UNVEILING LIMESTONE ORCHID HOTSPOTS IN THE KARST HILLS OF NORTHERN PENINSULAR MALAYSIA

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by

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LIST OF ABBREVIATIONS

AOO	Area of Occupancy
CR	Critically Endangered
DD	Data Deficient
DNA	Deoxyribonucleic Acid
EN	Endangered
EW	Extinct in the Wild
EX	Extinct
EOO	Extent of Occurrence
EIA	Environmental Impact Assessment
IPA	Important Plant Area
ICBN	International Code of Botanical Nomenclature
IUCN	International Union for Conservation of Nature
LC	Least Concern
NL	Not Listed
NT	Near Threaten
NPBD	National Policy on Biological Diversity
UMFR	Ulu Muda Forest Reserve
VU	Vulnerable
1 - D	Simpson's index
µm	Micrometer
$\mu mol\ m^{-2}\ s^{-1}$	Per second and square meter
asl	Above sea level
cm	Centimeter
E_H	Shannon Equitability Index
H'	Shannon-Wiener Index
K_D	Kernel Density
km	Kilometer
m	Meter
mm	Milimeter
p	Significant value
pH	Power of Hydrogen
c.	Approximately
e.g.	Example
et al.	And others (*et alia*)
sp.	Species (singular)
ssp.	Subspecies

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MERUNGKAI KAWASAN TUMPUAN HANGAT ANGGERIK BATU KAPUR DI BUKIT KARS DI UTARA SEMENANJUNG MALAYSIA

ABSTRAK

Masih terdapat jurang pengetahuan terhadap kepelbagaian anggerik yang di hutan batu kapur di bahagian utara Semenanjung Malaysia, terutama sekali di negeri Kedah dan Perak. Untuk mengisi jurang pengetahuan ini, penilaian yang menyeluruh dan dokumentasi sewajarnya perlu dilakukan terhadap kepelbagaian anggerik di habitat kars yang unik ini. Untuk itu, 10 penilaian lapangan telah dijalankan di antara tempoh Mac 2021 hingga November 2022 di lima bukit batu kapur terpilih di negeri Kedah dan sempadan Perak, bertujuan untuk menilai kepelbagaian anggerik batu kapur dan kekayaan spesiesnya, menilai ancaman terhadap anggerik tersebut dan habitat semula jadinya, mengenal pasti kawasan tumpuan hangat dengan kepelbagaian spesies yang tinggi, dan mencadangkan status pemuliharaan yang baharu untuk spesies anggerik yang jarang ditemui dan terancam, yang mana mempunyai kawasan taburan yang terhad dan saiz populasi yang kecil. Sejumlah 134 spesies anggerik mewakili 68 genera telah direkodkan dari Gunung Batu Putih, Gunung Pong, Gunung Baling, Gunung Pulai dan Gunung Fakir Terbang. Daripada lima bukit batu kapur ini, Gunung Batu Putih telah dikenal pasti mempunyai kepelbagaian dan kekayaan spesies anggerik tertinggi dengan jumlah 105 spesies dari 58 genera (H’ = 4.504 dan D = 0.9875), diikuti oleh Gunung Pong dengan 103 spesies dari 57 genera (H’ = 4.471 dan D = 0.9867), Gunung Baling dengan 93 spesies dari 50 genera (H’ = 4.366 dan D = 0.9853), Gunung Pulai dengan 90 spesies dari 49 genera (H’ = 4.296 dan D = 0.9838) dan terakhir Gunung Fakir Terbang dengan 67 spesies dari 29 genera (H’ = 3.88 dan D = 0.9756). Daripada jumlah ini, sebanyak 36 spesies telah dikenal pasti sebagai rekod baharu kepada negeri Kedah dan tiga spesies sebagai rekod baharu kepada Semenanjung Malaysia, iaitu *Anoectochilus sanguineus* P.T.Ong & P.O'Byrne, *Bulbophyllum meson* J.J.Verm., Schuit. & de Vogel dan *Luisia brachystachys* (Lindl.) Blume. Tiga spesies endemik kepada Semenanjung Malaysia turut diperoleh dalam kajian ini iaitu *Anoectochilus sanguineus*, *Cheirostylis goldschmidtiana* Schltr. dan *Phalaenopsis appendiculata* Carr. Kajian ini juga telah mendedahkan hubungan antara kepelbagaian anggerik dan peranan faktor alam sekitar tertentu. Hanya pH tanah dan kelembapan relatif (RH) telah dikenal pasti mempunyai korelasi positif terhadap kekayaan spesies anggerik. Analisis daripada data taburan spesies menunjukkan bahawa Gunung Batu Putih mempunyai kawasan tumpuan hangat tertinggi, diikuti oleh Gunung Pong, Gunung Baling, Gunung Pulai dan Gunung Fakir Terbang. Status pemuliharaan yang baharu telah dicadangkan untuk spesies anggerik terpilih yang jarang ditemui dan terancam, yang mana empat spesies telah dicadangkan sebagai Terancam Kritikal (CR) (*Aerides krabiensis*, *Anoectochilus albolineatus*, *Goodyera hispida* dan *Phalaenopsis appendiculata*), dan empat sebagai Terancam (EN) (*Anoectochilus sanguineus*, *Cheirostylis goldschmidtiana*, *Paphiopedilum niveum* dan *Spathoglottis hardingiana*).

