance values, particularly between Neotinea tridentata and other orchids. Principal Component Analysis (PCA) based on FTIR data further supports these findings, demonstrating its potential in refining taxonomic classification and enhancing conservation strategies through improved seed propagation techniques.

Threats to Orchid Species

Orchid populations are declining worldwide due to habitat loss and climate change, with conservation efforts hindered by limited knowledge of their ecological requirements and unresolved taxonomic issues (Kindlmann et al., 2023). Beyond their taxonomic significance, orchids are particularly vulnerable to habitat destruction, climate change, and unsustainable harvesting, which is often illegal and undocumented (Fay, 2018; Gale et al., 2018). Their intricate biological relationships with pollinators, mycorrhizal fungi, and specific habitat conditions make them highly sensitive to environmental disturbances. Conservation efforts are therefore critical not only for preserving orchid diversity but also for maintaining their ecological functions within natural ecosystems. Initiatives aimed at protecting orchids can help mitigate the impacts of habitat loss, safeguard rare species, and promote sustainable management practices to ensure their survival for future generations. While Bakar et al. (2023) stated that Kedah's limestone hills, which harbour rare and endemic orchid species, face significant threats from anthropogenic activities. Habitat destruction due to quarrying, deforestation, and land-use changes poses a severe risk to orchid populations, potentially leading to species extinction. Quarrying operations, in particular, result in irreversible damage by altering microhabitats, reducing suitable growing conditions, and disrupting ecological interactions essential for orchid survival. Additionally, deforestation driven by agricultural expansion and infrastructure development further fragments orchid habitats, making species more vulnerable to environmental stressors. The lack of comprehensive documentation on orchid diversity in these areas exacerbates the conservation challenge, as unrecorded species may be lost before their ecological significance is fully understood. Urgent conservation measures are needed to mitigate these threats and protect the fragile orchid ecosystems of Kedah's limestone hills.

The survival of wild orchids in Malaysia is increasingly threatened by habitat destruction, illegal poaching, and climate change. Rapid deforestation and land development, particularly through logging and construction, have led to significant habitat loss. Terrestrial orchids are especially vulnerable, as they are often uprooted or buried during land conversion. A striking example is *Gastrodia tembatensis*, which lost its original habitat in Terengganu due to dam construction, emphasizing how large-scale infrastructure projects can endanger rare species. This condition could also happen to orchids in Kedah. Illegal collection of orchids also poses a severe threat, with rare and visually striking species such as Slipper Orchids being heavily targeted for private collections and commercial trade. The rise of social media has worsened this issue, providing an unregulated marketplace where poachers can easily sell wild orchids, making enforcement efforts difficult. Additionally, climate change further threatens orchid populations by disrupting ecological conditions necessary for their survival. Rising temperatures, decreasing humidity, and prolonged dry spells have negatively impacted moss-rich montane environments, which serve as critical habitats for many orchid species. Without urgent conservation measures, the continued loss of these delicate ecosystems may push several wild orchids toward extinction before they can be adequately studied or preserved (Chacko, 2025).

However, non-native orchid species, such as *Dendrobium antennatum*, while not native to Malaysia, have also been observed in certain regions, such as Kedah. This species, native to Australia and the Pacific Islands, has occasionally been introduced to Malaysia, often through horticultural activities. Although *D. antennatum* does not naturally occur in Malaysian ecosystems, its presence offers valuable insight into the broader landscape of orchid distribution, particularly in the context of species introduction, hybridization, and conservation. Understanding the distribution of both native and non-native species can shed light on potential conservation challenges, such as the competition with native species and disruption of local habitats. Rahim and Mohd (2021) offer valuable insights into *D. antennatum* does, a notable species within the Orchidaceae family, underscoring its ecological and economic significance in Malaysia. Their study highlights the ornamental value of *D. antennatum*, which is widely cultivated for its aesthetic appeal, thereby contributing to the region's horticultural economy.

However, the identification of *Fusarium sacchari* as a pathogenic threat highlights the challenges faced by cultivators in managing fungal infections, which can significantly impact local growers. Conducted in Sungai Petani and Penang, the study's geographical context underscores the broader implications of disease transmission within adjacent regions, including Kedah. As a foundational investigation into orchid diseases, it highlights the critical need for continued research to monitor and mitigate emerging threats, ensuring the sustainable cultivation and conservation of this valuable species (Rahim & Mohd, 2021). Wild orchids face significant threats due to habitat destruction, environmental changes, and human activities (Bakar et al., 2023). One of the primary concerns is deforestation, which leads to the permanent loss or degradation of habitats where orchids thrive. Logging, quarrying, and land clearing disrupt the delicate ecological interactions that orchids rely on, such as their symbiotic relationships with mycorrhizal fungi, host trees, and pollinators. These disturbances alter climatic conditions, affecting factors like light availability, humidity, and wind patterns, all of which are crucial for orchid survival. Quarrying activities further exacerbate habitat loss by removing vegetation and modifying the landscape, making it difficult for orchid populations to recover. Given the increasing threats to wild orchids, urgent conservation measures are necessary to protect these species. Strict regulations should be implemented to prevent further habitat destruction, while conservation programs must focus on habitat restoration and sustainable land management. Preserving wild orchids is not only essential for maintaining biodiversity but also for safeguarding their ecological and cultural significance for future generations.

