STUDIES ON SPECIES DIVERSITY AND SYSTEMATIC IMPLICATIONS OF SEED COAT MORPHOLOGY OF ERICACEAE IN MIZORAM, INDIA

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STUDIES ON SPECIES DIVERSITY AND SYSTEMATIC IMPLICATIONS OF SEED COAT MORPHOLOGY OF ERICACEAE IN MIZORAM, INDIA

BY

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Submitted

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CERTIFICATE

This is to certify that Ms. **Laltlanhlui** has submitted the thesis entitled "**Studies on Species Diversity and Systematic Implications of Seed Coat Morphology of Ericaceae in Mizoram, India**" under my supervision, for the requirement of the award of the Degree of Doctor of Philosophy in the Department of Botany, Mizoram University, Aizawl. The work is authentic, content of the thesis is the original work of the Research Scholar, and the nature and the presentation of the work are the first of its kind in Mizoram.

It is further certified that no portion(s) or part(s) of the content of the thesis has been submitted for any degree in Mizoram University or any other University or Institute.

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DECLARATION

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MAY, 2025

I **LALTLANHLUI**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institute.

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Date: **(LALTLANHLUI)**

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LIST OF ABBREVIATIONS AND SYMBOLS

et al.	"et alia": and others
&	And
sp.	Species
RET	Rare, Endangered, Threatened
IUCN	International Union for Conservation of Nature
WHO	World Health Organisation
IPBES	International Science – Policy Platform on Biodiversity and Ecosystem Services
APG	Angiosperm Phylogeny Group
rbcL	Ribulose 1,5 – biphosphate carboxylase large chain
ITS2	Internal transcribed spacer 2
%	Percentage
e.g.	Example
km	Kilometer
°	Degree
′	Minute
FSI	Forest Survey of India
C	Celsius
mm	millimeter
DSLR	Digital Single Lens Reflex
GPS	Global Positioning System
GBIF	Global Biodiversity Information Facility
POWO	Plants of the World Online
ASSAM	BSI, Shillong
K	Kew
CAL	BSI, Kolkata
E	Edinburg

MZUH	Mizoram University Herbarium
g	Gram
ml	millilitre
F	Fahrenheit
cm	centimetre
SEM	Scanning Electron Microscope
BSI	Botanical Survey of India
NEHU	North Eastern Hill University
DNA	Deoxyribonucliec acid
CTAB	Cetyltrimethylammomium bromide
PCR	Polymerase Chain Reaction
MEGA X	Molecular Evolutionary Genetics Analysis, X
BIC	Bayesian Information Criterion
UPGMA	Unweighted Pair Group Method with Arithmetic Mean
N	North
E	East
m	metre
ARUN	BSI, Itanagar
µm	micrometre
=	Equal to
PCA	Principal Component Analysis
EN	Endemic
NT	Nearly Threatened
T	Threatened
LC	Least Concern
NE	Not Evaluated
UV	Use Value
RFC	Relative Frequency Citation
RI	Relative Importance

UR	Use Report
F	Food
O	Ornamental
M	Medicinal
C	Cultural Significance
E	Epiphytic
MH	Mycoheterotrophic
S	Shrub

CHAPTER 1

1. Introduction

1.1 General Introduction

The family name Ericaceae Durande (1782) is the conserved name, taking precedence over Ericaceae Juss. (1789), and is based on the type genus *Erica* L. (Turland & Watson, 2005). The name *Erica* originates from the Ancient Greek ἐρείκη (ereíkē), meaning "heath" or "heather", in reference to the shrubby plants typically found in rocky or acidic soils. This term was later adopted into Latin as *Erica*, used by Pliny the Elder and other classical authors to describe heath-like plants. The members are globally distributed, especially in acidic and nutrient-poor soil, and are ecologically adapted through features like urceolate corollas, evergreen leaves, and widespread mycorrhizal associations (Read, 1996; Crainey & Meharg 2003).

The first major documentation of Indian Ericaceae was carried out by Joseph Dalton Hooker during his exploration of the Eastern Himalayas (Sikkim) in the mid-19th century. His landmark monograph, Rhododendrons of the Sikkim-Himalaya (1849–1851), introduced several Indian *Rhododendron* species to global botanical science. Earlier contributions by William Griffith, Francis Buchanan-Hamilton, and Nathaniel Wallich, who curated Ericaceae species from Northeast India and the Western Himalayas (1828–1849), laid the foundation for subsequent taxonomic and floristic studies.

Ericaceae, historically classified based on floral morphology and ovary position, is now placed in the order Ericales within the Asterid clade, according to APG IV (2016) and molecular phylogenetics. The family is divided into subfamilies that are: Ekianthoideae, Cassiopoideae, Harrimanelloideae, Ericoideae, Vaccinioideae, Arbutoideae, Epacridoideae, and Monotropoideae, reflecting both morphological traits and genetic data (Kron *et al.*, 2002). Ericaceae occur worldwide in diverse habitats, from coastal lowlands and alpine regions to tropical cloud forests, and are especially dominant in temperate and boreal heathlands, moorlands, and tundra, thriving on acidic, nutrient-poor soils (Mujica *et al.*, 2024; Li, 2014). Their ecological versatility is supported by varied growth forms such as shrubs, trees, epiphytes, and mycoheterotrophs, along with ericoid mycorrhizal associations, specialized traits for drought and cold resistance, and a wide array of seed dispersal strategies, with many species valued for their ornamental beauty or edible fruits (Blauch, 1970; Eriksson & Bremer, 1991; Read, 1996; Cairney & Meharg, 2003; Brundrett, 2009; Choudhary *et al*., 2021).

The family comprises perennial herbs, shrubs, and small trees many with evergreen, simple, alternate leaves (Kron *et al*., 2002 a & b; Judd *et al*., 2016). Members have adapted to diverse ecological niches, including epiphytic and fully mycoheterotrophic life forms, notably in Monotropoideae, which lack chlorophyll and depend entirely on fungi (Zimmer *et al*., 2007). Flowers are typically showy, pentamerous, and zygomorphic, with four or two stamens and a unilocular ovary showing parietal placentation (Stevens, 2001). Most Ericaceae flowers are bisexual but unisexual forms occur rarely, and floral structures are actinomorphic or zygomorphic, pedicellate, and bracteate, with aposepalous, imbricate or valvate calyces and sympetalous corollas forming bell- or urn-like shapes (Stevens *et al*., 2004). The fruits of the family vary from berries and drupes to capsules, with wind-dispersed, lightweight seeds in capsular species, and animal-dispersed fleshy fruits in berry and drupe species and seeds adapted for respective dispersal mechanisms (Eriksson & Bremer, 1991).

1.2 Species diversity and distribution

The Ericaceae is a prominent family within the order Ericales, comprising approximately 4,100 species across 126 genera (Kron *et al.*, 2002). It has a cosmopolitan distribution, with major centers of diversity in temperate regions of the Northern Hemisphere, Southeast Asia, the Andes, and parts of Africa and Australia (Heads, 2003). The family is especially well represented in acidic, nutrient-poor environments, such as heathlands, montane forests, bogs, and alpine zones. In the Neotropics, Ericaceae is abundant in montane habitats, particularly in the Andes, where genera such as *Cavendishia*, *Psammisia*, and *Satyria* have radiated extensively

(Angulo Serrano, 2024). In the Paleotropics, significant diversity is found in Southeast Asia and Australasia, especially within the subfamily Epacridoideae (Huang *et al.*, 2020). In Africa, genus like *Erica* dominate fynbos ecosystems, with over 600 species endemic to the Cape Floristic Region (Pirie *et al.*, 2011). The family Ericaceae in India comprises approximately 11 genera and about 280 species, including around 46 endemic taxa, with the highest diversity occurring in the Himalayan and northeastern regions of the country (Sanjappa & Sastry, 2014) with 15 species across 5 genera of Ericaceae have been reported from Mizoram (Sinha *et al.*, 2012). Notably, species of *Rhododendron*, one of the largest genera in the family, are extensively diversified in Sikkim**,** Arunachal Pradesh, and the Meghalaya Hills, contributing to the reputation India as a key center of diversity for *Rhododendron* (Pradhan & Lachungpa, 1990).

1.3 Seedcoat Morphology

The ecological versatility of the family is reflected in significant morphological and anatomical adaptations, especially in seed structures (Stebbins, 1971). Seed coat morphology, or testa structure, represents one of the key traits used in understanding the systematics and evolutionary relationships. The seed coat, formed from the integuments of the ovule, serves multiple functional roles including protection against physical damage, desiccation, and predation, as well as regulation of germination in response to environmental cues (Boesewinkel & Bouman, 2017). In the Ericaceae, seed coats exhibit considerable interspecific and intergeneric variation in traits such as cell wall ornamentation, thickness, colour, shape, presence of wings etc. These characteristics not only influence seed dispersal and dormancy mechanisms but are also of diagnostic value in taxonomy. Understanding the diversity of seed coat morphology in Ericaceae contributes not only to systematics but also to insights into ecological adaptation and evolutionary developmental biology. This study aims to explore the morphological variation of seed coats within the Ericaceae family, examining their structural diversity, taxonomic implications, and potential adaptive significance across different habitats and life forms.

1.4 Palynology

Floral morphology within Ericaceae is highly variable, reflecting diverse pollination syndromes that include bees, butterflies, moths, birds**,** and in some tropical members, even bats (Luteyn, 2002). Pollen morphology has also proven useful in the classification of Ericaceae, with distinctive features like tetrads and spinulose exine patterns helping to delineate certain subfamilies and tribes (Pacini & Franchi, 1993; Furness & Rudall, 2006). However, convergent evolution in floral and vegetative traits has historically made taxonomic resolution difficult, particularly in the larger genera like *Rhododendron* and *Vaccinium* (Goetsch *et al.*, 2005).

1.5 RET (Rare, Endangered, Threatened) Species

Conservation assessment serves as a critical step in understanding the current status, distribution and vulnerability of plant species, particularly those inhabiting ecologically sensitive regions such as Mizoram. Despite their ecological and taxonomic significance, most Ericaceae taxa from Mizoram remain poorly represented in global conservation databases. Habitat loss due to shifting cultivation, deforestation, and anthropogenic disturbances further exacerbates the decline of these taxa (Sahoo *et al.*, 2018). Therefore, assessing their conservation status is essential to identify species at risk and to prioritize them for protection and management. The categories based on IUCN Red List Categories and Criteria (2024) reflect increasing levels of threat, from species at low risk to those facing imminent extinction:

1. **Least Concern (LC)**: Species that are widespread and abundant in the wild. These taxa face no immediate risk of extinction and generally have stable or large populations.
2. **Near Threatened (NT):** Species that do not currently meet the criteria for threatened categories but are close to qualifying or are likely to qualify in the near future due to ongoing decline or habitat pressures.

3. **Vulnerable (VU):** Species considered to be facing a high risk of extinction in the medium term, often due to a population reduction of at least 30%, limited distribution or continuing habitat loss.
4. **Endangered (EN):** Species facing a very high risk of extinction in the near future. They usually exhibit severely reduced population sizes (less than 250 mature individuals) or are restricted to few locations, often under Criterion C or D.
5. **Critically Endangered (CR):** Species facing an extremely high risk of extinction in the immediate future. These taxa typically have extremely small populations (fewer than 50 mature individuals) or are confined to a single or very few locations, making them highly vulnerable to any form of disturbance.
6. **Extinct in the Wild (EW):** Species known only to survive in cultivation, captivity, or as a naturalized population outside their historical range.
7. **Extinct (EX):** Species for which there is no reasonable doubt that the last individual has died despite exhaustive surveys in known and expected habitats.
8. **Not Evaluated (NE):** Species that have not yet been assessed against the IUCN criteria.
9. **Data Deficient (DD):** Species for which insufficient information is available to make a direct or indirect assessment of their risk of extinction.

1.6 Ethnobotany

Ethnobotany, the study of human-plant relationships, preserves cultural heritage and biodiversity by documenting traditional uses of plants for medicine, food, and rituals (Cotton, 1996; Albuquerque & Hanazaki, 2009). In developing countries, about 80% depend on plant-based remedies for healthcare (WHO, 2002). The Ericaceae family is known for its wide range of traditional medicinal applications. Various species have long been used to treat inflammatory ailments, relieve pain, address digestive issues, manage respiratory conditions such as the common cold and asthma, and heal different skin disorders. Despite their therapeutic value, some members of this family are also known to possess toxic properties. In fact, certain species have historically been utilized as sources of poison (Popescu & Kopp, 2013 a & b). Ethnobotanical knowledge is vital for sustainable resource use, drug discovery, and conservation efforts, especially in regions like Mizoram where indigenous communities retain extensive traditional plant knowledge.

1.7 Molecular Study

The foundations of molecular phylogenetics in Ericaceae trace back to early studies linking morphological classification with DNA data (Kron & Chase, 1993; Kron *et al.*, 1999). Initial molecular work focused on subfamily and genus-level relationships, revealing that traditional morphology-based classifications often failed to mirror true evolutionary histories. With advances in nuclear and chloroplast DNA analyses, phylogenetic studies resolved taxonomic ambiguities, especially in complex genera like *Rhododendron* and *Vaccinium*, leading to a revised, phylogenetically coherent classification that clarified intergeneric relationships and illuminated the biogeographic and evolutionary history of the family (Kron *et al*., 2002; Goetsch *et al*., 2005).

1.8 Relevance of the study

In recent years, global biodiversity has been increasingly threatened by habitat destruction, climate change, invasive species, overexploitation and other anthropogenic pressures (Myers *et al*., 2000; IPBES, 2019). Mizoram, situated in the Indo-Burma biodiversity hotspot, faces these challenges, risking the vulnerability and potential extinction of many plant species (Mao *et al*., 2016). The rugged and mountainous terrain of the region has resulted in several inaccessible and largely unexplored areas taxonomically. The Ericaceae family, though less studied than other angiosperm families, holds notable representation in the temperate and montane forests of Northeastern India, including Mizoram (Darlong *et al*., 2020). Historical floristic and ecological studies in adjacent regions are often outdated or based on limited herbarium collections, lacking current data on the distribution, ecological roles, and morphological variability of the family within Mizoram (Deb, 1983; Nayar & Sastry, 1987).

While some floristic and ecological studies have documented the presence of Ericaceae in adjacent regions, most are either outdated or based on limited herbarium collections from several decades ago (Deb, 1983; Nayar & Sastry, 1987). These historical records lack updated information regarding the current distribution, ecological roles, and morphological variability of the family within Mizoram. To bridge this knowledge gap, the present study undertakes a comprehensive exploration of the Ericaceae family in the state. This includes an in-depth investigation of species morphotaxonomy, diversity, distribution, seed coat micromorphology, palynology and molecular studies of collected taxa. The development of a morphological identification key, coupled with assessments of conservation status and ethnobotanical relevance, aims to enhance our understanding of the ecological significance and taxonomic complexity of the family. Importantly, the study integrates DNA barcoding techniques, providing a powerful tool for accurate species identification, resolving cryptic taxonomic boundaries, and documenting biodiversity in regions with limited historical collections. Combining traditional taxonomy, micromorphological studies, and molecular data facilitates robust species delimitation and informs effective conservation and management strategies, contributing valuable knowledge for one of India's ecologically significant regions (Givnish, 2010).

1.9 Objectives of the present studies

The study includes the following objectives:

1. To collect and study the species diversity of Ericaceae from Mizoram. (Barcoding of DNA is incorporated for accurate species identification and to resolve taxonomic uncertainties)
2. To study the seed coat diversity on all the taxa collected under Ericaceae from the state.
3. To prepare an identification key based on morphological characters and seed coat morphology (including palynology).
4. To study the distributions, conservation status and potential threats of the family members in Mizoram.
5. To document the ethnobotanical uses of Ericaceae members in Mizoram.

CHAPTER 2

2. Review of Literature

2.1 Brief History

The family Ericaceae (heath or heather family) has a long and evolving taxonomic history. Although Linnaeus (1753) included genera such as *Erica*, *Rhododendron*, *Vaccinium*, and *Andromeda* under *Ericales*, he did not formally define the family. The name Ericaceae Durande (1782), later accepted over the attribution to de Jussieu, was based on *Erica* and related genera. De Jussieu (1789) recognized the group as a natural family using floral traits like urn-shaped corollas and anthers with terminal pores**.** De Candolle (1813) broadened its concept by emphasizing sympetalous corollas and leathery leaves, while Don (1834) refined its limits through anther morphology. Bentham & Hooker (1862–83) provided the first comprehensive treatment, classifying taxa by ovary position and fruit type.

Later, Winkler (1891) distinguished the Australasian *Epacridaceae* from Ericaceae, though molecular evidence later revealed its placement within the family (Kron *et al*., 2002), now treated as subfamily Epacridoideae. Twentieth-century revisions by Sleumer (1949, 1967) further clarified subfamilial boundaries such as Ericoideae**,** Vaccinioideae and Rhododendroideae. With the rise of molecular phylogenetics, a more robust DNA-based system emerged, confirming Ericaceae as a major family within Ericales, comprising about 124 genera and nearly 4,000 species w orldwide.

2.2 Classification

The classification of the Ericaceae family has undergone a profound transformation over the past century and a half, reflecting shifts in taxonomic philosophy and methodological advancements. Earlier systems, such as those by Hooker (1876) and Drude (1889), primarily relied on morphological characteristics, leading to the recognition of numerous related but separate families such as Vacciniaceae, Pyrolaceae, Monotropaceae, and Epacridaceae. These systems often included detailed tribal groupings based on features such as flower structure, fruit type and habit. For instance, Hooker separated genera like *Agapetes*, *Rhododendron*, and *Gaultheria* across different tribes and families, while Drude introduced subfamilies and tribes within the broader Ericales but still maintained a relatively split framework.

By the mid-20th century, taxonomists like Rendle (1956), Watson *et al*. (1967) and Stevens (1971) began moving towards a more inclusive concept of Ericaceae, introducing subfamilies and tribal divisions to account for increasing knowledge of plant relationships. However, many systems still upheld the separation of certain families like Empetraceae and Epacridaceae. Hutchinson (1973) and Cronquist (1981) maintained several segregate families, although Cronquist acknowledged the emerging consensus around subfamilial groupings within Ericaceae, such as Ericoideae, Rhododendroideae, Arbutoideae and Vaccinioideae.

The shift toward a phylogenetic approach became more prominent in the late 20th century, as seen in the works of Thorne (1992) and Takhtajan (1997), who began integrating a greater number of genera into Ericaceae and recognized evolving molecular evidence. The most significant advancement came with the phylogenetic classification by Kron *et al*. (2002), who, through extensive molecular data, redefined Ericaceae as a single, broad family (*sensu lato*), encompassing many previously separate families. This modern framework established a robust classification system based on evolutionary relationships, dividing the family into subfamilies such as Enkianthoideae, Monotropoideae, Arbutoideae, Ericoideae, and Vaccinioideae, and further organizing them into 20 tribes.

Recent studies on molecular and morphological studies have helped clarify tribe delimitations, such as within the subfamily Ericoideae, where tribes like Bejarieae and Phyllodoceae are being redescribed due to weak support for their circumscription and relationships in earlier analyses (Gillespie & Kron, 2010). There remains ongoing debate regarding the circumscription and monophyly of subfamilies such as Monotropoideae and Pyroloideae. Studies on Monotropoideae show genetic distinctiveness among species complexes and highlight the complexity of relationships within this group (Jolles & Wolfe, 2012). The megagenus *Erica*, which contains over 850 species primarily in Southern Africa, has been redefined by integrating morphological and molecular data, enhancing species delimitation (Nelson *et al*., 2024)

2.3 Global Distribution

Ericaceae is a widespread family, primarily distributed in temperate and montane tropical regions, with centers of diversity in North America, East Asia, and Southeast Asia (Kron *et al*., 2002). The family comprises approximately 124 genera and about 4000 species worldwide (Stevens, 2001 onwards). In China, Ericaceae is particularly diverse, with 19 genera and over 600 species recorded, of which about 500 are endemic (Fang & Min, 1991). Southeast Asia harbours a considerable diversity as well, notably in the montane regions of Malaysia, Indonesia, and the Philippines, where genera such as *Rhododendron* and *Vaccinium* are well represented (Argent, 2006). In the Americas, the family reaches high diversity in the Andes, with numerous endemic genera and species, particularly in subfamilies such as Vaccinioideae and Ericoideae (Luteyn, 2002). In Africa, *Erica* has radiated extensively in the Cape Floristic Region with nearly 700 species, mostly endemic (Pirie *et al*., 2011). Australia and New Zealand also host members of Ericaceae, particularly from the Epacridoideae subfamily (Powell *et al*., 1996). Molecular phylogenetic studies, supported by field observations (Mao *et al*., 2016), suggest close biogeographical relationships of some Ericaceae lineages across Asia, Australasia and South America.

2.4 Distribution in India

The family Ericaceae is distributed across a wide range of ecological zones in India, from the temperate and subalpine Himalayas to the montane evergreen forests of the Western Ghats. The family Ericaceae in India comprises approximately 11 genera and about 280 species, including around 46 endemic taxa (Sanjappa & Sastry, 2014). The highest diversity occurs along the Himalayan belt, with distinct floristic compositions in the Eastern and Western Himalayas. Genera such as *Rhododendron*, *Agapetes*, *Vaccinium*, *Gaultheria* and *Pieris* dominate the high-elevation forests of this region. In the Western Himalayas, species like *Rhododendron arboreum*, *R. campanulatum*, and the recently described *R. rawatii* from Uttarakhand (Rawat *et al*., 2023) are common elements. In contrast, the Western Ghats of Peninsular India support scattered populations of species like *Gaultheria fragrantissima*, *Vaccinium leschenaultii*, and *Pieris ovalifolia*, typically restricted to shola forests and high-altitude grasslands (Pascal & Ramesh, 1997). The distribution of these taxa outside the Himalayas reflects relic populations likely linked to historical climatic and biogeographic events. Overall, the Ericaceae in India demonstrate a strong preference for cool, moist habitats, particularly in montane regions, and continue to be a focus of taxonomic and ecological research due to their high endemism and sensitivity to environmental change.

Northeast India, comprising states such as Arunachal Pradesh, Sikkim, Nagaland, and Meghalaya, is a major center of diversity for the Ericaceae family, with an estimated 250–300 species reported from the region (Mao *et al*., 2016; Paul *et al*., 2021). This diversity is primarily concentrated in the montane and subalpine zones of the Eastern Himalayas, where the combination of high rainfall, altitude variation, and temperate climate provides ideal conditions for temperate flora. The genus *Rhododendron* is particularly diverse, with over 100 species documented in Arunachal Pradesh alone (Pradhan & Lachungpa, 1990; Mao *et al*., 2016). In addition, *Agapetes* is well represented with more than 30 species, including several newly described taxa such as *A. arunachalensis*, *A. dalaiensis*, and *A. siangensis* (Banik & Sanjappa, 2023). Other prominent genera include *Vaccinium*, *Gaultheria*, and *Pieris*, which contribute significantly to the floristic composition of the region. Ongoing botanical exploration continues to uncover new species, underscoring the region's high endemism and the likelihood that the true diversity of Ericaceae in Northeast India is still underestimated (Krishna *et al*., 2012; Deka *et al*., 2018). These findings highlight Northeast India as a critical area for Ericaceae research and conservation.

2.5 Seedcoat Morphology

Before the late 1960s, seed illustrations of Ericaceae were primarily based on light microscopy (Sleumer, 1941; Luteyn, 1976). The seeds of the Ericaceae are often minute and require scanning electron microscopy (SEM) for detailed surface analysis. Most Ericaceae seeds are small, ranging from 0.2 mm to 2 mm, and are produced abundantly within capsules or berries (Luteyn, 1976). According to a study by Luteyn (1976), seeds of Vaccinioideae tend to have reticulate seed coats, while Ericoideae seeds often show longitudinally striated or smooth surfaces. Ivanina (1966) noted that differences in seed coat morphology could be linked to adaptations to diverse habitats. In their extensive study, Kron *et al*. (2002) found that seed surface characteristics generally correspond to tribal divisions within Ericaceae. Seed morphology, such as the presence of mucilage cells or elaborate testa ornamentation, supports classification at the generic level. In *Vaccinium*, capsules contain many small anatropous seeds with a reticulate or striate surface, while *Erica* species have smaller, smoother seeds (Kron & Luteyn, 2005). A comprehensive study by Szkudlarz (2009) examined seed morphology across 136 Erica species, predominantly from South Africa but including some from Europe and tropical Africa. Using light and scanning electron microscopy (SEM), the seeds were described based on shape, primary surface sculpture, and fine relief of the seed coat. Ten major diagnostic traits allowed grouping the species into 14 clusters with 40 morphologically homogenuous subgroups, suggesting seed traits have high taxonomic value and can aid species identification. The study also noted close seed coat similarities between species separated geographically, confirming the phylogenetic relevance of seed coat morphology. In the subfamily Monotropoideae, which includes mycoheterotrophic species with "dust seeds," recent work (Baskin & Baskin, 2021) showed these small seeds (<0.9 mm) lack differentiated embryos and require fungal association to germinate symbiotically. Such micro-morphological features are vital for distinguishing genera and species, especially in taxonomically complex groups.

2.6 Palynological Study

Several studies on the pollen morphology of the Ericaceae family have been published over time, with Erdtman (1952) being one of the pioneers in providing foundational work. However, most of these studies have focused on a limited number of species (Hideux, 1972; Furness, 1990) or on regional floras (Wolfe, 1973; Sarwar & Takahashi, 2006). Sarwar and Takahashi (2006) examined the pollen morphology of Asian species, while Hideux (1972) and Wolfe (1973) investigated the North American and European taxa, respectively. Pollen studies of natural hybrids in Ericaceae have been addressed by Kron and Luteyn (2005). In his survey of more than thirty species, Hideux (1972) reported diverse pollen types within Ericaceae, leading to greater focus on pollen variation within the family. According to Kron *et al*. (2002), pollen grain size and exine structure offer phylogenetic insights, but may have limited taxonomic utility at lower taxonomic levels in Ericaceae. However, Hideux (1972) and Sarwar & Takahashi (2006) emphasized that the exine sculpture patterns, such as reticulate, rugulate, or verrucate surfaces that assist in distinguishing genera and sometimes species. Ericaceae pollen is typically characterized by 3-colporate apertures and elaborate exine ornamentation (Furness, 1990; Sarwar & Takahashi, 2006).

Palynology has become an essential tool in systematics, providing crucial phylogenetic evidence (Dransfield *et al*., 2008; Doyle & Endress, 2010; Hesse & Blackmore, 2013). It focuses on lineage-specific pollen wall evolution and offers evolutionary insights into floral traits (Aftab & Perveen, 2006). Despite the vast number of angiosperm species recognized by The Plant List (350,699 species), only about 10% have undergone detailed pollen morphology study, with fewer still investigated at ultrastructural levels (Halbritter *et al*., 2018). Hence, continuous traditional and advanced palynological research remains necessary. In an era increasingly reliant on electronic resources, pollen databases like PalDat (Weber & Ulrich, 2017) serve as vital platforms for data sharing and pollen identification. Although journal publications are transitioning to electronic formats, illustrated monographs based on pollen morphology continue to be indispensable reference sources.

Limited palynological work has been conducted on Ericaceae species from regions like Northeast India, despite their ecological richness. While studies from Japan and Pakistan (Sarwar & Takahashi, 2006) exist, systematic palynological research focusing on Indian Ericaceae remains sparse. The present study aims to bridge this knowledge gap through comprehensive pollen morphology and seed micromorphology studies of Ericaceae species from Mizoram, India.

2.7 Threats and Conservation status

Endemic and RET species form the backbone of ecosystem resilience (Dee *et al*., 2019). Ericaceae members, owing to their ecological specialization, are often endemic to specific habitats, particularly in montane and temperate regions. Anthropogenic activities and climate change pose significant threats to these specialized taxa (Namgail *et al*., 2009). Collaborative conservation initiatives involving local communities are vital for protecting RET species and preserving biodiversity (Brooks *et al*., 2006). The Ericaceae family contains numerous RET species globally (Bryde, 1979; Nayar & Sastry, 1990). Globally, about 20–25% of Ericaceae species are considered at risk due to habitat loss (Stevens, 2001 onwards). In India, where biodiversity is exceptionally rich, about 10% of the flowering plants are threatened (Nayar & Sastry, 1987, 1990). In the Eastern Himalayas and Northeast India, many *Rhododendron sp.* are endangered due to habitat destruction and limited distribution (Mao & Sarmah, 2013). In Mizoram, 15 species under 5 genera under Ericaceae are reported (Sinha, 2012).

2.8 Ethnobotany

Ethnobotanical research plays an important role in understanding indigenous uses of plants (Bhattarai, 1992). Although less well documented compared to other families, certain Ericaceae species have traditional medicinal applications. The first ethnobotanical studies on Ericaceae were reported from North America and East

Asia (Small & Catling, 1998). Many members of the Ericaceae family are valued for their health benefits, particularly fruits like cranberry, blueberry, bilberry, bog bilberry, lingonberry, and huckleberry, which are rich in antioxidants and essential nutrients. Many species within the family are highly valued in horticulture due to their vibrant, ornamental flowers and adaptability to diverse climatic conditions. Additionally, several species are used in traditional medicine to treat inflammatory conditions, pain, gastrointestinal disorders, common cold, asthma, and various skin ailments. Some of the species, such as certain *Rhododendron* spp., are known for their toxic properties and have historically been used as a source of poison (Popescu & Kopp, 2013 -a & b). Other beneficial health-related outcomes, including antioxidant, antimicrobial, anti-inflammatory, and protective effects against diabetes, obesity, cancer, neurodegenerative diseases and cardiovascular disorders is also found (e.g., *Vaccinium sp.*) (Martău *et al.*, 2023). Additionally, several species are valued for their ornamental beauty and are widely cultivated in gardens and landscapes (e.g., *Rhododendron* sp., *Azalea* sp., *Calluna sp*.) (Johnson & Lyon, 1985). The first significant study on ethnobotany of Ericaceae in India was conducted by Panda (2008), focusing on the Eastern Himalayas and Northeastern India, excluding Mizoram and Tripura. Despite their significance, the ethnobotanical knowledge of Ericaceae plants remains poorly documented in regions like Mizoram, likely due to their limited occurrence, unique geographical conditions, and lack of extensive research compared to other states.

2.9 Molecular Phylogeny

Molecular studies, such as those by Kron *et al*. (2002), strongly support the monophyly of Ericaceae. The family is placed within the Ericales order and is considered to be closely related to families such as Clethraceae and Cyrillaceae (APG III, 2009; APG IV, 2016). Early molecular work by Anderberg (1993) and subsequent studies (Bremer *et al*., 2002; Anderberg, 2002) helped clarify the relationships among subfamilies. Kron *et al*. (2002 a & b) proposed a classification recognizing seven subfamilies, including Vaccinioideae, Ericoideae, and Enkianthoideae. Molecular phylogenetic methods using chloroplast genes (*rbcL,* *matK*) and nuclear ribosomal ITS regions have revolutionized our understanding of Ericaceae systematics (Stevens, 2001 onwards; Goetsch *et al*., 2005). These studies revealed unexpected relationships, such as the close affinity between Vaccinioideae and Arbutoideae (Goetsch *et al*., 2005), and showed that traditional classifications based solely on morphology often do not reflect evolutionary history. Molecular data further indicated that several genera (*Rhododendron*) are paraphyletic and require reclassification (Gustafsson *et al*., 2008).

In India, molecular studies on Ericaceae remain limited, especially in Northeast India, where numerous endemic taxa are found. Molecular phylogenetic research using DNA barcoding and sequencing of plastid and nuclear markers can illuminate the evolutionary relationships among Ericaceae species of Mizoram, contributing to global data repositories.

CHAPTER 3

3. Study Area

3.1 Mizoram

Mizoram, located in northeast India, forms part of the Indo-Burma biodiversity hotspot is one of the most species-rich regions in the world. Its rugged hills, deep valleys, and subtropical climate support diverse ecosystems such as tropical and subtropical forests, bamboo groves, and moist evergreen forests, harboring numerous Ericaceae species. The complex topography and ecological variation make the state a key area for biodiversity and ecological research.

3.1.1 Geographical Location

Covering about 21,087 km² between 21°58′–24°35′ N and 92°16′–93°29′ E (Statistical Abstract of Mizoram, 2000 - 2001), Mizoram borders Myanmar (east, south), Bangladesh (west), and the Indian states of Assam, Manipur, and Tripura. It has eleven districts, with Aizawl as the capital. Forests occupy roughly 86% of the total area (FSI, 2017), comprising 138 km² of very dense, 5,858 km² of moderately dense, and 12,752 km² of open forest

3.1.2 Physiography

The state is characterized by north–south trending hill ranges and narrow valleys, grouped into high (>1300 m), medium (500–1300 m), and low (<500 m) elevations. Western Mizoram features dissected hills and valleys that serve as fertile agricultural zones.

3.1.3 Geology

Mizoram lies within a sedimentary basin rich in sandstone, clay, limestone, coal, and petroleum. The terrain is shaped by folded sedimentary layers forming anticlines and synclines. The Surma Group (west) shows trellis drainage, while the Barail Group (east) exhibits dendritic patterns (Munshi, 1964).

3.1.4 Drainage

A dense network of monsoon-fed rivers flows mainly north or south (Verma, 2011). Major northern rivers include Tlawng, Tuivawl, and Tuirial, while southern systems like Chhimtuipui and Khawthlangtuipui drain into Myanmar and Bangladesh, forming 25 distinct watersheds.

3.1.5 Climate

Mizoram experiences a moderate climate with temperatures from 10°C–32°C and an annual mean of ~22°C. Rainfall ranges between 2000–3500 mm, mainly from May–September, with high humidity (Anonymous, 2008). A gradual rise in temperature and decline in rainfall have been observed in recent decades (Sati, 2017).

3.1.6 Soil

Soils are young, sandy to loamy, and acidic (pH 4.5–6.0), derived from sedimentary rocks. They are nutrient-poor but rich in organic matter and iron (Sarker & Nandy, 1976). Classified as Entisols, Inceptisols, and Ultisols, these soils support forest and plantation crops (Kumar *et al*., 2008).

3.1.7 Vegetation and Forests

Based on Champion and Seth (1968), forests of Mizoram include:

- **Tropical Wet Evergreen Forests** — luxuriant stands of *Dipterocarpus turbinatus*, *Terminalia myriocarpa*, and *Mangifera indica*.
- **Tropical Semi-Evergreen Forests** — mixed species like *Artocarpus chama*, *Schima wallichii*, and *Bombax insigne*.
- **Montane Subtropical Pine Forests** — high-altitude forests dominated by *Rhododendron* sp., *Lithocarpus dealbatus*, *Prunus cerasoides*, and *Pinus kesiya*.

  This vegetation diversity underpins the state's rich ecological balance.

3.2 People and Culture

Mizoram hosts 37 sub-tribes and 14 Scheduled Tribes (Anonymous, 1991), with the Mizo (Lushai) people forming the majority (Shakespeare, 1912). Major ethnic groups include the Lai (Pawi), Mara, Hmar, Lusei, and Chakma (Dutta, 1992). The Mizo language, derived from Lushai, is the lingua franca (Phukan, 1992; Thanga, 1992).