UNVEILING LIMESTONE ORCHID HOTSPOTS IN THE KARST HILLS OF NORTHERN PENINSULAR MALAYSIA

ABSTRACT

A significant knowledge gap remains regarding the diversity of orchids in the limestone hills of northern Peninsular Malaysia, especially in Kedah and Perak. Addressing this knowledge gap requires thorough comprehensive assessments and proper documentations of orchid diversity and endemism in this unique karst habitat. To fulfill this, 10 field assessments have been carried out between Mac 2021 to November 2022 to five selected limestone hills in Kedah and Perak state boundary, aimed to assess the diversity of limestone orchids and their species richness, evaluating the threats facing by the orchids and their natural habitat, determining areas with high diversity hotspots, and proposing new conservation status for the rare and endangered orchid species with restricted distribution and small population size. A total of 134 orchid species represented in 68 genera have been recorded from Gunung Batu Putih, Gunung Pong, Gunung Baling, Gunung Pulai and Gunung Fakir Terbang. From the five limestone hills, Gunung Batu Putih was known to have the most richest and diverse orchid species with a total of 105 species from 58 genera (H’ = 4.504 and D = 0.9875), followed by Gunung Pong with 103 species from 57 genera (H’ = 4.471 and D = 0.9867), Gunung Baling with 93 species from 50 genera (H’ = 4.366 and D = 0.9853), Gunung Pulai with 90 species from 49 genera (H’ = 4.296 and D = 0.9838) and lastly Gunung Fakir Terbang with 67 species from 29 genera (H’ = 3.88 and D = 0.9756). From the account, 36 species are recognized as new records to Kedah and three species as new records to Peninsular Malaysia, namely *Anoectochilus sanguineus* P.T.Ong & P.O’Byrne, *Bulbophyllum meson* J.J.Verm., Schuit. & de Vogel and *Luisia* *brachystachys* (Lindl.) Blume. Three species endemic to Peninsular Malaysia were gathered in this study which are *Anoectochilus sanguineus*, *Cheirostylis goldschmidtiana* Schltr. and *Phalaenopsis appendiculata* Carr. This study has also revealed the relationships between the diversity of orchids and the influences of certain environmental factors. Only soil pH and relative humidity (RH) were found to be positively correlated with orchid's species richness. The analysis on species distribution data has shown that Gunung Batu Putih to have the highest number of hotspot areas followed by Gunung Pong, Gunung Baling, Gunung Pulai and Gunung Fakir Terbang. New conservation status have been proposed to the selected rare and endangered orchids, which four species were proposed as Critically Endangered (CR) (*Aerides krabiensis*, *Anoectochilus albolineatus*, *Goodyera hispida* and *Phalaenopsis appendiculata*), and four as Endangered (EN) (*Anoectochilus sanguineus*, *Cheirostylis goldschmidtiana*, *Paphiopedilum niveum* and *Spathoglottis hardingiana*).

CHAPTER 1 INTRODUCTION

1.1 Research Background

The state of Kedah is located in the uppermost part of northern Peninsular Malaysia. The state covers a total area of approximately 9,425 km^2, bordering up to Perlis and Thailand towards north. The total forest cover in Kedah based on the most updated record made in 2017 was about 332,646 hectares that includes the terrestrial and mangrove forest (Wan Mohd Jaafar et al., 2020). The state is rich and diverse with rare and exotic flora species which are captured and preserved by the vast area of land covered by various types of forests (Auyob et al., 2016; Rafidah et al., 2020). However, due to the challenging terrain of some of the Kedah hills, particularly the limestone hills; limited botanical excursions have ever been attempted before to this karst habitat.

Studies on the limestone flora of Kedah are scarce, leading to the dearth of important literature on the diversity of wild orchids that may be found in this unique habitat. In contrast to the other states in Peninsular Malaysia, Kedah has a poor botanical record on its limestone hills, with Pulau Langkawi being the only main focus (Kiew, 1993). The majority of limestone hills in Kedah are dispersed up to the north of Perlis. Records of botanical surveys on the limestone hills in the northern part of Kedah are concentrated in regions that are easier to access, for example in the district of Baling and Sik (Rafidah et al., 2020).

The only prominent reference on the diversity of limestone orchids in the northern most region of Peninsular Malaysia has been thoroughly compiled by Go et al. (2010; 2005), focusing primarily on the limestone hills in Perlis along the Nakawan Range. In Kedah, similar assessment has been carried out on one of the important botanical localities, the Kedah Peak (Gunung Jerai). Auyob et al. (2016) has provided a complete checklist of orchids from Gunung Jerai with a total of 70 species in 40 genera. Some notable findings with new locality records to Malaysia, such as the discovery of *Bulbophyllum sigaldiae* Guillaumin and *Liparis nana* Rolfe have proven that the wild forestland of Kedah may offer fascinating discoveries worth to be explored. However, Gunung Jerai does not fall under the category of a limestone hill, as it is an isolated mountain range which the core was made up of mostly granite.

Unlike the other forest types, the limestone hills in Kedah have received little attention due to their uncharted nature and restrictions to access majority of the hills. Botanical surveys conducted several decades ago by Chin (1977; 1979; 1983a; 1983b) highlighted on the varied habitats in a limestone hills, contributes to the rich and diverse flora. These distinctive characteristics from the remarkable diversity of habitats within limestone regions was also mentioned by Kiew (2021). Reports from Liew et al. (2016) and Liew et al. (2021) highlight the extent to which our knowledge of limestone hills remains limited. Their findings reveal a remarkable 50% increase in the discovery and mapping of limestone hills in Peninsular Malaysia within a span of six years.

Henceforth, the limestone hills are an intriguing subject worth to explore. A series of botanical search to this unique habitat would lead to the new knowledge on the diversity of orchids confined to these limestone hills, species richness and their degree of endemism, discovery of species with new locality records, or even species that could be new to science. Moreover, these diversity assessments will also provide insight on the effects of abiotic factors such as temperature, relative humidity and soil pH on the limestone orchid diversity and species distribution on the karst hills.

Thus, diversity assessments of the orchids in the limestone hills in Kedah should not be further delayed, as more habitat loss will lead to the extirpation of orchid species could be endemic to this unique habitat.

1.2 Problems Statements

Limestone hills have been botanized as early as 1930s due to their unique characteristics by having highly diverse vegetation and their appealing karst formation. However, previous botanical survey conducted in the northern part of Peninsular Malaysia has been predominantly centered only in the state of Perlis (Go et al., 2010). The research on limestone orchids specifically in Kedah is still being understudied. This has resulting to the insufficient information and better understanding on the limestone orchids. The ambiguity of accessing the challenging topography of limestone hills and the lack of researchers were the primary causes of the dearth of information on the diversity of limestone orchids.

Besides of that, lack of awareness towards the conservation of limestone orchids and their natural habitat has only increased the risks of them being in threats from the scarcity of body literatures and lack of data. Quarrying activities and forest clearance for agricultural purposes are some of threats to obscure species that may be novel to science. The declining of wild orchids species can also be attributed to the detrimental human activities including the recalcitrant orchid collectors. The orchids were smuggled out of their natural habitat to be sold to enthusiastic orchid collectors and amateurs (Go et al., 2005).

Thus, the needs for more comprehensive research on the limestone orchids are severely important as to assess the diversity of orchids in this unique karst habitat, and recognizing species with new distribution records or even new species, and providing an updated body literature for the limestone orchids. Actions on this are needed to be done immediately to protect the orchids and their habitat.

Findings from this study should provide a notable contribution in the forms of an updated checklist and proper documentations on the limestone orchids from northern Peninsular Malaysia specifically, and contributing to the latest records of total Peninsular Malaysia's orchids, generally. Findings from this study too, will serve as a fundamental reference in planning strategies for effective conservation efforts for the limestone orchids and their natural habitat.

1.3 Objectives of Study

Hence, the objective of this study are:

i) To assess the diversity of orchids in five selected karst hills in the northern part of Peninsular Malaysia;

ii) To identify orchid species based on taxonomic keys developed from the macro- and micromorphological characters examined;

iii) To investigate the relationships between orchid species diversity and environmental variables;

iv) Mapping of species distribution in determining hotspots at the stage of high species richness in the selected karst hills.