In Peninsular Malaysia, undisturbed forests had a significantly higher orchid density (2.433 plants/km^2) than disturbed forests (0.228 plants/km^2) and disturbed forests had a higher diversity (H = 4.934), which was explained by the abundance of epiphytic orchids that colonised fallen trees. Key elements favouring orchid growth and high density were found to be the microclimatic conditions of undisturbed forests, which included temperatures between 27.8 and 31.2°C, humidity levels between 77.1% and 89.6%, and light intensities between 23.8 and 171.7 μmol m−2s−1. However, habitat deterioration resulted from disturbances like logging, with canopy openings causing drastic variations in temperature, humidity, and light intensity (Besi et al., 2023b). While the primary threats to orchid species in Malaysia encompass habitat destruction caused by logging, agricultural land clearance, and infrastructure development, all of which profoundly disrupt their natural environments. Illegal collection and poaching of high-value species such as *Paphiopedilum* and *Phalaenopsis* further intensify their decline, driven by a lucrative market often facilitated through e-commerce platforms. Moreover, climate change poses additional risks to the fragile ecosystems that sustain orchids, while insufficient awareness among local communities about sustainable practices hampers conservation efforts. These combined factors have resulted in the classification of numerous orchid species as threatened or endangered, underscoring the pressing need for effective conservation strategies (Go et al., 2020).

The survival of *Corybas* species in Peninsular Malaysia is increasingly threatened by environmental changes, particularly climate-related factors. The decline of montane moss carpets, which serve as critical microhabitats for these orchids, poses a significant risk to their persistence. Observations indicate that mosses in montane forests are becoming thinner and more fragmented due to rising temperatures, decreasing relative humidity, and prolonged dry spells. Such climatic shifts create unfavourable conditions for *Corybas* species, many of which are narrow endemics with extremely limited distributions. The reduction in suitable habitat not only decreases population sizes but also heightens the vulnerability of these orchids to extinction, as they are unable to adapt quickly to rapidly changing environmental conditions (Go et al., 2015).

Invasive plant species can significantly impact native orchids by competing for essential resources and disrupting critical symbiotic relationships. For instance, invasive plants often release allelopathic compounds that can inhibit the growth of arbuscular mycorrhizal fungi (AMF), which are vital for orchid seed germination and nutrient uptake. Research indicates that allelopathic substances from invasive species can decrease AMF infection rates in native plants, thereby hindering orchid establishment and survival (Guo et al., 2023). Additionally, invasive plants like *Alliaria petiolata* (garlic mustard) produce secondary chemicals toxic to soil microorganisms, including mycorrhizal fungi. This toxicity can lead to physiological stress in native forest understory plants, such as orchids, reducing their population growth rates (Roche et al., 2021). Moreover, the presence of invasive orchids, such as Spathoglottis plicata, has been shown to negatively affect native orchid species through mechanisms like apparent competition. The invasive orchid attracts shared herbivores, which can increase damage to native orchids and contribute to their decline (Recart et al., 2013). These findings underscore the importance of managing invasive species to protect native orchid populations and maintain ecosystem health.

Recommendations for Policy and Conservation Actions

Deforestation in Kedah, driven by logging, agricultural expansion, and urban development, has led to significant habitat loss, particularly in ecologically sensitive areas. Over the past two decades, approximately 9% of forest cover has been lost, equating to more than 33,000 hectares (Jaafar et al., 2020). This loss is especially concerning in critical habitats such as limestone hills and montane forests, which are home to rare and endemic orchids like *Corybas geminigibbus* and *Corybas calopeplos*. The removal of trees not only directly eliminates orchid habitats but also disrupts essential ecological interactions, such as mycorrhizal associations crucial for seed germination and growth (Go et al., 2015).