Cultural life revolves around festivals such as Mim Kut**,** Chapchar Kut, and Pawl Kut, celebrating agricultural cycles. Traditional dances like Cheraw (Bamboo Dance) and Chheihlam are integral to social life. The Rhododendron Festival (Chokhlei Kut)**,** first held in 2018 at Sentetfiang near Phawngpui, highlights the importance of the floral diversity in the region.

The traditional attire, puan, is a handwoven cloth with intricate patterns. Rice is the staple food, complemented by traditional dishes like *Mizo Bai* and *tlak*. Wild edible plants such as *Clerodendrum colebrookeanum*, *Eryngium foetidum*, *Hibiscus sabdariffa*, *Parkia timoriana*, and *Zingiber officinale* contribute to nutrition and livelihoods (Kar *et al*., 2013), reflecting deep ethnobotanical knowledge and sustainable practices.

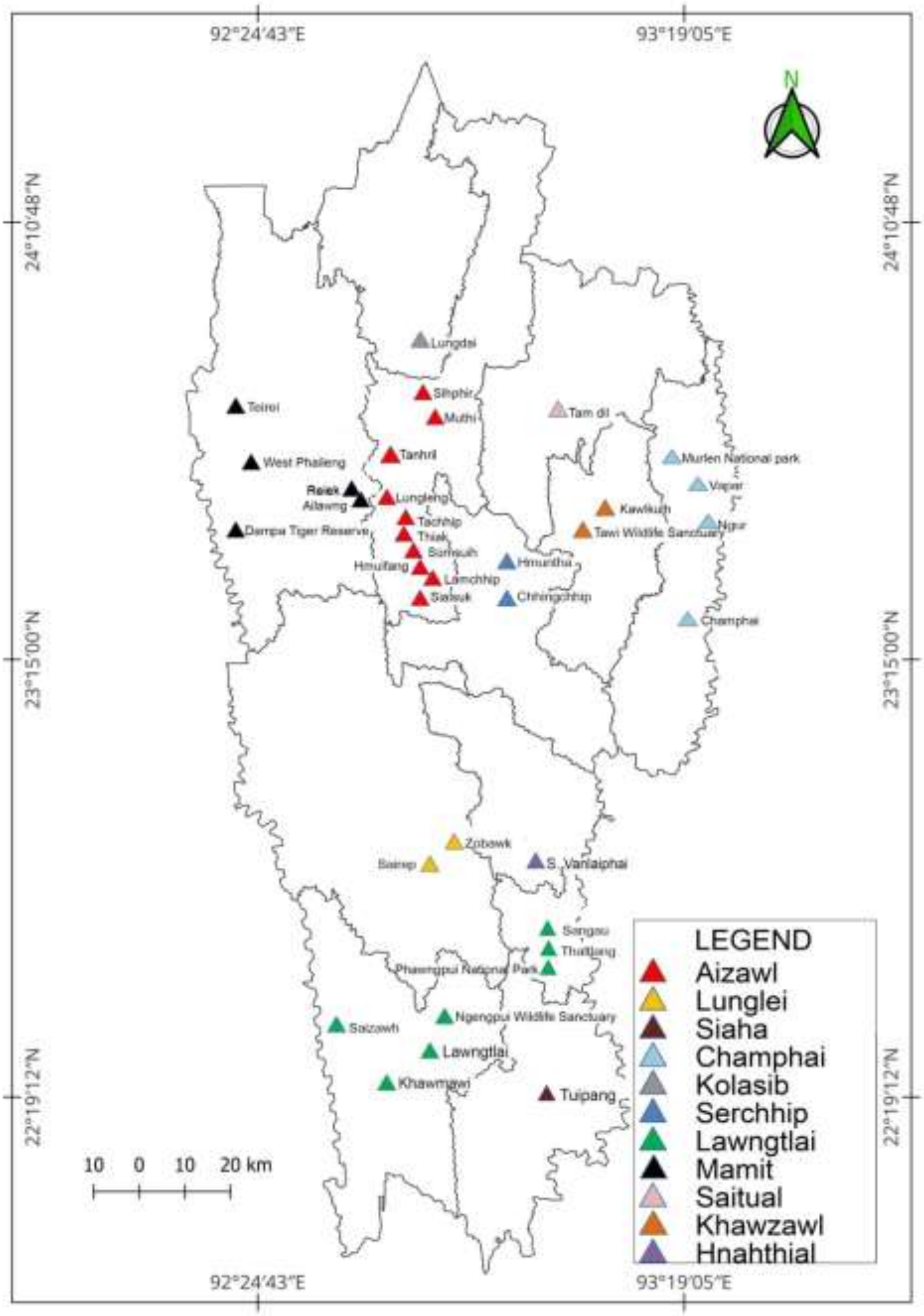

Figure 3.1: A map of Mizoram showing the location of the study sites.

CHAPTER 4

4. Materials and Methods

4.1 Field Surveys and Data Collection

Taxonomic field investigations were carried out at multiple locations throughout Mizoram, India. From 2018 to 2023, intensive field surveys were conducted, particularly during the flowering and fruiting seasons, to collect specimens belonging to the Ericaceae family. However, the COVID-19 pandemic significantly disrupted field-based research efforts. Restrictions on travel, quarantine protocols and limited access to remote or protected areas during 2020 and 2021 hindered timely plant collection, causing delays in key studies. Fieldwork extended across five major protected areas Phawngpui National Park, Murlen National Park, Ngengpui Wildlife Sanctuary, Tawi Wildlife Sanctuary and Dampa Tiger Reserve. Additionally, surveys were carried out in 31 villages across 11 districts of Mizoram, with a focus on state forest reserves, public parks, and community-managed forests (Fig. 3.1). These study sites were selected to represent the major ecological, altitudinal and biogeographical gradients of the state. Site selection was guided by herbarium records, published floras, accessibility, habitat diversity and known occurences of Ericaceae taxa. Villages within each district were chosen to cover both protected and community-managed forest areas, ensuring comprehensive sampling of the taxonomic and ecological diversity of the family. Collection sites included diverse microhabitats such as stream banks, waterfalls, rocky outcrops, and cool, shaded moist environments. Photographic documentation was a critical part of the study, with high-resolution images capturing plant morphology that include leaves, flowers, fruits, and surrounding habitat taken using a DSC-W610 digital camera (Sony, Tokyo, Japan) and a D5300 DSLR camera (Nikon, Tokyo, Japan). GPS coordinates were recorded for each collection site to ensure accurate geolocation of the specimens.

4.2 Plant Collection

During the field surveys, specimens were thoughtfully collected by selecting healthy and representative plants. Comprehensive field notes were taken for each sample, documenting details such as the habitat, nearby plant species, and any unique or distinguishing characteristics. The collected specimens were then carefully pressed and dried to maintain their structural integrity for subsequent analysis and preservation.

4.3 Plant Identification

All morphological traits, including plant habit, height, color, inflorescence type and arrangement, were thoroughly recorded. Floral structures were dissected using standard dissection tools, with particular attention given to the number, size, texture, shape, and arrangement of petals, sepals (calyx), stamens, and pistils. Microscopic details such as trichomes, pollen grains, and seeds were studied using a range of equipment including simple, light, stereo, and scanning electron microscopes. Precise measurements of plant parts were taken using a ruler. Observations were systematically documented through detailed descriptions, illustrations, and photographs. Fresh specimens from individual plants were used for comprehensive morphological assessment.

Species identification was conducted by examining and comparing traits with relevant taxonomic literature such as Kron *et al.* (2002), Stevens *et al.* (2004) and Sinha *et al.* (2012). Additional references included online databases like the Global Biodiversity Information Facility (GBIF, 2023), Plants of the World Online (POWO, 2024), the World Flora Online (WFO, 2022), and Tropicos (2023) of the Missouri Botanical Garden (2022). Herbarium collections at ASSAM (BSI, Shillong) and CAL (BSI, Kolkata) were reviewed, along with digital herbarium records from the Royal Botanic Garden, Kew (K) and Edinburgh (E). All specimens were prepared following the standard herbarium techniques outlined by Jain & Rao (1977) and subsequently deposited in the Mizoram University Herbarium (MZUH), Department of Botany.

4.4 Herbarium Methodology

A herbarium serves as a scientific repository for plant specimens systematically arranged and classified using standard taxonomic principles.

(a) Plant Collection

Specimens were collected during flowering and fruiting seasons to capture diagnostic features during 2018-2023. Woody taxa were represented by flowering or fruiting twigs, while entire herbaceous plants, including underground parts, were gathered. Standard procedures of Jain & Rao (1977) and Womersley (1981) were followed for processing and preservation. Field photographs were taken to aid identification and documentation.

(b) Field Notes and Numbering

Detailed observations were recorded in pre-numbered field notebooks, and each specimen was tagged with a matching number for accurate traceability during processing and cataloging.

(c) Pre-Drying Preservation

Collected specimens were wrapped in newspapers, bundled, and placed in polythene bags soaked in 30% paraformaldehyde (300 g in 3 L warm water) to maintain freshness. On returning to the lab, specimens were aired to remove fumes before pressing.

(d) Pressing and Drying

Specimens were flattened to standard herbarium size (11 × 16 in). Oversized or bulky materials were sectioned, ensuring visibility of key traits. Labels were attached, and presses were tightened regularly. Drying was done in a heated oven (95–113°F) with good ventilation to prevent mold.

(e) Pest Protection

Dried specimens were treated with 10 % formalin protected with naphthalene balls, replaced every three months to prevent insect and fungal damage.

(f) Mounting and Stitching

Specimens were mounted on durable white sheets (28 × 42 cm) using Fevicol adhesive. Bulky parts were stitched with strong thread, and sheets were pressed overnight for firm adhesion.

(g) Labelling

Labels (4 × 2.5 inch) affixed on the lower right corner contained essential data—collection number and date, family, species, locality, phenological stage, distribution notes, field remarks, and collector details—ensuring accuracy and retrievability.

4.5 Seed Coat Morphology and Palynology

For seed-coat micromorphology, seed size, shape, appendages, apical structures, cell architecture, and cell orientation were documented using the framework following Corner (1976), Barthlott (1981), Fagúndez & Izco (2009) and Fagúndez *et al.* (2010). Fresh pollen and seed samples were dried in a desiccator, mounted on brass stubs with double-sided adhesive tape, and sputter-coated with gold using a Fine Coat Ion Sputter JFC-1100. High-resolution images were captured on a JEOL JSM-6360 field-emission SEM at Cyto-Gene Research & Development (Lucknow) and the SAIF facility at NEHU, Shillong. Palynological analysis was carried out on fresh pollen from all collected Ericaceae taxa (Schlag-Edler & Kiehn, 2001). Pollen grains were measured in micrometres as Polar length (P), tetrad diameter (D), equatorial diameter (d) and pollen diameter (E for monad). Terminology follows Erdtman (1952), Punt *et al*. (2007), Halbritter *et al*. (2018).

4.6 Cluster analysis of Pollen grains and Seed coat characters

Species were grouped according to similarities in pollen and seed-coat micromorphology by performing hierarchical clustering on a character matrix derived from these traits. The Unweighted Pair Group Method with Arithmetic Mean (UPGMA) and Euclidean distance were applied in R (v4.1.2; R Core Team, 2021) to generate a dendrogram illustrating species relationships. In addition, a principal component analysis (PCA) was conducted in RStudio (v4.1.2) to explore trait variation and quantify the major axes of morphological divergence. Data visualization employed the ggplot2 (Wickham, 2016), FactoMineR, factoextra (Kassambara & Mundt, 2020), corrplot (Wei & Simko, 2024), and ggrepel (Slowikowski, 2024) packages.

4.7 Preparation of Identification Keys

The identification keys were developed based on a comprehensive analysis of taxonomic, seed coat, and pollen morphological characters**.** These diagnostic traits were carefully selected to distinguish among the studied taxa with precision. Key vegetative and reproductive features such as leaf morphology, inflorescence structure, floral characteristics, and fruit type were integrated with micromorphological data derived from scanning electron microscopy (SEM) observations of seed coat patterns and pollen sculpturing.

Special attention was given to palynological features including pollen shape, size, aperture type, and exine ornamentation which provide reliable taxonomic markers within the family Ericaceae. Similarly, seed coat micromorphology, encompassing surface texture, cell wall patterns, and testa structure, offered additional diagnostic criteria for species delimitation.

The combination of these morphological and micromorphological attributes enabled the formulation of an identification key, facilitating accurate differentiation of closely related taxa.

4.8 Conservation status and threat assessment:

The conservation status of Ericaceae taxa recorded from Mizoram was evaluated following the IUCN Red List Categories and Criteria (2024). Both global assessments, based on the official IUCN database, and regional evaluations derived from extensive field surveys were incorporated to determine the relative risk of extinction for each taxon. Field investigations were conducted across multiple localities in Mizoram during the flowering and fruiting seasons to ensure accurate species identification and reliable population estimates. For each species, data on the number of mature individuals and the number of known populations or locations were systematically recorded. The regional conservation status was assessed using a standardized framework aligned with IUCN criteria, ensuring consistency and comparability. Each taxon was evaluated against quantitative parameters such as population size, rate of decline, geographic range, and degree of fragmentation. This approach provides a robust basis for identifying species at risk and prioritizing conservation actions within the region.

4.9 Ethnobotany

4.9.1 Ethnobotanical survey and data collection

An ethnobotanical field survey was conducted between 2022 and 2023 to gather traditional knowledge associated with the Ericaceae plant family in Mizoram. The survey spanned seven districts Aizawl, Lunglei, Lawngtlai, Siaha, Serchhip, Champhai, and Mamit where these plants are commonly found. Fourteen villages were included in the study: Muthi, Durtlang, Sihphir, Tuipang, Zobawk, Sairep, Thaltlang, Hmuifang, Murlen, Ngur, Vapar, Reiek, Ailawng, and Dampa. These study sites were chosen on the basis of the availability of the plants from the studied family.

Adopting the methodology outlined by Martin (1995), the study involved 60 respondents from the indigenous Mizo communities, aged between 40 and 90 years. Among these key informants, 26 were women (43.33%) and 34 were men (56.67%).

Ethnobotanical information was collected through structured questionnaires, in-depth personal interviews, and open-ended group discussions (Figure 4.1). Prior Informed Consent (PIC) was obtained from all participants before data collection.

Figure 4.1: Photograph of the informants

4.9.2 Data analysis

The collected data were systematically organized using Microsoft Excel, with separate columns capturing information such as traditional uses, scientific and local names, plant habits, and modes of usage. Statistical analysis was conducted using GraphPad Prism software version 8.0.1 (244). For quantitative evaluation and the generation of a chord diagram illustrating usage patterns, the *ethnobotanyR* package was utilized within R software version 0.1.8.2021.

4.9.3 Quantitative Indices

1. Use value (UVs) and Relative Frequency Citations (RFCs)

Use Value (UV)

To determine the relative importance of the plant, Use Value (UVs) is used (Philips & Gentry 1993). Use Value is calculated using the following formula

$$UV = \frac{U}{n}$$

Where, U is the total number of citations, use reports or mentions by each informants for a particular species and n is the total number of informants interviewed. When the UV value is high, then the species has more mentions and citations. It counts as one use report or citation each time an informant identifies or describes a species of medicinal plant that is being used to treat a condition or for another reason.

Relative Frequency Citation (RFCs)

The relative frequency citation (RFC) is employed (Tardio & Pardo de Santayana 2008) to assess how often a reference or mention is made by study participants who acted as informants. It is calculated using a specific formula

$$RFC = \frac{FC}{N}$$

Here, FC represents the number of informants who cited or mentioned the plant, and N stands for the total number of informants. Values close to 1 indicate that almost all informants referenced a specific medicinal plant for treating a particular illness, while lower values suggest that the plant's usage was mentioned by only a few or, at times, a single informant.

2. Relative Importance Index (RI)

The relative significance of medicinal plants based on their use category was determined using relative importance (RI) (Tardio & Pardo de Santayana ,2008) and calculated with the following method.

$$RI = \frac{[RFC_{(\max)} + \ RNU_{(\max)}]}{2}$$

$RFC_{(max)}$, defined as the RFC of a medicinal plant species, is calculated by dividing the frequency citation of that specific species (FC) by the frequency citation of the species with the highest citation (FC_{max}). Similarly, $RNU_{(max)}$, ($RNU_{(max)}=NU/NU_{max}$), representing the relative number of use categories, is obtained by dividing the number of use categories for a particular species (NU) by the number of use categories of the species with the most categories (NU_{max}). High values suggest that a plant is widely used, while low values indicate that its application is limited to a few, or occasionally just one, use category.

4.10 Molecular Studies

4.10.1 Collection, Extraction and Amplification of Plant Sample

Young, fresh leaves were collected from the study sites to facilitate complete genomic DNA isolation. DNA extraction was carried out using the conventional CTAB protocol developed by Doyle and Doyle (1987). For each sample, around 100 mg of leaf tissue was used in the extraction process. The isolated DNA was then subjected to amplification using ITS2 and rbcL primers, with the primer specifications provided in Table 4.1.

Table 4.1. List of the barcoding primers used for PCR of the isolated DNA of the studied Ericaceae family

Sl. No.	Region	Primer	Sequences (5′ to 3′)
1	ITS2	Forward	ATGCGATACTTGGTGTGAAT
		Reverse	GACGCTTCTCCAGACTACAAT
2	*rbcL*	Forward	ATGTCACCACAAACAGAGACTAAAGC
		Reverse	GAAACGGTCTCTCCAACGCAT

4.10.2 PCR Amplification

PCR amplification for both ITS2 and *rbcL* primers was carried out in a total reaction volume of 25 µL. Amplifications were performed using a Veriti 96-Well Thermal Cycler (Fisher Scientific, Massachusetts, USA) and analyzed with a Bio-Spectrometer (Eppendorf, Hamburg, Germany). The PCR protocol included an initial denaturation at 94°C for 1 minute, followed by 35 cycles of denaturation at 94°C for 1 minute, annealing at 55°C for 30 seconds, and a final extension at 72°C for 10 minutes. PCR products were separated on 1.5% agarose gels for visualization, and high-quality products were sent to Eurofins Genomics India Pvt. Ltd., Bangalore for sequencing. The obtained ITS2 and rbcL sequences were submitted to the GenBank database, where accession numbers were assigned to each taxon.

The sequences, along with those of closely related species, were aligned using the ClustalW algorithm in MEGA X software (Cheng *et al*., 2022). Manual adjustments were made to resolve gaps and ambiguous regions to ensure accurate alignment. Phylogenetic analysis was performed using MEGA X. A model test was conducted to identify the best-fitting nucleotide substitution model based on the lowest Bayesian Information Criterion (BIC) score. Subsequently, a Maximum Likelihood (ML) phylogenetic tree was constructed using the Kimura-2-Parameter (K2P) model with a discrete Gamma distribution (G) and 1000 bootstrap replications. Reference sequences retrieved from GenBank were incorporated into the phylogenetic reconstruction, and two species from the Fabaceae were used as outgroups. The resulting tree was analyzed to determine the phylogenetic placement of the collected taxa in relation to established lineages.

CHAPTER 5

5. Results and Discussion

5.1 General characters of Ericaceae

Members of the Ericaceae exhibit diverse growth forms ranging from shrubs such as (*Vaccinium griffithianum*) to small trees (*Rhododendron arboreum*) with many species being evergreen, particularly in temperate regions (*Lyonia ovalifolia*). Some members show specialized adaptations, including mycoheterotrophy (*Monotropa uniflora*) and epiphytic growth (*V. vacciniaceum*). Roots are generally fibrous (*V. vacciniaceum*), sometimes with tuber-like swellings (*Agapetes odontocera*) shallow in trees (*R. arboreum*) or highly modified in mycoheterotrophic taxa (*M. uniflora*). Stems are usually woody (*R. formosum*), though herbaceous forms occur (*M. uniflora*) they may be erect, prostrate, or climbing (*A. odontocera*)

Leaves are simple, exstipulate, and often leathery; they may be evergreen (*Rhododendron* spp.) or deciduous (*Vaccinium* spp.) and are arranged alternately (*V. vacciniaceum*) opposite (*R. arboreum*), or sometimes in whorls (*A. odontocera*). Inflorescences may be racemose (*Vaccinium* spp.) or cymose (*Rhododendron* spp.) and occur as solitary, axillary, or terminal flowers, occasionally bracteate and pendulous. The calyx usually consists of 4–5 lobes, often fused at the base forming a tube, persistent in fruit (*Vaccinium* spp.), disc-shaped (*Rhododendron* spp.) and sometimes hairy or glandular.

The corolla is typically sympetalous and varies from urceolate (*L. ovalifolia*), to campanulate, with colours ranging from white to red. The androecium usually comprises 8–10 stamens with poricidal anthers, a feature facilitating buzz pollination. The gynoecium is generally syncarpous with about five fused carpels; the ovary is typically superior (*R. formosum*), though partly inferior in some taxa such as *V. sprengelii*, and may be unilocular (*M. uniflora*) or multilocular with axile placentation (*L. ovalifolia*). Fruits are either capsules (*L. ovalifolia*) or berries (*Vaccinium* spp.), and the seeds are numerous and minute.

5.1.11 Systematic treatment

The species in this study have been systematically arranged following the classification framework proposed by Kron *et al*. (2002). Accepted scientific names of Ericaceae species were obtained from Plants of the World Online (POWO) and the International Plant Names Index (IPNI). Morphological descriptions and terminology were adopted from Beentje (2010). The systematic treatment comprises comprehensive elements including taxonomic citation, synonymy, type information, detailed morphological descriptions, phenological data (flowering and fruiting periods), ecological notes, and distribution range. It also incorporates field-examined specimens, diagnostic illustrations, and photographic plates of floral dissections. The present study encompasses a total of ten taxa (nine species and one variety) belonging to five (5) genera, which are distributed across four (4) tribes of the family. Identification keys are provided separately at both the genus and species levels. Specimen records are documented with full details, including distribution, specific locality, altitude, date of collection, collector's name, and corresponding herbarium voucher numbers.

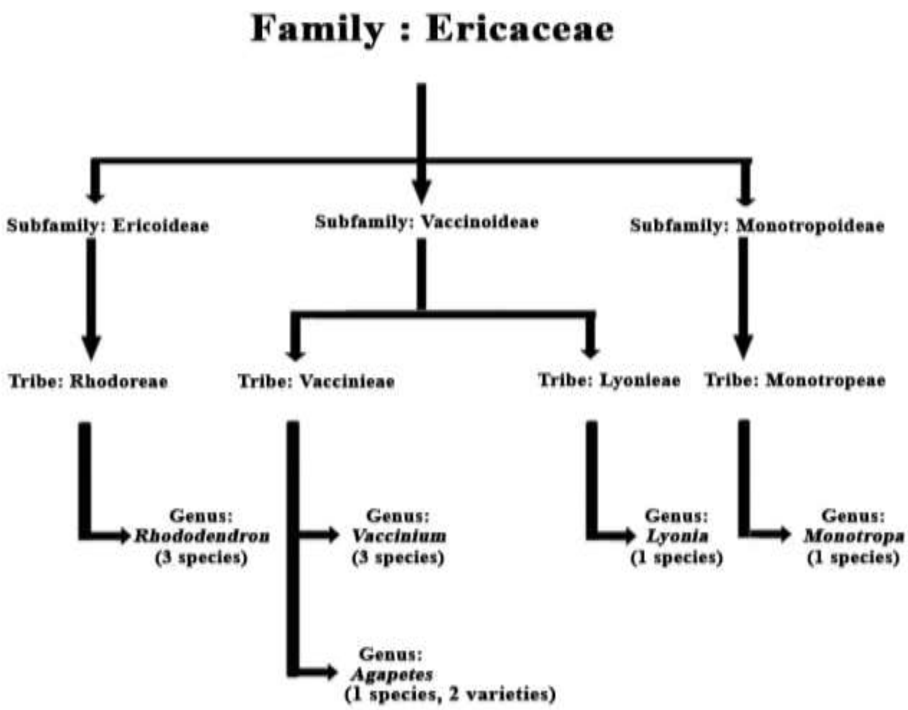

Figure 5.1: Genera of Ericaceae of Mizoram, India in accordance with the new classification of Kron *et al*. (2002).

Key to the genera:

1a. Terrestrial herb, shrub or epiphytic shrub, pollen tetrad... **2**

1b. Mycohetrotrophic perennial herb, pollen monad…………..……… **3. *Monotropa***

2a. Calyx disc shaped, persistent, pollen with viscin thread…..…….. **4. *Rhododendron***

2b. Calyx not disc shaped, pollen without viscin thread……………………………………………………………..……..………. **3**

3a. Seed shape sub-globose, plants are terrestrial shrub……………..… **5. *Vaccinium***

3b. Seed shape otherwise, plants can either be shrub or epiphytic……………………………………………………………………...... **4**

4a. Fruit capsule, anther basifixed and not spurred, hilum protuberant……. **2. *Lyonia***

4b.Fruit berry, anther basifixed and spurred, hilum not protuberant…………………………………………………………..… **1. *Agapetes***

***Agapetes* D. Don ex. G. Don**

Agapetes is a genus of epiphytic or terrestrial shrubs or subshrubs in the Ericaceae family, commonly found in subtropical to montane forests. Stems are woody, often pendent or scandent, sometimes forming tuberous roots. Leaves are simple, alternate, leathery, and evergreen, typically with entire margins and a glossy surface. Inflorescences are axillary or terminal, bearing few to many pendulous, tubular to campanulate flowers. The corolla is brightly coloured—usually red, pink or orange and often ornamented with darker markings or ribs. Stamens are typically 10, with long filaments and anthers that dehisce by terminal pores. The ovary is inferior to half-inferior, typically 5-locular with axile placentation. Fruits are berries, often fleshy and globose, containing numerous small seeds. The genus is predominantly distributed in the Eastern Himalayas, Southeast Asia, and southern China.

Key to the varieties:

1a. Corolla pubescent, fruits green to dark green, seed coat winged on one terminal……………………………..………. **1. *A. odontocera* var. *mizoramensis***

1b. Corolla glabrous throughout, fruits bright red, seed coat not winged…………………………….…………… **2. *A. odontocera* var. *odontocera***

Agapetes odontocera var. ***mizoramensis*** Banik & Sanjappa J. Bot. Res. Inst. Texas 1 : 908 (2007) G.P. Singh *et al.* Fl. Mizoram 2: 12, M. Sanjappa, & A.R.K Sastry Fascicles of Fl.Ind. 25: 1-468.2014, Banik, D., PP, B., & Sharma, S. (2015). *Agapetes odontocera* var. *mizoramensis*, J. Jpn. Bot. 90(3), 218-222. (**Figure 5.3, Plate 1**)

Type: India, Mizoram, Aizawl district, Reiek, alt. 1580 m, 24 April 2014, B.K. Sinha & Su. Datta 208994 (holotype: CAL; isotype: ASSAM).

Taxonomic Description: Epiphytic, evergreen plant, usually 1 – 1.5 m, branches slender, reddish brown, glabrous; Leaves pseudo-whorled, margin serrated to entire, oblanceolate- lanceolate, apex acute or acuminate, base cuneate, both surfaces glabrous, adaxial dark green, abaxial pale green; 12.2 – 18.5 × 3.1 – 4.2 cm; Petiole 0.2 – 0.25 cm, slender; Inflorescence in corymbs, 3 – 7 flowered; Pedicels 1– 1.5 cm long, glabrous; Calyx 0.2 – 0.25 × 0.5 – 0.6 cm, dark red with greenish apex, pubescent, 5 , fused at base, apex acute- acuminate; Corolla dark red with stripes, pubescent, tubular- urceolate, 3– 3.5 cm long, lobes 2– 4 mm slightly curved; Bracts present, 2; Stamens 1.8-2 cm long, spatulate, anthers spurred 1.9- 2.1 cm long; Ovary superior, 5-locular; style filiform, longer than stamens; stigma capitate, green with red spots, 2.4 – 2.5 cm, glabrous; Fruit a berry, globose, 0.6 cm length, fleshy.

Phenology: Flowering from April to May; fruiting from June to August.

Habitat and Ecology: Grows on moist, shaded forest slopes at elevations around 1500–1700 m. Often found on ridges and along trails within montane evergreen forests.

Distribution: Endemic to Mizoram (Phawngpui, Sairep) (Figure 5.2)

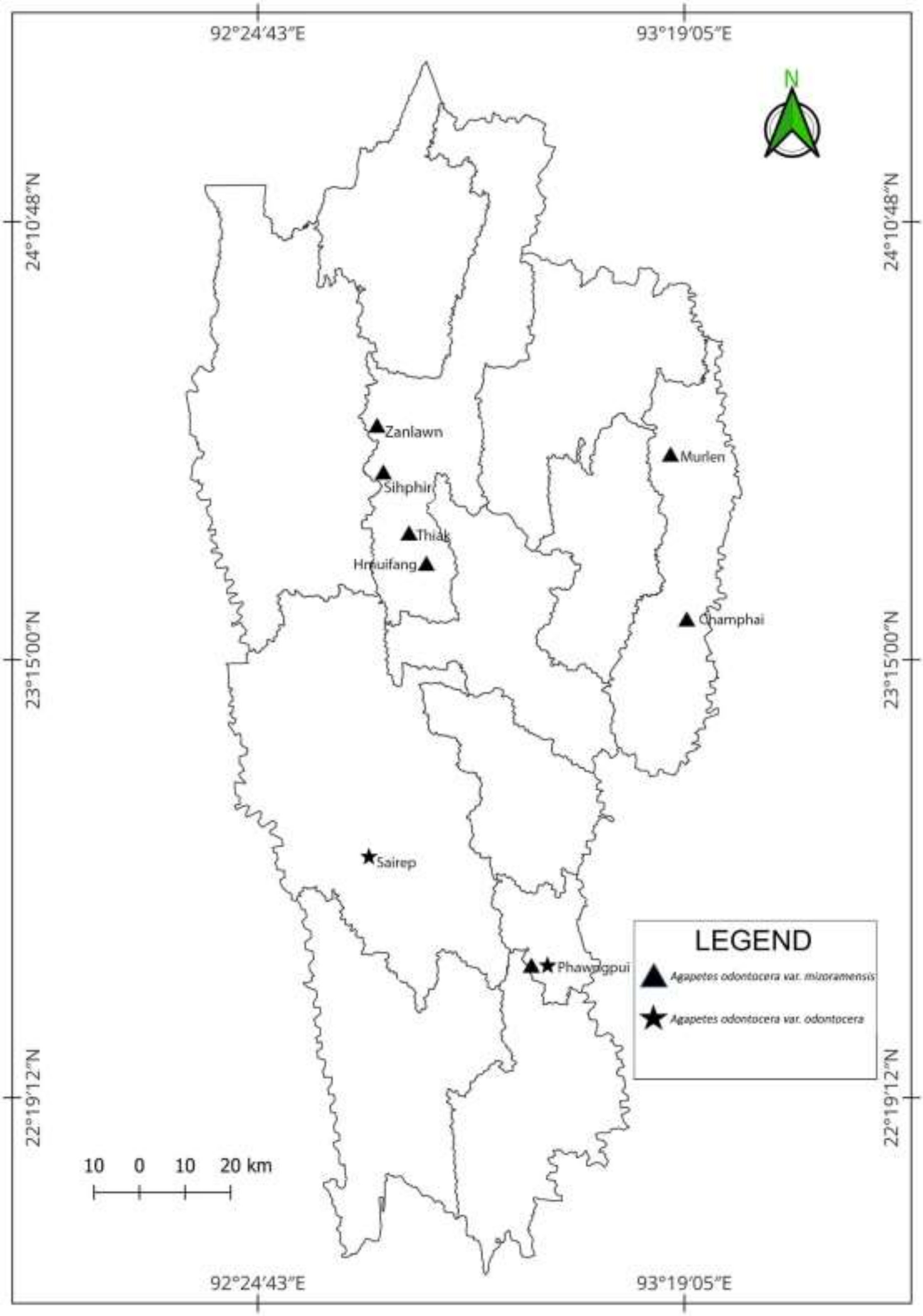

Figure 5.2: Distribution map of *Agapetes odontocera* D. Don ex. G. Don in Mizoram**.**

Vernacular name: Bawltehlantai

Species Examined: INDIA. Mizoram, Lawngtlai District, Phawngpui National Park, 22.69’11.2” N 93˚04’94.5” E, 1674 elevation, 24 April 2019, Tlanhlui 101005 (MZUH002529).

Agapetes odontocera (Wight) Hook. f. var. ***odontocera***, *Notizbl. Bot. Gart. Berlin-Dahlem* 13: 194. 1936; Hook.f., *Fl. Brit. India* 3: 475. 1882 (as *Vaccinium odontocera* D. Don); Kanjilal & al., *Fl. Assam* 2: 284. 1938; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 211. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 40. 2016 (**Figure 5.4, Plate 2**).

Type: Nepal, D. Don s.n. (holotype: BM, image seen).

Synonyms: *Vaccinium odontocera* D. Don, *Prodr. Fl. Nepal.* 181. 1825. *Agapetes odontocera* var. *nepalensis* Sleumer, *Notizbl. Bot. Gart. Berlin-Dahlem* 13: 195. 1936.

Taxonomic Description: Epiphytic, evergreen plant, usually 1 – 1.5 m, stems terete, young branches reddish or brownish, glabrous or finely pubescent; Leaves pseudowhorled, margin serrated to entire, oblanceolate- lanceolate, apex acute or acuminate, base cuneate,11.5 – 19 × 3 – 4.5 cm, margin serrulate or entire; adaxial surface dark green, glabrous, abaxial surface lighter, occasionally with fine hairs; Petiole short, slender 0.15 – 0.2 cm; Inflorescence in corymbs, 3 – 7 flowered; Pedicels 1–2 cm long, slender, glabrous; Calyx 2– 2.5 × 5.5– 6 mm, red, glabrous, 5, fused at base, apex acute; Corolla red with white stripes, glabrous, tubular,2.53– 3.5 cm long, lobes 1 – 3 mm slightly curved; Stamens 1.8– 2 cm long, 10 nos., spatulate, anthers spurred 1.9 – 2.1 cm long; Ovary superior, 5-locular, style slender, 2 – 2.5 cm glabrous; Fruit a berry, globose, 0.5 – 0.8 cm across, purple when mature, fleshy, few-seeded.

Phenology: Flowering from March to June; fruiting from July to September.