CHAPTER 2 LITERATURE REVIEW

2.1 The Northern Region of Peninsular Malaysia

The northern region of Malaysia is consisted of states located at the northernmost part of Peninsular Malaysia, inclusive of the state of Perlis, Kedah, some part of Perak and Pulau Pinang (Figure 2.1). The states of Perlis and Kedah are neighbouring to the Peninsula Thailand boundaries by going up further north.

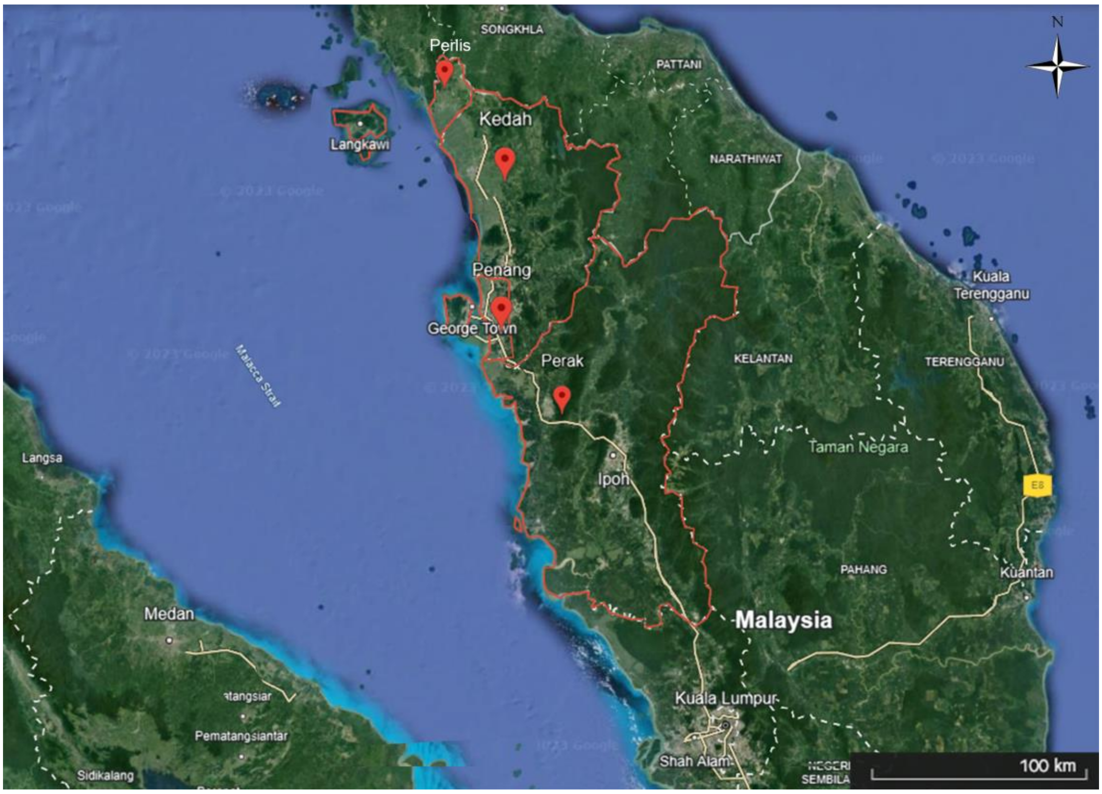

Figure 2.1 States that are located in the northern region of Peninsular Malaysia. Image retrieved January 1, 2022, from https://earth.google.com/web

The northern region of Peninsular Malaysia of experiences notably low rainfall, especially during the southwest monsoon season (May to September). This arid condition persists even during the northeast monsoon (November to March) due to the presence of the Titiwangsa Range, a geographical feature that acts as a natural rain barrier (Syafrina et al., 2015). The northern region boasts remarkable plant diversity, characterized by its close relationship with the Thai – Burmese elements, especially in the upper northeastern part, while the remaining areas are more closely related to Malesian and Indo-Malaya elements (Sharma, 1992; Kiew, 1993; Hanum et al., 2001).

2.2 Limestone Forests

The karstic habitat with limestone hills are considered the indispensable components of Malaysia's geoheritage (Leman et al., 2008). One of the eccentric value of Malaysia is the remarkable limestone hills popularly known as the "arks of biodiversity" due to the high level of species endemism particularly in Peninsular Malaysia (Clements et al., 2006). According to Paton (1961), many of these hills were once connected and belong to the same geological formation or bedrock. However, some of the hills are lenticular and believed to not connected to the other hills. Peninsular Malaysia holds and account of 1393 limestone hills documented, with majority are located in the State of Kelantan (298 hills), Pahang (183 hills), Kedah (173 hills) and Perak (138 hills). Although being the fourth largest number of limestone hills, the state of Perak has the largest operating quarries (Liew et al., 2021).

The limestone hills in Peninsular Malaysia are often built of tower karsts with utter white cliffs rising up to 300 m dominating the surrounding landscape (Kiew et al., 2019). Majority of the limestone outcrops in Malaysia is often small in size, with only 124 hills (9%) are larger than 1 km^2. Kedah (with six limestone hills in Pulau

Langkawi) and Sarawak have far bigger outcrop bases, with 17 and seven being greater than 4 km^2, respectively. Only 0.4% of the limestone hills cover the total Peninsular land area, and is known to have high species richness and endemism. About 1216 species of plants representing 14% of total Peninsular Malaysia's flora have been recorded from the limestone areas. From this account, approximately 21% are endemic to Peninsular Malaysia and 11% are obligate calciphiles restricted to growing on limestone (Chin, 1977, 1979, 1983a, 1983b).

However, only small number of limestone hills have been intensively studied botanically, namely, Batu Caves in Selangor and Gunung Kanthan in Perak. Findings from the studies over a long period of time have showed that a single hill harbours only 22% of the total limestone flora confined to this type of habitat. Challenges arise when conserving a single hill will only conserve a fraction of the whole limestone flora (Kiew, 2014; Kiew et al., 2014).

With regard to its floristic assemblage, limestone hills are distinctly different from the lowland rain forest by the absence of the dominant tree family, Dipterocarpaceae (Kiew et al., 2019). Study on soil characteristics in a limestone habitat done by Crowther (1982) has revealed that the junctions between karst hills and the surrounding alluvial plains were often abrupt. The steepness and soil depth are also different from each other. For example, the common herbaceous species in the lowland rain forest such as *Tacca integrifolia* (white bat flower) is replaced by *Tacca chantrieri* (black bat flower) in the limestone forest (Kiew et al., 2019).