Furthermore, deforestation alters microclimatic conditions, including humidity, temperature, and soil composition, which are vital for orchid survival. The loss of canopy cover can lead to increased exposure to sunlight and reduced moisture retention, negatively affecting orchids that thrive in shaded, humid environments (Li et al., 2022). Additionally, habitat fragmentation may limit pollinator availability, reducing reproductive success and genetic diversity among orchid populations (Sáyago et al., 2018). Given these threats, urgent conservation measures, such as habitat restoration and the establishment of protected areas, are necessary to safeguard Kedah's orchid diversity.

Climate change poses a significant threat to the orchids of Kedah. Over the past five decades, Malaysia has experienced surface temperature increases ranging from 0.32°C to 1.5°C (Hassan et al., 2023). Additionally, annual rainfall depth in the region is projected to rise by approximately 0.9% per year (Tukimat & Harun, 2015). These climatic shifts can alter microhabitats essential for orchid development. For instance, prolonged dry spells and reduced humidity have been observed to negatively impact moss-rich montane environments, which are crucial for many orchid species (Go, 2015). If current climate trends persist, areas that presently support high orchid diversity may become less suitable, potentially leading to the loss of rare species. The illegal collection of orchids, particularly rare and visually striking species such as *Spathoglottis hardingiana*, poses a significant threat to their populations. Studies have documented the rise of unregulated markets for wild orchids facilitated by social media platforms, where collectors and suppliers engage in the trade of these species (Hinsley et al., 2016). This trend not only threatens species survival but also undermines conservation efforts due to a lack of accountability and enforcement.

Besi et al. (2023a) provided an overview of the key legislations that regulate plant diversity conservation in Malaysia, highlighting the role of various forestry policies and legal frameworks in ensuring sustainable forest management and species protection. The National Forestry Act 1984 (amended 1993) and the National Forestry Policy 1978 serve as the foundation for regulating forest resources, with the primary objective of balancing conservation efforts with timber production. These legislations are reinforced by the Wood-Based Industries Act 1984, which ensures the sustainable development of industries reliant on forest resources. To safeguard biodiversity, the Permanent Reserved Forests (PRF) were established under the National Forestry Act 1984, categorized into 12 functional classes such as Timber Production Forest, Wildlife Sanctuary, and Water Catchment Forest. The management of these areas is under the jurisdiction of the Forest Departments of Peninsular Malaysia (FDPM), whereas national parks and wildlife sanctuaries fall under the authority of the Department of Wildlife and National Parks Peninsular Malaysia (PERHILITAN). In Sabah and Sarawak, conservation laws are dictated by state-specific policies. Sabah enforces the State Forest Policy of 1954 and the Forest Enactment Policy of 1968, while Sarawak adheres to the Statement of Forest Policy of 1954 and the Forests Ordinance of 1954. Additionally, Sarawak's Wildlife Protection Ordinance 1998 plays a crucial role in safeguarding all orchid species, emphasizing their ecological and conservation significance. These legal frameworks collectively demonstrate Malaysia's commitment to protecting its diverse plant species while addressing the challenges posed by habitat loss and industrial expansion.

Strengthening legal frameworks is crucial for safeguarding orchid species and their habitats. Enforcing stricter penalties for illegal collection and designating protected areas for critical habitats can significantly enhance conservation outcomes. Research indicates that while environmental protections exist, they may be ineffective without targeted actions against specific threats to orchids (Scramoncin et al., 2024). Additionally, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) serves as a primary legislative body for orchid conservation worldwide, encompassing all orchid species and representing more than 90% of the plant species protected by the Convention (Li et al., 2024). By implementing and enforcing such legal protections are vital steps in preserving orchid populations and their ecosystems.

Integrating Environmental Impact Assessments (EIAs) into developmental projects within sensitive areas is crucial for the conservation of orchid habitats. EIAs serve as a preventive measure, identifying potential threats to these ecosystems before project initiation, thereby facilitating a balance between development and environmental preservation. Research has demonstrated that habitat fragmentation and anthropogenic disturbances significantly impact orchid diversity and distribution. For instance, a study analysing orchid communities in Australia's Mount Lofty Ranges found that habitat configuration and the presence of exotic species explained a substantial variance in orchid richness and diversity (Martín-Forés et al., 2022). By requiring EIAs, such potential threats can be identified and mitigated proactively, ensuring that development projects do not compromise the integrity of orchid ecosystems.