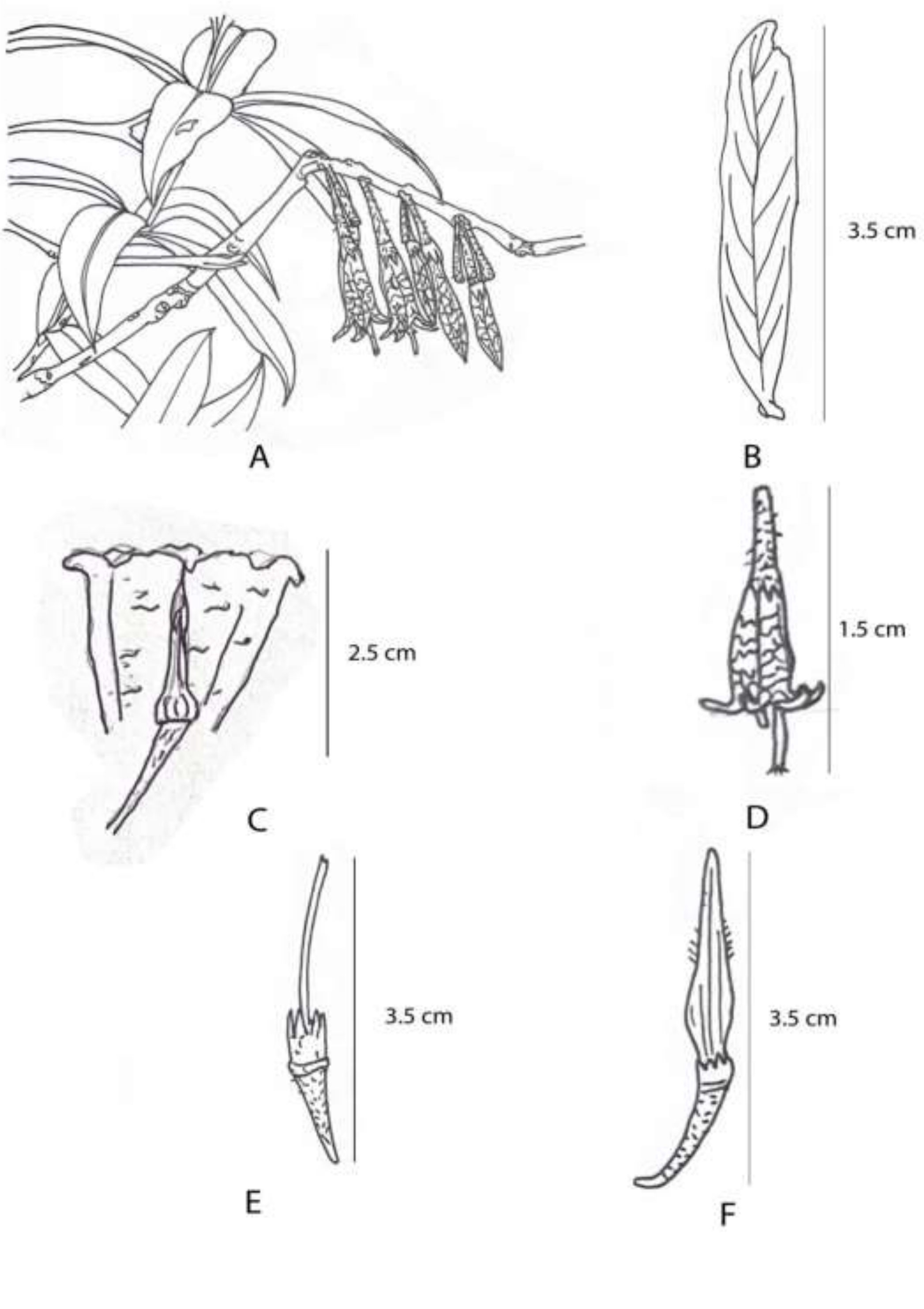

Figure 5.3: Illustration of *Agapetes odontocera* var. *mizoramensis* D. Banik & Sanjappa. A. Habit; B. Leaves; C. Open flower; D. Flower; E. Gynoecium; F. Androecium.

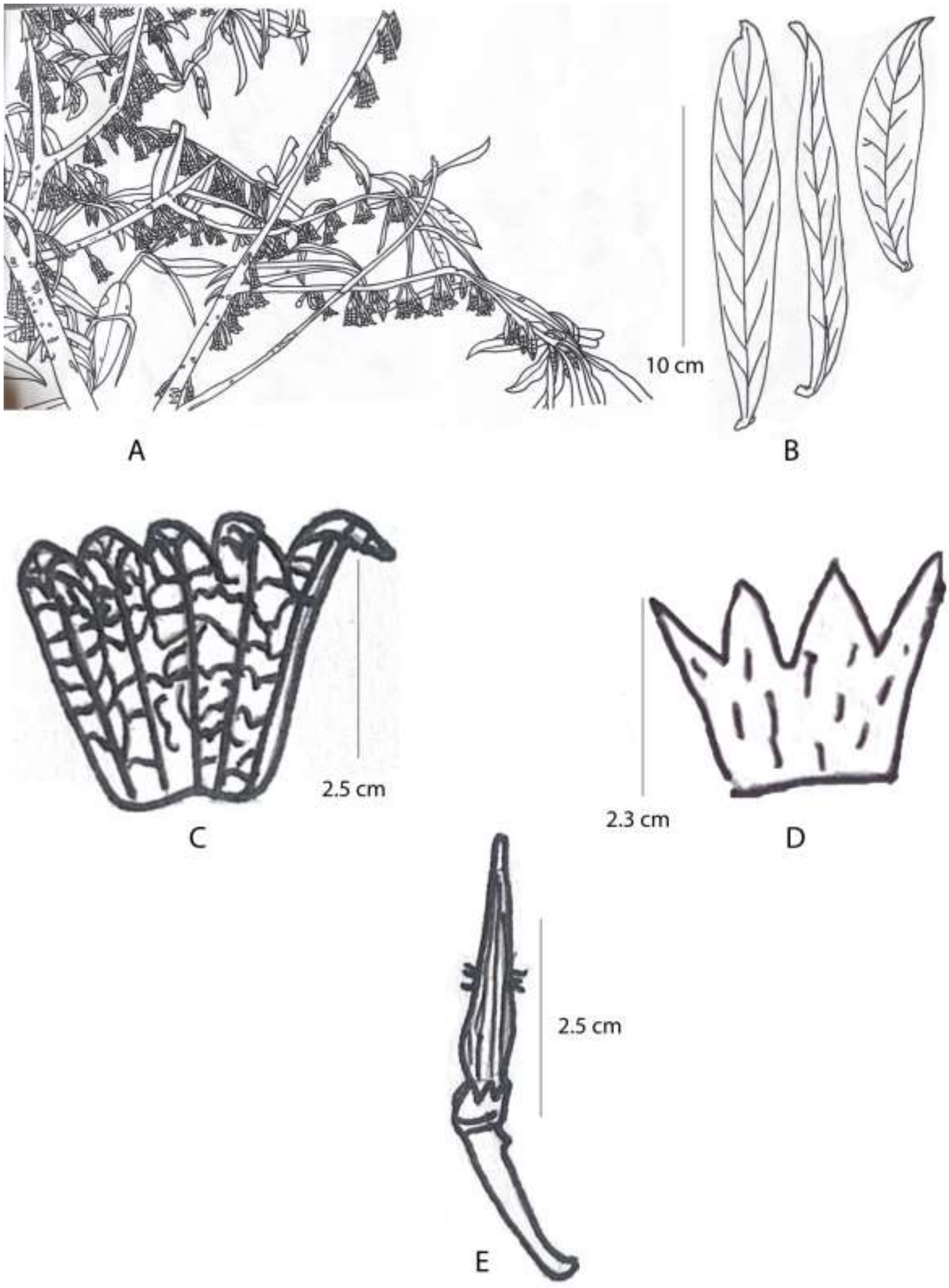

Figure 5.4: Illustration of *Agapetes odontocera* (Wight) Hook. f. var. *odontocera*. A. Habit; B. Leaves; C. Corolla; D. Calyx; E. Androecium & Gynoecium.

Habitat and Ecology: Grows as an epiphyte or on forest slopes in moist temperate forests, often associated with oaks and rhododendrons. Prefers shady, humid habitats at elevations of 1800–2800 m.

Distribution: Native to Southeast Asia and the Eastern Himalayas. Found in Mizoram (Zanlawn, Sihphir Thiak, Hmuifang, Phawngpui, Murlen, Champhai), India **(**Arunachal Pradesh**,** Sikkim, Nagaland, Meghalaya, Manipur), Nepal**,** Bhutan, China**,** Myanmar**,** Vietnam & Thailand **(**Figure 5.2).

Vernacular name: Bawltehlantai

Species Examined: INDIA. Mizoram, Aizawl District, Thiak Village, *23.48'33''* N: 92.70'00''E, 960 m elevation, 9 May 2019, Tlanhlui 101004 (MZUH002528).

Lyonia ovalifolia (Wall.) Drude, *Nat. Pflanzenfam.* 4(1): 121. 1889; Hook.f., *Fl. Brit. India* 3: 434. 1882 (as *Pieris ovalifolia* Wall. ex D. Don); Kanjilal & al., *Fl. Assam* 2: 282. 1938; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 213. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 42. 2016 (**Figure 5.6. Plate 3**).

Type: Nepal, Wallich 832 (K – holotype, image seen).

Synonym: *Pieris ovalifolia* Wall. ex D. Don, *Prodr. Fl. Nepal.* 201. 1825.

Taxonomic Description: Shrub or small tree, upto 4 m in height, branches woody, glabrous or slightly pubescent; Leaves ovate, elliptic, base obtuse to cordate, apex roughly acuminate, margin serrulate or entire; Adaxial surface dark green, glabrous; abaxial surface lighter, often pubescent, 3.7 – 16.5 × 2 – 9.2 cm; Petiole 0.7 – 1.7 cm, pubescent at base; Inflorescence raceme, axillary, pubescent, 9.2 – 15.6 cm, 20 – 30 flowered; Bracts leaf-like, green turned brown at maturity, 2 ; Calyx 5, deeply lobed, white-greenish in colour with brown streaks, 0.1– 0.2 × 0.1– 0.2 cm, triangular; Corolla white, tubular with small lobes, corolla tube 0.7– 1 cm, glabrous, corolla lobe <1 × 0.1cm; Stamens 10 Nos., filament white at base and brownish at apex, densely pubescent, curved, 0.4 – 0.9cm, anthers brown, basifixed, 0.5 cm; Ovary superior, pubescent, 5–locular; style slender, stigma capitate; Fruit capsule brown, globose, pubescent, depressed at apex.

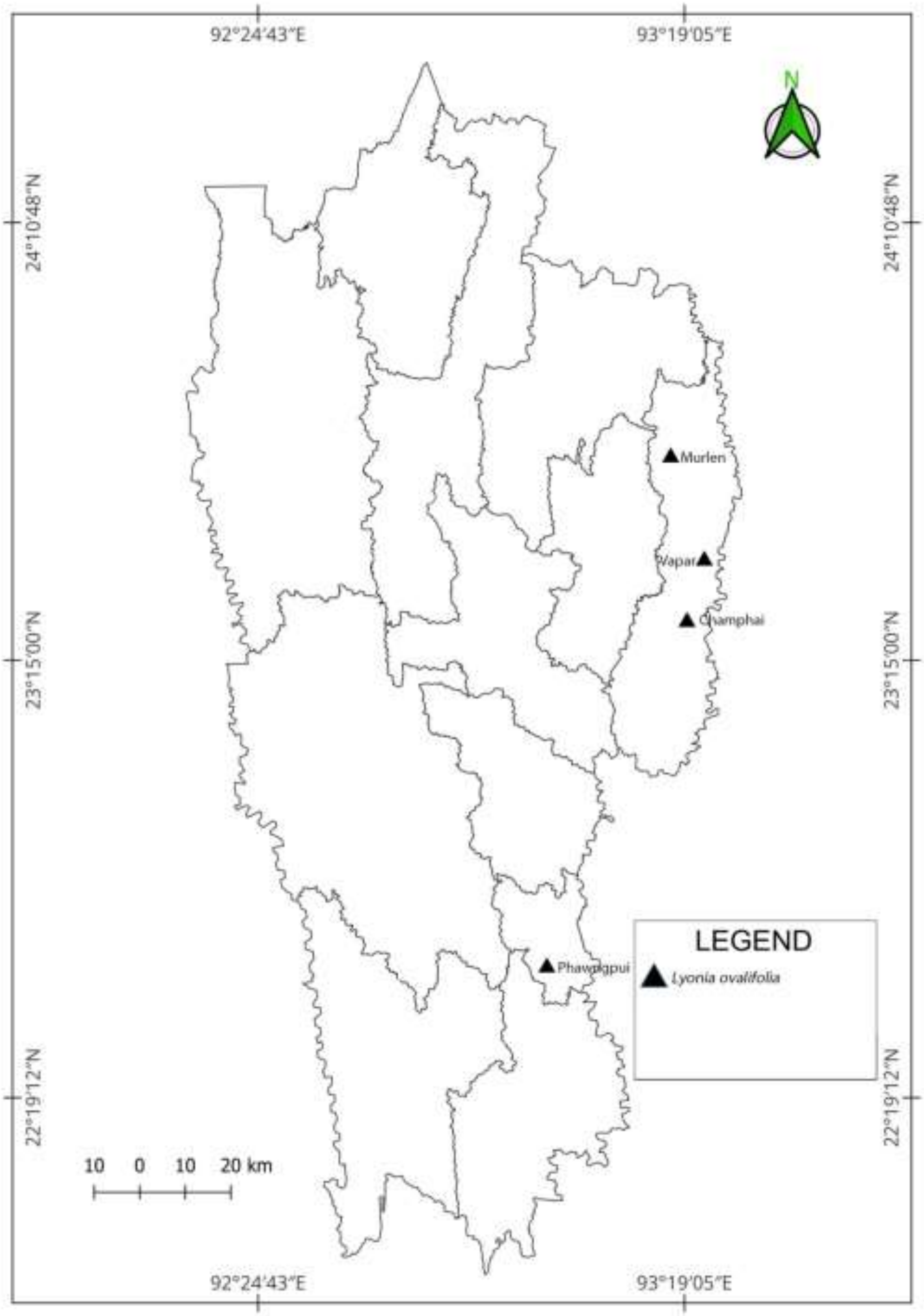

Figure 5.5: Distribution map of *Lyonia ovalifolia* in Mizoram.

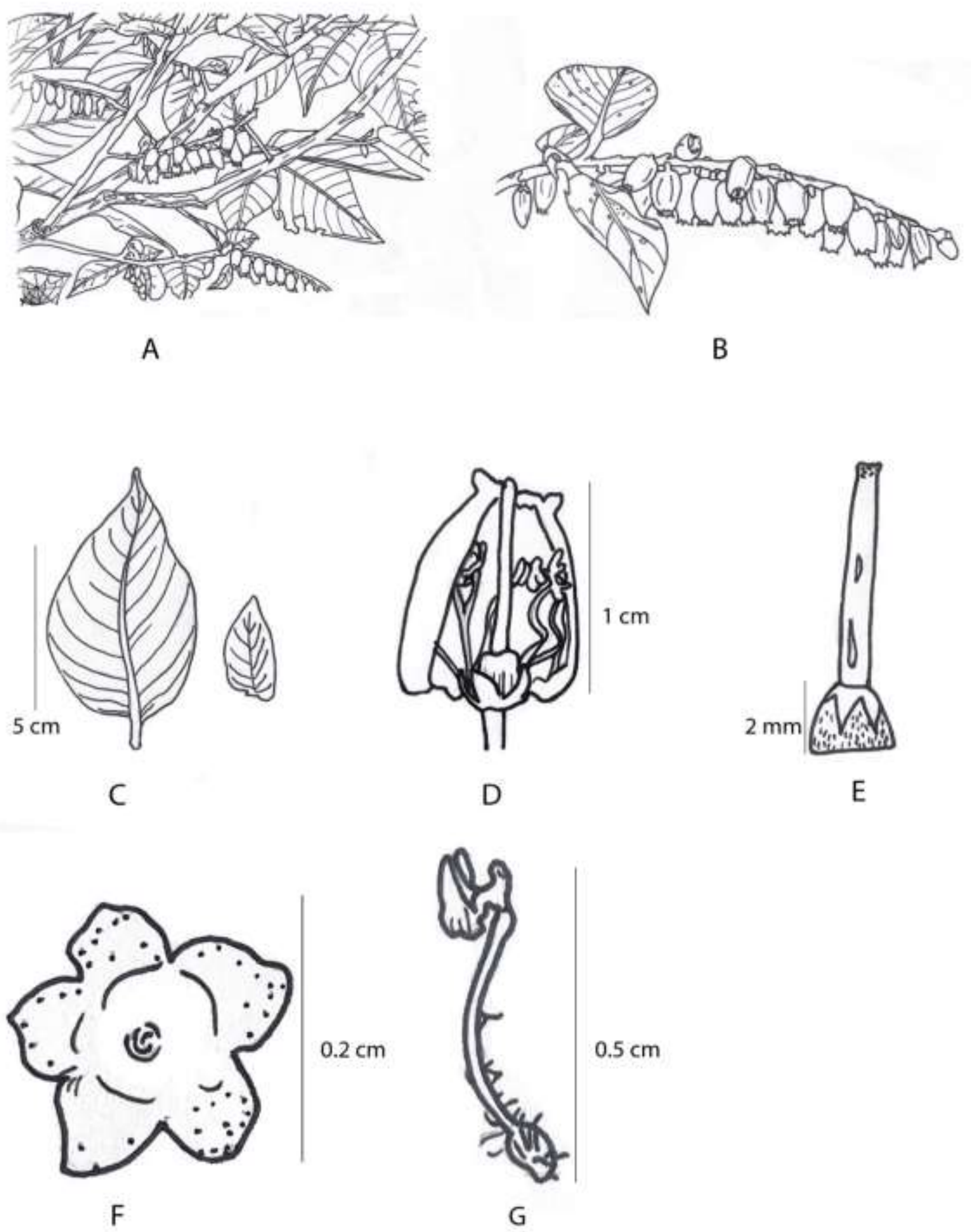

Figure 5.6: Illustration of *Lyonia ovalifolia* (Wall.) Drude. A. Habit; B. Inflorescence; C. Leaves; D. Open flower; E. Gynoecium; F. Calyx; G. Androecium.

Phenology: Flowering from March to May; fruiting from June to August.

Habitat and Ecology: Occurs in subtropical to temperate forests, forest margins, and slopes at elevations of 1200–2800 m. Often found in association with *Rhododendron* and *Quercus* species in Himalayan forests.

Distribution: Mizoram (Murlen, Vapar, Champhai, Phawngpui), India (Arunachal Pradesh, Sikkim, West Bengal), China, Japan Cambodia, Myanmar, Thailand, Vietnam, and Malaysia (Figure 5.5).

Vernacular name: Tlangham

Species Examined: INDIA. Mizoram, Champhai District, Ngur Village, 23°32'16" N 93°22'23" E 1566 m elevation, 26 July 2022, Tlanhlui 101009 (MZUH002533).

Monotropa uniflora L., *Sp. Pl.* 2: 386. 1753; Hook.f., *Fl. Brit. India* 3: 473. 1882; Grierson & Long in Grierson & Long, *Fl. Bhutan* 2(2): 718. 1991; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 217. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 49. 2016 (**Figure 5.8, Plate 4**).

Type: U.S.A., Herb. Linnaeus No. 671.12 (LINN – holotype).

Synonyms: *Monotropa lanuginosa* Michx. *Hypopitys uniflora* (L.) Small (misapplied name in some North American floras).

Taxonomic Description: Leafless, mycoheterotrophic, perennial herbs, 10 – 20 cm, entirely white, sometimes with a pinkish or translucent tinge, stem solitary or in small clumps, erect, unbranched, smooth or slightly puberulous, often arising from a rhizome-like base; Leaves reduced to scale-like bracts, alternate, sheathing, white almost transparent, margin serrulate to lobulate, ovate, apex aristulate, sessile, 1 – 1.3× 0.5 – 0.6 cm; Inflorescence of a solitary, terminal, nodding flower, pendent; Calyx disc-like or absent or reduced to 2–3 small bract-like sepals; Corolla white, campanulate, 5 nos., succulent, vertical grooves, slightly pubescent inside, glabrous outside, lobes obovate, 2 – 2.5 × 0.3 – 0.5 cm; Stamens 10 Nos, filaments slightly pudescent, 1 – 1.5 cm, anther yellowish, peltate; Ovary glabrous, ovoid, with prominent grooves, superior, unilocular; style short; stigma 4–5-lobed, 0.7 – 0.8 cm in diameter, style shorter than ovary, 0.3 – 0.4 cm; Fruit capsule, ellipsoid-globose, 0.8 – 1 × 0.5 – 1cm, seeds numerous.

Phenology: Flowering from June to September; fruiting from August to October.

Habitat and Ecology: Grows in moist, shaded forest floors, particularly in rich humus under pine, oak, or rhododendron canopies; entirely dependent on mycorrhizal fungi for nutrition mycoheterotrophic). Found at elevations between 1200–3000 m.

Vernacular name: NA

Distribution: Mizoram (Ngengpui, Saizawh East, Reiek, Ailawng), India (Uttarakhand, Sikkim, Arunachal Pradesh**)**, United States**,** Canada**,** Mexico China Japan Nepal, Bhutan, Myanmar Russia Central & South America (Figure 5.7).

Species Examined: INDIA. Mizoram, Mamit District, Ailawng Village, 23.41’06.7’’ N 92.36’78.9’’ E 1302 m elevation, 24 September 2019, Tlanhlui 101010 (MZUH002534)

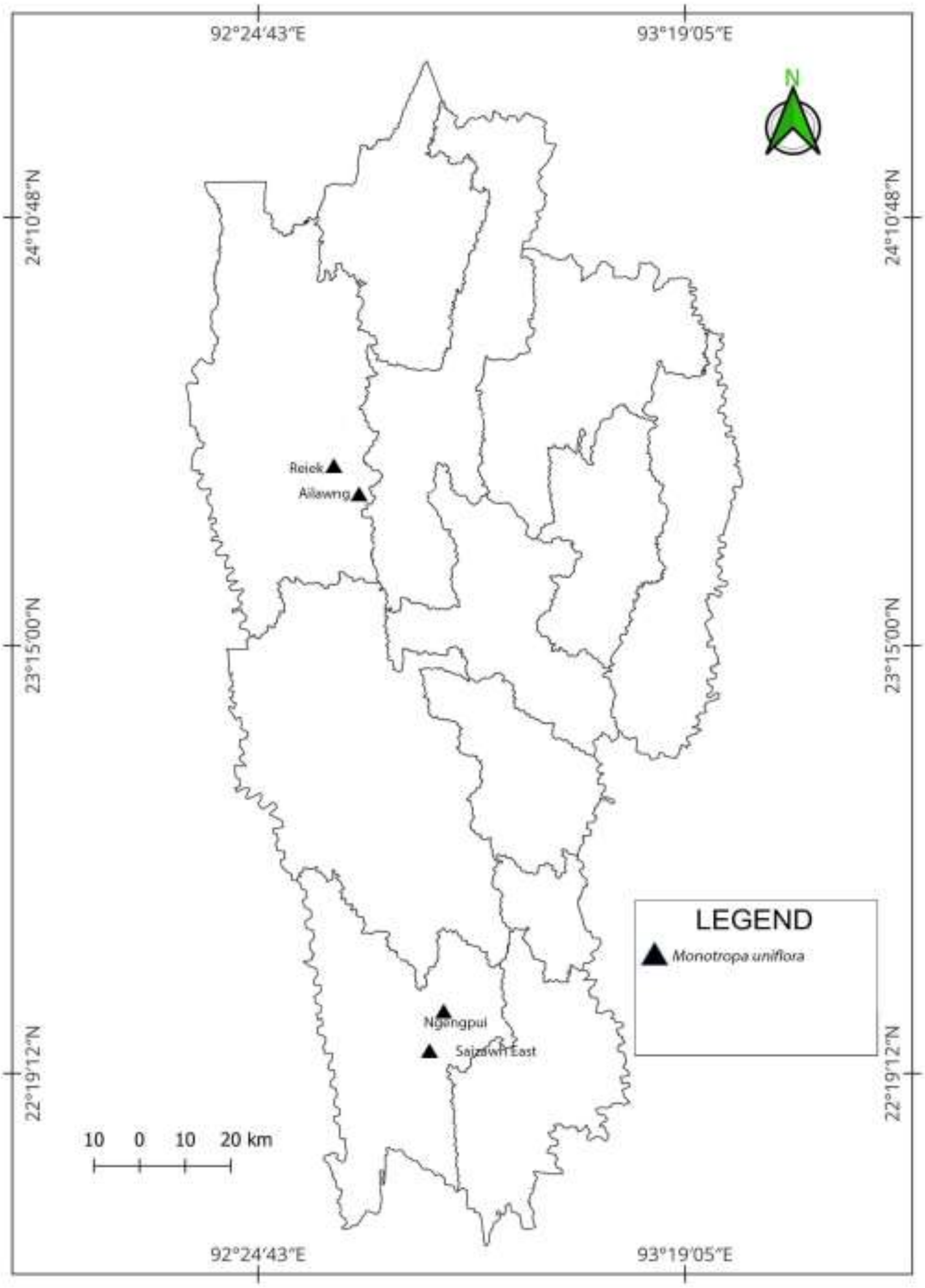

Figure 5.7: Distribution map of *Monotropa* L. in Mizoram.

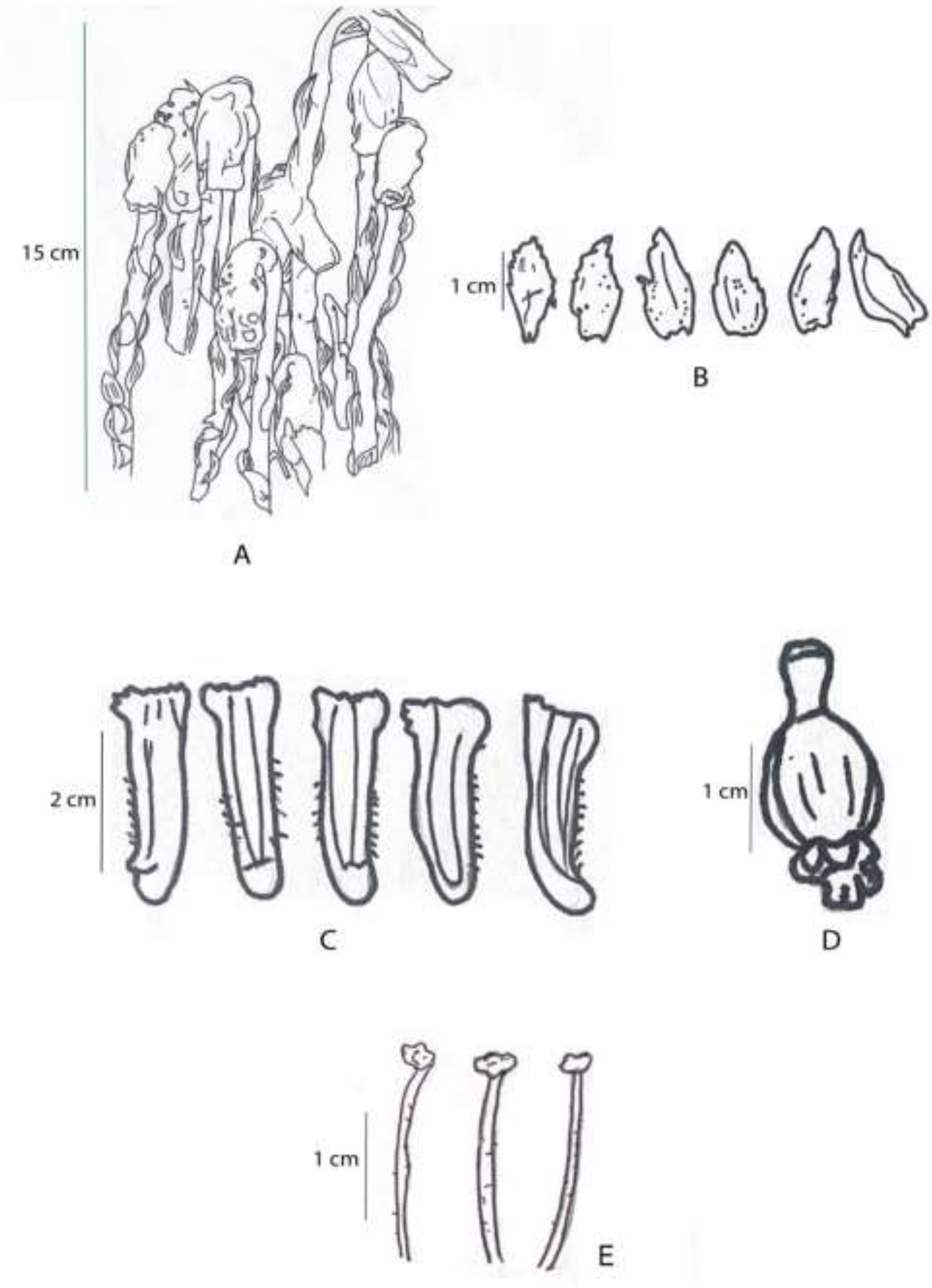

Figure 5.8: Illustration of *Monotropa uniflora* L., A. Habit; B. Leaves; C. Corolla; D. Gynoecium; E. Androecium.

Rhododendron L.

Rhododendron is a diverse genus within the Ericaceae family, comprising shrubs or small trees, rarely herbs. Most species are evergreen, though some are deciduous. Leaves are usually leathery, spirally arranged, and vary greatly in size and shape. Flowers are often showy, actinomorphic, and arranged in terminal clusters or solitary. The corolla is typically funnel-shaped or campanulate with five lobes. Stamens are usually 5 to 10, and the ovary is superior, typically 5-locular with axile placentation. The fruit is a capsule that splits septicidally to release many small seeds. Species are found in temperate to alpine regions, especially in Asia, with high diversity in the Himalayas and Southeast Asia.

Key to the species:

1a. Terrestrial evergreen shrub, apocolpial region having same sculpturing element as other part of exine…………………..…………………………………………….. **2**

1b. Epiphytic shrub, Corolla white, with yellow blotch inside, sweet smell, apocolpial region having different sculpturing element as other part of exine……………………………………………………….…… **3. *R. vietchianum***

2a. Corolla red with black streaks inside with nectar pouches, seeds coat winged on both terminals……………………………………………………….…. **1. *R. arboreum***

2b. Corolla white with yellow and pink patch inside, without nectar pouches, seed coat not winged……………………………………….………..…. **2. *R. formosum***

Rhododendron arboreum Sm., *Exot. Bot.* 2: 109, t. 116. 1804; Hook.f., *Fl. Brit. India* 3: 480. 1882; Kanjilal & al., *Fl. Assam* 2: 272. 1938; Raizada & Sahni, *Trees & Shrubs of Kumaon*: 254. 1958; Bennet, *Name Changes in Flowering Plants of India & Adjacent Regions*: 264. 1987; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 203. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 39. 2016 (**Figure 5.10, Plate 5**).

Synonym: *Azalea arborea* (Sm.) Kuntze in Revis. Gen. Pl. 2: 386 (1891), nom. illeg. *Rhododendron venustum* Salisb. in Prodr. Stirp. Chap. Allerton: 287 (1796), nom. superfl.

Type: India, cultivated in England from Nepalese seeds – s.n. (BM, image seen).

Taxonomic description: Evergreen trees, up to 30m tall; Bark rough; Young shoots densely tomentose; branches spreading, young twigs with brown or reddish indumentum; Leaves elliptic to oblanceolate, leathery, brittle, prominent mid-rib, margin entire and slightly curved at the margin, 3.9 – 12 × 1.3 – 4.9 cm wide, dense compacted white tomentose beneath, uniseriate or biseriate, green, above; Petiole 1–3 cm long, stout, tomentose; Inflorescence a compact terminal raceme or umbel-like cluster, 8 –18 fIowered; Peduncle short or absent; Pedicels 1–2.5 cm long, glandular-pubescent; Calyx small, disc – shaped, 0.2 – 0.5 mm long, persistent, colours varies from green to pink, covers with white hairs, 0.2 – 0.3 × 0.1– 0.2 cm; Corolla5-Iobed, campanulate, with nectar pouches, inner tube having black streaks, bright red in colour, 3.5 – 4 cm long, the red colour of the petal fades towards the tube; Stamens 10, 2.5 – 3.5 cm long, unequal, filaments hairy at base, anthers dorsifixed, dehiscing by longitudinal slits, red colour at the end; with a superior, 5-locular ovary, densely hairy; Ovary superior, style 2.5 – 3.5 cm long, stigma capitate; Fruit a capsule, oblong, 1.5 – 2.5 cm long, dehiscing septicidally, many-seeded; Seeds small, winged.

Phenology: Flowering from February to April; fruiting from May to July.

Habitat and Ecology: Grows in temperate to subalpine forests, often forming pure stands or occurring with oaks and conifers. Found on mountain slopes and ridges at elevations of 1500–3000 m. Prefers acidic, well-drained soils and thrives in cool, moist climates.

Distribution: Mizoram (Champhai, Phawngpui), India (Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland, Manipur) Nepal, Bhutan, China, Myanmar and Sri Lanka (Figure 5.9).