Based on Kiew (1991), species richness is attributed to the diversity of microhabitats stacked on a single hill. Different species of plants can be found growing on large limestone boulders that surrounds the forest, or on the steep earth slopes up to the cliff faces, in gullies and valleys as well on rocky scree slopes with accumulated boulders. Vertical cliff faces in particular, consist of a variety of microhabitats which include the dry deeply shaded overhangs at the base, humid cliff base, wet shaded areas where water regularly drops, lightly shaded cliff faces or fully exposed cliff faces. The summit also encompass a variety of microhabitats, for example cracks and crevices in the rough limestone where roots can penetrate the exposed limestone rock, pockets of soils and light shade of the tree canopy that supports rich epiphyte flora.

Early botanical search on the limestone flora were so limited as limestone hills were only previously accessible by railway lines. Checklist on limestone flora compiled by Chin (1977, 1979, 1983a, 1983b) have documented 1216 species representing 14% of the Peninsula's flora of 8000 species, of which 21% are endemic to Peninsular Malaysia and 11% are obligate calciphiles restricted to growing only on limestone hills. As time progresses, the continous surge in developments have opened up path ways for more extensive research in limestone hills. However, this unique karst habitat were still understudied due to extensive labour needed to explore on the harsh karst topographic and highly cost expenditure. To date, only few limestone hills throughout Malaysia have been botanized which include Perlis (Go et al., 2005; Go et al., 2009), the hills in Felda Chiku, Kelantan (Kiew, et al., 2019), Batu Caves in Selangor (Kiew, 2014; 2021) and a few selected limestone hills in Sarawak (Go et al., 2009).

2.3 Orchidaceae - The Orchid's Family

In the early orchid classification, pollinia was used as an organ from the floral morphologies in the classification processes. The most widely used system in the early days was from Schlechter's prepared in 1926, where orchids are classified into two subfamilies and three tribes (as cited in Dressler, 1993). The system was then revised and modernized, classifying them into five subfamilies, which are Apostasioideae, Cypripedioideae, Epidendroideae, Neottioideae and Orchidoideae (Dressler, 1981; Dressler, 1993).

Nonetheless, in the taxonomic revisions conducted by Seidenfaden & Wood (1992) to classify the orchids in Malaya (Peninsular Malaysia and Singapore then), they have organized the orchid family into six distinct subfamilies. These subfamilies consisted of Apostasioideae, Epidendroideae, Cypripedioideae, Neottioideae, Orchidoideae, and Vandoideae. In the year of 1993, Dressler has updated his classification system by embedding subfamily Vandoideae into Epidendroideae due the much similarities between the tribes (Dressler, 1993). Thus forming a newly classification system that composed of only five subfamilies namely Apostasioideae, Cypripedioideae, Epidendroideae, Orchidoideae and Spiranthoideae.

The previous classification systems, which placed significant emphasis on floral structures like pollinaria, caudicles, stipes, or viscidia, have posed challenges at higher taxonomic levels due to the plasticity in floral morphologies (Pridgeon et al., 1999). Thereby, the incorporation of molecular markers and cladistic methods has led to a more intricate classification of orchids, improving upon the traditional system (Go et al., 2010). Following that, subfamily Spiranthoideae was merged under Orchidoideae and vanilloid were treated as a distinct subfamily, Vandoideae, through molecular systematic study (Pridgeon et al., 1999; Chase, 2005). Consequently, the most recent classification system for orchids now is divided into five subfamilies; Apostasioideae, Cypripedioideae, Epidendroideae, Orchidoideae and Vandoideae.

2.3.1 Subfamily Apostasioideae

This subfamily consists of less than 20 species and considered to be the most primitive orchids. They are native to the Asian and Australian tropics which include only two genera, *Apostasia* and *Neuwiedia*. The morphology of the plant is very distinct with stilt root and hard stem. *Neuwiedia* is considered to be more primitive by having three anthers on a fairly long stalk as compared to *Apostasia* which only two anthers were formed and are shortly stalked (Dressler 1981, 1993; Seidenfaden & Wood 1992).

2.3.2 Subfamily Cypripedioideae

The species from this subfamily is categorized by one distinct character which is the formation of synsepalum of the lateral sepals. They are distributed throughout the American, Asian and Australian tropics, and include the genera *Cypripedium*, *Mexipedium*, *Selenipedium*, *Phragmipedium* and *Paphiopedilum*. Only genus *Paphiopedilum* is represented in Peninsular Malaysia (Dressler 1981, 1993; Seidenfaden & Wood 1992; Pridgeon et al. 1999)

2.3.3 Subfamily Orchidoideae

The majority of species within this subfamily exhibit terrestrial characteristics, and consequently, they possess succulent rhizomes or tubers. These tuberoids store food that helps the plant to survive in dormancy during winter or drought. This group is recognized as one of the largest after Epidendroideae, comprising of 14% of from the total described orchids (Chase, 2017).

2.3.4 Subfamily Vanilloideae

The subfamily Vanilloideae includes 14 genera and 245 species with various lifestyles, including epiphytic, terrestrial and mycoheterotroph (Chase et al., 2015). The most well - known genus in this subfamily is *Vanilla* with five species distributed in Peninsular Malaysia.

2.3.5 Subfamily Epidendroideae

This is the largest and most diverse group amongst the five orchid subfamilies. There are more than 50% of all orchid species included within this one subfamiliy (Chase, 2005). Fifty genera with 535 species were found in Peninsular Malaysia (Dressler 1981; Seidenfaden & Wood 1992).

2.4 Hierarchy categories for the family Orchidaceae

The nomenclature for Orchidaceae followed the principle of International Code of Botanical Nomenclature (ICBN). The scientific names of all taxa are treated as Latin. Here are the instance of nomenclature categories for *Paphiopedilum niveum*:

Kingdom: Plantae

Division: Magnoliophyta

Class: Liliopsida

Order: Asparagales

Family: Orchidaceae

Subfamily: Cypripedioideae

Genus: *Paphiopedilum*

Species: *Paphiopedilum niveum* (Rchb.f.) Stein

2.5 The Diversity and Distribution of Orchids

Orchids is known as one of the largest and most diverse family among flowering plant family (Chase et al., 2003, 2015; Willis, 2017). Orchids are found in almost all terrestrial ecosystem, with various ecological roles and economic importance (Djordjević & Tsiftsis, 2022). There are an estimated 27,000 species in about 1000 genera of orchids that have been identified around the world. Orchidaceae is an actively evolving plant family with estimated 500 new species are being described every year (Swarts & Dixon; 2009; Kurzweil & Lwin, 2014; POWO, 2022).