Implementing incentive programs that reward landowners and local communities for conserving natural habitats can effectively promote sustainable practices. Financial mechanisms, such as Payments for Ecosystem Services (PES), provide compensation to those who manage and protect ecosystems, ensuring the continued provision of vital services. PES schemes have been successfully applied in various contexts, offering economic incentives to landowners for maintaining biodiversity and ecosystem health. For instance, a study highlighted the role of PES in promoting conservation by compensating land users for preserving natural environments, thereby ensuring the flow of ecosystem services (Herbert et al., 2010). In the context of orchid conservation, PES can motivate stakeholders to protect orchid-rich ecosystems. Orchids provide a range of ecosystem services, including cultural, provisioning, supporting, and regulating services. A global analysis of orchid-related ecosystem services found that cultural services were the most documented, followed by provisioning, supporting, and regulating services (Hernández-Mejía, Rosa-Manzano et al., 2024). By recognizing and financially valuing these services, PES programs can encourage the preservation of habitats critical to orchid survival. Additionally, understanding local perceptions and drivers of engagement in PES programs is essential for their success. Research indicates that aligning PES initiatives with community values and providing clear economic benefits can enhance participation and effectiveness (Izquierdo-Tort et al., 2024). Therefore, designing PES schemes that are context-specific and collaboratively developed with local stakeholders can lead to more sustainable conservation outcomes.

In addition, promoting ecotourism that focuses on orchid diversity can generate economic benefits while fostering an appreciation for local biodiversity. Examples include guided tours through orchid habitats, educational sessions on the role of orchids in ecosystems, and participatory citizen science projects. A study in Central Veracruz, Mexico, highlighted that native orchid tourism serves as a tool for conservation, as tourists show interest in learning about orchids and their natural environments, thereby supporting local economies and conservation efforts (Hernández-Mejía, Baltazar-Bernal et al., 2024). Establishing a centralized database is crucial for tracking the distribution, population health, and habitat conditions of orchid species, thereby facilitating effective conservation planning. Such databases provide a foundation for data-driven decision-making, enabling stakeholders to identify population trends and habitat changes over time. For instance, OrchidBase 4.0 compiles whole-genome sequences and annotations of multiple orchid species, serving as a valuable resource for researchers and conservationists (Hsiao et al., 2021). Furthermore, integrating geospatial technologies, such as remote sensing and GIS mapping, can further enhance real-time monitoring and improve conservation strategies. A study demonstrated the use of remote sensing and image processing techniques for identifying and mapping wild orchids, highlighting the potential of these technologies in conservation efforts (Ahmed et al., 2024).

CONCLUSION

The comprehensive documentation of orchid species in Kedah underscores the region's ecological significance as a vital centre of orchid diversity. The identification of unique habitats and the discovery of rare and endemic species highlight Kedah's critical role within Malaysia's broader biodiversity landscape. While advancements in research methodologies have improved species classification and distribution insights, they also reveal pressing threats such as habitat destruction and climate change. Effective conservation measures such as establishing protected areas, engaging local communities in habitat restoration, and implementing targeted policies are crucial to address these challenges. Future research should focus on understudied habitats, the effects of climate change on orchid populations, and the role of community engagement in conservation efforts. By fostering sustainable practices and promoting awareness about the importance of orchid biodiversity, we can ensure the protection and survival of Kedah's unique orchid populations. Ultimately, safeguarding this botanical legacy is essential for maintaining ecological balance and contributing to global biodiversity, serving as a testament to Kedah's rich natural heritage.

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REFERENCES

Ahmed, S., Lightbown, J., Rutter, S. R., Basu, N., Nicholson, C. E., Perry, J. J., & Dean, J. R. (2024). Use of remote sensing and image processing for identification of wild orchids. *Frontiers in Environmental Science*, *12*, Article 1371445. https://doi.org/10.3389/fenvs.2024.1371445

Auyob, N. A., Zulkifli, S. Z., Nordin, F. A., Annathura, Abdullah, J. A., Yong, C. S. Y., & Go, R. (2016). Notes on new record of orchids on the summit of Gunung Jerai, Kedah, Peninsular Malaysia. *Malayan Nature Journal*, *68*(1&2), 49-55

Aytar, E. C., Durmaz, A., Basılı, T., Sentürk, B., Harzli, İ., Cökmez, B., & Kömpe, Y. Ö. (2024). Chemical characterization of the seed coats of orchids from the subfamily orchidaceae: A micromorphological approach using FT-IR spectroscopy. *Biology Bulletin*, *51*, 1556–1567. https://doi.org/10.1134/S1062359024608498

Bakar, S. N. A., Rashid, F., Jamaluddin, M. H., Md Azmi, M. F., Othman, A. S., Zakaria, R., Abd Rahman, A., Raffi, A., & Nordin, F. A. (2023). Unveiling Limestone Orchid Hotspots in the Karst Hills of Northern Peninsular Malaysia. *Diversity*, *15*(7), Article 819. https://doi.org/10.3390/d15070819