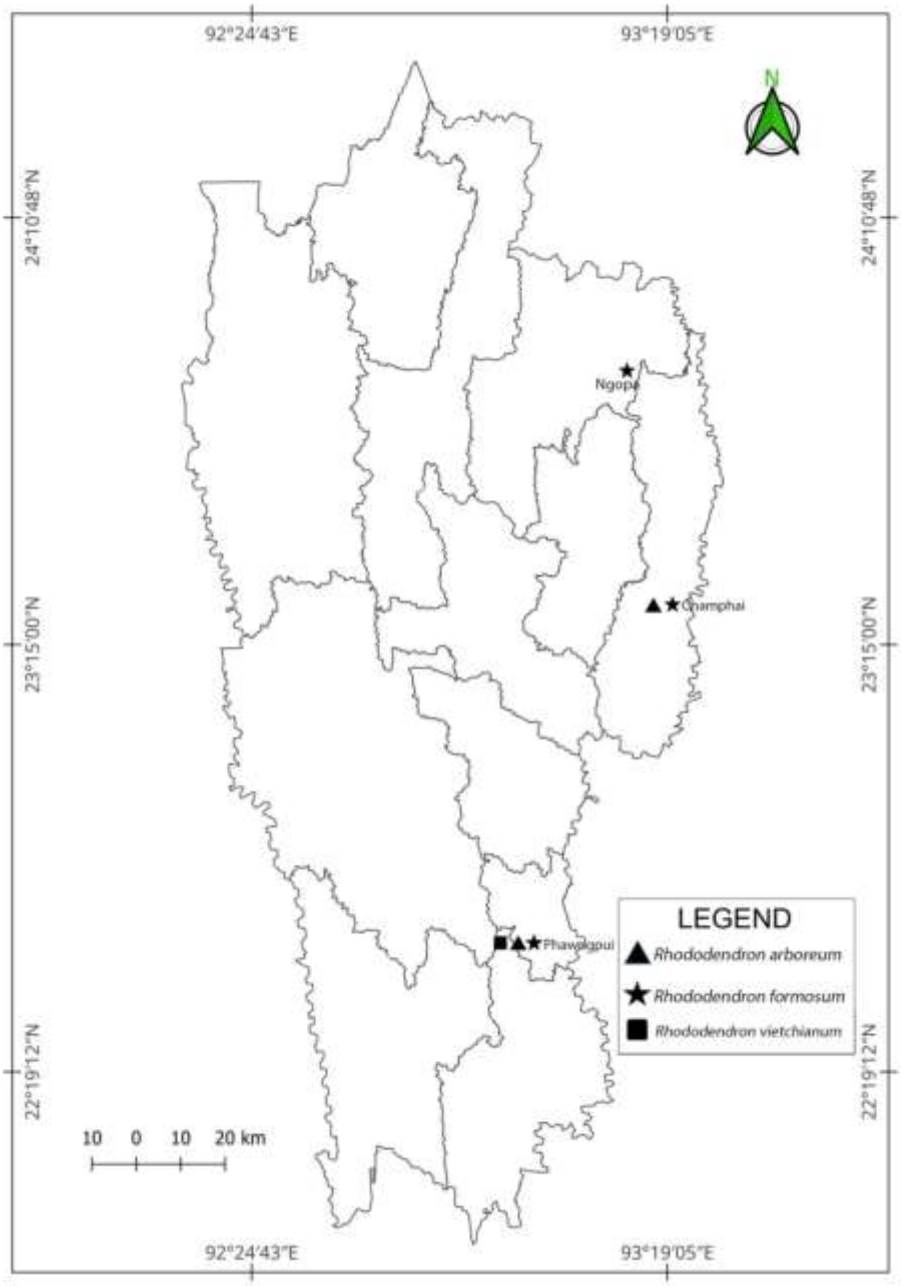

Figure 5.9: Distribution map of *Rhododendron* L. in Mizoram**.**

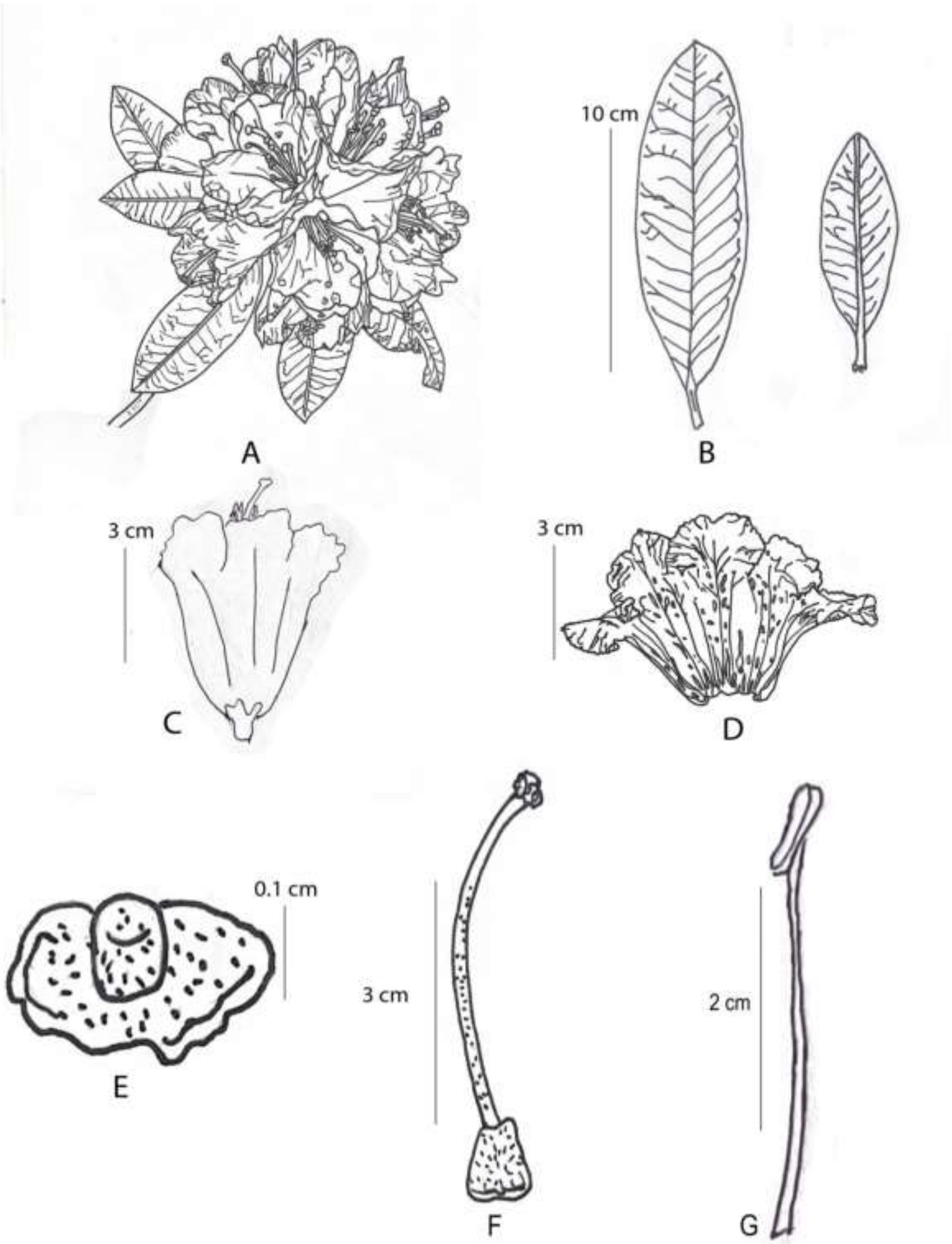

Figure 5.10: Illustration of *Rhododendron arboreum* Sm.: A. Habit; B. Leaves; C. Flower; D. Corolla; E. Calyx; F. Gynoecium; G. Androecium.

Vernacular name: Chhawkhlei – par – sen

Species Examined: INDIA. Mizoram, Lawngtlai District, Phawngpui National Park, 22.62’77” N 93˚04’26.2” E, 1947 elevation, 20 January 2019, Tlanhlui 101001 (MZUH002525); Shillong, 9nd August 1885, C.B. Clarke 38653; Dungbo Hills, 26th March 2011, A.A. Mao 23307 (ARUN), 115117 (ASSAM)

Rhododendron formosum Wall. Pl. Asiat. Rar. 3: 3 (1831); Hook.f., *Rhododendr. Sikkim-Himalaya* t. 15. 1849; Hook.f., *Fl. Brit. India* 3: 476. 1882; Kanjilal & al., *Fl. Assam* 2: 270. 1938; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 202. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 39. 2016 (**Figure 5.11, Plate 6**).

Type: India, East Himalaya, Wallich Cat. No. 178 (K, isolectotype BM, CAL – image seen).

Synonyms: *Rhododendron gracile* Wall. ex G. Don, *Gen. Hist.* 3: 846. 1834. *Rhododendron gibsonii* Hook.f., *Fl. Brit. India* 3: 476. 1882. *Azalea formosa* (Wall.) Kuntze, *Rev. Gen. Pl.* 2: 388. 1891.

Taxonomic description: Terrestrial shrub, 1.5 – 2m tall, branchlets slender, young parts puberulous, stem reddish, glabrous; Leaves alternate elliptic-oblanceolate, base cuneate, apex acuminate, base cuneate, 5.8 – 8.5 × 2.3 – 3.3 cm, reticulate veination, margin entire, adaxial surface glabrous, abaxial surface with scattered hairs along the midrib, petiole loriform 0.4 – 0.5 cm; Inflorescence terminal, umbel to corymb, 2 – 4 flowered, bracts and bracteoles present in numerous; Pedicel long, pubescent, 1 – 1.5 cm; Calyx disc shaped, light green, inconspicuous; Corolla campanulate, white with yellow patch and pink streak in one petal, corolla tube 2.2 – 3.2 cm, lobes 1.5 – 2cm, inner base of the tube is pubescent, outside lepidote; Stamens 10, free, 3 – 3.5cm filament white, pubescent at base, anther brown, dorsifixed, 0.3 – 0.4 cm; Ovary superior, 5 – locular, lepidote, ridged, 0.5 – 0.7cm; Fruit a capsule, cylindrical, 1.3 – 1.7 cm, brown at maturity, lepidote.

Phenology: Flowering from March to May; fruiting from June to August.

Habitat and Ecology: Grows in moist, shaded montane forests, often along streams or forest margins. Prefers cool, humid environments at elevations of 1500–2500 m. Found in both primary and secondary forests, sometimes cultivated as an ornamental.

Distribution: India (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, West Bengal); Bhutan, Nepal, Myanmar. Also cultivated in gardens and arboreta in temperate regions (Figure 5.9).

Vernacular name: Chhawkhlei – par – var

Species Examined: INDIA. Mizoram, Lawngtlai District, Phawngpui National Park, 22.67’18.6” N 93˚04’41.3” E, 1948m elevation, 15 February 2022, Lal Tlanhlui 101002 (MZUH002526); Naga Hills, Nagaland, N.L. Bor 21176 (CAL).; Arunachal Pradesh, 4th May 2011, A. A. Mao 20311 (ARUN).

Rhododendron veitchianum Hook.f., *Rhododendr. Sikkim-Himalaya* t. 21. 1851; Hook.f., *Fl. Brit. India* 3: 474. 1882; Kanjilal & al., *Fl. Assam* 2: 268. 1938; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 201. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 38. 2016. (**Figure 5.12, Plate 7**)

Type: Burma [Myanmar], collected by Thomas Lobb in the Shan Hills, introduced by Messrs. Veitch to England in 1850 (K – image seen).

Synonyms: *Rhododendron veitchianum* var. *lobbii* Hook.f. *Azalea veitchiana* (Hook.f.) Kuntze, *Revis. Gen. Pl.* 2: 388. 1891.

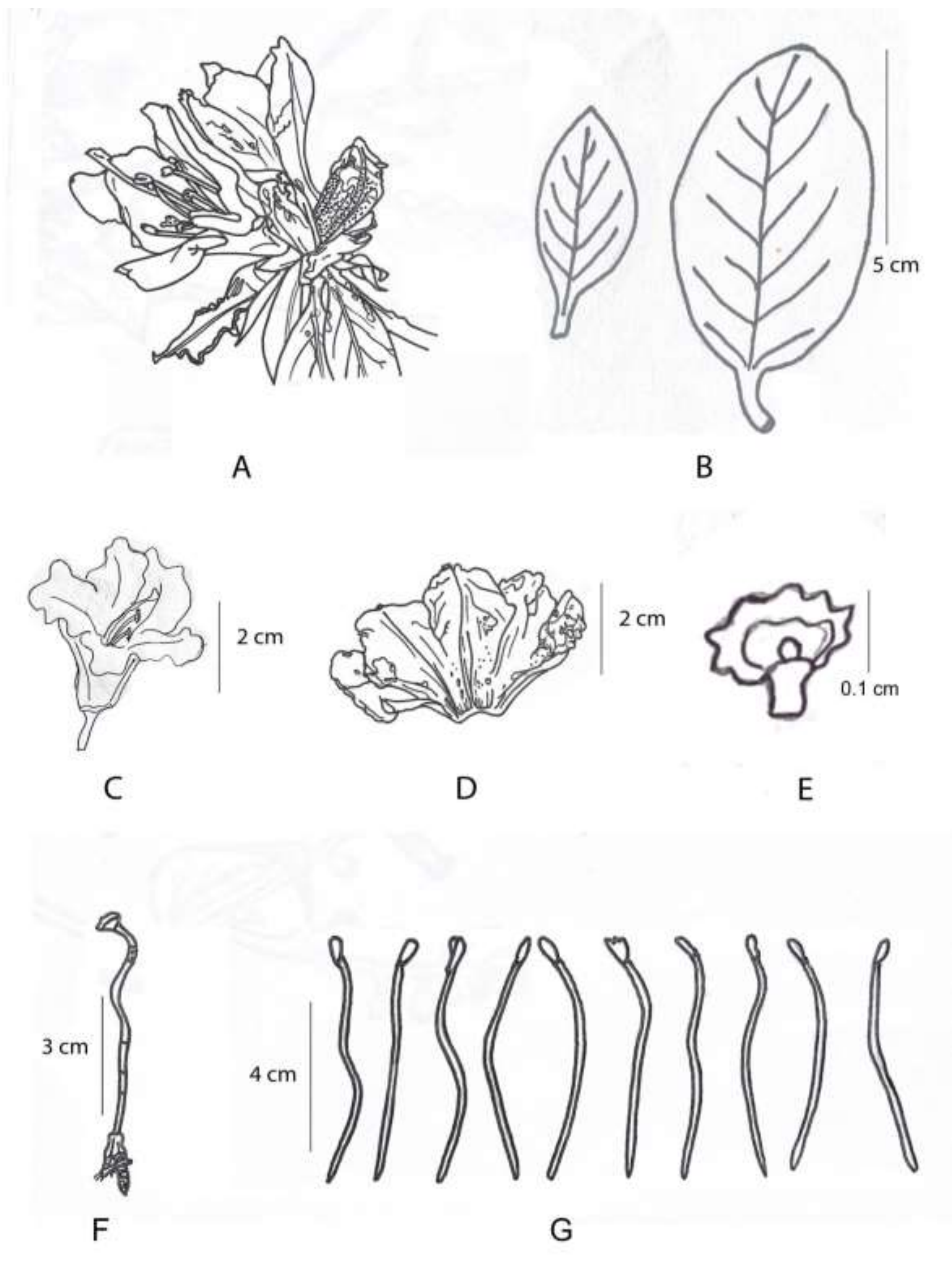

Figure 5.11: Illustration of *Rhododendron formosum* Wall. A. Habit; B. Leaves; C. Flower; D. Corolla; E. Calyx; F. Gynoecium; G. Androecium.

Taxonomic Description: Epiphytic shrub, upto 2m tall, young branches brownish, tomentose; Leaves ovate-elliptic, acute at base, slightly acuminate at apex, upper surface dark green lower surface lighter, sparely lepidote around mid-rib, 6 – 10.5 × 2.6 – 3 cm , stipules present; petiole lepidote, 1.1 – 2 cm; Inflorescence terminal, raceme, 4 – 5 flowered; Pedicel 0.5 – 1cm, lepidote ; Flower white with yellow blotch inside, sweet smell, campanulate or funnel shape; calyx disc-like, small, scarcely lobed, lepidote, margin pubescent; corolla white, campanulate, 5-lobed, tube 3.5 – 3.7 cm, lobes 2.8 – 3 × 3.5 cm, slightly pubescent at base, lepidote on the adaxial surface; 10 stamens, anther white, basifixed, filaments white, pubescent at base, 4 – 5cm; Ovary green, superior, 0.9 – 1 cm, ridged, lepidote; Fruit a capsule, ridged, 2 – 2.5 cm, green when young, brown at maturity, open apically on dehiscence.

Phenology: Flowering from March to May; fruiting from June to August.

Habitat and Ecology: Grows in montane forests and grassy slopes, often in open, sunlit areas at elevations of 1800–2500 m. Prefers acidic, well-drained soils and a cool, moist climate.

Distribution: India (Arunachal Pradesh, Nagaland, Manipur, Mizoram); Myanmar, northern Thailand, Laos, Vietnam. Also cultivated in high-altitude gardens and botanical collections (Figure 5.9).

Vernacular name: Chhawkhlei – par – var

Species Examined: INDIA. Mizoram, Lawngtlai District, Phawngpui National Park, 22.66’68.8” N 93˚04’21.6” E, 1937 elevation, 4 April 2023, Tlanhlui 101003 (MZUH002527); A.A. Mao 1104821 (ASSAM).

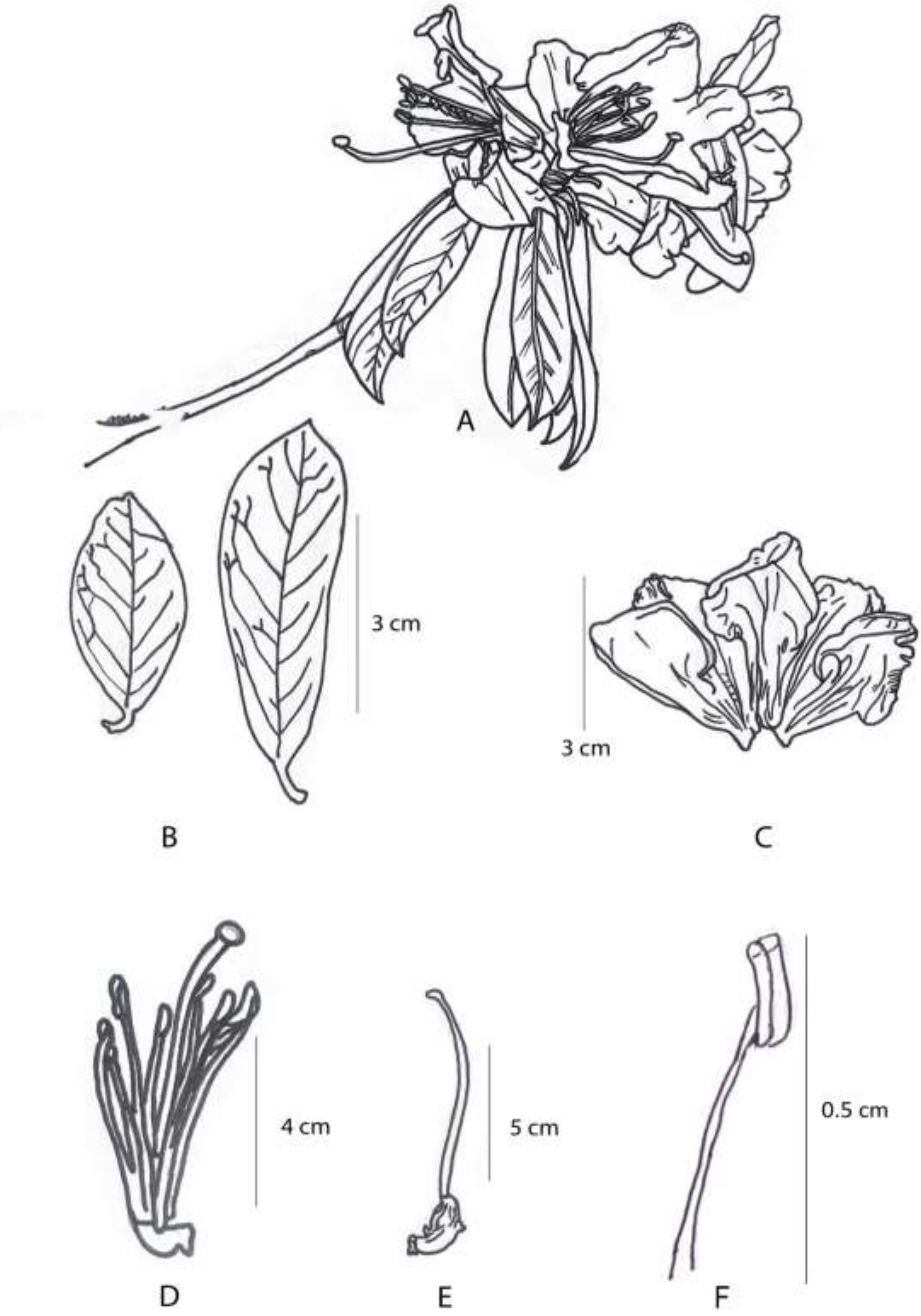

Figure 5.12: Illustration of *Rhododendron vietchianum* Hook. A. Habit; B. Leaves; C. Corolla;D. Reproductive part; E. Gynoecium; F. Androecium.

***Vaccinium* L.**

Vaccinium is a large and diverse genus in the Ericaceae family, comprising shrubs or small trees, often evergreen, and sometimes epiphytic. Plants can be erect or scandent, with woody stems and smooth or pubescent branches. Leaves are simple, alternate, leathery or thin, with entire or finely serrate margins. Inflorescences are typically racemose or fascicled, axillary or terminal, bearing small to medium-sized, bell-shaped to tubular flowers. The corolla is usually white, pink, or pale red, with 4–5 united petals. Stamens are 8–10, with anthers that often have terminal tubules and open by pores. The ovary is usually superior, 4–5-locular, with axile placentation. Fruits are fleshy berries, commonly blue, black, or red when ripe, and often edible. *Vaccinium* is widely distributed in temperate to tropical montane regions, with high diversity in Southeast Asia, the Himalayas, and parts of North and South America.

Key to the species:

1a.Terrestrial shrub, inflorescence not arising from whorl of leaves……………………………………………..……..………………. **2**

1b. Epiphytic herbs, inflorescence arising from whorl of leaves………………………………………………………..…… **2. *V. vaccineacium***

2a. Upto 10 m tall, bracts and bracteoles present, perforated periclinal cell wall of seed coat ……………………………………………...…….…….. **1. *V. sprengelii***

2b. Upto 3 m tall, without bracts and bractreole, periclinal cell wall of seed coat not perforated………………………………………...…………..... **3. *V. griffithianum***

Vaccinium griffithianum Wight, *Ic. Pl. Ind. Or.* 4(2): t. 1587. 1850; Hook.f., *Fl. Brit. India* 3: 456. 1882; Kanjilal & al., *Fl. Assam* 2: 289. 1938; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 215. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 46. 2016 (**Figure 5.14, Plate 8**).

Type: India, Khasi Hills, Griffith 2209 (holotype: K – image seen).

Taxonomic Description: Shrub, upto 3m tall, branches glabrous, young branches angular, reddish-brown, glabrous or minutely puberulous; Leaves lanceolate-elliptic, base round, apex acute, margin serrated, 2 – 3 × 1 – 1.5 cm, glabrous, pubescent along margins, lateral nerves 5 – 6 pairs, adaxial surface shiny dark green, glabrous; abaxial lighter, occasionally sparsely pubescent on veins; Petiole <1cm, pubescent; Inflorescence raceme, 8 – 10 flowered; Pedicels 0.8 – 1.5 cm long, slender, often reddish; Calyx light green to yellow with brown tips, triangular, 5 Nos., fused at base, 0.1 – 0.2cm long, pubescent; Corolla white, campanulate, tube 0.5 – 0.6 cm, lobes 0.2 – 0.3 cm, glabrous outside but pubescent inside; Stamens 10, filaments short, anthers with terminal tubules, dehiscing by pores; Ovary superior, 5-locular; style slender, exserted; stigma capitate; Fruit berry type, globose.

Phenology: Flowering from March to May; fruiting from June to August.

Habitat and Ecology: Grows in montane evergreen or semi-evergreen forests, along moist slopes and forest edges, at elevations of 1500–2400 m. Often found near rhododendron or oak-dominated patches.

Distribution: Mizoram (Phawngpui, Champhai), India (Meghalaya, Arunachal Pradesh), China (Figure 5.13).

Vernacular name: Sir te

Species Examined: INDIA. Mizoram, Champhai District, Champhai, 23.62’85’’ N 93.33’57’’ E, 1678m elevation, 21 May 2019, Tlanhlui 101008 (MZUH002532).

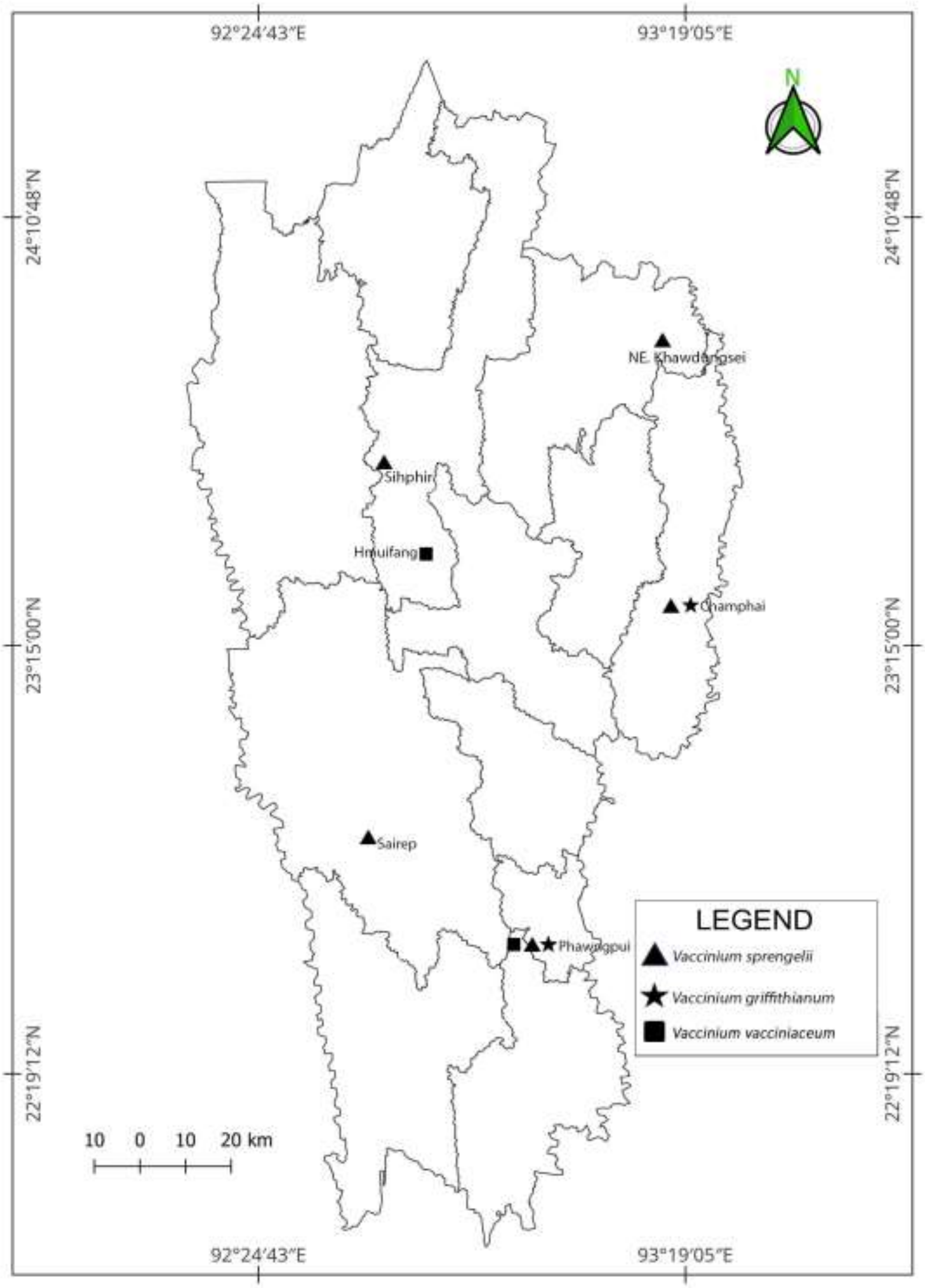

Figure 5.13: Distribution map of *Vaccinium* L. in Mizoram.

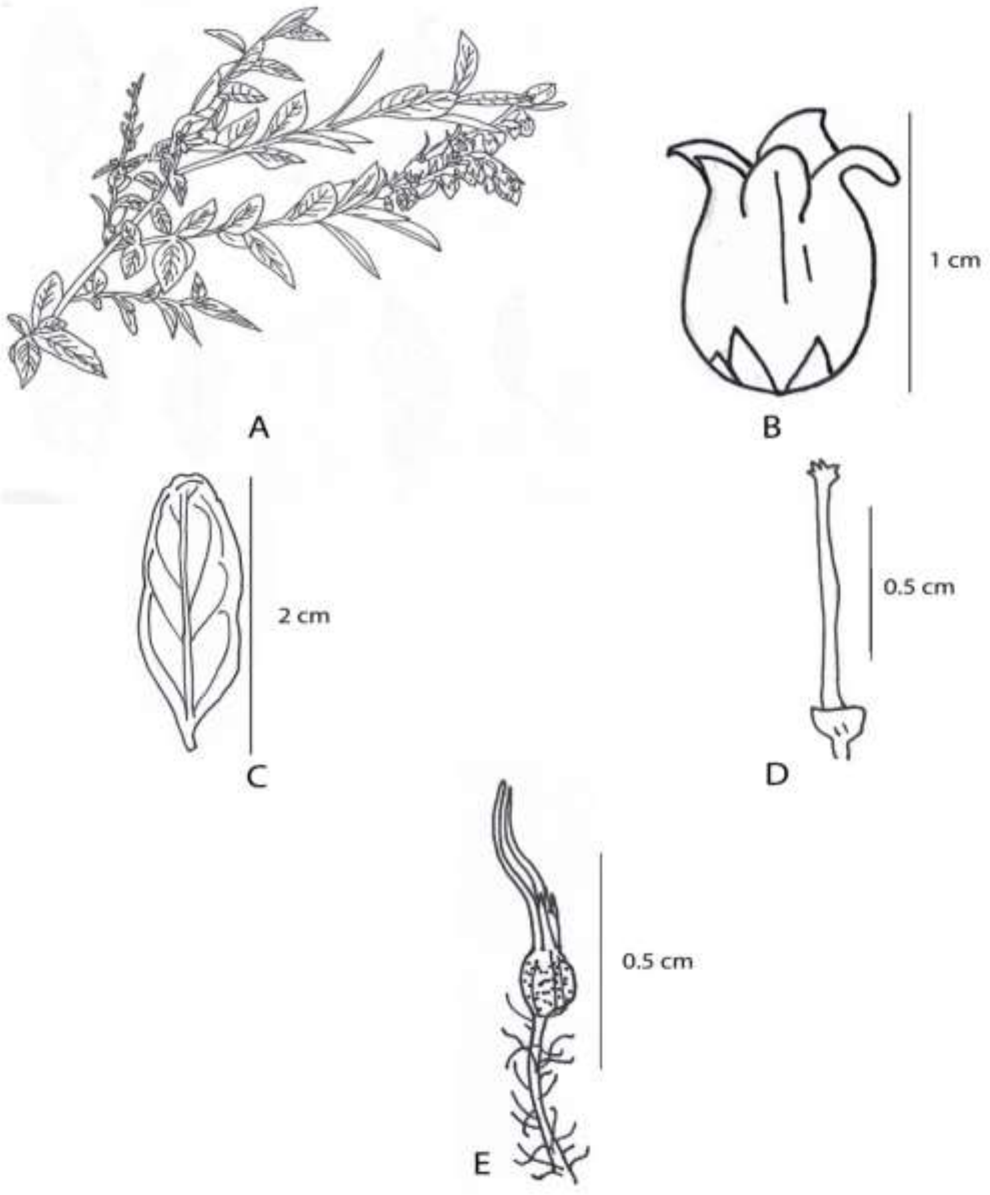

Figure 5.14: Illustration of *Vaccinium griffithianum* Wight. A. Habit; B. Flower; C. Leaves; D. Gynoecium; E. Androecium

Vaccinium sprengelii (G. Don.) Sluemer ex Rehder, *Gen. Hist.* 3: 849. 1834; Hook.f., *Fl. Brit. India* 3: 454. 1882; Kanjilal & al., *Fl. Assam* 2: 288. 1938; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 214. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 43. 2016 (**Figure 5.14, Plate 9**).

Type: India, East Himalaya, Wallich Cat. No. 832 (K – image seen).

Synonyms: *Vaccinium arboreum* Wall. ex C.B. Clarke (nom. nud., pro syn.). *Vaccinium rostratum* Wall. ex C.B. Clarke (nom. nud., pro syn.).

Taxonomic Description: Small tree or Shrub, evergreen, growing upto 10 m; Branchlets slender, glabrous; Leaves oblanceolate-lanceolate, aequilateral at base, apex acuminate, 3.1 – 7.6 × 1.5 – 2.7 cm, alternate arrangement, alternate veination, glabrous, margins entire or minutely serrulate; adaxial surface dark green, glabrous, abaxial paler, slightly pubescent on veins; Petiole 0.3 – 0.4 cm; Inflorescence, raceme, axillary, 8 – 23 flowered; Pedicels slender, 0.8 – 1.5 cm long, articulated near base; Calyx white with green tube, 5 Nos., fused at base, calyx teeth triangular in shape, pubescent, 0.2 – 0.3 cm long; Corolla campanulate, pink-white, corolla tube 0.5 – 0.6 cm, lobes 0.1 – 0.2 cm, lobes triangular in shape; Bracts pink, lanceolate, <1mm; Bracteole present; Stamens 10 Nos., 0.1 – 0.2 cm filaments short, glabrous; anthers long, with terminal tubules or awns, dehiscing by apical pores; Ovary superior, 5-locular, glabrous; style slender, stigma simple or slightly capitate; Fruit berry type, globose- sub globose.

Phenology: Flowering from March to May; fruiting from June to August.

Habitat and Ecology: Occurs in montane evergreen forests, forest edges, and open slopes, preferring acidic, well-drained soils at elevations of 1500–2700 m.

Distribution: Native to parts of South and Southeast Asia Found in Mizoram (Phawngpui, Sairep, Sihphir, North East Khawdungsei, Champhai), India (Assam, Meghalaya and Arunachal Pradesh), China, Cambodia, Laos, Myanmar and Thailand (Figure 5.13).

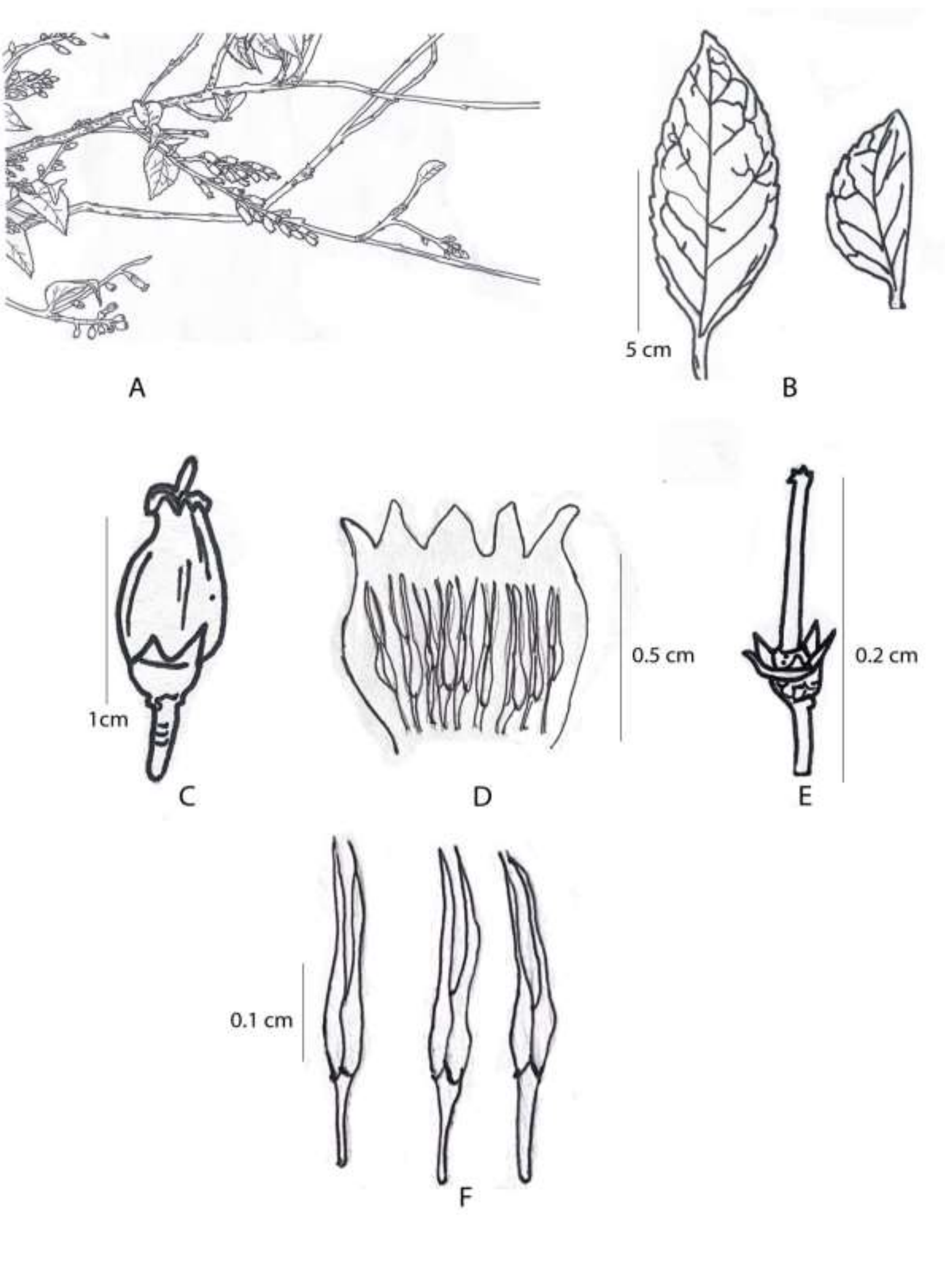

Figure 5.15: Illustration of *Vaccinium sprengelii* (G. Don) Sluemer ex Rehder. A. Habit; B. Leaves; C. Flower; D. Open flower; E. Gynoecium; F. Androecium.