As one of the largest flowering plant families, Orchidaceae can be found in almost every part of the vegetated continents throughout the world. However, the orchids are distributed abundantly in the tropics (Chase, 2005). Their distribution in the tropics also varies widely between continents and regions. Regions that particularly rich in orchids are the northern Andes of South America, the mountains of the narrow neck of meso-America, Madagascar, Indo-China and South-West China, Sumatra, Borneo, New Guinea, and temperate South-West Australia. A quarter of all known species could be found in the Andes of Colombia and Ecuador which is the smallest country in Andean South America (Barthlott et al., 1996; Myears et al., 2000). These countries are known to have the highest diversity of orchids among all places.

Peninsular Malaysia has an impressive diversity, with around 900 species and expected to reach c. 1000 species as more previously inaccessible area were being explored. The lush biodiverse forest of Borneo are home to 2500 to 3000 species of orchids, which is equivalent to 10% of the world's orchids and 75% of the Malesian orchid flora (Lamb, 1991; Baeman et al., 2001; Ong et al., 2017). The tallest mountain in Malaysia, Mount Kinabalu situated in the island of Borneo has recorded over 866 species of orchids (Wood *et al*., 2011). The abundance of orchids found there is as many found in the whole East Africa, about more than three times the number found in North America and fifteen times the number in Britain. The island of Sumatra has reported over 1200 species and about 1000 species of orchids from Madagascar (Comber, 2001; Du Puy *et al*., 1999).

2.6 Habitat of the Orchids

Orchids have a diverse range of habitats, growing anywhere from sea level to elevations as high as 2500 meters. They can be found globally in any part of the world, with the exception of those that experience extreme cold and dry conditions. Most of the orchid species are most abundant in the tropical and subtropical regions (Chase, 2005). On a regional scale, the presence of high number of epiphytic orchids is primarily observed in humid montane forests at elevations ranging from 1500 to 2000 meters above sea level. However, they can also be found in warmer forests at elevations of 500 to 1000 meters above sea level (Hietz & Hietz-Seifert, 1995; Krömer et al., 2005; Guzmán-Jacob et al., 2020).

In a more focused area, orchids can be found on the wet and shaded forest floor (e.g. *Nervilia concolor*), up on the high branches of forest trees exposed to sunlight and rainwater (e.g. *Grammatophyllum speciosum*), in the rock crevasses filled with leaf litters (e.g. *Paphiopedilum niveum*), left - over opening and by the roadsides (e.g. *Spathoglottis aurea*) and in the grassy and swampy areas (e.g. *Arundina graminifolia*).

2.7 The Wild Orchids in Peninsular Malaysia

The latest prominent study of wild orchids in Peninsular Malaysia was by Ong et al. (2017) and the total enumeration of wild Peninsular Malaysia's orchids recorded was 972 species in 146 genera. This evolutionary advanced group of Orchidaceae has a remarkable number of 198 endemic species located in Peninsular Malaysia (Go & Hamzah, 2008; Go et al., 2010).

Botanical surveys focused on orchids in Peninsular Malaysia have gained a significant importance due to the growing necessity to safeguard these plants from an array of increasing threats (Lu et al., 2013). Thus, there are several botanical surveys that have been conducted by reputable researchers in each specific states of Peninsular Malaysia with the goal of addressing these challenges and also to update the current checklist of wild orchids. Perlis with the extensive limestone hills, has primarily been the subject of botanical research conducted by the efforts of Go et al. (2005) and Go et al. (2009). In the mainland of Kedah, Gunung Jerai was the sole hill that went through a comprehensive botanical survey (Auyob et al., 2016). While, the Machinchang range in Pulau Langkawi known for its unique geological and vegetation features was botanised to document the original flora in response to the development of eco - tourism; cable car system (Chua et al., 2005). The renowned Penang Hill was also been a subject for orchids' diversity reassessment after a span of 115 years in Pulau Pinang (Go et al., 2011).

Kelantan and Terengganu have been prominent focal points for the assessment of orchid diversity. Besi et al. (2019; 2023a; 2023b) primary research revolves around exploring orchid diversity within degraded tropical rainforests impacted by human activities, aiming to derive insights that can be applied to conservation efforts in both of the states. Other significant botanical surveys in east coast of Peninsular Malaysia include; Kiew et al. (2019) in the research conducted on the distribution and conservation implications of limestone flora in Kelantan as well as Siti Fatimah et al. (2015) with the checklist of vascular plants and uses of some species for livelihood - making and orchids in coastal heath forest in Terengganu.

The botanical survey in Pahang was focused in the highest mountain peak in Peninsular Malaysia, Gunung Tahan. The floral assessment was done with a view to update the last orchid collections which was almost 126 years ago (Isa et al., 2018). Available published documentation on orchids in Selangor were mostly from Kiew et al. (2018) in the first limestone hill that has been continually sampled by botanists for the last 130 years and the survey of orchids in Gunung Nuang Forest Reserve which was the highest mountain peak in Selangor by Eng et al. (2010).

Lastly in the southern part of Peninsular Malaysia, a comprehensive assessment on the orchid flora of Gunung Ledang, Johor, was done by Nordin et al. (2021) with the aim to re - assess the works by Ridley in 1901. The botanical surveys resulted in the finding of 122 species in 62 genera, which potrayed the rich orchid flora found on the mountain region.

2.8 Characteristics of the Orchids

Orchids have been classified within the order Asparagales, which include Alliaceae, Amaryllidaceae, Asparagaceae, Hyacinthaceae, Hypoxidaceae and Iridaceae and among others. Liliaceae in the strict sense is a member of another order, Liliales, which are only distantly related to Asparagales (Fay & Chase, 2000). However, Huber (1969) has summarized about 16 differences between Asparagales and Liliales. Some of the examples that made Asparagales distinct over Liliales were by having thickened and fleshy roots, shrubby habit, reticulate leaves, abundance of raphides, succulence in leaves or stem and many others.