Besi, E. E., Hooi, W. K., Pungga, R. S., Yong, C. S. Y., Mustafa, M., & Go, R. (2022). Rare orchid species in Malaysia: New records, recollections and amended descriptions. *Plos One*, *17*(4), Article e0267485. https://doi.org/10.1371/journal.pone.0267485

Besi, E. E., Jia, L. S., Mustafa, M., Yong, C. S. Y., & Go, R. (2021). Comparative floral surface micromorphology helps to discriminate between species of *Paphiopedilum* (Orchidaceae: Cypripedioideae) from Peninsular Malaysia. *Lankesteriana*, *21*(1), 17-31. http://dx.doi.org/10.15517/lank.v21i1.46714

Besi, E. E., Mustafa, M., Yong, C. S. Y., & Go, R. (2023a). Deforestation impacts on diversity of orchids with inference on the conservation initiatives: Malaysia case study. *The Botanical Review*, *89*(4), 386-420. https://doi.org/10.1007/s12229-023-09292-y

Besi, E. E., Mustafa, M., Yong, C. S. Y., & Go, R. (2023b). Habitat ecology, structure influence diversity, and host-species associations of wild orchids in undisturbed and disturbed forests in peninsular Malaysia. *Forests*, *14*(3), Article 544. https://doi.org/10.3390/f14030544

Besi, E. E., Nikong, D., Mustafa, M., & Go, R. (2019). New records for orchids in Terengganu and Kelantan, Malaysia. *Journal of Sustainability Science and Management*, *2*, 1-25.

Burzacka-Hinz, A., Narajczyk, M., Dudek, M., & Szlachetko, D. L. (2022). Micromorphology of labellum in selected *Dendrobium Sw.* (Orchidaceae, Dendrobieae). *International journal of molecular sciences, 23*(17), Article 9578. https://doi.org/10.3390/ijms23179578

Chacko, R. P. (2025, Januari 22). Endangered beauties: Challenges in conserving Malaysia's wild orchids. *Heinrich Böll Foundation.* https://th.boell.org/en/2025/01/22/conserving-malaysias-wild-orchids.

Chattopadhyay, P., Banerjee, G., & Banerjee, N. (2017). Distinguishing orchid species by DNA barcoding: Increasing the resolution of population studies in plant biology. *OMICS: A Journal of Integrative Biology, 21*(12), 711-720. https://doi.org/10.1089/omi.2017.0131

Chen, Z., Gao, L., Wang, H., & Feng, S. (2024). Molecular identification and phylogenetic analysis of cymbidium species (Orchidaceae) based on the potential DNA barcodes matK, rbcL, psbA-trnH, and internal transcribed spacer. *Agronomy, 14*(5), Article 933. https://doi.org/10.3390/agronomy14050933

Choudhary, D., Mashkey, V. K., Goutam, E., Shrivastava, M., Rawat, M., Kumari, A., & Tripathi, V. (2023). Medicinal orchids: Traditional uses and recent advances. *Annals of Phytomedicine*, *12*(1), 1-9. http://dx.doi.org/10.54085/ap.2023.12.1.3

Dixon, K. W., Kell, S. P., Barrett, R. L., & Cribb, P. J. (2003). *Orchid conservation*. Natural History Publications.

Fay, M. F. (2018). Orchid conservation: How can we meet the challenges in the twenty-first century?. *Botanical studies*, *59*, Article 16. https://doi.org/10.1186/s40529-018-0232-z.

Gale, S. W., Fischer, G. A., Cribb, P. J., & Fay, M. F. (2018). Orchid conservation: Bridging the gap between science and practice. *Botanical Journal of the Linnean Society*, *186*(4), 425-434. https://doi.org/10.1093/botlinnean/boy003

Ginibun, F. C., Arens, P., Vosman, B., Bhassu, S., Khalid, N., & Othman, R. Y. (2018a). Genetic diversity of endangered terrestrial orchids' *Spathoglottis plicata*'in Peninsular Malaysia based on AFLP markers. *Plant Omics*, *11*(3), 135-144. http://dx.doi.org/10.21475/poj.11.03.18.p1227

Ginibun, F. C., Jaafar, M. A., Khalid, N., Bhassu, S., & Othman, R. Y. (2018b). Intra-and interspecies variation of terrestrial orchid *Spathoglottis* species in Peninsular Malaysia using chloroplast DNA. *Proceedings of the International Orchid Symposium, 1262*, 195-204. https://doi.org/10.17660/ActaHortic.2019.1262.26

Go, R. (2015). *Orchids in the montane forests of Peninsular Malaysia*. Universiti Putra Malaysia Press.