Vernacular name: Sir kam

Species Examined: INDIA. Mizoram, Lawngtlai District, North East Khawdungsei Village, 23.97’51.4’’ N 93.21’43.7’’E, 1157 m elevation, 5 May 2023, Tlanhlui 1010006 (MZUH002530).

Vaccinium vacciniaceum (Roxb.) Sleumer, *Notizbl. Bot. Gart. Berlin-Dahlem* 13: 205. 1936; Sleumer, *Fl. Malesiana*, Ser. I, 6(7): 912. 1967; G.P. Sinha in G.P. Sinha & et al., *Fl. Mizoram* 2: 215. 2012; B.K. Sinha & Su. Datta, *Nelumbo* 58: 45. 2016 (**Figure 5.16, Plate 10**).

Type: Indonesia, Sumatra, Toba, Lake region, Junghuhn s.n. (L – holotype, image seen).

Synonyms: None widely accepted; sometimes confused with *Vaccinium pseudovacciniaceum* in older literature.

Taxonomic Description: Epiphytic, rising upto 30 – 35 cm, branchlets slender, terete, often reddish, glabrous; Leaves in whorl, glabrous, 3.5 – 6.5 × 0.7 – 1.6 cm, lanceolate-oblanceolate, apex acute slightly apiculate, base cuneate, reticulate veination, margin serrate-serrulate, both surfaces glabrous, adaxial surface shiny; Petiole 0.2 – 0.25 cm; Inflorescence arising from whorl of leaves, raceme type, 10 – 11 flowered; Pedicels 0.8 – 1.2 cm long, slender, glabrous; Calyx green, with brown tips, 5 nos., 0.2 – 0.3 cm long, fused at base, calyx teeth triangular in shape; Corolla campanulate to urceolate, white with greenish lobes, tube 0.3 – 0.4cm long, lobes 0.1 – 0.2 cm long; Stamens 10 nos., anther basifixed, spurred, dark brown, free, filament white, 0.2 – 0.3 cm; Ovary superior, 5 – locular, stigma capitate, style slender; Fruit berry type, globose to sub – globose.

Phenology: Flowers from April to June; fruits from July to September.

Habitat and Ecology: Occurs in subtropical to montane evergreen forests, along ridges and moist slopes at elevations of 1600–2600 m. Prefers acidic, humus-rich soils.

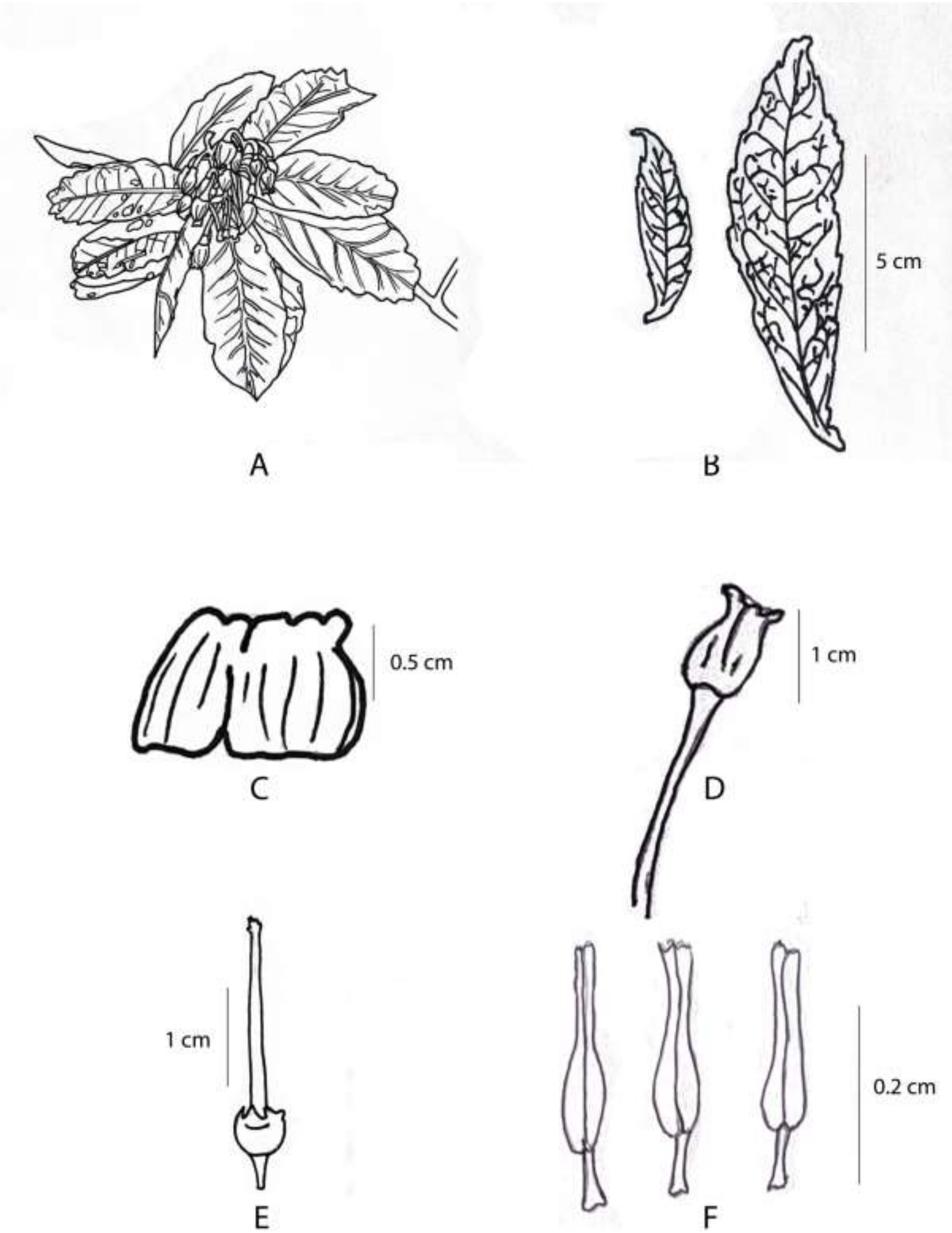

Figure 5.16: Illustration of *Vaccinium vaccineacium* (Roxb.) Sleumer A. Habit; B. Leaves; C. Corolla; D. Flower; E. Androecium; F. Gynoecium.

Distribution: Native to parts of the Himalayas and Southeast Asia. Found in Mizoram (Hmuifang, Phawngpui), India (Assam and Eastern Himalayas), Nepal, Bhutan, Myanmar and Tibet (Figure 5.13).

Vernacular name: Hmuiphang Sirte

Species Examined: INDIA. Mizoram, Aizawl District, Hmuifang, 22.84'42.3" N 92.82'01.3" E, 1181m elevation, 24 April 2019, Tlanhlui 101007 (MZUH002531).

5.1.12 Discussion

The morphological characteristics of Ericaceae species studied in Mizoram provide an essential framework for accurate taxonomic identification and classification. Morphotaxonomy continues to play a crucial role in systematics, particularly in biodiversity-rich yet underexplored regions such as Northeast India. According to Stuessy (2009), the comparative analysis of morphological featuressuch as leaf arrangement, floral structure, and fruit type remains a primary tool in species delimitation. Judd *et al*. (2016) also highlighted the importance of morphological data in phylogenetic and taxonomic studies, especially in scenarios where molecular information is limited or unavailable.

In the current study, notable morphological variations were observed among species like *Rhododendron arboreum*, *Vaccinium griffithianum*, and *Agapetes odontocera* var. *mizoramensis*. These differences encompassed plant habit (ranging from trees to climbers), leaf phyllotaxy, floral symmetry, calyx size, and ovary position most of which were superior. Fruit morphology further distinguished these taxa, with *Rhododendron* bearing dehiscent capsules and *Vaccinium* producing berries. Corolla shape and coloration also showed significant diversity, reflecting the ecological adaptability and evolutionary divergence within the family.

Floral characters remain among the most informative taxonomic features within Ericaceae. Variations in corolla shape, size, and color were evident among the studied taxa, suggesting possible specialization for different pollination syndromes. For instance, the campanulate to tubular corollas commonly observed in many species of *Rhododendron* are generally associated with insect or bird pollination, whereas the urceolate corolla typical of *Vaccinium* species is considered an adaptation that restricts access to specific pollinators. Differences in the number and arrangement of stamens, along with ovary position and style length, further contribute to species-level differentiation within these genera.

Fruit morphology also provided clear diagnostic characters in the studied taxa. Members of *Rhododendron* typically produce dry dehiscent capsules, facilitating wind-mediated seed dispersal, while species of *Vaccinium* bear fleshy berries that are primarily dispersed by birds and mammals. Such variation in fruit type reflects differences in dispersal strategies and ecological interactions, indicating evolutionary diversification within the family. In addition, the epiphytic habit observed in taxa such as *Agapetes odontocera* var. *mizoramensis* represents a specialized ecological adaptation to humid montane forests, where nutrient acquisition and moisture retention play critical roles in survival.

Differentiating closely related species, especially within *Rhododendron*, often relies on subtle traits such as corolla color, stamen number, and leaf indumentum. In *Vaccinium*, calyx lobe shape, fruit characteristics, and growth habit such as epiphytic and terrestrial serve as key diagnostic features. However, overlapping morphological traits and environmental plasticity frequently lead to species misidentification and taxonomic ambiguity. In such contexts, morphotaxonomy serves as a critical preliminary tool, which should ideally be supplemented with molecular approaches, such as DNA barcoding using *rbcL* and ITS2 regions, for greater resolution.

Micromorphological features, including pollen exine patterns and seed appendages, further supported species-level identification and contributed to a clearer taxonomic understanding. The frequent confusion between *Agapetes odontocera* and *Aeschynanthus parviflorus* (Gesneriaceae), as well as misidentification of *Lyonia ovalifolia* as *Vaccinium sprengelii*, underscores the necessity of integrative taxonomic approaches.

Notably, the absence of previously documented taxa such as *Agapetes parishii* var. *cultrata*, *Vaccinium bancanum*, and *Rhododendron wattii* as recorded by Sinha *et al.* (2012) suggests significant ecological changes. Their disappearance from historically known habitats may be attributed to climate change, habitat degradation, and land-use modification which have disrupted local ecosystems and altered species distributions.

A particularly concerning observation is the consistent absence of flowering in *Vaccinium griffithianum* over a five-year period in Mizoram. This phenomenon likely results from a complex interplay of environmental, ecological, and biological factors, such as shifts in photoperiod, nutrient limitations, or climatic stresses. These findings highlight the urgency for sustained monitoring and the development of targeted conservation strategies to preserve the remaining Ericaceae diversity in this regional biodiversity hotspot.

5.2 Palynology

5.2.1 Collection of pollen and preparation

The pollen samples used in this study were obtained from freshly collected plant specimens during their respective flowering periods. Fully bloomed flowers with mature anthers were carefully chosen, as these are most likely to yield viable pollen. In contrast, immature or unopened flowers were avoided due to their reduced or unreleased pollen content. The mature anthers were delicately removed and gently brushed onto a brass stub coated with double-sided adhesive tape, ensuring effective pollen transfer. The samples were then coated with a thin layer of gold using a Fine Coat Ion Sputter JFC-1100 to prepare them for imaging. Scanning Electron Microscopy (SEM) was employed to capture detailed images and document pollen morphology for analysis.

5.2.2 Investigation of pollen morphological features using SEM

The Scanning electron micrographs were mainly used for the studying the shape, size, aperture, exine ornamentation and elements to collect information about the pollen detail characters. Size of pollen grain was expressed in micrometre (μm). Measurements included the Polar length (P), tetrad diameter (D), equatorial diameter (d) and pollen diameter (E for monad).

Some common pollen terminology based on Erdtman (1952), Punt *et al*. (2007), Halbritter *et al*. (2018)

Monad	: A pollen grain dispersed as an individual unit
Tetrad	: A general term used for a group of four united pollen grains as a dispersal unit
Tetrahedral Tetrad	: A multiplanar tetrad in which each member is in contact with three others so that the centre of the grain defines a tetrahedron
Colpi	: An elongated aperture
Colpate	: A pollen grain having an aperture
Colporate	: A pollen grain having both an aperture as well as a pore
Colpus margin	: The outline of the colpus
Apocolpial region	: A region of the pole of a pollen grain where the apices of the colpi meets
Exine	: The outer layer of the pollen wall
Oblate	: Pollen grain having P/E ratio less than 1
Uneven	: Surface sculpturing different in all areas
Rugged	: Broken, rocky and uneven surface
Rugulate	: Elongated sculpturing elements greater than 1μm long; pattern irregularly arranged
Scabrate	: Sculpturing elements less than 1 μm in diameter

Granulate : Sculpturing elements less than 1 µm in diameter (pattern may appear less irregular compared to scabrate)

Granuloid : Covered with tiny granules or bead-like projections**,** giving it a rough texture.

Psilate : Smooth surface

Verrucate : A wart – like element

Elliptic : An elongated circle, stretched like an oval

Pollen morphological description

The analysis of studied Ericaceae family in 9 taxa show diverse palynotaxonomic variations. The detailed micromorphology characters of each species are given below with their SEM photoplate no. as follows:

Agapetes odontocera var. *mizoramensis* Banik & Sanjappa (**Plate 11: 1a & 1b**)

Pollen grains in tetrahedral tetrad; viscin thread absent; tricolporate, colpus with pores. The polar length (P) ranging from 15 – 15.3 µm, tetrad diameter (D) 35 – 35.1 µm and equatorial diameter (d) 23 – 23.62 µm, significantly wider at middle and acute towards apex; exine sculpture verrucate to rugulate, psilate towards aperture and apocolpial region.

Agapetes odontocera var. *odontocera* (Wight) Benth. & Hook. **Plate 11: 2a & 2b**

Pollen grains tetrahedral tetrad; viscin thread absent; tricolporate, colpus with pores. The polar length (P) ranging from 17.5 – 18.75 µm, tetrad diameter (D) 35.5–37.6 µm, and equatorial (d) 26.5 – 26.87 µm, wider at middle and acute towards apex; exine sculpture granulate to rugulate throughout even on the apocolpial region and aperture area.

Lyonia ovalifolia (Wall.) Drude (**Plate 11: 3a & 3b**)

Pollen grains are in normal tetrahedral tetrad; viscin thread absent; tricolporate, colpus having pores. The polar length (P) ranging from 20 – 20.5 µm, tetrad diameter D 32 – 33 µm, equatorial diameter (d) 2.13 – 2.15 µm, wider at the pore side and acute towards apex, colpus margin distinct; exine scabrate without secondary structures, psilate towards apocolpus.

Monotropa uniflora L. (**Plate 12: 1a & 1b)**

Pollen grains monad; viscin thread absent, 2 – 3 colpate, colpi circular to elliptic. The polar length (P) ranging from 22.2 – 23 µm, diameter 21 – 21.5 µm; roughly oblate; exine sculpture finely granulate to regulate.

Rhododendron arboreum Sm. (**Plate 12: 2a & 2b**)

Pollen grains in tetrahedral tetrad; viscin thread present; oblate; tricolporate, with long aperture, colpus having pores. The polar length (P) ranging from 26.4 – 26.6 µm, tetrad diameter (D) 44.8 – 47.5 µm and equatorial diameter (d) 1.38 – 1.41 µm, significantly wider at middle and acute apex; colpus margin distinct; exine sculpture uneven and rugged including apocolpial region.

Rhododendron formosum Wall. (**Plate 12: 3a & 3b)**

Pollen grains in tetrahedral tetrad; viscin thread present; tricolporate, with long aperture, colpus having pores. The polar length (P) ranging from 20 – 26.9 µm, tetrad diameter (D) 59.2 – 60 µm and equatorial diameter (d) 1.69 – 1.74 µm, wider at middle and acute at apex; colpus margin distinct; exine sculpture finely rugulate; apocolpial and aperture region granulate to scabrate.

Rhododendron vietchianum Hook. (**Plate 13: 1a & 1b**)

Pollen grains tetrahedral tetrad, somewhat shrunk; viscin thread present; tricolporate, colpus with pores. The polar length (P) ranging from 11 – 27 µm, tetrad diameter (D) 40 – 59 µm and equatorial diameter (d) 3.03 – 3.93 µm, elongate with tapering apex; colpus margin distinct; exine sculpture gemmate to pilate throughout.

Vaccinium sprengelii (G. Don) Sluemer ex Rehder (**Plate 13: 2a & 2b)**

Pollen grains tetrahedral tetrad where one or two grain is deformed or shrunk; viscin thread absent; tricolporate, colpus with pores. The polar length (P) ranging from 11 – 11.5 µm, tetrad diameter (D) 38.5 – 38.8 µm and equatorial diameter (d) 1.7 – 1.73 µm, wider at the middle and acute at apex; colpus margin distinct; endoaperture indistinct; exine sculpture slightly rugulate and psilate at the apocolpial region.

Vaccinium vacciniaceum (Roxb.) Sleumer (**Plate 13: 3a & 3b**)

Pollen grains tetrahedral tetrad; viscin thread absent; tricolporate, colpus with pores. The polar length (P) ranging from 17 – 17.22 µm, tetrad diameter (D) 35.1 – 36.02 µm and equatorial diameter (d) 1.89 – 1.93 µm, wider at the middle and acute at apex; colpus margin distinct; exine sculpture rugulate at the middle and psilate towards the aperture, apocolpial region granulate.

Table 5.1: Pollen characters and characters states for the cluster analysis of Ericaceae. The numbers are the codes for character states. **(Plate 11 - 13)**

Sl. No	Characters	Character states
1	Configuration	Tetrahedral tetrad=0, Monad=1
2	D	21 - 30= 0, 31 - 40 = 1, 41 - 50 = 2, 51 - 60 = 3
3	P	11 - 13= 0, 14-16=1, 17 - 19 = 2, 20 - 22=3, 23 - 25 = 3, >26 = 5
4	Exine sculpturing	uneven & rugged = 0, finely rugulate = 1, gemmate to psilate = 2, granulate to rugulate=3, verrucate to rugulate = 4, slightly rugulate = 5, rugulate to psilate = 6, scabrate = 7, finely granulate = 8
5	Apocolpial sculpturing	uneven & rugged = 0, granulate to scabrate = 1, gemmate - psilate= 2, granulate to rugulate = 3, psilate = 4, granulate = 5, granulate to rugulate = 6
6	Colpus margin	distinct = 0, indistinct = 1
7	Aperture	tricolporate = 0 di or tricolpate = 1
8	Presence of viscin threads	present = 0, absent = 1

Table 5.2: Data matrix used in cluster analysis of Ericaceae species based on pollen features.

Sp. Name/Characters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Agapetes odontocera var. *mizoramensis* Banik & Sanjappa	0	1	1	4	4	1	0	1
Agapetes odontocera var. *odontocera* (Wight) Hook.f.	0	1	2	3	3	1	0	1
Lyonia ovalifolia (Wall.) Drude	0	1	3	7	4	1	0	0
Monotropa uniflora L.	1	0	3	8	6	1	1	1
Rhododendron arboreum Sm	0	2	5	0	0	0	0	0
Rhododendron formosum Wall.	0	3	3	1	1	0	0	0
Rhododendron vietchianum Hook.	0	2	4	2	2	0	0	0
Vaccinium sprengelii (G. Don.) Sluemer ex. Rehder	0	1	0	5	4	1	0	0
Vaccinium vacciniaceum (Roxb.) Sleumer	0	1	2	6	5	1	0	0

5.2.3 Pollen cluster analysis using dendrogram

Hierarchical cluster analysis (Table 5.1 & 5.2) was applied to categorize species according to similarities in their pollen characteristics using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) approach, based on EUCLIDEAN distance. For this analysis, eight distinct pollen traits were considered: configuration, tetrad diameter, polar axis length, exine sculpturing, sculpturing of the apocolpial region, presence of viscin threads, type of aperture, and features of the colpus margin.

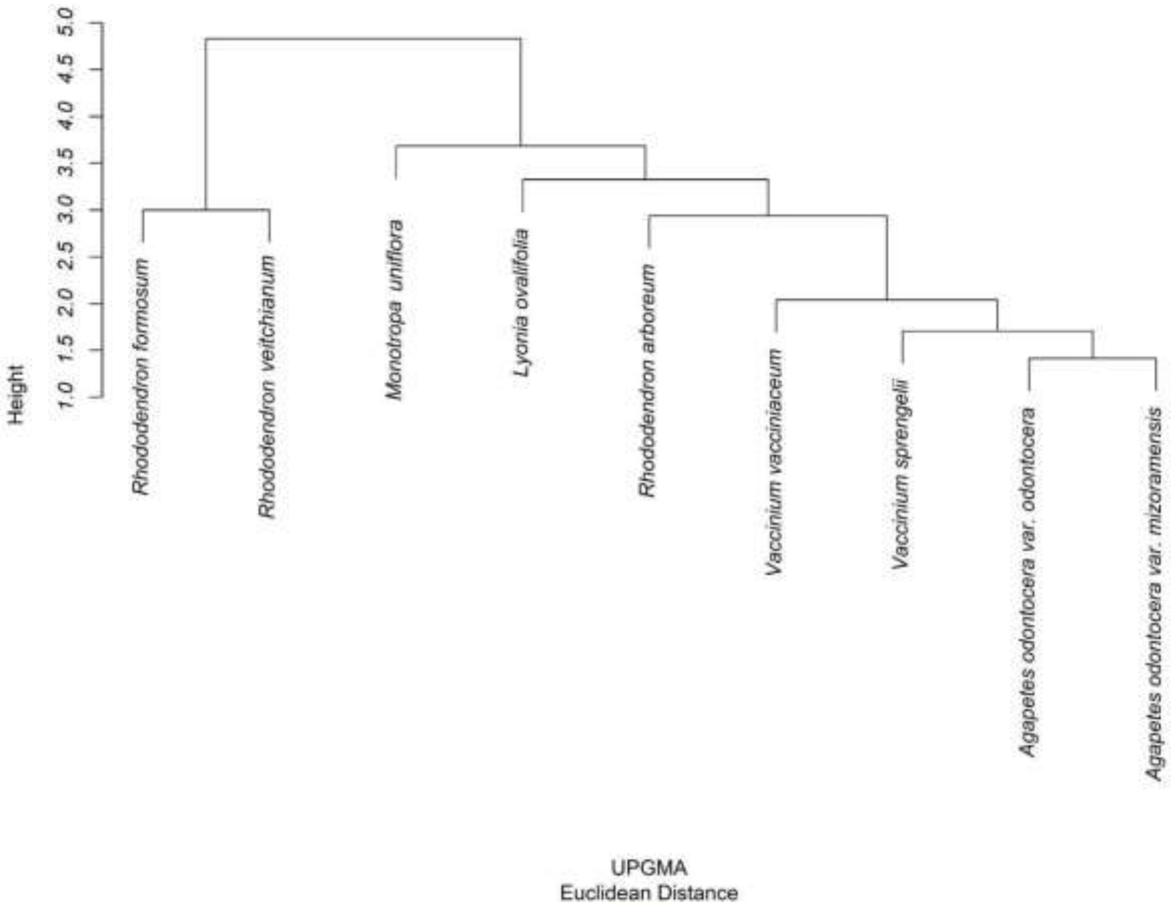

Figure 5.17: Dendrogram based on cluster analysis of pollen morphological characters using UPGMA (Unweighted Pair Group Method with Arithmetic Mean) with Euclidean Distance.

The constructed dendrogram produced two major clades. The Clade 1 (left major clade) includes the species *R. formosum and R. vietchianum*. The Clade 2 (right major clade) includes *M. uniflora, L. ovalifolia, R. arboretum, V. vaccineacium, V. sprengelii, A. odontocera* var. *odontocera* and *A. odontocera* var. *mizoramensis* Dendrogram based on cluster analysis of pollen morphological characters Using UPGMA (Unweighted Pair Group Method with Arithmetic Mean) with Euclidean Distance.

Although there is difference in exine and apocolpial region sculpturing, all other pollen characteristics are similar in *Agapetes odontocera* var. *odontocera* and *Agapetes odontocera* var. *mizoramensis* hence they form a closely related cluster, indicating a high degree of similarity in their pollen traits. This grouping indicates that the species may have undergone similar evolutionary influences or share a common genetic lineage. This pair is subsequently grouped with *Vaccinium sprengelii*, possibly due to the presence of psilate sculpturing in the apocolpial region shared by both *V. sprengelii* and *Agapetes odontocera* var. *mizoramensis*.

Another distinct group includes *Vaccinium vacciniaceum*, which is grouped with the previous cluster at a slightly higher Euclidean distance, showing moderate similarity. *Rhododendron arboreum*, *Lyonia ovalifolia* and *Monotropa uniflora* form a separate clade, indicating shared characteristics *i.e.* same range of Polar length (20 – 25 µm) that distinguish them from the *Vaccinium* and *Agapetes* groups. On a separate branch, *Rhododendron formosum* and *Rhododendron veitchianum* which have the same pollen size are paired together, suggesting strong similarity between them, which then joins with the rest of the taxa at a higher distance level. This is consistent with previous findings that quantitative traits, such as pollen grain size, play an important role in subfamily classification (Smith *et al.*, 1997). The overall clustering pattern reflects the taxonomic coherence at the genus and varietal levels, reinforcing the utility of pollen morphological traits in understanding phylogenetic relationships within Ericaceae.

Principal Component Analysis of Pollen

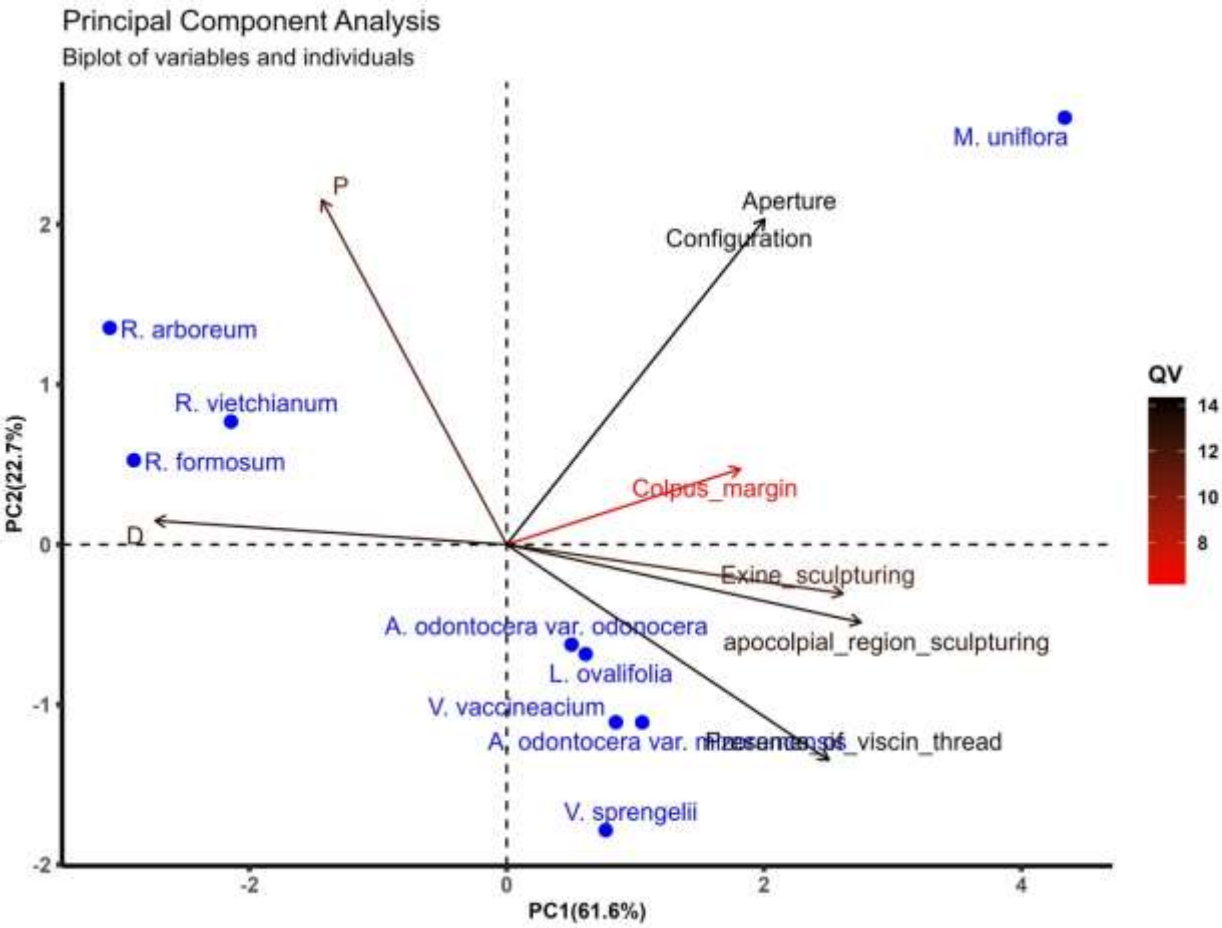

Figure 5.18: Principal component analysis (PCA) for pollen characteristics of different samples: Biplot of individuals and variables (PC1 & PC2).

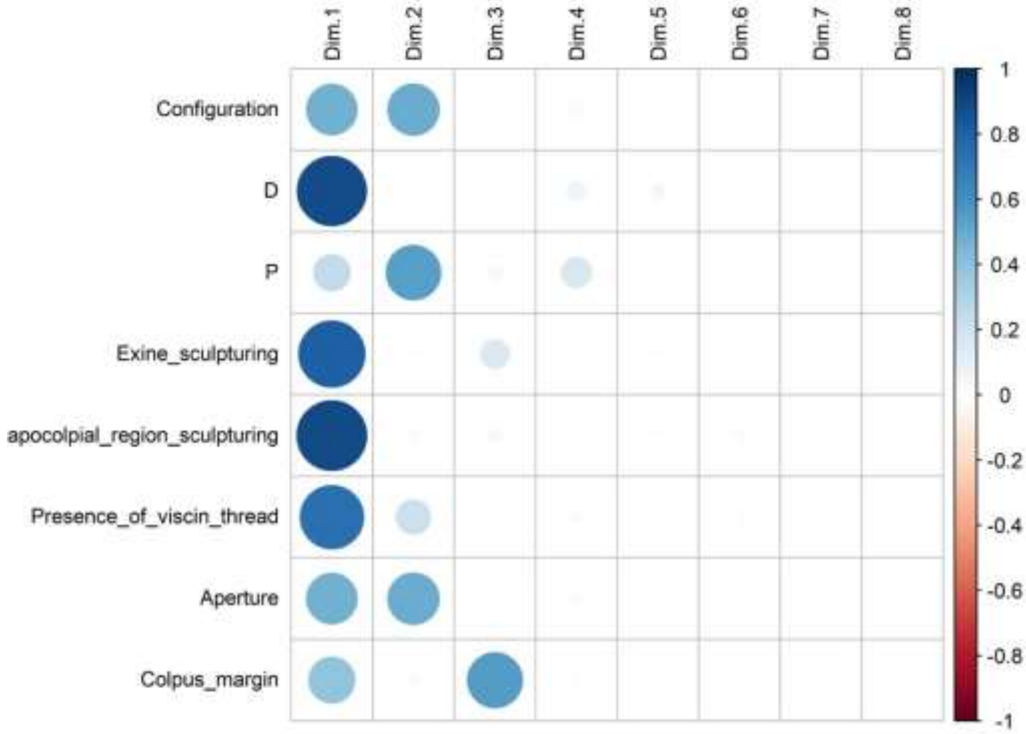

Figure 5.19: Heatmap of Principal component analysis (PCA) for pollen characteristics of different samples: Principal components and their relation with variables.

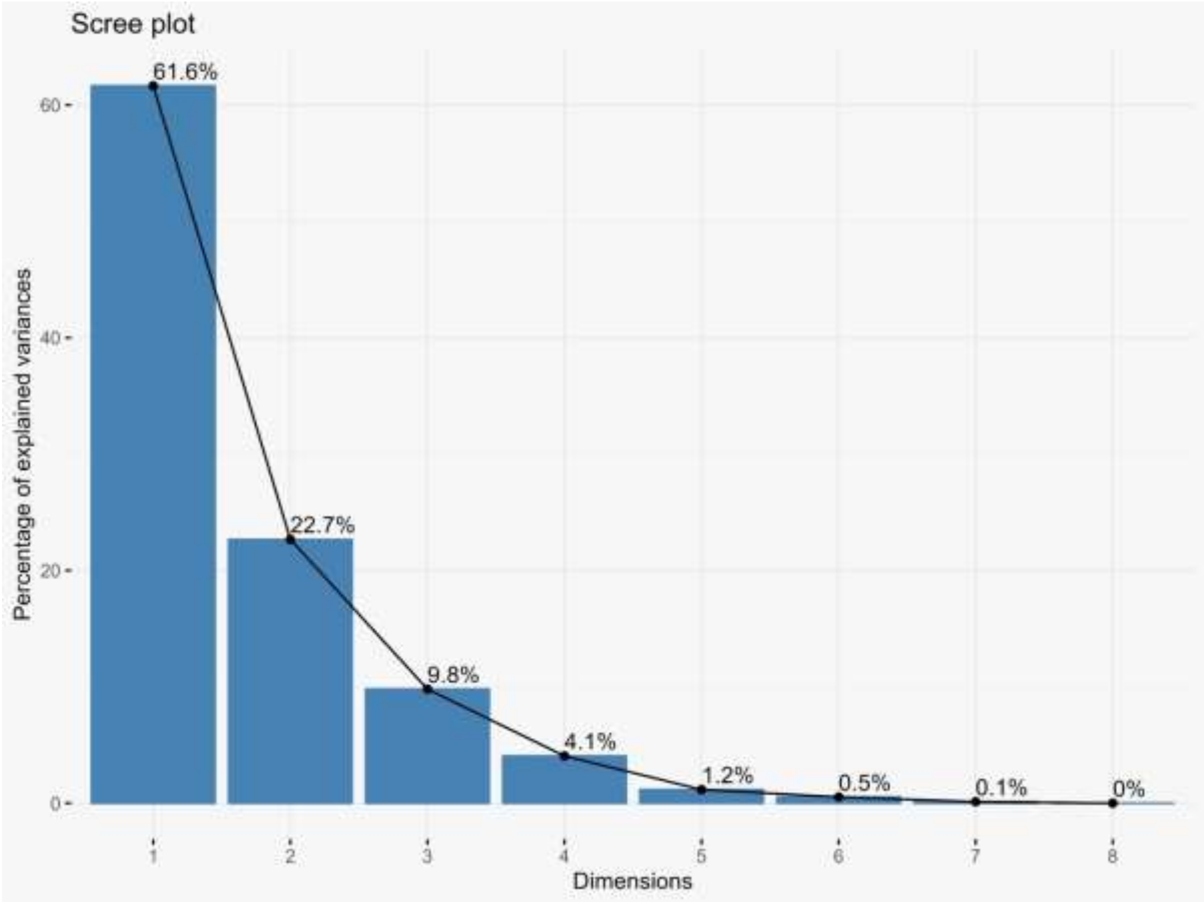

Figure 5.20: Principal component analysis (PCA) for Pollen contribution of each principal component to total variance.