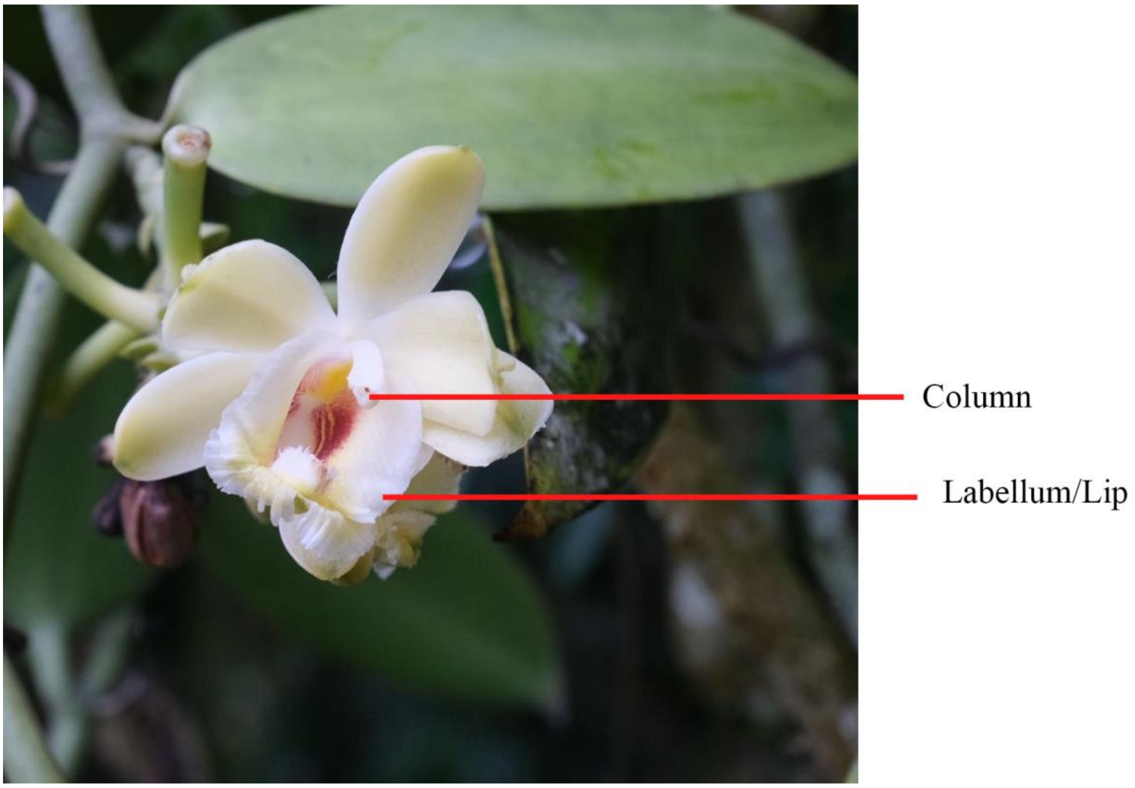

Figure 2.2 Flower structure of *Vanilla griffithii*, focusing on the column and labellum

The most distinguishable feature of the orchid family is their flower structure. The flower of a typical orchid has three sepals and three petals. One of the petals is modified into a structure called as labellum or lip, which is typically quite different from the other two. The labellum is a unique feature can only be seen in the orchids (Figure 2.2). It usually functions to attract an insect pollinator. The other special feature unique to the Orchidaceae is the position of the male and female reproductive organs, stamen (anther and filament) and pistil (stigma, style and ovary) that are fused together to form a single reproductive structure called the gynostemium or column.

Another fascinating phenomenon in orchids is the process of resupination. Before anthesis, the position of lip is on the uppermost and column in the lowermost in the bud. In most orchids as the buds open, resupination occur whereby the position of lip and column are rotated 180˚. However in some cases, some species retain the position of lip and labellum without resupination and described as being borne upside down. This position also can be resulted from a hyper-resupination, where the buds turned 360˚ ending up as they started with the lip is positioned upwards (Dressler, 1981; Arditti, 2016).

2.9 Growth Habit of the Orchids

Orchids exhibit two distinct growth habits which are monopodial and sympodial (Figure 2.3). In monopodial orchids, the stem emerges from a single bud, elongates and produces leaves from the apex each year. Most of the monopodial groups of orchids have been evolved from their sympodial habits (Dressler 1981, 1993). Example of monopodial orchids are *Phalaenopsis*, *Vanda* and *Vanilla*.

Figure 2.3 Growth habits of orchid A) Creeping *Coelogyne foerstermanii* showing sympodial growth B) *Agrostophyllum majus* exhibiting a monopodial growth

In sympodial orchids, the plant follows a pattern of generating a sequence of neighboring shoots that reach a specific size, flower, and subsequently ceasing their growth, making way for new shoots to take their place. Sympodial epiphytic orchids often exhibit a distinctive adaptation in the form of a thickened structure at the base of the stem, referred to as a pseudobulb. The adaptation in this function as a reservoir, storing essential nutrients and water, particularly during dry period (Dressler, 1981; De, 2020). Sympodial growth habit can be seen in the genus of *Dendrobium*, *Bulbophyllum* and *Cymbidium*. Both sympodial and monopodial orchids may have erect, creeping or pendulous stem (Figure 2.4).

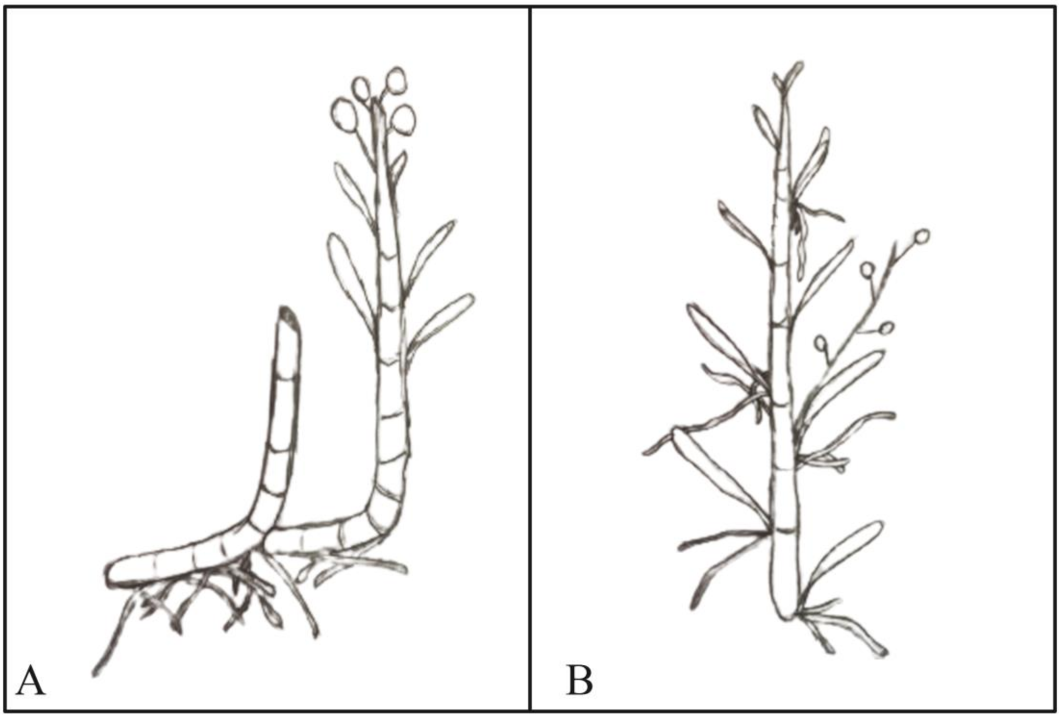

Figure 2.4 Plant growth habits in the orchid family. A) Sympodial growth. B) Monopodial growth

2.10 Plant Habit and Size

Adaptation towards harsh climatic conditions particularly on the fluctuations of temperature and water conservation on a daily and seasonal basis have effected the development of orchids' vegetative structures (Dressler, 1981; Benzing, 1990; Pridgeon *et al*., 1999). The orchids may exhibit a life form as either epiphyte, a terrestrial species or a lithophyte.