Go, R., Besi, E. E., Dahalan, M. P., Ahmad, R., Ahmadni, A. S. A., & Pungga, R. S. (2020). Orchid conservation initiatives in Malaysia. *Preprints*. https://doi.org/10.20944/preprints202011.0656.v1

Go, R., Ching, T. M., Nuruddin, A. A., Abdullah, J. O., Jin, N. Y., Nordin, F. A., Eng, K. H., & Nulit, R. (2015). Extinction risks and conservation status of *Corybas* (Orchidaceae; Orchidoideae; Diurideae) in Peninsular Malaysia. *Phytotaxa*, *233*(3), 273-280. http://dx.doi.org/10.11646/phytotaxa.233.3.4

Gostel, M. R., & Kress, W. J. (2022). The expanding role of DNA barcodes: Indispensable tools for ecology, evolution, and conservation. *Diversity, 14*(3), Article 213. https://doi.org/10.3390/d14030213

Guo, X., Liu, X. Y., Jiang, S. Y., Guo, S. X., Wang, J. F., Hu, Y., Li, S. M., Wang, T., Sun, Y. K., & Li, M. Y. (2023). Allelopathy and arbuscular mycorrhizal fungi interactions shape plant invasion outcomes. *NeoBiota, 89*, 187-207. https://doi.org/10.3897/neobiota.89.110737

Hassan, N. A., Hashim, J. H., Wan Puteh, S. E., Wan Mahiyuddin, W. R., Mohd, M. S. F., Shaharudin, S. M., Aidid, E. M., & Sapuan, I. (2023). Investigation of the impacts of climate change and rising temperature on food poisoning cases in Malaysia. *PloS one, 18*(10), Article e0283133. https://doi.org/10.1371/journal.pone.0283133

Herbert, T., Vonada, R., Jenkins, M., & Bayon, R. (2010). *Environmental funds and payments for ecosystem services: RedLAC capacity building project for environmental funds (Report).* RedLAC. https://www.forest-trends.org/wp-content/uploads/imported/redlac_pes-workshop_english-pdf.pdf.

Hernández-García, A., Baltazar-Bernal, O., & Ramírez-Valverde, B. (2024). Sustainable native orchid tourism demand in Central Veracruz, Mexico. *Sustainability, 16*(23), Article 10695. https://doi.org/10.3390/su162310695

Hernández-Mejía, J. A., Rosa-Manzano, E. D. L., & Delgado-Sánchez, P. (2024). Ecosystem services provided by orchids: A global analysis. *Botanical Sciences, 102*(3), 671-685. https://doi.org/10.17129/botsci.3478

Hinsley, A., Lee, T. E., Harrison, J. R., & Roberts, D. L. (2016). Estimating the extent and structure of trade in horticultural orchids via social media. *Conservation Biology, 30*(5), 1038-1047. https://doi.org/10.1111/cobi.12721

Hsiao, Y. Y., Fu, C. H., Ho, S. Y., Li, C. I., Chen, Y. Y., Wu, W. L., Wang, J. S., Zhang, D. Y., Hu, W. Q., Yu, X., Sun, W. H., Zhou, Z., Liu, K. W., Huang, L., Lan, S. R., Chen, H. W., Wu, W. S., Jian-Liu, Z., & Tsai, W. C. (2021). OrchidBase 4.0: A database for orchid genomics and molecular biology. *BMC Plant Biology, 21*(1), Article 371. https://doi.org/10.1186/s12870-021-03140-0

Imsomboon, T., & Thammasiri, K. (2020). Cryopreservation of *Paphiopedilum exul* (Ridl.) Rolfe seeds using encapsulation-vitrification and encapsulation-dehydration methods. *I International Symposium on Botanical Gardens and Landscapes, 1298*, 195-204. https://doi.org/10.17660/ActaHortic.2020.1298.28

Imsomboon, T., Thammasiri, K., & Kosiyachinda, P. (2017). Effects of pH and sucrose on seed germination of *Paphiopedilum exul* (Ridl.) Rolfe. *International Symposium on Tropical and Subtropical Ornamentals, 1167,* 95-100. https://doi.org/10.17660/actahortic.2017.1167.14

Izquierdo-Tort, S., Alatorre, A., Arroyo-Gerala, P., Shapiro-Garza, E., Naime, J., & Dupras, J. (2024). Exploring local perceptions and drivers of engagement in biodiversity monitoring among participants in payments for ecosystem services schemes in southeastern Mexico. *Conservation Biology, 38*, Article e14282. https://doi.org/10.1111/cobi.14282

Jaafar, W. S. W. M., Maulud, K. N. A., Kamarulzaman, A. M. M., Raihan, A., Sah, S. M., Ahmad, A., Saad, S. N. M., Azmi, A. T. M., Syukri, N. K. A. J., & Khan, R. W. (2020). The influence of deforestation on land surface temperature—A case study of Perak and Kedah, Malaysia. *Forests*, *11*(6), Article 670. https://doi.org/10.3390/f11060670