Table 5.3: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for pollen characteristics of different samples.

PCA	*Eigenvalue*	% of variance	Cumulative %
1	4.93	61.64	61.64
2	1.81	22.67	22.67

The Principal Component Analysis (PCA) results highlight notable trends in pollen traits among the sampled taxa. The calculated eigenvalues show that the first principal component (PCA1) captures a major share of the total variation, representing 61.64% of the observed variability. The second component (PCA2) adds another 22.67% to the explanation of variance. Together, PCA1 and PCA2 account for a combined 84.3% of the total variation, emphasizing their importance in revealing the core structure and distribution patterns within the dataset (Table 5.3 and Figure 5.20).

The cluster analysis of PCA shows *Rhododendron* sp. (*R. arboreum, R. vietchianum, R. formosum*) are grouped closely in the upper left quadrant. This clustering suggests that these species share similar pollen traits, especially in exine sculpturing and aperture configuration, contributing less to variation across PC1 and PC2. Their position reflects uniformity in characters like colpus margin and pollen size**.** *Monotropa uniflora* is clearly separated on the far right of PC1 and upper region of PC2. Its isolation indicates highly distinct pollen features, likely influenced by its monad pollen type and unique aperture configuration. This supports previous findings that *M. uniflora* is morphologically divergent from other Ericaceae members. *Agapetes odontocera* (var. *odontocera* & var. *mizoramensis*)**,** *Lyonia ovalifolia***,** *Vaccinium vaccineaceum*, and *V. sprengelii* appear in the lower quadrants. These taxa share similar apocolpial sculpturing and viscin thread presence, contributing to their close proximity. Variability is still evident, particularly for *V. sprengelii*, which is slightly more dispersed, likely due to unique sculpturing traits.

An analysis of the correlations between the original variables and the principal components reveals that specific pollen traits are strongly associated with the principal axes. Notably, PC1 demonstrated strong positive loadings for key pollen traits such as exine sculpturing, apocolpial region sculpturing, and the presence of viscin threads, suggesting that these characteristics significantly drive the variation captured along this axis. In contrast, pollen size (P) and polar distance (D) exhibited negative correlations with PC1, indicating an inverse relationship between these size-related features and sculptural attributes. Conversely PC2 showed positive associations with aperture configuration, colpus margin, as well as P and D, highlighting its alignment with structural and dimensional aspects of pollen morphology. Meanwhile, PC2 was negatively correlated with exine sculpturing, apocolpial sculpturing, and viscin thread, suggesting a trade-off between structural elaboration and sculptural complexity along this axis.

Further analysis shows that these relationships emphasize that different sets of characters contribute uniquely to species separation. While PC1 effectively discriminates taxa based on surface sculpturing and adhesive features, PC2 highlights variations in pollen aperture type and overall grain size. The complementary nature of these components reinforces the utility of multivariate analysis in resolving fine-scale morphological distinctions among closely related Ericaceae species.

5.2.4. Discussion

The palynological analysis conducted on nine taxa of the Ericaceae family from Mizoram revealed significant variations in pollen morphology, underscoring their taxonomic and phylogenetic value. These findings align with and build upon previous studies that have highlighted the importance of palynology in understanding systematic relationships among Ericaceae taxa (Moore *et al*., 1991; Smith *et al*., 1997). The use of Scanning Electron Microscopy (SEM) allowed for a high-resolution examination of intricate pollen features such as exine sculpturing, aperture type, and viscin thread presence traits that are often critical for taxonomic differentiation. One of the central observations of this study is the tetrad pollen configuration in most taxa, which is consistent with the general palynological trend within the Ericaceae (Hesse *et al*., 2009). The tetrahedral tetrads, which dominate in genera such as *Rhododendron* spp., *Agapetes* spp., and *Vaccinium* spp. have long been considered a diagnostic trait of the family (Halbritter *et al*., 2018). The presence or absence of viscin threads, however, proved to be a variable and informative character. While species such as *Rhododendron arboreum* and *R. formosum* showed clear viscin thread formation, members of *Agapetes* and *Vaccinium* lacked these structures. Viscin threads are often associated with pollination biology, especially in taxa relying on animal-mediated dispersal (Skvarla & Rowley, 2004). The variation observed here may thus reflect differing pollination strategies, which warrants further ecological investigation.

Exine sculpturing emerged as a highly differentiating feature among the taxa. Previous studies by Punt *et al*. (2007) and Wrońska-Pilarek *et al*. (2013) emphasized the diagnostic importance of exine patterns in angiosperm palynology. In our study, diverse sculpturing types were recorded, ranging from finely rugulate in *R. formosum* to gemmate in *R. vietchianum* and granulate-rugulate in *Agapetes odontocera*. These features are not merely structural but may also influence pollen-pistil interactions and pollen viability, which are crucial for reproductive success (Hebda & Chinnappa, 1994). The shared sculpturing traits in *Agapetes odontocera* var. *mizoramensis* and *Vaccinium sprengelii* suggest a potential evolutionary convergence or close affinity, supported by their clustering in both UPGMA and PCA analyses. Hierarchical cluster analysis using UPGMA, based on eight pollen characters, confirmed clear groupings at genus and varietal levels. The close clustering of *R. formosum* and *R. vietchianum* is particularly noteworthy and supports previous morphological and molecular phylogenetic classifications that place these species within the same subgeneric group (Goetsch *et al.*, 2005). Similarly, the close proximity of *Agapetes* and *Vaccinium* species in the dendrogram corresponds with traditional taxonomic treatments and reflects a high degree of morphological coherence in pollen traits (Kron *et al*., 2002). Of special interest is the position of *Monotropa uniflora*, which appeared as an outlier in both UPGMA and PCA. Its distinct monad pollen configuration and unique colpus structure clearly separate it from the tetrad-bearing taxa. This morphological distinctiveness has been documented in earlier studies, which emphasized the divergent evolutionary trajectory of monotropoids due to their mycoheterotrophic lifestyle and unique reproductive biology (Bidartondo & Bruns, 2002; Wallace & Jansen, 2002). Our findings reaffirm that *M. uniflora* occupies a distinct phylogenetic position within Ericaceae, as also noted by Hesse *et al*. (2009), further highlighting the utility of pollen characters in resolving deep phylogenetic branches.

The Principal Component Analysis (PCA) corroborated the hierarchical clustering, identifying two major axes (PC1 and PC2) that together explained 84.3% of total variance. This high explanatory power underlines the relevance of the selected pollen traits in capturing meaningful morphological variation. PC1 primarily reflected traits associated with surface sculpturing and viscin thread presence, whereas PC2 emphasized structural features like aperture configuration and grain size. This division mirrors the dual emphasis seen in previous morphometric studies, which often separate surface and aperture traits as orthogonal axes of variation (Chanda & Mukhopadhyay, 1986; Harley & Clarke, 1990). The PCA plot revealed clustering patterns that were consistent with known taxonomic groupings. The tight grouping of *Rhododendron* species in the upper left quadrant suggests a conserved palynological profile within the genus, likely reflective of shared evolutionary ancestry. In contrast, *Vaccinium vacciniaceum* and *V. sprengelii* showed some degree of separation, possibly due to subtle differences in exine ornamentation and tetrad size, consistent with observations made by Wrońska-Pilarek *et al*. (2013) in European *Vaccinium* taxa. Interestingly, the taxa with shared apocolpial sculpturing and absence of viscin threads (*Agapetes odontocera* and *Vaccinium sprengelii*) also formed a distinct group in PCA, suggesting these traits are evolutionarily informative. The results echo those of previous authors (Hebda & Chinnappa, 1990), who emphasized that apocolpial features and colpus characteristics often show genus-level specificity.

The observed morphological patterns also have ecological and conservation implications. Several studied species, including *R. vietchianum* and *A. odontocera* var. *mizoramensis*, are rare or endemic to high-altitude regions of Mizoram. As noted by Mao & Hore (2006), such restricted distributions combined with habitat degradation increase extinction risks. Our study provides crucial baseline data for these taxa, which can aid in their conservation assessment and policy formulation. Palynological features, especially those related to pollen viability and dispersal capacity, can indirectly inform reproductive success and population sustainability (Fægri & Iversen, 1989). Moreover, the differences in pollen aperture and sculpturing may reflect adaptive responses to different environmental conditions, such as humidity, altitude, or pollinator types. This supports the ecological palynology framework proposed by El-Ghazaly and Rowley (1999), wherein pollen morphology is seen as a reflection of ecological pressures and evolutionary constraints.

So, the present palynological study adds a significant dimension to the systematics of Ericaceae in Mizoram. It validates previous findings on the utility of pollen morphology in taxonomic resolution (Skvarla *et al.*, 1978; Moore *et al.*, 1991) while extending the knowledge base by incorporating previously unstudied endemic and threatened species. The use of SEM studies coupled with multivariate analysis (UPGMA and PCA) has enabled a fine-scale morphological characterization, revealing both conserved and divergent traits across taxa. These insights not only enrich our understanding of Ericaceae evolution but also underscore the importance of integrating palynology in conservation strategies.

5.3 Seed Micromorphology

5.3.1 Collection of seeds and preparation

Fruits of the Ericaceae species from Mizoram were collected during their respective fruiting periods from the study sites to examine the seed micromorphological characteristics. Seeds were carefully mounted on brass stubs using double-sided adhesive tape with the aid of fine forceps to ensure stability. The mounted specimens were then coated with a thin layer of gold using a Fine Coat Ion Sputter JFC-1100 to enhance conductivity for Scanning Electron Microscopy (SEM). SEM imaging was employed to capture detailed micrographs, which were subsequently used to analyze and document various seed features, including shape, size, presence of wings, seed coat sculpturing, shape of epidermal cells, characteristics of epidermal cell walls, and their surface texture.

Glossary on terminology of seedcoat morphology based on Corner (1976), Barthlott (1981), Fagúndez & Izco (2009) and Fagúndez *et al.* (2010) is given below:

Ellipsoid : elongated oval shape that is longer than it is wide

Wings : membranous extensions that aid in wind dispersal and are typically found around the seed margin or at the apex

Anticlinal cell wall : wall of an epidermal cell that is perpendicular to the surface

Periclinal cell wall	: cell wall that is parallel to the surface
Reticulate	: texture that appears net-like or mesh-like
Oblong	: shape that is longer than it is wide**,** with sides that are nearly parallel, resembling an elongated rectangle
Sinuous	: wavy, curving, or serpentine form or outline
Undulate	: smooth, wave-like curves, not sharp or angular
Striate	: texture characterized by parallel lines or grooves that run in a uniform direction
Globose	: shape that is spherical or nearly spherical, resembling a globe or a ball

The analysis of seed coat micromorphology in the studied Ericaceae family across 9 taxa reveals significant diversity in surface sculpturing and epidermal cell patterns. The detailed micromorphological features of each species are presented below, along with their corresponding SEM photoplate numbers.

Agapetes odontocera var. *mizoramensis* Banik & Sanjappa (**Plate 14: 1a & 1b**)

Seed size ranges from 1.5 – 1.8 × 0.5 – 0.6 mm. It is dark brown in colour and oblong - ellipsoid shape. The hilum is non-protuberant and wings are present on one terminal of the seed. The seed surface has a reticulate sculpture, irregular polygonal shaped epidermal cell. The anticlinal cell wall is straight with no thickening found; the wall level is raised. The periclinal wall is flat to concave in shape with smooth wall texture.

Agapetes odontocera var. *odontocera* (Wight) Benth. & Hook. (**Plate 14: 2a & 2b**)

Seed size ranges from 1.7 – 1.9 × 0.5 – 0.7 mm. It is brown in colour and ellipsoid shape. The hilum is non-protuberant and wings are absent. The seed surface has a reticulate sculpture, irregular shaped epidermal cell. The anticlinal cell wall is undulate with no thickening found; the wall level is raised. The periclinal wall is flat to concave in shape with striate wall texture

Lyonia ovalifolia (Wall.) Drude (**Plate no 14:3a & 3b**)

Seed size ranges from 1.3 – 1.6 × 0.21 – 0.25 mm. It is brown in colour and oblong in shape. The hilum is protuberant and wings are absent. The seed surface has a faintly reticulate sculpture, linear shaped epidermal cell. The anticlinal cell wall is straight to sinuous with no thickening found, the wall level is raised. The periclinal wall is flat to flat shape with smooth wall texture.

Monotropa uniflora L. (**Plate 15: 1a & 1b**)

Seed size ranges from 1.1 – 1.3 × 0.1 – 0.2 mm. It is white in colour and oblong in shape. The hilum is non - protuberant and wings are absent. The seed surface has a reticulate sculpture, irregular polygonal cell shaped epidermal cell. The anticlinal cell wall is straight to sinuous with no thickening found, the wall level is raised. The periclinal wall is flat to flat shape with smooth wall texture.

Rhododendron arboreum Sm. (**Plate 15:2a & 2b**)

Seed size ranges from 1.6 – 1.7 × 0.6 – 0.7 mm. It is black colour and ellipsoid shape. The hilum is non-protuberant and wings are present on both terminals of the seed. The seed surface has a reticulate sculpture, sub-linear shaped epidermal cell. The anticlinal cell wall is straight to sinuous with thickening in the anticlinal wall and the wall level is raised. The periclinal wall is flat with smooth wall texture.

Rhododendron formosum Wall. (**Plate 15: 3a & 3b**)

Seed size ranges from 3.8 – 4.1 × 0.22 – 0.24 mm. It is pale yellow in colour and oblong shape. The hilum is non-protuberant and are faintly winged. The seed surface has a reticulate sculpture, linear shaped epidermal cell. The anticlinal cell wall is straight to sinuous with thickening and raised wall level. The periclinal wall is concave in shape with faintly reticulate wall texture.

Rhododendron vietchianum Hook. (**Plate 16: 1a & 1b**)

Seed size ranges from 4.5 – 4.8 × 0.4 – 0.5 mm. It is pale yellow in colour and oblong shape. The hilum is non-protuberant and are faintly winged. The seed surface has a reticulate sculpture, linear shaped epidermal cell. The anticlinal cell wall is sinuous with thickening and raised wall level. The periclinal wall is flat to concave in shape with smooth wall texture.

Vaccinium sprengelii (G. Don) Sluemer ex Rehder (**Plate 16: 2a & 2b**)

Seed size ranges from 3.5 – 3.7 × 1 – 1.2 mm. It is green in colour and sub – globose in shape. The hilum is slightly protuberant and wings are absent. The seed surface has a reticulate sculpture, irregular polygonal shaped epidermal cell. The anticlinal cell wall is straight with no thickening found; the wall level is raised. The periclinal wall is concave to concave in shape with perforated wall texture.

Vaccinium vacciniaceum (Roxb.) Sleumer (**Plate 16: 3a & 3b**)

Seed size ranges from 1.8 – 2 × 0.8 – 0.9 mm. It is dark green in colour and sub – globose in shape. The hilum is non-protuberant and wings are absent. The seed surface has a faintly reticulate sculpture, polygonal shaped epidermal cell. The anticlinal cell wall is straight with thickening found; the wall level is raised. The periclinal wall is flat to concave shape with smooth to striate wall texture.

Table 5.4: Seed characters and character states for the cluster analysis of Ericaceae. The numbers in brackets are the codes for character states.

Sl No.	Seed Characters	Character states
1	Colour	black (1) pale yellow (2) brown (3) dark brown (4) green (5) dark green (6) white (7)
2	Shape	ellipsoid (1) oblong (2) oblong-ellipsoid (3) sub-globose (4)
3	Hilum	protuberant (1) slightly protuberant (2) non-protuberant (3)
4	Length	less than 1mm (1) 1-2mm (2) more than 2mm (3)
5	Width	less than 1mm (1) 1-2mm (2) more than 2mm (3)
6	Surface	reticulate (1) faintly reticulate (2) striate (3) reticulate-smooth (4)
7	Margin	winged (1) faintly winged (2) not winged (3)
8	seed coat pattern sclupture	reticulate (1) undulate (2)
9	outer epidermal cell shape	linear (1) sublinear (2) irregular (3) polygonal (4) irregularly polygonal (5)
10	anticlinal wall shape	straight to sinous (1) sinous (2) undulate (3) straight (4)
11	anticlinal wall thickening	thick (1) thin (2)
12	anticlinal wall level	raised (1) grooved (2)
13	periclinal wall level	flat (1) concave (2) flat-concave (3) flat - convex (4)
14	periclinal wall texture	smooth (1) faintly reticulate (2) striate (3) perforated (4) smooth-striate (5)

Table 5.5: Data matrix used in cluster analysis of Ericaceae species of Mizoram based on seed features **(Plate 14 - 16).**

Characters/ Species	*A. odontocera* var. *mizoramensis*	*A. odontocera* var. *odontocera*	*L. ovalifolia*	*M. uniflora*	*R. arboreum*	*for*
colour	4	3	3	7	1	
shape	3	1	2	2	1	
hilum	3	3	1	3	3	
length	2	2	2	2	2	
width	1	1	1	1	1	
surface	1	4	2	1	1	
margin	1	3	3	3	1	
seed coat pattern sclupture	1	1	2	1	1	
outer epidermal cell shape	5	3	1	5	2	
anticlinal wall shape	4	3	2	1	1	
anticlinal wall thickening	2	2	1	2	1	
anticlinal wall level	1	1	1	1	1	
periclinal wall level	1	2	1	1	1	
periclinal wall texture	1	3	1	1	1	

5.3.3 Seed cluster analysis using dendrogram

The UPGMA dendrogram constructed (Figure 2.1) using Euclidean distances reveals the hierarchical clustering of nine Ericaceae taxa based on seed coat morphological characters (Table 5.4 & 5.5). The analysis delineates two major clusters, reflecting underlying structural similarities and distinctions among the studied species.

The first major cluster comprises *Agapetes odontocera* var. *odontocera*, *Agapetes odontocera* var. *mizoramensis*, *Rhododendron arboreum*, *Rhododendron formosum*, and *Rhododendron veitchianum*. Within this group, the two *Agapetes odontocera* varieties are closely aligned, suggesting minimal divergence in their seed coat traits which is likely due to varietal-level differentiation rather than species-level. These two taxa further cluster with *Rhododendron* species, indicating a broader morphological similarity within the Vaccinioideae subfamily. The close association among *Rhododendron arboreum*, *R. formosum*, and *R. veitchianum* may reflect conserved seed coat features such as reticulate surface patterning, anticlinal wall thickening, and the presence of distinct epidermal cell ornamentation, which are often used as taxonomic markers in Ericaceae.

The second major cluster includes *Vaccinium sprengellii*, *Vaccinium vacciniaceum*, *Lyonia ovalifolia*, and *Monotropa uniflora*. The two *Vaccinium* species form a distinct subgroup, reflecting a shared suite of seed coat traits typical of the genus, such as fine reticulations and smaller seed size. *Lyonia ovalifolia* clusters relatively closely with the *Vaccinium* species, which may indicate some degree of morphological convergence or shared ancestral characters. Notably, *Monotropa uniflora* is the most divergent among the taxa studied, as evident by its long branch length. This deviation is expected, given its mycoheterotrophic nature and unique ecological adaptations, which may be mirrored in distinct seed coat features, such as reduced ornamentation or altered cell wall patterns.

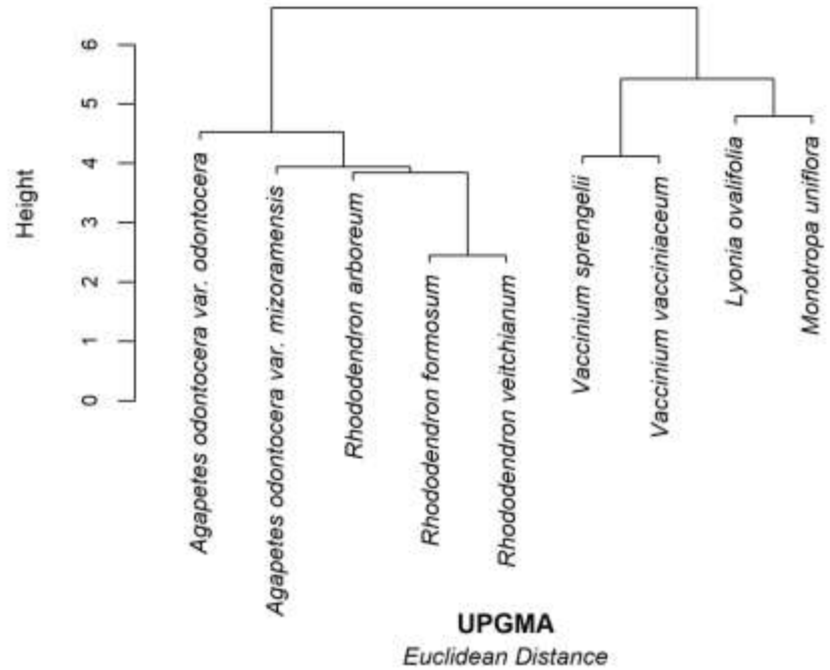

Figure 5.21: Dendrogram based on cluster analysis of seed morphological characters Using UPGMA (Unweighted Pair Group Method with Arithmetic Mean) with Euclidean Distance.

Overall, the dendrogram supports several known taxonomic relationships while also highlighting variations that may suggest evolutionary divergence or adaptation to different ecological niches. The clustering pattern largely reflects taxonomic affinities within Ericaceae, particularly the grouping of species from closely related genera. However, some intergeneric associations tha include *Vaccinium* and *Lyonia* may warrant further anatomical or molecular investigation to better understand their phylogenetic significance. These findings reinforce the utility of seed coat morphology as a diagnostic tool in taxonomic and phylogenetic studies within Ericaceae. The application of multivariate clustering techniques like UPGMA provides a robust framework for visualizing character-based relationships and complements traditional classification systems.

5.3.4 Principal Component Analysis of Seeds

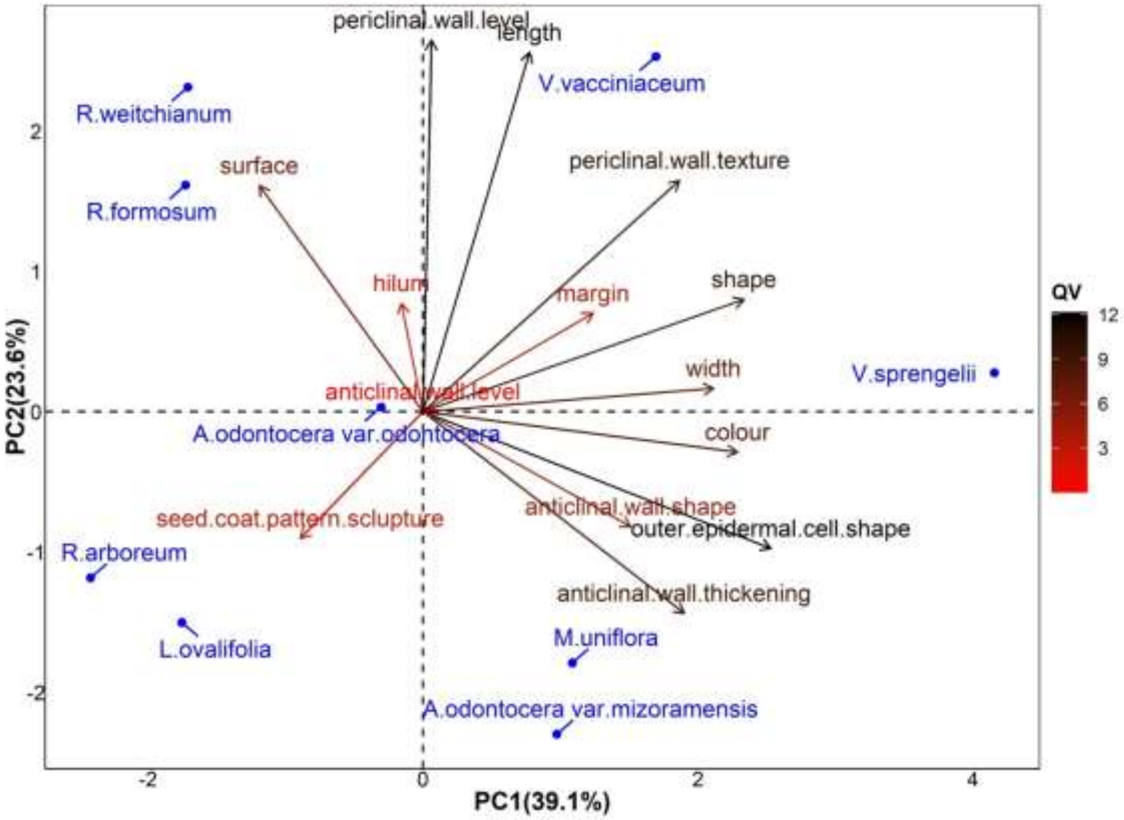

Figure 5.22: Principal component analysis (PCA) for seed characteristics of different samples: Biplot of individuals and variables (PC1 & PC2).

The Principal Component Analysis (PCA) biplot provides a comprehensive overview of the variation in seed coat morphological characters among nine Ericaceae taxa (Figure 5.22). The first two principal components account for a substantial proportion of the total variance, with PC1 explaining 39.1% and PC2 explaining 23.6%, cumulatively capturing 62.7% of the total variation. This indicates that the selected seed coat traits are highly informative in distinguishing among the studied taxa.

PC1 is primarily associated with traits such as shape, width, colour, anticlinal wall thickening, outer epidermal cell shape, and anticlinal wall shape. Taxa that score highly on PC1 such as *Vaccinium sprengellii*, *Monotropa uniflora*, and *Agapetes odontocera* var. *mizoramensis* exhibit stronger expression of these features, suggesting they possess broader, more distinctively shaped seeds with thicker anticlinal walls and well-defined epidermal cell outlines. Conversely, taxa on the negative side of PC1, such as *Rhododendron arboreum* and *Lyonia ovalifolia*, show weaker expression of these characters.

PC2 on the other hand, is influenced by variables such as surface texture, hilum structure, and seed coat pattern sculpture. Notably, *Rhododendron formosum* and *R. veitchianum* score positively along PC2, indicating their seed coats exhibit prominently sculptured surfaces and distinctive hilum features. In contrast, taxa closer to the origin, such as *Agapetes odontocera var. odontocera* display more intermediate or generalized seed coat characteristics.

The positioning of *Vaccinium vacciniaceum* in the upper right quadrant suggests significant contributions from periclinal wall length and texture, distinguishing it from other *Vaccinium* species like *V. sprengellii*, which aligns more with colour, shape, and width. *Monotropa uniflora*, located in the lower right quadrant, is uniquely characterized by a combination of thickened anticlinal walls and distinct epidermal structures, reflecting its divergent ecological adaptations as a mycoheterotroph.

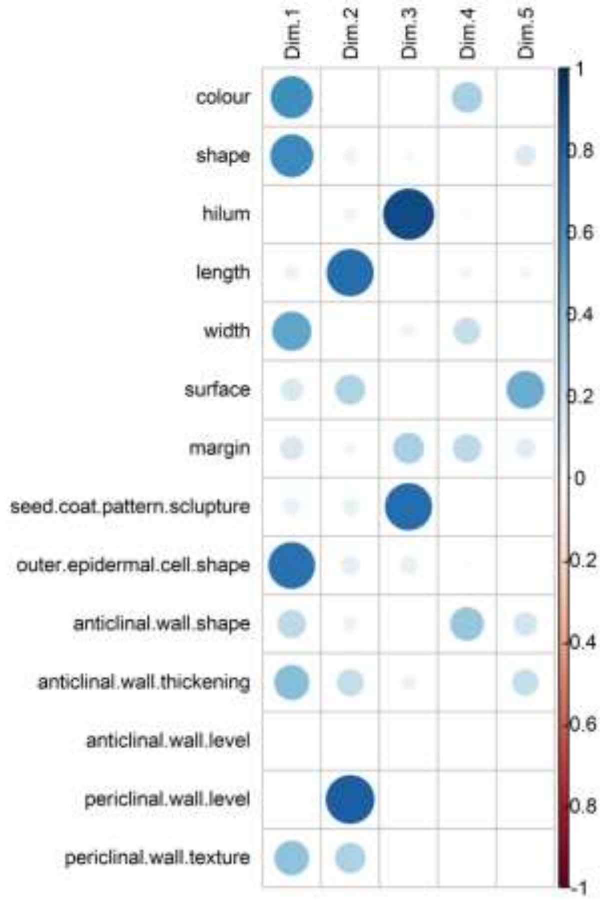

Figure 5.23: Heatmap of Principal component analysis (PCA) for seed characteristics of different samples: Principal components and their relation with variables.

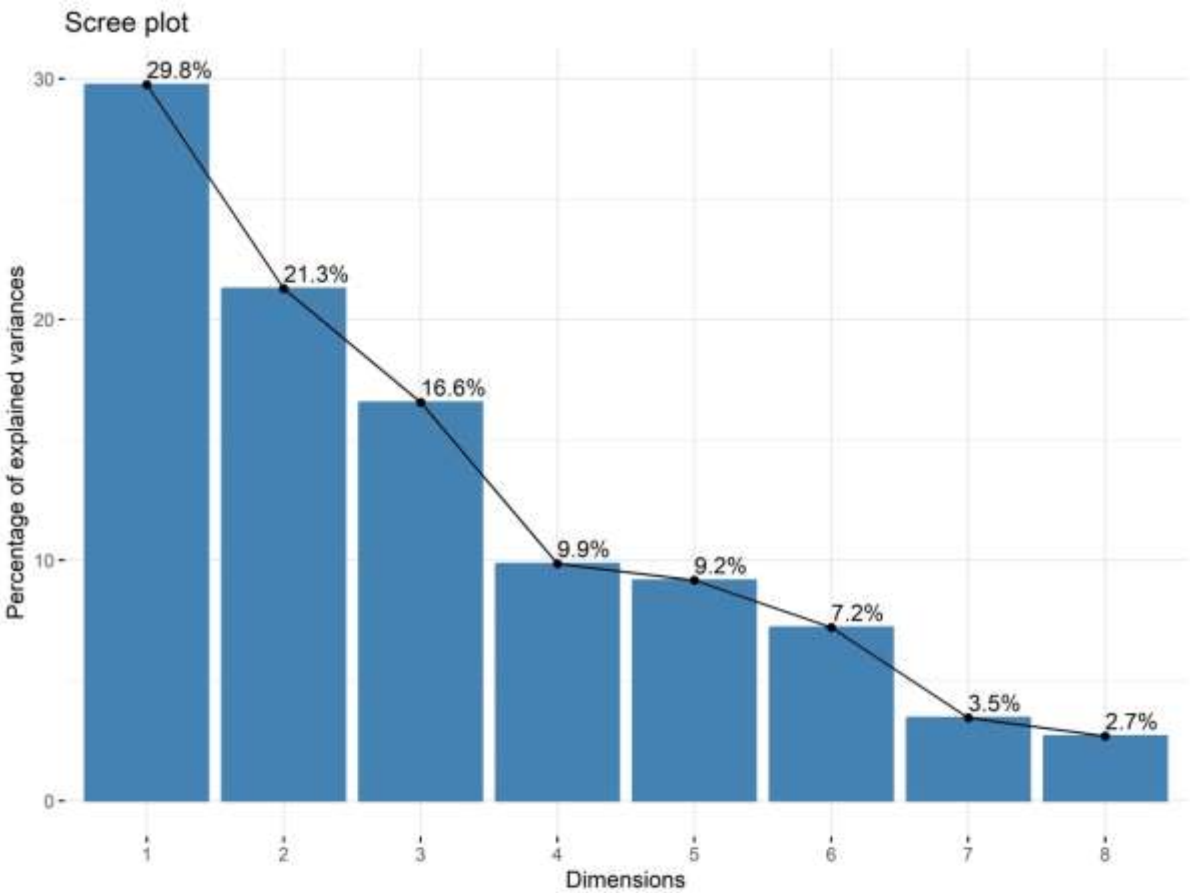

Figure 5.24: Principal component analysis (PCA) for seed contribution of each principal component to total variance.

Table 5.6: Eigenvalues, variance explained % and cumulative proportion of total variance from principal component analysis (PCA) components for seed characteristics of different samples.

PCA	*Eigenvalue*	% of variance	Cumulative %
1	4.1306	39.1%	29.77%
2	2.9536	23.6%	51.06%

Overall, the PCA plot complements the UPGMA dendrogram by illustrating the multivariate relationships among taxa based on seed coat micromorphology. It highlights the diagnostic value of traits such as periclinal and anticlinal wall features, seed shape, and epidermal cell structure. These findings reinforce the relevance of seed coat characters in taxonomic differentiation within the Ericaceae and support their continued use in comparative morphological and evolutionary studies.

5.3.4 Discussion

The micromorphological analysis of seed coat characteristics among nine Ericaceae taxa reveals significant interspecific and intergeneric variations, underscoring their taxonomic and ecological relevance. These findings align with studies emphasizing the diagnostic value of seed morphology in plant systematics. The UPGMA dendrogram delineated two primary clusters. The first cluster comprising *Agapetes odontocera* (var. *odontocera* and var. *mizoramensis*), *Rhododendron arboreum*, *R. formosum*, and *R. veitchianum* exhibits shared features such as reticulate surface sculpturing and thickened anticlinal walls. This morphological coherence suggests conserved evolutionary traits within these taxa. Similar patterns have been observed in other studies focusing on *Rhododendron* species, where seed coat characteristics provided insights into phylogenetic relationships (Chowdhury & Panda, 2016).

The second cluster includes *Vaccinium sprengellii*, *V. vacciniaceum*, *Lyonia ovalifolia*, and *Monotropa uniflora*. The grouping of *Vaccinium* species reflects their shared seed traits, such as globose shape and specific surface textures. The inclusion of *Lyonia* and *Monotropa* indicates potential morphological convergence or retention of ancestral features. Notably, distinct position of *Monotropa uniflora* aligns with its unique ecological adaptations as a mycoheterotroph, which are often associated with specialized seed characteristics (Merckx *et al*., 2013 a & b).

Principal Component Analysis (PCA) further elucidates these relationships, with the first two components accounting for 62.7% of the total variation. PC1 is influenced by traits like seed shape, width, and anticlinal wall thickening, distinguishing taxa with robust ornamentation from those with simpler forms. PC2 captures variations in surface texture and hilum structure, highlighting distinctions among closely related species. Such multivariate analyses have proven effective in previous studies for resolving taxonomic ambiguities within Ericaceae.

Overall, the integration of seed coat micromorphology with multivariate statistical methods provides a robust framework for understanding taxonomic relationships within Ericaceae. The observed morphological patterns not only corroborate existing classifications but also offer insights into evolutionary trajectories and ecological adaptations.

5.4 Molecular Studies

To investigate the relationships among the studied Ericaceae species, a phylogenetic analysis was conducted using concatenated sequences of the ITS2 and *rbcL* primers.

5.4.1 Bioinformatics Analysis

The forward and reverse sequences obtained from the PCR products amplified with ITS2 and *rbcL* primers were trimmed and aligned using bioinformatics tools. The resulting contig sequences were submitted to the Basic Local Alignment Search Tool (BLASTn) at the National Center for Biotechnology Information (NCBI) for a homology search. GenBank accession numbers (Table 5.7) were assigned to the submitted taxa, and the sequences were further analyzed to explore the phylogenetic relationships among the species within the Ericaceae family.

Table 5.7: List of the *rbcL* and ITS2 GenBank accession no. of the Ericaceae taxa of Mizoram.