Epiphytes are defined by plants that germinate and root without becoming parasitic on other plants (Benzing, 1990). The orchid family stands out to possess over 70% of epiphytic species, making up around 10% of all vascular plants (Benzing, 2004). Meanwhile, a significant number of Orchidaceae representing the epiphytic lifestyle (~20,000 spp.), which is almost two third of the total orchids known worldwide. Among all of the subfamilies in Orchidaceae, subfamily Epidendroideae and subfamily Orchidoideae are the largest in the family, comprising of 84% and 14% of described species, respectively. Majority of the species from subfamily Epidendroideae are tropical epiphytes. Several genera hold a large number of species, such as *Bulbophyllum* Thouars (2168 species), *Dendrobium* Sw. (1606 species), and *Epidendrum* L. (1830 species) (Atwood, 1986a; Lavarack et al., 2000; Zotz, 2013).

Epiphyte orchids strive in tropical forests as non-parasitic organisms growing on other living plants for support. By providing a diversity of insects, birds, and other animals with sustenance and habitat under the forest canopy, epiphytic orchids help supporting the ecology of the forest and maintaining its biological diversity and abundance (Benzing, 1990). In the tropical and subtropical regions, most of the vascular epiphytes normally grow on tree trunks, or can be found attached to the rock surfaces in valleys. In comparison to the terrestrial plants, epiphytes are known for their aerial roots, which are not in contact with the soils. This creates an adaptation towards their survival, growth and distribution due to insufficient water supply through the presence of velamen (Zotz & Bader, 2009). The velamen is located externally to the exodermis, the outer layer of the cortex, and constitutes a multiple epidermis composed of dead cells. Functionally, the velamen is taken as a facilitator in water and nutrient absorption, barrier to loss of water and capable of conferring mechanical resistance (Benzing et al., 1982; Pridgeon, 1987). As a result, epiphytes manifest more adaptive characteristics towards drought tolerance as compared to the terrestrial species.

Meanwhile, terrestrial orchids are the minority group in Orchidaceae (Dressler, 1981; Seidenfaden & Wood, 1992). Unlike epiphytes which adapted by developing aerial roots, terrestrial orchids developed a ground-dwelling, thick, fleshy and with storage functions (Black, 1973). According to Dressler (1993), the tubers are able to survive during dry season, and nourish the plant when it is necessary. Some of the common, widely distributed terrestrial species that can be seen growing abundantly on the roadside are *Arundina graminifolia* and *Spathoglottis plicata Bl.*.

Both terrestrial orchids and lithophytic orchids grow on the ground. However, lithophytic orchids are more favorable growing on boulders or rocky surfaces rather than in thin soils. Lithophytic orchids can be found growing on limestones or granite rocks, where they have adapted to nutrient limitations and high levels of alkaline and calcium carbonate (Soepadmo, 1998; Bayman & Otero, 2006). Epiphytes can also grown to be lithophyte in the same locality if suitable environment conditions is met (e.g. *Dendrolirium ornatum*) (Xing et al., 2015).

2.11 The Biology of Orchids - Vegetative structures

Vegetatively, the orchids composed of several structures which include pseudobulb, leaf, roots and the inflorescence shown in Figure 2.5, Figure 2.6 and Figure 2.7.

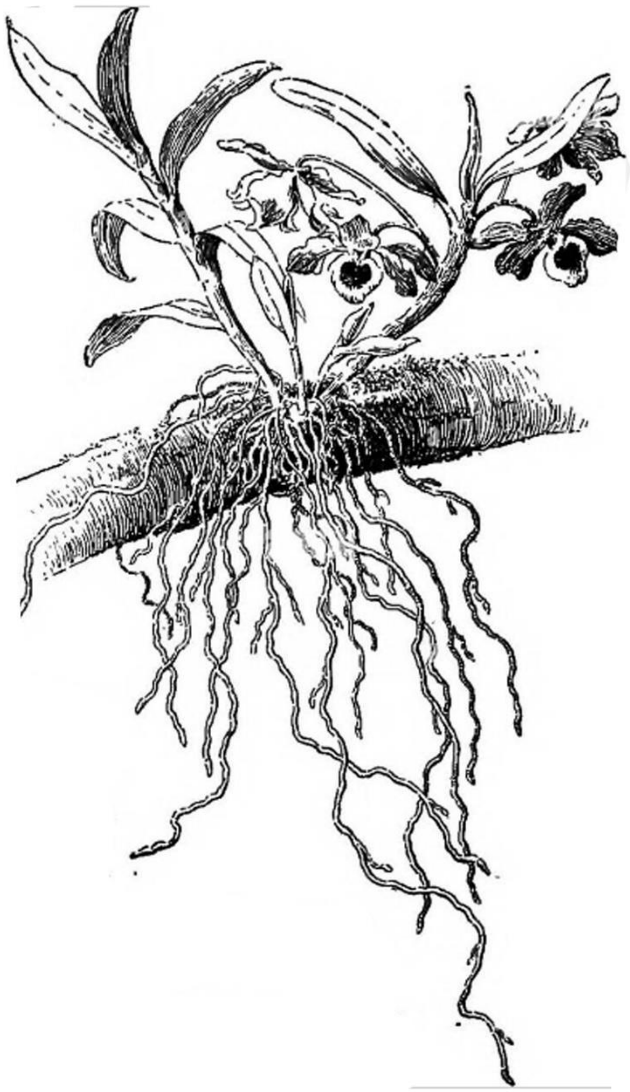

Figure 2.5 Vegetative structures of an epiphytic orchid. Adapted from Bergen, 1908