Karbarz, M., Szlachcikowska, D., Zapał, A., & Leśko, A. (2024). Unlocking the genetic identity of endangered *Paphiopedilum* orchids: A DNA barcoding approach. *Genes, 15*(6), Article 689. https://doi.org/10.3390/genes15060689

Kindlmann, P., Kull, T., & McCormick, M. (2023). The distribution and diversity of orchids. *Diversity, 15*(7), Article 810. https://doi.org/10.3390/d15070810

Lal, A., Pant, M., Kumar, A., Palni, L., Singh, A., Siddiqui, M. R., & Husen, A. (2025). DNA barcoding of epiphytic orchids for species level identification. *The Journal of Horticultural Science and Biotechnology, 100*(1), 127-137. https://doi.org/10.1080/14620316.2024.2371591

Li, S., Liang, C., Deng, S., Chen, C., Yuan, L., Liu, Z., Wu, S., Lan, S., Tang, Z., Liu, Z., & Zhai, J. (2024). Comparison of orchid conservation between China and other countries. *Diversity, 16*(11), Article 692. https://doi.org/10.3390/d16110692

Li, Z., Wang, Y., & Mu, L. (2022). How does deforestation affect the growth of *Cypripedium* (Orchidaceae) species? A simulation experiment in Northeast China. *Forests, 13*(2), Article 166. https://doi.org/10.3390/f13020166

Mahadani, P., Chakrabarti, S., Pal, R., Jain, S. K., & Sevanthi, A. M. (2022). Application of DNA barcoding tool for authentication of traditionally important medicinal Dendrobium (Orchidaceae) species from Sikkim Himalaya. *South African Journal of Botany*, *146*, 905-911. https://doi.org/10.1016/j.sajb.2022.04.013

Martín-Forés, I., Bywaters, S. L., Sparrow, B., & Guerin, G. R. (2022). Simultaneous effect of habitat remnancy, exotic species, and anthropogenic disturbance on orchid diversity in South Australia. *Conservation Science and Practice, 4*(4), Article e12652. https://doi.org/10.1111/csp2.12652

McCormack, C. K. (2018). *Collection and discovery: botanical collection in south and southeast asia, 1754-1885* [Doctoral Dissertation, Washington State University]. ProQuest LLC. https://www.proquest.com/openview/5b01a3d5c499550d8a9197621c55f9c7/1?cbl=18750&pq-origsite=gscholar

Mirioba, J. N., Emitaro, W., Obwanga, B., Gaya, H., Leley, N., Otuoma, J., Maina, J. M., & Kawaka, F. (2024). Orchid species diversity across a forest disturbance gradient in west Mau forest, Kenya. *Plos One*, *19*(8), Article e0307887. https://doi.org/10.1371/journal.pone.0307887

Nordin, F. A., Othman, A. S., Zainudin, N. A., Khalil, N. A., Asi, N., Azmi, A., Mangsor, K. N. A., Harun, M. S., & Zin, K. F. M. (2021). The orchid flora of Gunung Ledang (Mount Ophir), Malaysia-120 years after ridley. *Pertanika Journal of Tropical Agricultural Science*, *44*(2), 369-387. https://doi.org/10.47836/pjtas.44.2.07

Nordin, F. A., Saibeh, K., Go, R., Abu Mangsor, K. N., & Othman, A. S. (2022). Molecular phylogenetics of the orchid genus *Spathoglottis* (Orchidaceae: Collabieae) in Peninsular Malaysia and Borneo. *Forests*, *13*(12), Article 2079. https://doi.org/10.3390/f13122079

Ong, P. T., & Nordin, F. A. (2017). An updated description of Spathoglottis hardingiana from Peninsular Malaysia. In A. Schuiteman (Ed.) *Malesian Orchid Journal* (Vol. 20, p. 128). Natural History Publications.