Sl. No.	Name of taxa	ITS2 Accession No.	*rbcL* Accession No.
1.	*Agapetes odontocera* var. *mizoramensis*	PQ788144	PP514342
2.	*Agapetes odontocera* var. *odontocera*	PP476590	PP514336
3.	*Lyonia ovalifolia*	OQ692628	PP514337
4.	*Monotropa uniflora*	OQ692629	PP514341
5.	*Rhododendron arboreum*	OQ692630	PP514338
6.	*Rhododendron formosum*	PQ788146	PP514343
7.	*Rhododendron vietchianum*	PQ788145	PP514338
8.	*Vaccinium griffithianum*	PQ788146	PP788146
9.	*Vaccinium sprengelii*	OQ692631	PP514339
10.	*Vaccinium vaccineacium*	PP476589	PP514340

5.4.2 Phylogeny studies

Phylogenetic analysis using a maximum likelihood tree (MLT) in a K2P model with bootstrap-1000 of Ericaceae species showed a high similarity in the BLASTn search to the available sequences in the NCBI database. For the *rbcL* and ITS2 sequences, 9 taxa within 5 genera of the family Ericaceae were used to construct the ML tree in this study. The phylogenetic trees illustrate well-supported evolutionary relationships within the Ericaceae family based on molecular data, particularly using *rbcL* and ITS2 markers.

The *Rhododendron* genus forms a distinct and well-supported clade, indicating its monophyletic nature. Species such as *Rhododendron formosum* and *R.*

veitchianum group were found very close, corroborating earlier morphological studies and suggesting a strong molecular similarity. Other species like *R. arboreum*, *R. delavayi*, *R. agastum*, and *R. simiarum* also cluster together, reinforcing the genetic integrity of this genus. Multiple samples of *Monotropa uniflora* form a compact cluster with very short branch lengths, signifying minimal genetic divergence and high genetic similarity, possibly indicating limited variability in the analyzed regions or recent divergence. *Lyonia ovalifolia* and its variants (including *var. elliptica*) consistently form a highly supported clade (bootstrap = 100), showing clear genetic cohesion and validating their taxonomic classification. Members such as *V. sprengelii*, *V. griffithianum*, and *V. vacciniaceum* cluster into a distinct group, reflecting their shared ancestry. Notably, *V. griffithianum* clusters closely with *Agapetes odontocora* var. *mizoramensis*, suggesting some degree of intergeneric affinity between *Vaccinium* and *Agapetes* possibly due to shared evolutionary traits or incomplete lineage sorting.

5.4.3 Discussion

The phylogenetic analysis based on concatenated ITS2 and *rbcL* sequences successfully clarified interspecies relationships within the Ericaceae family, highlighting the effectiveness of these markers even though they are relatively conserved. The maximum likelihood tree (MLT), constructed using the K2P model, revealed distinct and well-supported clades that confirmed the monophyly of several genera. *Rhododendron* species grouped together in a single clade, reinforcing morphological classifications and demonstrating genetic consistency. Likewise, *Lyonia ovalifolia* and its variety var. *elliptica* clustered tightly with strong bootstrap support (100), indicating robust taxonomic cohesion. Minimal genetic divergence observed in *Monotropa uniflora* points to recent speciation or limited sequence variability in the regions analyzed.

The *Vaccinium* group including *V. sprengelii*, *V. griffithianum*, and *V. vacciniaceum* also formed a tight cluster, indicating common ancestry. The close relationship between *V. griffithianum* and *Agapetes odontocora* var. *mizoramensis* may imply intergeneric connections due to convergent evolution or incomplete lineage sorting. The study demonstrates that combining ITS2 and *rbcL* markers offers a reliable method for understanding genus-level phylogenetic relationships. Strong bootstrap values across clades enhance confidence in the tree structure, which is consistent with traditional taxonomy. These findings support the conclusions of Zimmer *et al*. (2007), Quinn *et al.* (2003) and Gillespie & Kron (2010) affirming the usefulness of these markers in taxonomic studies of Ericaceae.

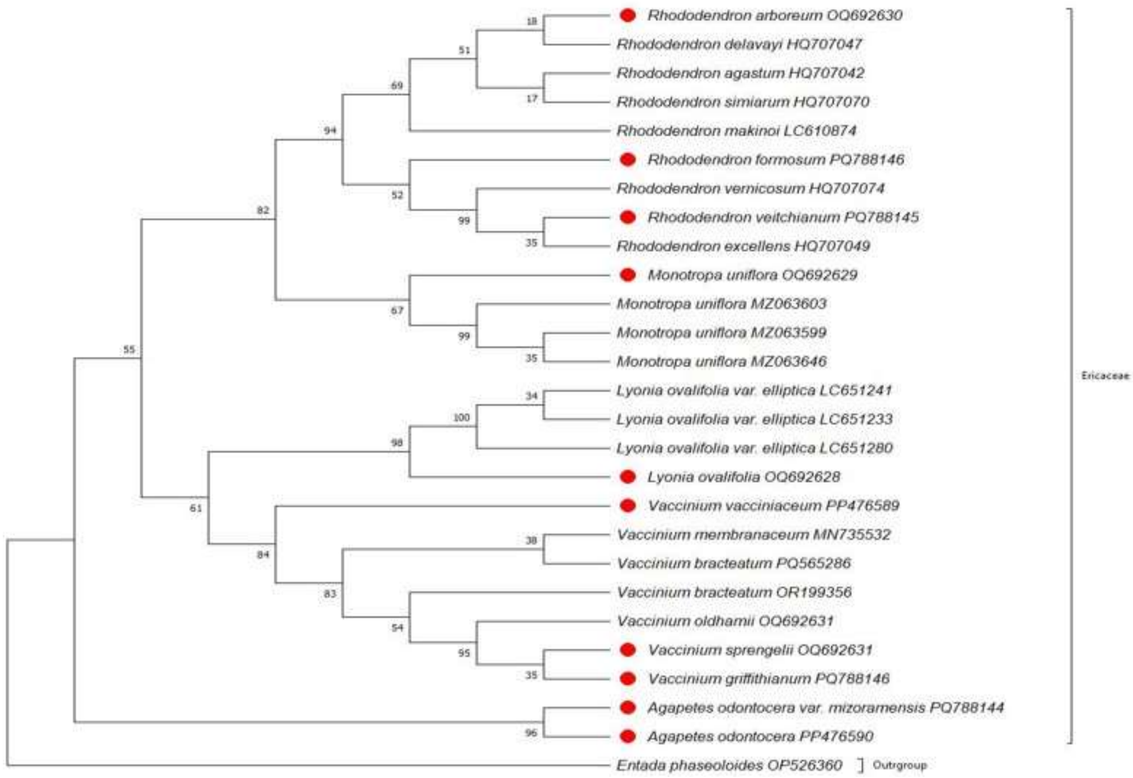

Figure 5.25: Maximum Likelihood (ML) Based Phylogenetic Tree analysis of ITS2 Sequences using MEGA X (Bootstrap value:1,000).

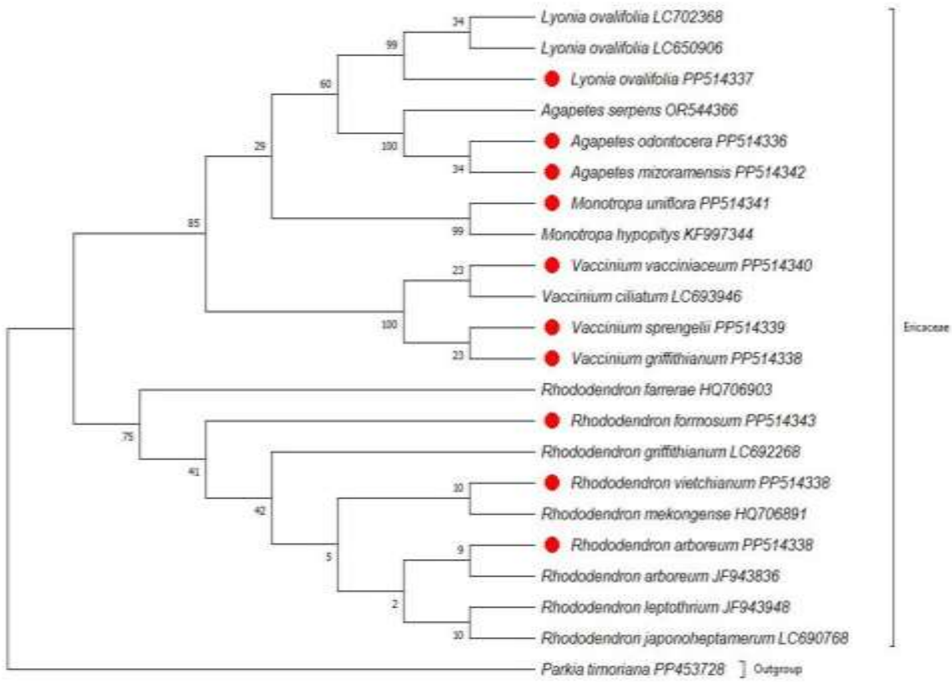

Figure 5.26: Maximum Likelihood (ML) Based Phylogenetic Tree analysis of *rbcL* Sequences using MEGA X (Bootstrap value:1,000).

5.5 Conservation status and Threat Assessment

The conservation status of the Ericaceae taxa recorded from Mizoram was evaluated following the IUCN Red List Categories and Criteria (IUCN, 2024), incorporating both global (where available) and local assessments based on field observations done during 2018 - 2023. Among the studied taxa, only a few have been globally assessed by the IUCN, while most remain 'Not Evaluated' at the international level. Consequently, local population data, including the number of mature individuals and distributional range, were used to determine their conservation categories.

The majority of the taxa exhibit restricted distribution, often confined to one or two localities, with very limited numbers of mature individuals. Such narrow population bases render these taxa highly susceptible to habitat loss, fragmentation, and environmental pressures. Based on local evaluations, several species, including *Agapetes odontocera* var. *mizoramensis*, *Rhododendron formosum*, *R. vietchianum*, and *Vaccinium griffithianum,* qualify as Critically Endangered (CR) under Criterion D. Others, such as *Lyonia ovalifolia*, *Monotropa uniflora*, *Rhododendron arboreum*, *Vaccinium sprengelii*, and *V. vacciniaceum*, meet the thresholds for Endangered (EN) status under Criteria C or D. These findings (Table 5. 8) highlight the urgent need for conservation action, continuous monitoring, and habitat protection to ensure the survival of these ecologically and taxonomically significant taxa in Mizoram.

Agapetes odontocera var. *mizoramensis* Banik & Sanjappa

IUCN Assessment: Not Evaluated

Local Conservation Assessment: This taxon has been documented from seven distinct locations, with an estimated population of only 20 to 25 mature individuals. Based on IUCN Criterion D, it is provisionally assessed as Critically Endangered (CR).

As an endemic species, its distribution is restricted solely to the study area. The expansion and construction of roads often lead to the clearing of roadside vegetation, resulting in the loss and degradation of natural habitats. In addition, increased human access, soil destabilization, and edge effects further exacerbate habitat fragmentation, making the species more vulnerable to decline.

Agapetes odontocera (Wight) Hook.f. var. *odontocera*

IUCN Assessment: Not Evaluated

Local Conservation Assessment: This taxon is currently documented from seven distinct locations, with an estimated population of only 20 to 25 mature individuals. Based on IUCN Criterion D, it provisionally assessed as Critically Endangered (CR).

No significant threats were identified during the study, indicating that the species is not presently considered at risk within the formal conservation assessments of the state. Additionally, local communities actively cultivate these plants in home gardens, lawns, and small agricultural plots, which contribute to their sustainable use and supports informal *in-situ* and *ex-situ* conservation efforts.

Lyonia ovalifolia (Wall.) Drude

IUCN Assessment: Least Concern (LC)

Local Conservation Assessment: This species has been recorded from four distinct locations, with an estimated population of 50 to 100 mature individuals. Based on these observations and in accordance with IUCN Criterion D, it is provisionally assessed as Endangered (EN).

No potential threats were detected during the study, indicating that the species currently faces minimal immediate risk within its natural habitat.

Monotropa uniflora L.

IUCN Assessment: Not Evaluated

Local Conservation Assessment: This species has been recorded from four distinct locations, with an estimated population of 50 to 100 mature individuals. Based on these observations and in accordance with IUCN Criterion D, it is provisionally assessed as Endangered (EN).

Due to its distinctive and attractive appearance, the species is susceptible to illegal collection by onlookers, making poaching a potential threat.

Rhododendron arboreum Sm.

IUCN Assessment: Least Concern (LC)

Local Conservation Assessment: This species is currently documented from two known locations. In one area, the population is estimated at 100 to 150 mature individuals, while the second location supports approximately 20 to 50 individuals. Based on these figures and following IUCN Criterion C, the species is provisionally classified as Endangered (EN).

The study did not reveal any major threats, suggesting that the species is currently not regarded as vulnerable under the conservation criteria of the state.

IUCN Assessment: Not Evaluated

Local Conservation Assessment: This species is currently known from a single location, with an estimated population of 50 to 100 mature individuals. Based on IUCN Criterion D, it is provisionally assessed as Critically Endangered (CR).

Clearing of land for jhum cultivation and ongoing land-use changes pose potential threats, especially since the species occurs outside strictly protected reserve areas.

Rhododendron veitchianum Hook.

IUCN Assessment: Not Evaluated

Local Conservation Assessment: This species is currently known from a single location, with an estimated population of 20 to 50 mature individuals. Based on IUCN Criterion D, it is provisionally assessed as Critically Endangered (CR).

No potential threats were observed during the course of the study. Increasing public awareness and involving local communities in basic monitoring efforts will help ensure its long-term survival.

Vaccinium griffithianum Wight

IUCN Assessment: Not Evaluated

Local Conservation Assessment: This species is currently known from only two locations, with an estimated population of 20 to 50 mature individuals. Based on IUCN Criterion D, it is provisionally assessed as Critically Endangered (CR).

The plant did not produce flowers during the course of study, natural propagation cannot occur, which may hinder population renewal and pose a potential threat to its long-term survival.

Vaccinium sprengelii (G. Don) Sluemer ex Rehder

IUCN Assessment: Least Concern

Local Conservation Assessment: This species has been documented from five distinct locations, with an estimated population of 100 to 150 mature individuals. Based on IUCN Criterion C, it is provisionally assessed as Endangered (EN).

The collection of immature fruit by locals poses a potential threat to natural regeneration, and its brittle stems make the plant highly vulnerable to breakage from natural factors.

Vaccinium vacciniaceum (Roxb.) Sleumer

IUCN Assessment: Not Evaluated

Local Conservation Assessment: This species is currently documented from only two known locations, with an estimated population of 100 to 150 mature individuals. Based on IUCN Criterion C, it is provisionally assessed as Endangered (EN).

No significant threats were identified, as the species grows epiphytically high on the trunks and branches of mature trees within climax forest communities, where it remains largely protected from direct disturbance.

Table 5.8: List of taxa with vernacular name, conservation status and Local conservation assessment.

Taxa	Vernacular Name	Conservation status (IUCN)	Local Conservation Assessment (IUCN)
Agapetes odontocera var. *mizoramensis*	Bawltehlantai	NE	CR
Agapetes odontocera var. *odontocera*	Bawltehlantai	NE	CR
Lyonia ovalifolia	Tlangham	LC	EN
Monotropa uniflora	Sanghar vaibel suak	NE	EN
Rhododendron arboreum	Chhawkhlei	LC	EN
Rhododendron formosum	Chhawkhlei par var	NE	CR
Rhododendron vietchianum	Chhawkhlei par var	NE	CR
Vaccinium griffithianum	Sirte	NE	CR
Vaccinium sprengelii	Sirkam	LC	EN
Vaccinium vaccineacium	Hmuiphang Sirte	NE	EN

Agapetes odontocera var. *mizoramensis* is a narrowly endemic variety of Ericaceae found exclusively in Mizoram, specifically in Phawngpui National Park (23.15311° N 93.09292° E, 1674 m) and Sairep village (23.36167° N 93.36167° E, 1340 m). Described by Banik and Sanjappa, this taxon is morphologically distinct from the typical variety by its specific floral traits and localized distribution. It thrives in high-elevation montane evergreen forests at altitudes above 2000 meters, where it experiences cool temperatures, persistent cloud cover, and high relative humidity—factors that create a unique ecological niche.

The endemicity of *A. odontocera* var. *mizoramensis* may be attributed to isolation, limited seed dispersal, and habitat specificity in a geographically confined montane environment. These factors likely restrict its expansion beyond the known localities. Additionally, the Lushai Hills form a biogeographic transition zone between the Eastern Himalayas and Indo-Burmese regions, which often gives rise to endemism through localized speciation (Mao *et al*., 2016). Anthropogenic pressures such as shifting cultivation (jhum), forest degradation, and climate variability may further limit its distribution and make it vulnerable to habitat disturbance. Due to its rarity and restricted range, this variety deserves focused conservation assessment and ecological study to ensure its long-term survival.

5.5.1 Discussion

The conservation assessment of Ericaceae taxa from Mizoram reveals a concerning pattern of restricted distribution, small population sizes, and heightened vulnerability to environmental and anthropogenic pressures. Although some species such as *Lyonia ovalifolia* and *Rhododendron arboreum* are globally categorized as *Least Concern (LC)*, local assessments indicate a higher level of threat, reflecting the influence of region-specific ecological and human factors on population stability. These findings highlight the importance of conducting local-scale evaluations to supplement global IUCN assessments, especially for taxa with geographically confined or fragmented populations (Mace *et al.,* 2008).

Among the studied taxa, *Agapetes odontocera* var. *mizoramensis*, *Rhododendron formosum*, *R. veitchianum*, and *Vaccinium griffithianum* are categorized as *Critically Endangered (CR)* based on Criterion D, owing to their extremely limited population sizes (often fewer than 50 mature individuals) and confinement to one or two locations. Such a pattern is indicative of relict or micro-endemic taxa that may have evolved under specific ecological conditions but are now increasingly threatened by rapid habitat alteration. Similarly, species such as *Lyonia ovalifolia*, *Monotropa uniflora*, *Rhododendron arboreum*, *Vaccinium sprengelii*, and *V. vacciniaceum* qualify as *Endangered (EN)* under Criteria C or D, signifying small, fragmented populations and restricted ranges.

The primary threats affecting these taxa are habitat loss, fragmentation, and degradation due to shifting cultivation (jhum), deforestation, road construction, and expansion of human settlements (Haridasan & Rao, 1985). The unique topography of Mizoram characterized by steep slopes and narrow valleys—exacerbates these pressures, as even limited land-use changes can significantly alter microhabitats and forest dynamics. Additionally, climatic fluctuations, such as irregular rainfall patterns and increasing temperature variability, may further influence the reproductive success and regeneration potential of these montane species.

Another major concern is the lack of representation of these taxa in global databases and *ex situ* conservation programs. Most of the Ericaceae members recorded from Mizoram remain Not Evaluated (NE) in the IUCN Red List, resulting in an underestimation of their actual conservation urgency. This underscores the necessity of detailed population monitoring, ecological niche studies, and molecular assessments to refine their taxonomic and conservation status.

To ensure the long-term survival of these taxa, conservation efforts should prioritize habitat protection, especially in areas threatened by jhum cultivation, land-use change, and roadside disturbances. Regular monitoring of population size, flowering behavior, and regeneration is essential, particularly for species with poor reproductive output or absence of flowering. For taxa vulnerable to fruit collection or mechanical damage due to brittle stems, strict protection measures and awareness among local communities are recommended. Species growing in fragile or restricted habitats should benefit from microhabitat restoration, such as maintaining canopy cover, moisture levels, and soil quality. For taxa with limited natural propagation, assisted methods like vegetative propagation, controlled nursery-based multiplication, and ex-situ conservation in botanical gardens can support population enhancement. Endemic species with extremely narrow distribution require focused monitoring, strict habitat preservation, and long-term ecological studies to understand their ecological needs and strengthen conservation planning.

5.6 ETHNOBOTANY

5.6.1 Informants demographics

The study included a collective of 60 participants as shown in Table 5.9. Out of the total, 34 individuals were male, accounting for 56.67% of the group, while 26 individuals were female, making up 43.33% of the group. The informants' age distribution was as follows: 23.3% were aged 40-49 years (14 individuals), 36.6% were aged 50-59 years (22 individuals), 28.3% were aged 60-69 years (17 individuals), 6.6% were aged 70-79 years (4 individuals), and 5% were aged 80-89 years (3 individuals). All 60 participants (100%) were classified as key informants, with no general informants taking part in the study. The presence of a diverse range of informants in terms of demographics ensures a wide variety of traditional knowledge, hence increasing the dependability and comprehensiveness of the study's results.

Table 5.9: Informant demography in the study area

Parameters	Category	Number	Frequency
Sex	Male	34	56.67%
	Female	26	43.33%
Age	40-49	14	23.30%
	50-59	22	36.60%
	60-69	17	28.30%
	70-79	4	6.60%
	80-89	3	5%
Healing Experience	Key informants	60	100
	General informants	0	0

In this study, the plant use diversity was classified into four main categories: decorative, culinary, medicinal, and cultural relevance. A total of 10 taxa were identified in the analysis and found to be used throughout these categories. Among the detected species, the ornamental use category had the highest level of diversity, encompassing a total of 8 species. Next, the food category was introduced, with a total of 5 distinct species. Both the medical and cultural relevance categories contained three species each. This distribution showcases the diverse uses of plant species in various cultural and practical settings among the population under study.

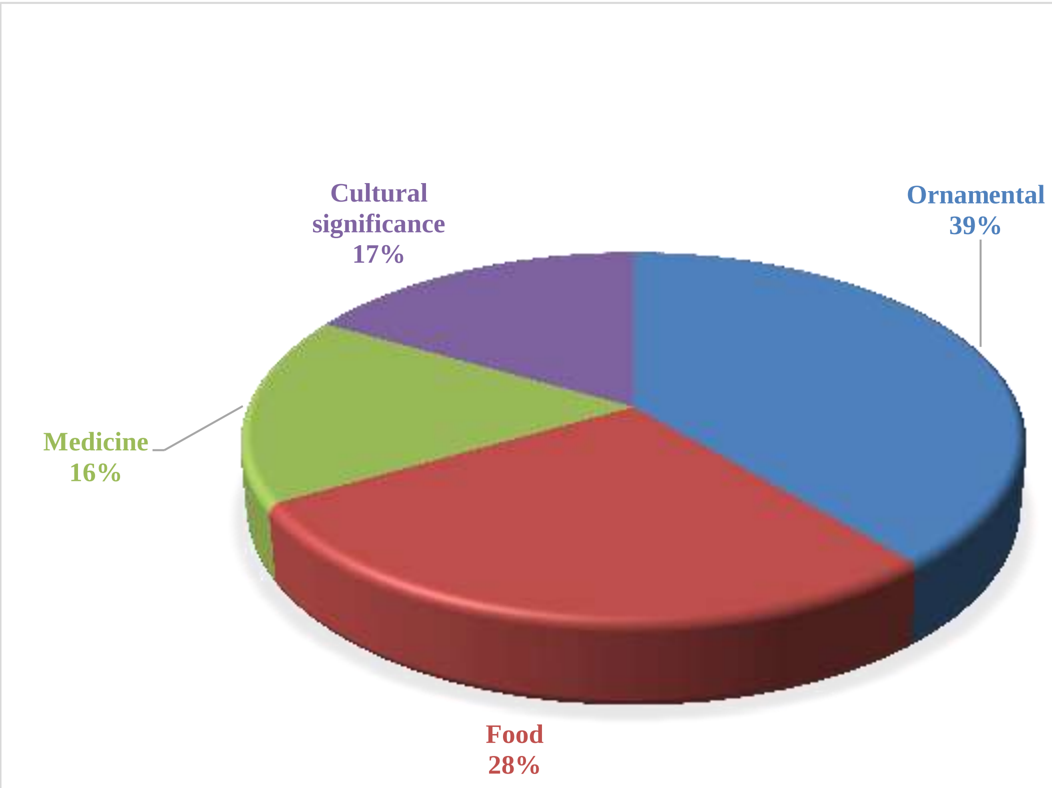

Figure 5.27: Diversity of Plant Use

5.6.3 Plant Parts Used

The study investigated the use of 10 taxa in many areas including ornamentals, medicinal, food, and cultural relevance (Table 5.10). *Rhododendron arboreum* exhibited exceptional versatility, since its flowers were employed for decorative purposes and as a source of sustenance, its trunk possessed medicinal properties, and the entire plant held significance in cultural practices. *Rhododendron formosum* and *Rhododendron weitchianum* were also utilised for decorative purposes, as the entire plant holds cultural significance. *Agapetes odontocera var. odontocera* possessed ornamental, medicinal, and culinary applications, but *Agapetes odontocera var. mizoramensis* Banik & Sanjappa was highly regarded for its ornamental and culinary qualities. The edible flowers of *Vaccinium sprengelii* and *Vaccinium vacciniaceum* were seen, whereas *Vaccinium griffithianum* was utilised for decorative purposes. *Lyonia ovalifolia* had dual functions as both a decorative and medicinal plant. *Monotropa uniflora* also posess an ornamental value.

Table 5.10: Utilization of Plant Species across Different Categories.

Species name	**Ornamentals**	**Medicine**	**Food**	**Cultural Significance**
Agapetes odontocera var. *mizoramensis*	Whole plant	0	Flower	0
Agapetes odontocera var. *odontocera*	Whole plant	Ligno tuber	Flower	0
Lyonia ovalifolia	Whole plant	Leaf	0	0
Monotropa uniflora	Whole plant	0	0	0
Rhododendron arboreum	Flower	Trunk	Flower	Whole plant
Rhododendron formosum	Flower	0	0	Whole plant
Rhododendron veitchianum	Flower	0	0	Whole plant
Vaccinium griffithianum	Whole plant	0	0	0
Vaccinium sprengelii	0	0	Flower	0
Vaccinium vacciniaceum	0	0	Flower	0

5.6.4 Use Value (UV) and Relative Frequency Citation (RFCs)

To determine the Use Value (UV) of the documented medicinal plants, we utilized the Use Report (UR), which allowed us to assess their relative importance in the research area and identify the preferred species used. The UV of *Rhododendron* *arboreum* Sm. was found to be 4, while *Agapetes odontocera var. odontocera* had a UV of 3. *Agapetes odontocera* var. *mizoramensis* Banik & Sanjappa, *Lyonia ovalifolia*, *Rhododendron formosum* Wall., and *Rhododendron weitchianum* Hook. each had a UV of 2. Conversely, *Vaccinium griffithianum* Wight, *Vaccinium sprengelii*, and *Vaccinium vacciniaceum* had the lowest UV, each scoring 1. Notably, all the documented plants shared the same Relative Frequency of Citation (RFC) value of 1, indicating equal recognition among informants. This comprehensive evaluation highlights the most valued species and their respective significance within the community.

5.6.5 Relative Importance Index (RI)

The number of uses for each plant across different categories was determined using the Relative Importance (RI) index. *R. arboreum* had the highest RI value of 1, followed by *A. odontocera* var. *odontocera* with an RI of 0.87. *A. odontocera var. mizoramensis*, *L. ovalifolia*, and *R. formosum* each had an RI of 0.75. These RI results are consistent with the UV values, as shown in Table 5.11, reinforcing the significance of these species in various medicinal applications. The alignment between RI and UV values highlights the reliability of these metrics in evaluating the importance of Ericaceae plants within the state.

Table 5.11: Ethnobotanically important plants of Ericaceae in Mizoram. Use Mode: O= Ornamental; M= Medicine; F= Food; C= Cultural importance. Habit: E= Epiphyte; EH= Epiphytic Herb; S= Shrub; PH= Perennial Herb; MH= Mycoheterotrophs.

Species name	Traditional use	Vern Name	Use mode	Habit	UV	RI	RFC
Agapetes odontocera var. *mizoramensis*	Flower eaten raw, ornamental	Bawltehlantai	F, O	E	2	0.75	1
Agapetes odontocera var. *odontocera*	Flower eaten raw, ornamental, decoction of leaf and roots is used as treatment for Pulmonary edema	Bawltehlantai	F, O, M	E	3	0.87	1
Lyonia ovalifolia	Used in skin disease, ornamentals	Tlangham	M, O	S	2	0.75	1
Monotropa uniflora	Ornamental	Sanghar vaibel suak	O	MH	1	0.62	1
Rhododendron arboreum	Ornamental, skin care, cultural importance, used in herbal tea	Chhawkhlei	O, M	S	4	1	1
Rhododendron formosum	Ornamental, cultural importance	Chhawkhlei par var	O, C	S	2	0.75	1
Rhododendron veitchianum	Ornamental, cultural importance	Chhawkhlei par var	O, C	E	2	0.75	1
Vaccinium griffithianum	Ornamental	Sirte	O	S	1	0.62	1
Vaccinium sprengelii	Fruit eaten raw	Sirkam	F	S	1	0.62	1

5.6.7 R-chord

In this study, *A. odontocera var. odontocera* emerged as the most dominant species, while *R. arboreum* holds the greatest ethnobotanical importance. The significance of each species is visually represented in the following Figure 5.28, which was created using R software. This figure provides a clear depiction of how each species contributes to the ethnobotanical knowledge and biodiversity of the region. The analysis highlights the diverse roles these species play in local traditions, medicine etc. The study also revealed that the majority of Ericaceae species reported in Mizoram fall under the ornamental category, followed by those used for food, cultural significance and medicinal purposes, as illustrated in Figure 5.27. Nearly all species found in Mizoram are noted for their use as ornamental plants. This widespread ornamental use underscores the aesthetic and cultural value these plants hold in the region, enhancing both public and private spaces while also contributing to the local biodiversity and ecological aesthetics.

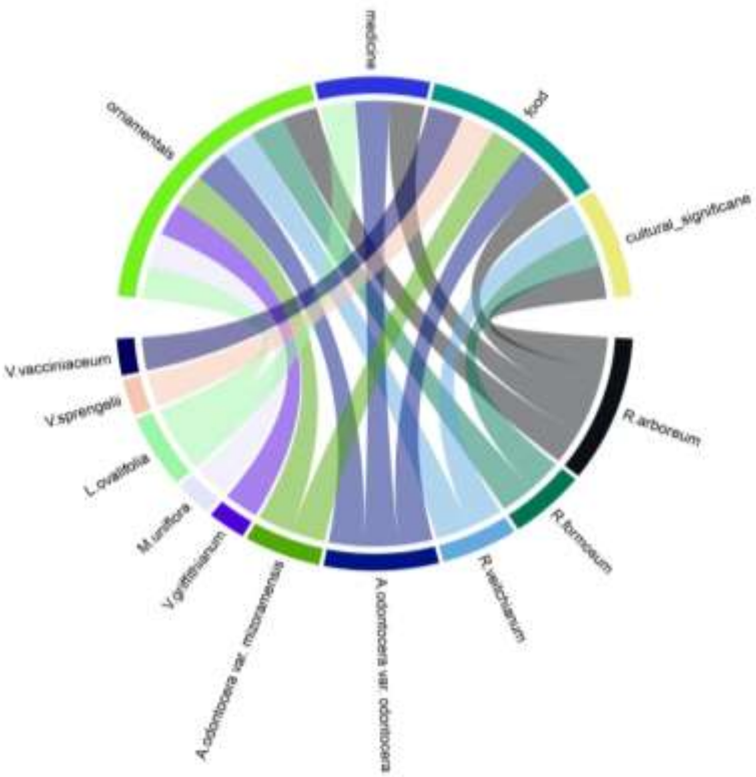

Figure 5.28: R-chord of Plant species with usage.

5.6.11 Discussion

The present study offers a comprehensive taxonomic and ethnobotanical analysis of Ericaceae species in Mizoram, enhancing our understanding of the region's rich floral diversity and its cultural significance. Through detailed morphological assessments and supportive molecular insights, ten species were successfully identified and classified, emphasizing the ecological importance of this plant family within the Indo-Burma biodiversity hotspot. These findings reaffirm the role of accurate taxonomic documentation in the broader context of biodiversity conservation (Ghosh & Jain, 2019). Ethnobotanical data collected from indigenous Mizo communities reveal that Ericaceae species are deeply embedded in local traditions. These plants are commonly used for medicinal, nutritional, and ceremonial purposes demonstrating a profound ecological literacy that has been sustained through oral transmission and cultural practices (Singh *et al*., 2020). The uses range from treating respiratory ailments and digestive disorders to playing a role in food preparation and spiritual rituals, highlighting their multifaceted importance.

Nevertheless, several challenges persist. A number of Ericaceae species remain underrepresented in scientific literature, and the validation of traditional knowledge through phytochemical and pharmacological studies is still limited. Additionally, the threats posed by habitat loss, overharvesting, and climate change are accelerating, placing both plant populations and the cultural wisdom associated with them at risk (Chakraborty & Kalita, 2016). To mitigate these threats, there is an urgent need for integrated conservation approaches. These include sustainable harvesting practices, habitat restoration, and community-led conservation models that actively involve indigenous knowledge holders. Strengthening links between ethnobotanical studies and conservation policy can facilitate the protection of both natural ecosystems and cultural traditions (Upadhyay *et al*., 2011). Furthermore, documentation and digitization of local plant knowledge, alongside scientific validation, will serve as a critical bridge between tradition and innovation.

CHAPTER 6

6. Conclusion

6.1 Species diversity and distribution

A total of ten taxa comprising nine species and one variety belonging to five genera within the family Ericaceae were collected, identified, and systematically documented from various regions of Mizoram, Northeast India. These taxa are taxonomically distributed across three subfamilies and four tribes, reflecting the complex diversity of the family in this ecologically sensitive and floristically unique region.

The growth forms among the recorded taxa are diverse: approximately 30% are epiphytic species, another 30% are small trees, 20% are shrubs, and the remaining 20% include herbaceous forms, notably mycoheterotrophs. This range of life forms indicates a high degree of ecological adaptation to the varied altitudinal and microclimatic conditions present in Mizoram. Notably, one of the documented taxa *Agapetes odontocera* var. *mizoramensis* is strictly endemic to Mizoram, while the majority exhibit narrow distribution patterns, being endemic to the Himalayan belt and the broader Southeast Asian region.

The identification, classification, and systematic treatment of these taxa were accomplished using an integrative taxonomic approach. This included traditional morphotaxonomy by analyzing vegetative and floral characteristics as well as micromorphological features such as seed coat structure and pollen exine patterns. These were further complemented with molecular tools, particularly DNA barcoding using *rbcL* and ITS2 markers, to resolve ambiguities at the species level. This multi-faceted methodology not only enhanced the accuracy of taxonomic resolution but also provided deeper insights into the phylogenetic relationships and biogeographic affinities of Ericaceae species in Mizoram.

6.2 Habitat

The ecological assessment of the ten documented Ericaceae taxa in Mizoram reveals a diverse range of habitat preferences shaped by elevation, forest type, and microclimatic conditions. These species are predominantly distributed across moist temperate to montane evergreen forests, thriving in elevations between 1200 and 3000 meters. While some, like *Agapetes odontocera* var. *odontocera* and *Vaccinium griffithianum* favor shaded forest slopes and ridges, others such as *Monotropa uniflora* exhibit highly specialized ecological strategies, being mycoheterotrophic and entirely dependent on symbiotic fungi in humus-rich environments. Epiphytic behavior as observed in *A. odontocera* var. *mizoramensis*, indicates adaptation to high humidity and dense canopy cover, particularly in oak–rhododendron forest systems. *Rhododendron* species, including *R. arboreum*, *R. formosum* and *R. vietchianum*, demonstrate preferences for acidic soils, cool climates, and varied degrees of sunlight exposure, ranging from shaded streamsides to open grassy slopes. Similarly, *Vaccinium* species commonly occur in acidic, humus-rich, and well-drained soils, co-occurring with oaks and rhododendrons. These findings underscore the critical role of elevational and habitat heterogeneity in shaping Ericaceae distribution. Given the ecological specificity and restricted ranges of several taxa, conservation strategies must prioritize habitat protection, long-term monitoring, and further research into their ecological requirements and adaptive mechanisms in the face of environmental change.