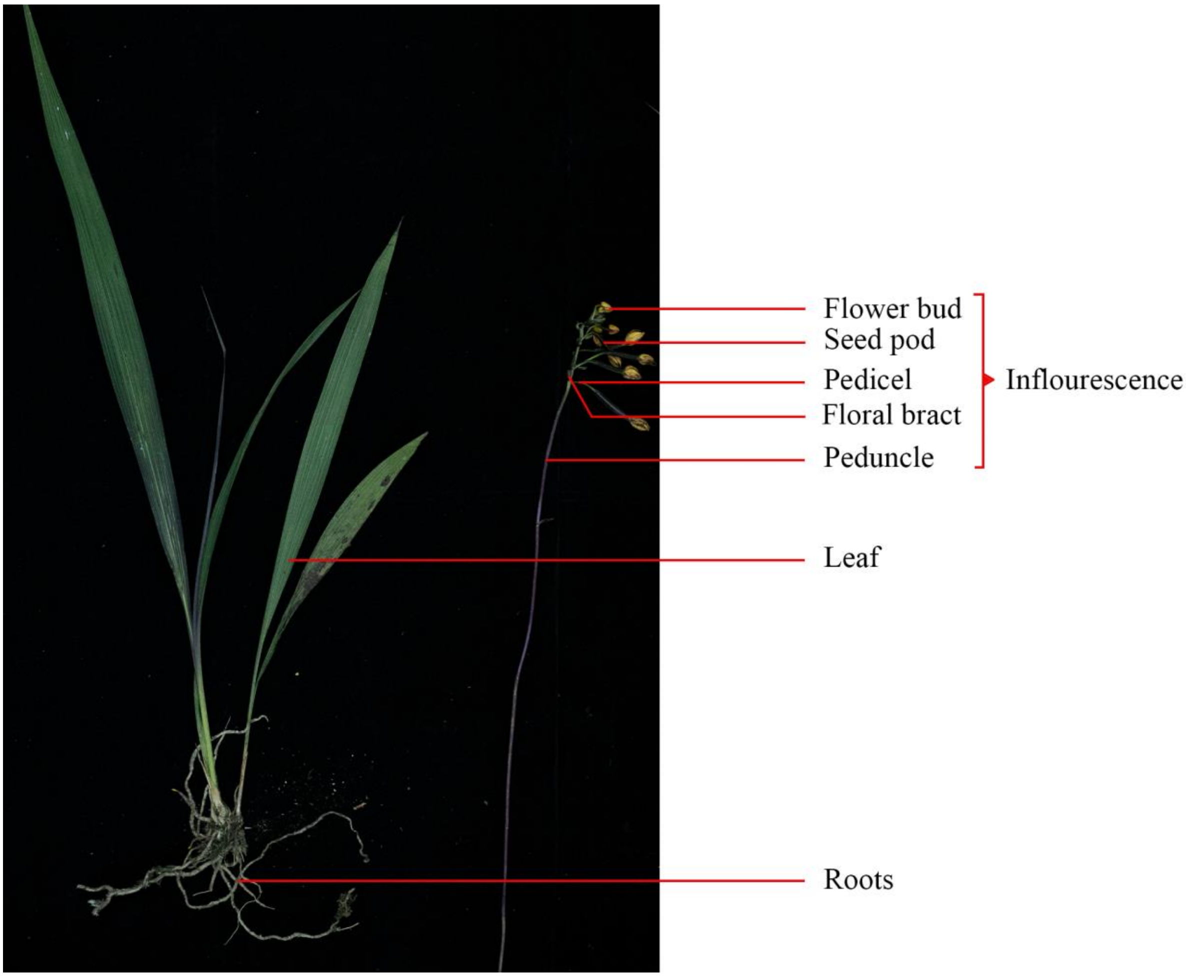

Figure 2.6 Vegetative structures of a terrestrial orchid, *Spathoglottis aurea*

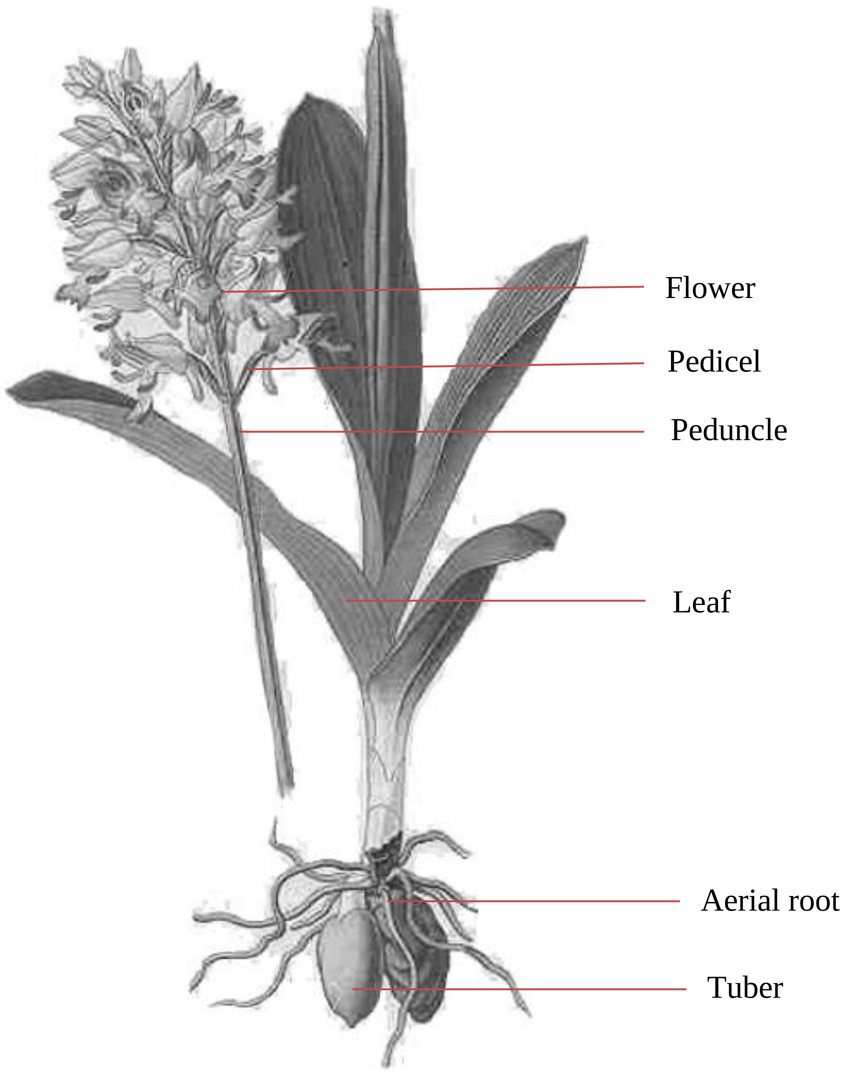

Figure 2.7 Vegetative structures of a terrestrial orchid. Adapted from Correvon, 1923

2.11.1 Roots and Rhizomes

The orchid family has a root system that is composed of secondary roots or adventitious roots that arise from the stem. Orchids are different from the dicots where the roots can never be a carrot - like tap root or have a primary root (Dressler, 1993; Dressler, 1981). However, they are not as thin or fibrous as the roots of grass. In most