Rahim, H. S. A., & Mohd, M. H. (2021). First report of *Fusarium sacchari* causing leaf blotch of orchid (*Dendrobium antennatum*) in Malaysia. *Crop Protection, 143*, Article 105559. https://doi.org/10.1016/j.cropro.2021.105559

Rajaram, M. C., Yong, C. S., Gansau, J. A., & Go, R. (2019). DNA barcoding of endangered *Paphiopedilum* species (Orchidaceae) of Peninsular Malaysia. *Phytotaxa, 387*(2), 94-104. https://doi.org/10.11646/phytotaxa.387.2.2

Raskoti, B. B., & Ale, R. (2021). DNA barcoding of medicinal orchids in Asia. *Scientific Reports, 11*(1), Article 23651. https://doi.org/10.1038/s41598-021-03025-0

Rasmussen, H. N., Dixon, K. W., Jersáková, J., & Těšitelová, T. (2015). Germination and seedling establishment in orchids: A complex of requirements. *Annals of Botany, 116*(3), 391-402. https://doi.org/10.1093/aob/mcv087

Recart, W., Ackerman, J. D., & Cuevas, A. A. (2013). There goes the neighborhood: Apparent competition between invasive and native orchids mediated by a specialist florivorous weevil. *Biological Invasions, 15,*(2), 283-293. http://dx.doi.org/10.1007/s10530-012-0283-0

Rewicz, A., Kolanowska, M., Kras, M., & Szlachetko, D. L. (2022). Preliminary studies on variation in the micromorphology of the seed coat in *Habenaria sl* (Orchidaceae) and relatives. *Botanical Journal of the Linnean Society, 200*(1), 104-115. https://doi.org/10.1093/botlinnean/boac007

Ridley, H. N. (1901). The flora of Mount Ophir. *Journal of the Straits Branch of the Royal Asiatic Society*, (35), 1-28.

Roche, M. D., Pearse, I. S., Bialic-Murphy, L., Kivlin, S. N., Sofaer, H. R., & Kalisz, S. (2021). Negative effects of an allelopathic invader on AM fungal plant species drive community-Level responses. *Ecology, 102*(1), Article e03201. https://doi.org/10.1002/ecy.3201

Sáyago, R., Quesada, M., Aguilar, R., Ashworth, L., Lopezaraiza-Mikel, M., & Martén-Rodríguez, S. (2018). Consequences of habitat fragmentation on the reproductive success of two Tillandsia species with contrasting life history strategies. *AoB PLANTS, 10*(4), Article ply038. https://doi.org/10.1093/aobpla/ply038

Scramoncin, L., Gerdol, R., & Brancaleoni, L. (2024). How effective is environmental protection for ensuring the vitality of wild orchid species? A case study of a protected area in Italy. *Plants, 13*(5), Article 610. https://doi.org/10.3390/plants13050610

Seidenfaden, G., & Wood, J. J. (1992). *The orchids of peninsular Malaysia and Singapore*. Olsen & Olsen.

Şeker, Ş. S., Akbulut, M. K., & Şenel, G. (2016). Labellum micromorphology of some orchid genera (Orchidaceae) distributed in the Black Sea region in Turkey. *Turkish Journal of Botany, 40*(6), 623-636. http://dx.doi.org/10.3906/bot-1512-7

Swarts, N. D., & Dixon, K. W. (2009). Terrestrial orchid conservation in the age of extinction. *Annals of botany, 104*(3), 543-556. https://doi.org/10.1093/aob/mcp025

Tsaballa, A., Kelesidis, G., Krigas, N., Sarropoulou, V., Bagatzounis, P., & Grigoriadou, K. (2023). Taxonomic identification and molecular DNA barcoding of collected wild-growing orchids used traditionally for Salep production. *Plants, 12*(17), Article 3038. https://doi.org/10.3390/plants12173038

Tukimat, N. N. A., & Harun, S. (2015). Climate change impact on rainfall and temperature in Muda irrigation area using multicorrelation matrix and downscaling method. *Journal of Water and Climate Change, 6*(3), 647-660. https://doi.org/10.2166/wcc.2015.015

Turner, I. M. (1995). A catalogue of the vascular plants of Malaya: Orchidaceae. *The Gardens' Bulletin Singapore*, *47*(2), 559–620.

Xu, S., Li, D., Li, J., Xiang, X., Jin, W., Huang, W., Jin, X., & Huang, L. (2015). Evaluation of the DNA barcodes in *Dendrobium* (Orchidaceae) from mainland Asia. *PloS one, 10*(1), Article e0115168. https://doi.org/10.1371/journal.pone.0115168

Yoh, K. H., Yong, C. S. Y., Abdullah, J. O., & Go, R. (2022). Phylogenetic relationships of the orchid genus *Coelogyne* in Peninsular Malaysia inferred from morphological characteristics and internal transcribed spacer (ITS) sequence data. *Sains Malaysiana*, *51*(3), 643-656. http://doi.org/10.17576/jsm-2022-5103-02

Zhang, D., Zhao, X. W., Li, Y. Y., Ke, S. J., Yin, W. L., Lan, S., & Liu, Z. J. (2022). Advances and prospects of orchid research and industrialization. *Horticulture Research*, *9*, Article uhac220. https://doi.org/10.1093/hr/uhac220