6.3 Clustering analaysis of Palynology and Seed coat anatomy

The hierarchical cluster analysis of both pollen and seed coat traits among Ericaceae taxa in Mizoram reveals clear patterns of morphological affinity and divergence. Pollen-based clustering using UPGMA and Euclidean distance highlighted groupings based on eight key palynological features, aiding in species discrimination. Similarly, seed coat morphology distinguished two principal clusters. The first cluster, composed of *Agapetes* varieties and *Rhododendron* species, indicates strong intra-group similarity, especially among closely related taxa. Their shared characteristics, such as reticulate seed surfaces and thickened anticlinal walls, support their placement within the Vaccinioideae subfamily. The second cluster includes *Vaccinium* species, *Lyonia ovalifolia*, and the morphologically distinct *Monotropa uniflora*. Divergence of the latter taxa is consistent with its unique ecological strategy and simplified seed structure. These results confirm the utility of combining palynological and seed coat traits for taxonomic resolution, providing a deeper understanding of evolutionary relationships and adaptations within this ecologically significant family.

6.4 Molecular studies

The molecular phylogenetic analysis using concatenated ITS2 and *rbcL* sequences effectively resolved interspecies relationships among Ericaceae taxa in Mizoram. The maximum likelihood tree (MLT) based on the K2P model revealed well-supported clades, confirming the monophyly of genera such as *Rhododendron* and *Lyonia*. *Monotropa uniflora* showed minimal divergence, while *Vaccinium* species clustered tightly, indicating shared ancestry. The close grouping of *V. griffithianum* with *Agapetes odontocera* var. *mizoramensis* suggests possible intergeneric affinity. Overall, the results validate traditional classifications and demonstrate that ITS2 and *rbcL* markers are effective tools for resolving phylogenetic relationships within the Ericaceae, aligning with prior studies.

6.5 Ethnobotany

The ethnobotanical exploration of Ericaceae species in Mizoram has revealed the deep-rooted relationship between indigenous Mizo communities and their surrounding plant biodiversity. The study documented traditional knowledge associated with various Ericaceae taxa, highlighting their diverse applications in local medicine, food and cultural practices. These species serve diverse purposes, including medicinal, nutritional, ornamental, and ritualistic uses. Notably, *R. arboreum* emerged as a highly versatile species, utilized for its edible flowers, medicinal bark, and cultural importance. Other species, such as *A. odontocera* and *V. sprengelii*, were valued for their culinary and medicinal applications. These uses reflect centuries of ecological understanding passed down through oral traditions, emphasizing the role of Ericaceae not only as botanical resources but also as vital components of community health and heritage. The knowledge gathered from 60 key informants across multiple districts illustrates the richness of ethnobotanical practices in the region. The discovery of edible flowers in both the varieties of *Agapetes odontocera* is a novel finding, shedding light on a previously underexplored ethnobotanical use. However, this valuable traditional wisdom is at risk due to habitat degradation, modernization, and a generational gap in knowledge transmission. With increasing environmental and socio-economic pressures, there is a pressing need to document and validate these practices scientifically. Incorporating ethnobotanical knowledge into conservation and sustainable resource management strategies can greatly support biodiversity protection while empowering local communities. This study underscores the urgency of preserving both the plants and the traditional knowledge systems they are embedded in. Continued collaboration between researchers and indigenous knowledge holders is essential for safeguarding this biocultural heritage for future generations.

6.6 Endemic and RET species

The conservation assessment of Ericaceae taxa from Mizoram reveals that several species face a high risk of extinction due to their restricted distribution and small population sizes. Local evaluations indicate that most taxa fall under Endangered (EN) or Critically Endangered (CR) categories, highlighting the urgent need for conservation interventions. The endemicity of *Agapetes odontocera* var. *mizoramensis* may be attributed to isolation, limited seed dispersal, and habitat specificity within a geographically confined montane environment. These factors likely restrict its expansion beyond the known localities. The Lushai Hills, situated within a biogeographic transition zone between the Eastern Himalayas and Indo-Burmese regions, often foster endemism through localized speciation.

Given these threats, *A. odontocera* var. *mizoramensis* and other narrowly distributed Ericaceae taxa warrant focused conservation assessment, ecological monitoring, and habitat protection to ensure their long-term survival and to preserve the floristic uniqueness of Mizoram.

6.7 Conservation Status

Habitat preservation for Ericaceae species in Mizoram is vital due to their ecological sensitivity and restricted distribution, especially in high-altitude montane forests. Many species are adapted to specific microhabitats often acidic, nutrient-poor soils and are highly vulnerable to environmental changes. Conservation strategies must prioritize the protection of fragile ecosystems by controlling deforestation, unsanctioned harvesting, and habitat fragmentation. Special attention should be given to endemic and Rare, Endangered, and Threatened (RET) taxa like *Agapetes odontocera* var. *mizoramensis* and *Rhododendron veitchianum*, which face heightened extinction risks due to limited populations and anthropogenic pressures.

The present study on the Ericaceae of Mizoram reveals a complex and vulnerable flora with significant ecological and evolutionary value. Integrative analyses using morphological, palynological, seed coat anatomical, and molecular data have deepened understanding of lineage diversification and adaptive strategies in this family. *Agapetes odontocera* var. *mizoramensis* is a narrowly endemic plant species, known to occur only in two specific locations within the state of Mizoram. This limited distribution highlights its ecological significance and potential vulnerability. Members of the Ericaceae family, are frequently characterized by high levels of endemism, particularly in Southeast Asian regions. This pattern is largely attributed to the region's complex topography, diverse microclimates, and long-term geological stability, which have fostered speciation and niche.

In conclusion, the Ericaceae of Mizoram exemplifies the interconnection between biodiversity and cultural heritage. Sustained research, community engagement, and conservation action are essential to safeguard these valuable resources for future generations.

APPENDICES

Appendix 1

Questionnaire on Ethnobotanical Data Collection of Ericaceae family:

Informants detail:
Name/ Hming : ____

Gender : Male (Mipa) / Female (Hmeichhia) Age/

Kum: ______________________________

- *Data on ethnobotanical importance of Ericaceae plants:*
  Local name of plant/ Thlai hming: ______________________________

  Habit of plant/ Nihphung: ______________________________

  Mode of usage/ Hman dan: ______________________________

  Parts used: ______________________________

Season of availability/ A awm hun:

i) Whole year/ Kumtluanin

ii) From ____________to ____________(Months/ Thla) Mo

____

Cultural significance (If any)/ Hnam ziarang nen inlaichinna a nei em?

____

Consent:

I ______________________________ hereby give my full consent and willingly accept to participate in this study and declare that the information provided by me during the course of interview is true and acuurate to the best of my knowledge

(Kei ______________________________ hian he zirna ah hian tel ve ka in huam a, ka thil hriat ka hrilh chhawn pawh ka thiamna chinah a dik vek a ni tih ka pawm e.)

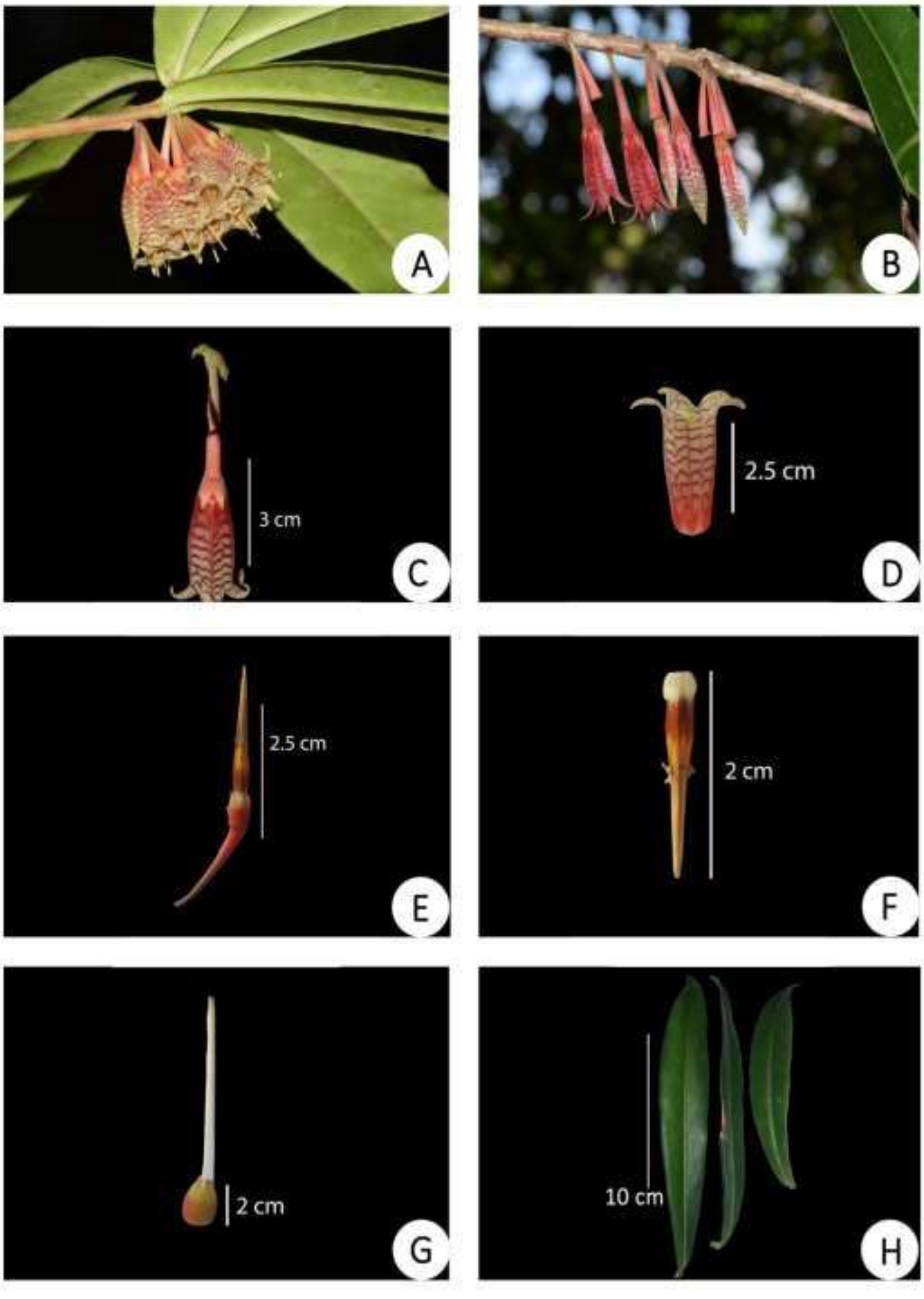

Plate 1: *Agapetes odontocera* (Wight) Hook. f. var. *mizoramensis* D. Banik & Sanjappa

A. Habit; B. Flowering twig; C. Flower; D. Corolla; E. Reproductive part; F. Androecium; G. Gynoecium; H. Leaves.

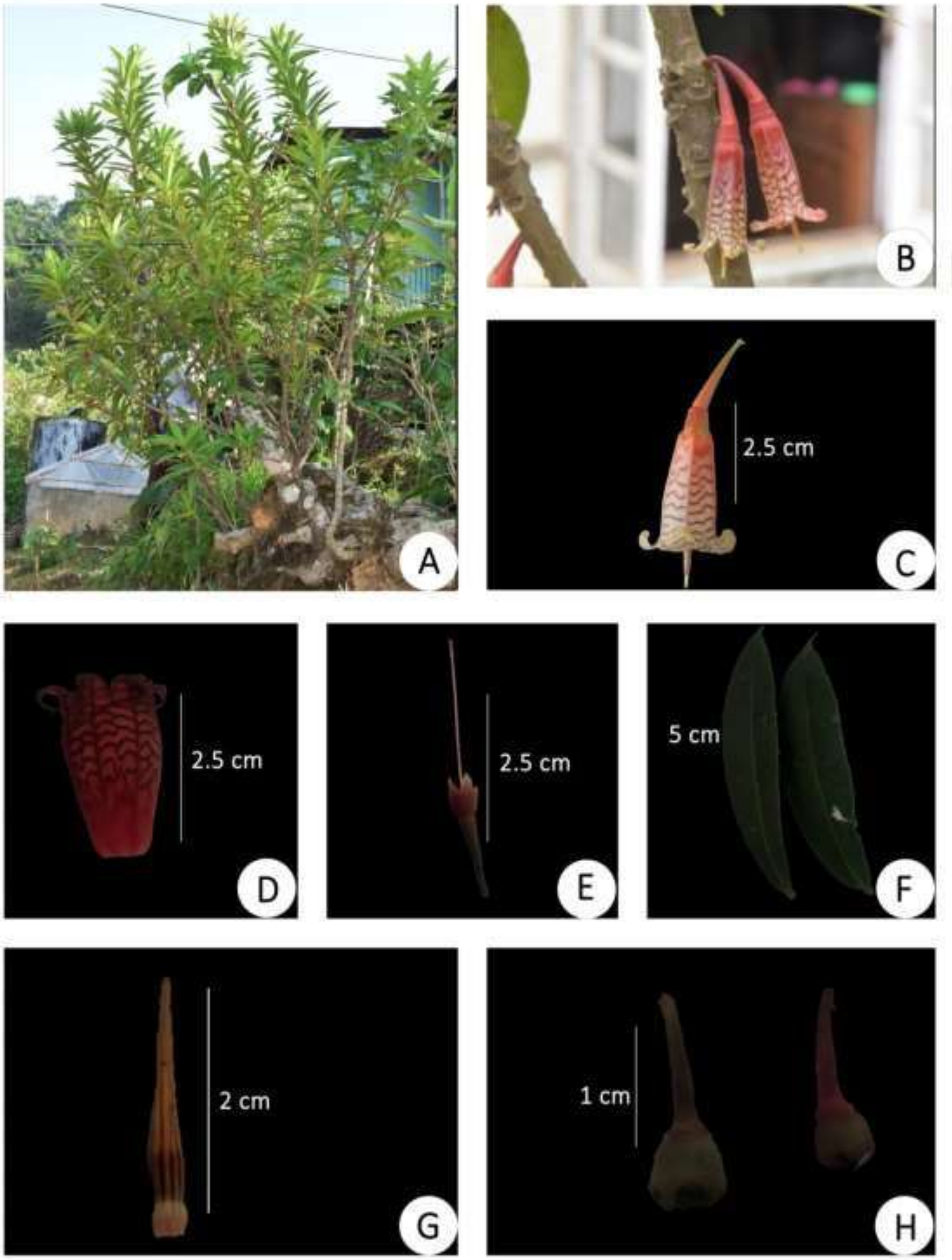

Plate 2: *Agapetes odontocera* (Wight) Benth. & Hook. var. *odontocera* A. Habit; B. Flowerring twig; C. Flower; D. Corolla; E. Gynoecium; F. Leaves; G. Androecium; H. Fruits.

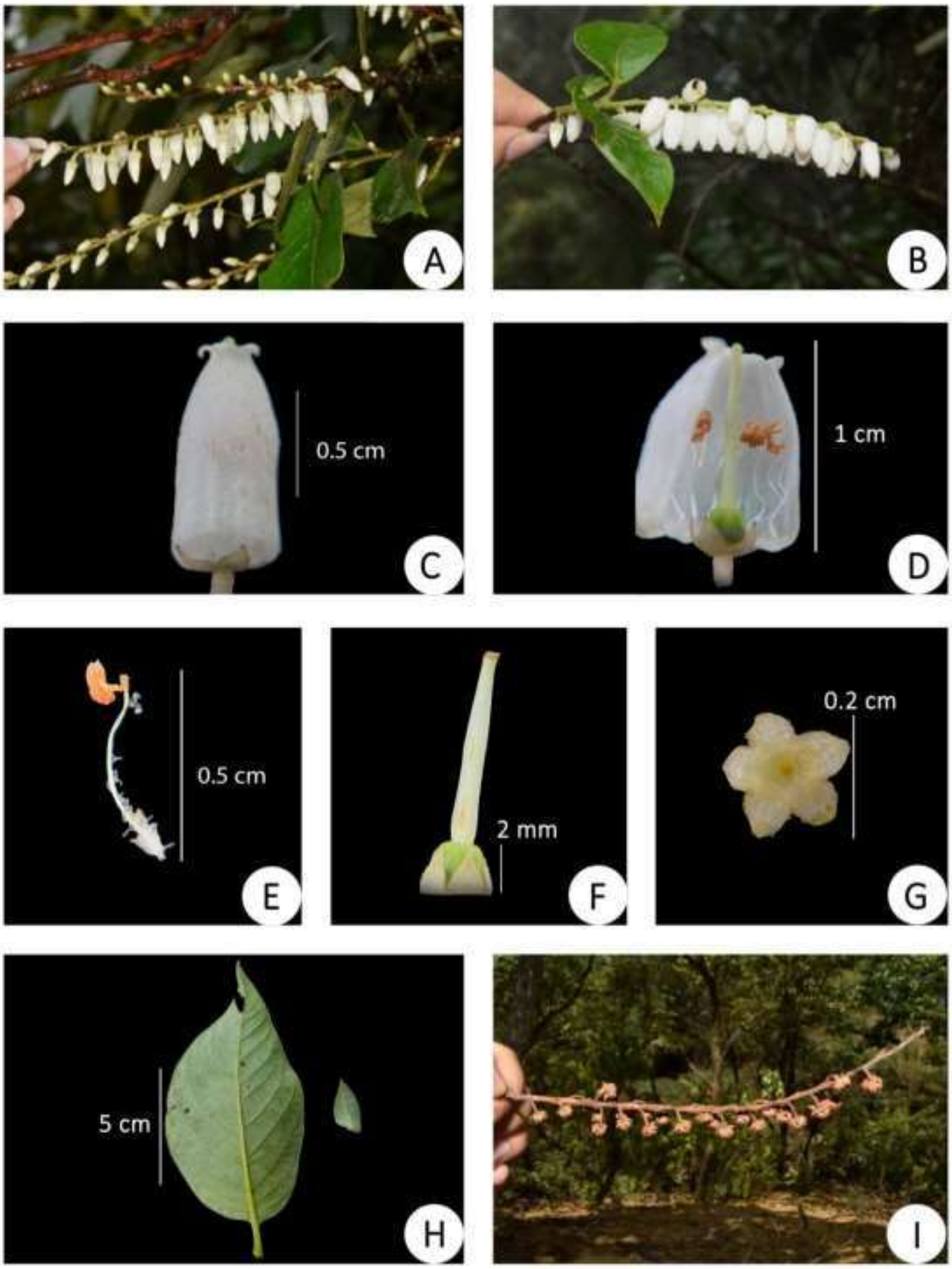

Plate 3: *Lyonia ovalifolia* (Wall.) Drude A. Habit; B. Flowerring twig; C. Flower; D. Open flower; E. Androecium; F. Gynoecium; G. Calyx; H. Leaves; I. Fruits

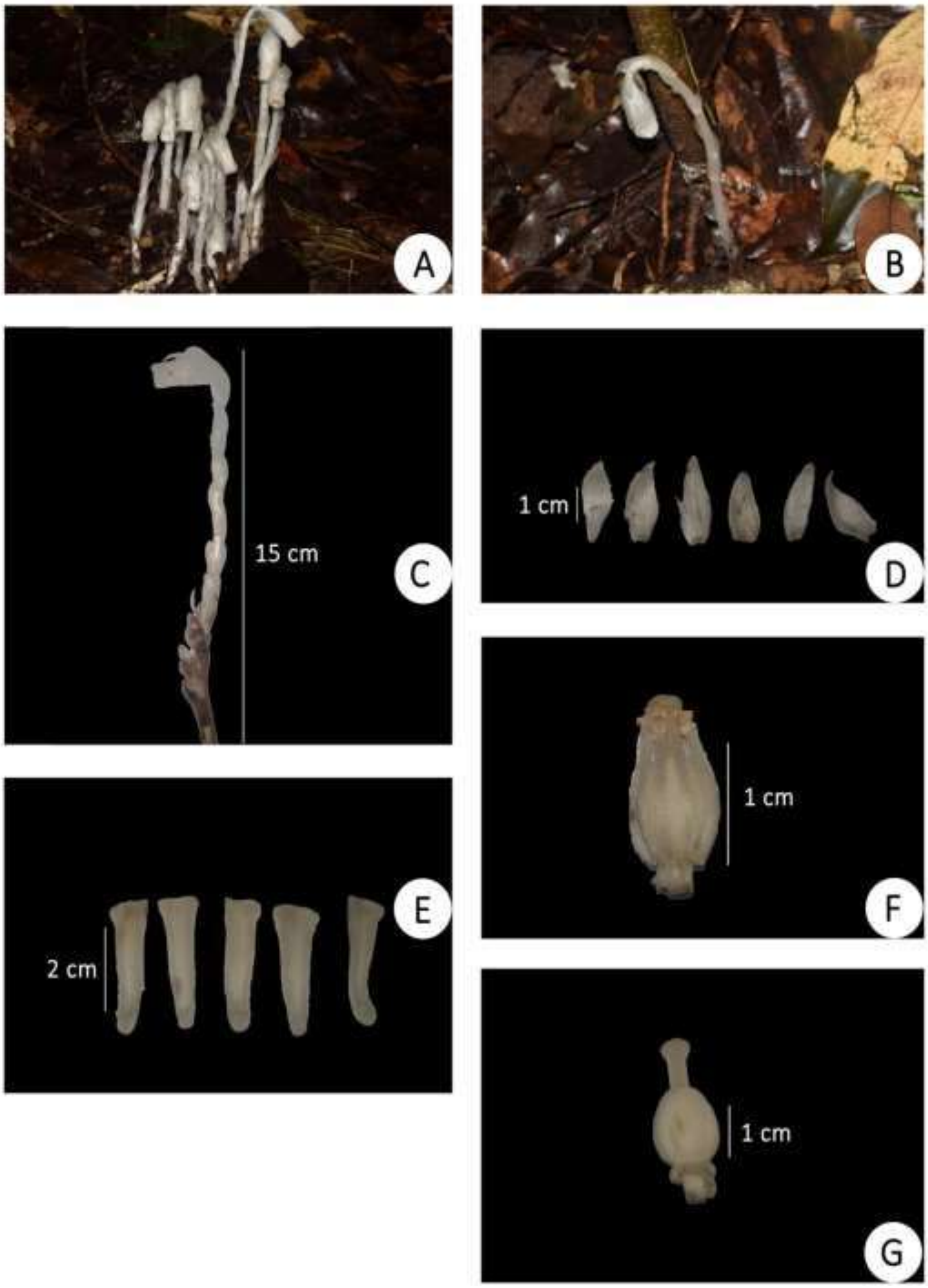

Plate 4: *Monotropa uniflora* L.A. Habit; B. Flowerring twig; C. Whole plant; D. Leaves; E. Petals; F. Reproductive part; G. Gynoecium.

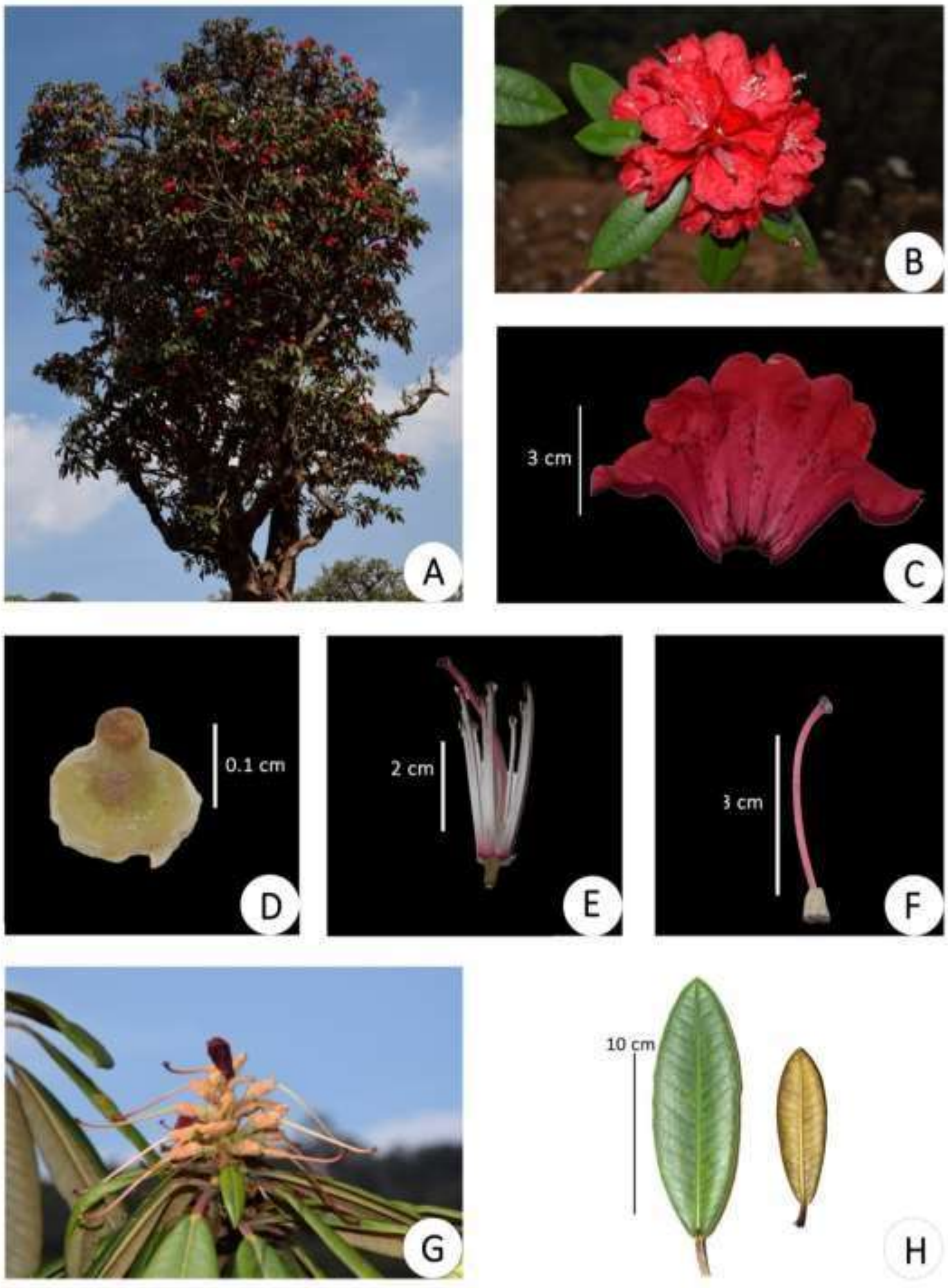

Plate 5: *Rhododendron arboreum* Sm. A. Habit; B. Flowerring twig; C. Corolla; D. Calyx; E. Reproductive part; F. Androecium; G. Fruits; H. Leaves.

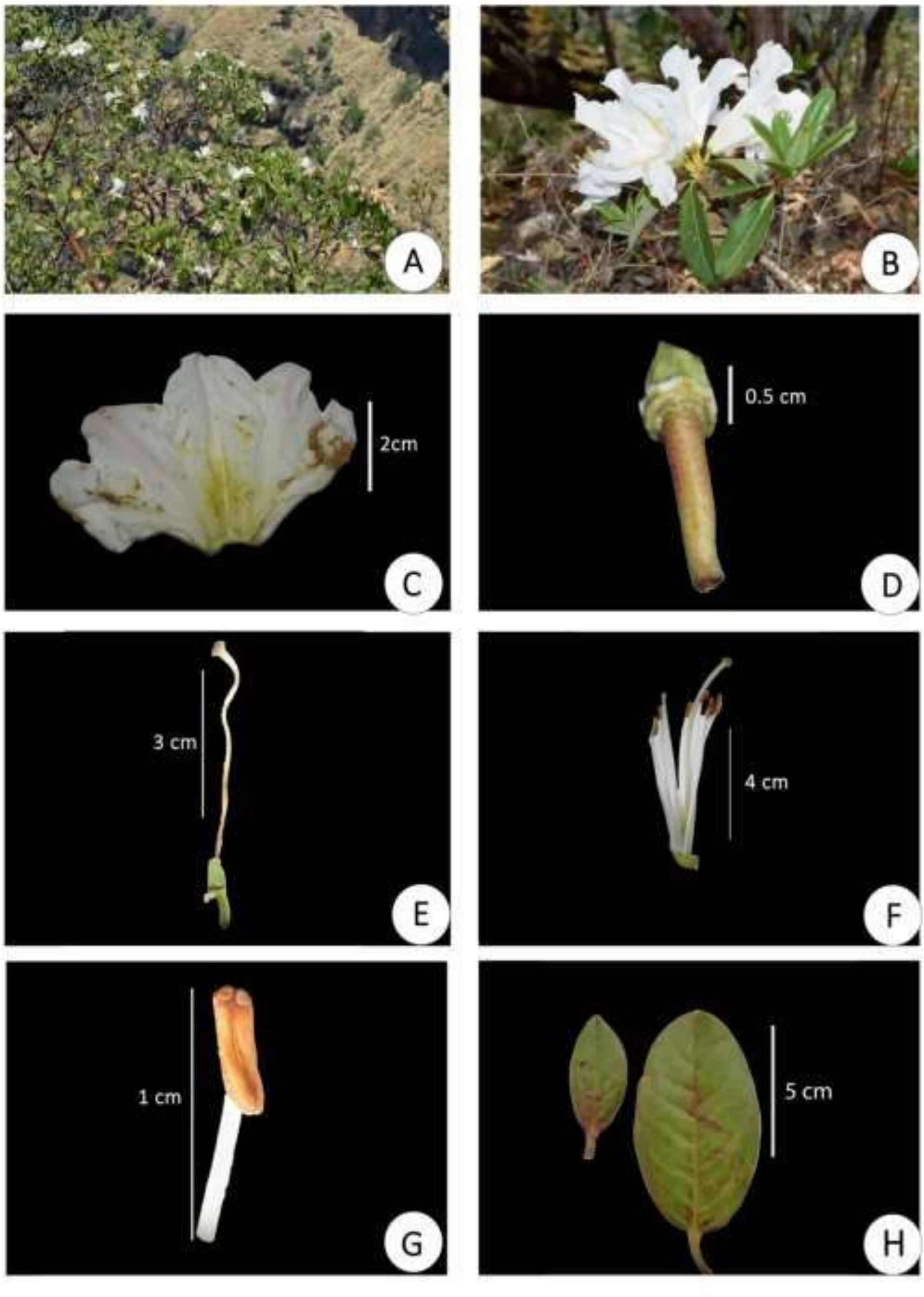

Plate 6: *Rhododendron formosum* Wall. A. Habit; B. Flowerring twig; C. Corolla; D. Calyx; E. Gynoecium; F. Reproductive part; G. Androecium; H. Leaves.

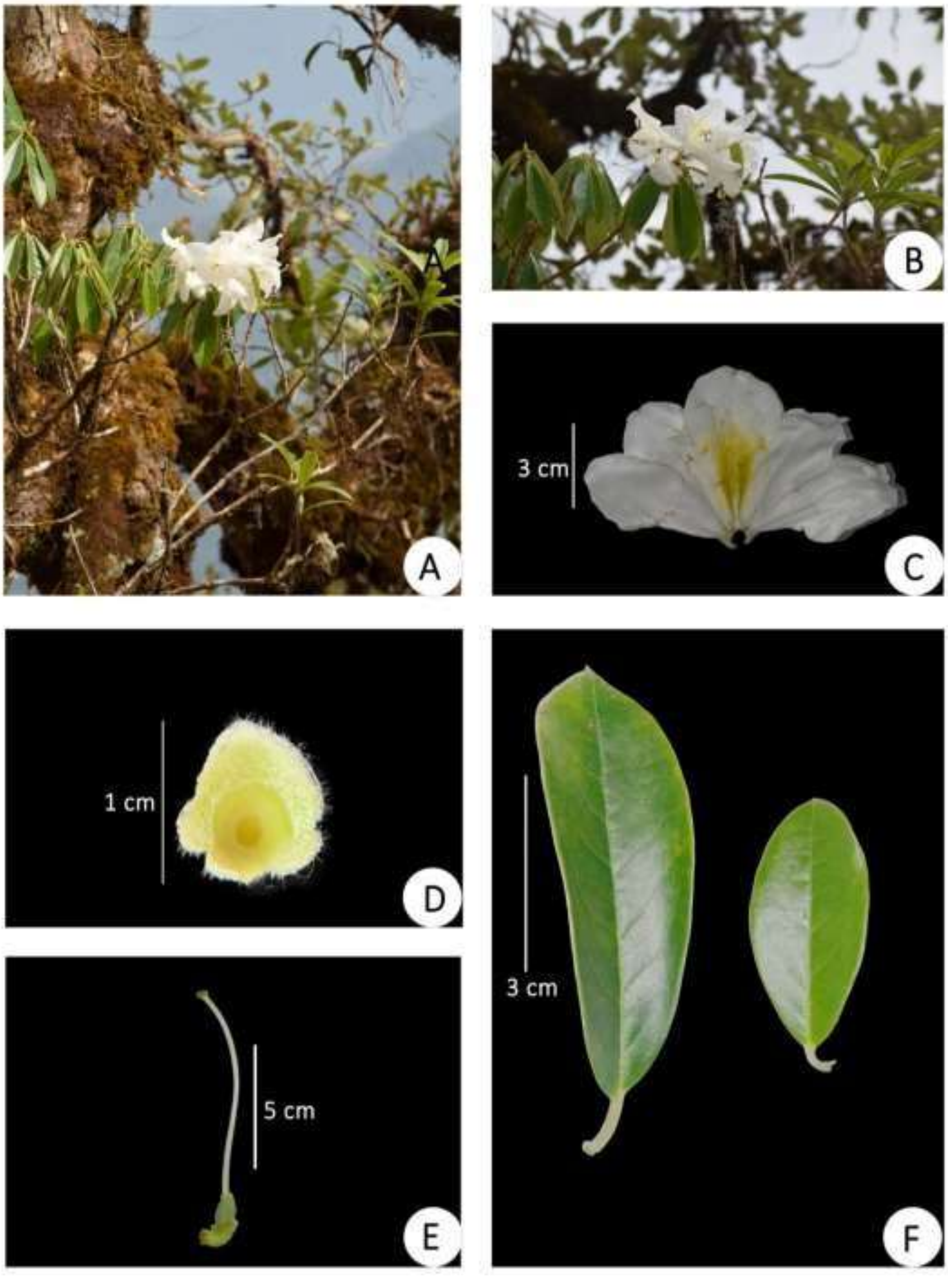

Plate 7: *Rhododendron veitchianum* Hook. A. Habit; B. Flowering twig; C. Corolla; D. Calyx; E. Gynoecium; F. Leaves

Plate 8: *Vaccinium griffithianum* Wight. A. Habit; B - D. Branch.

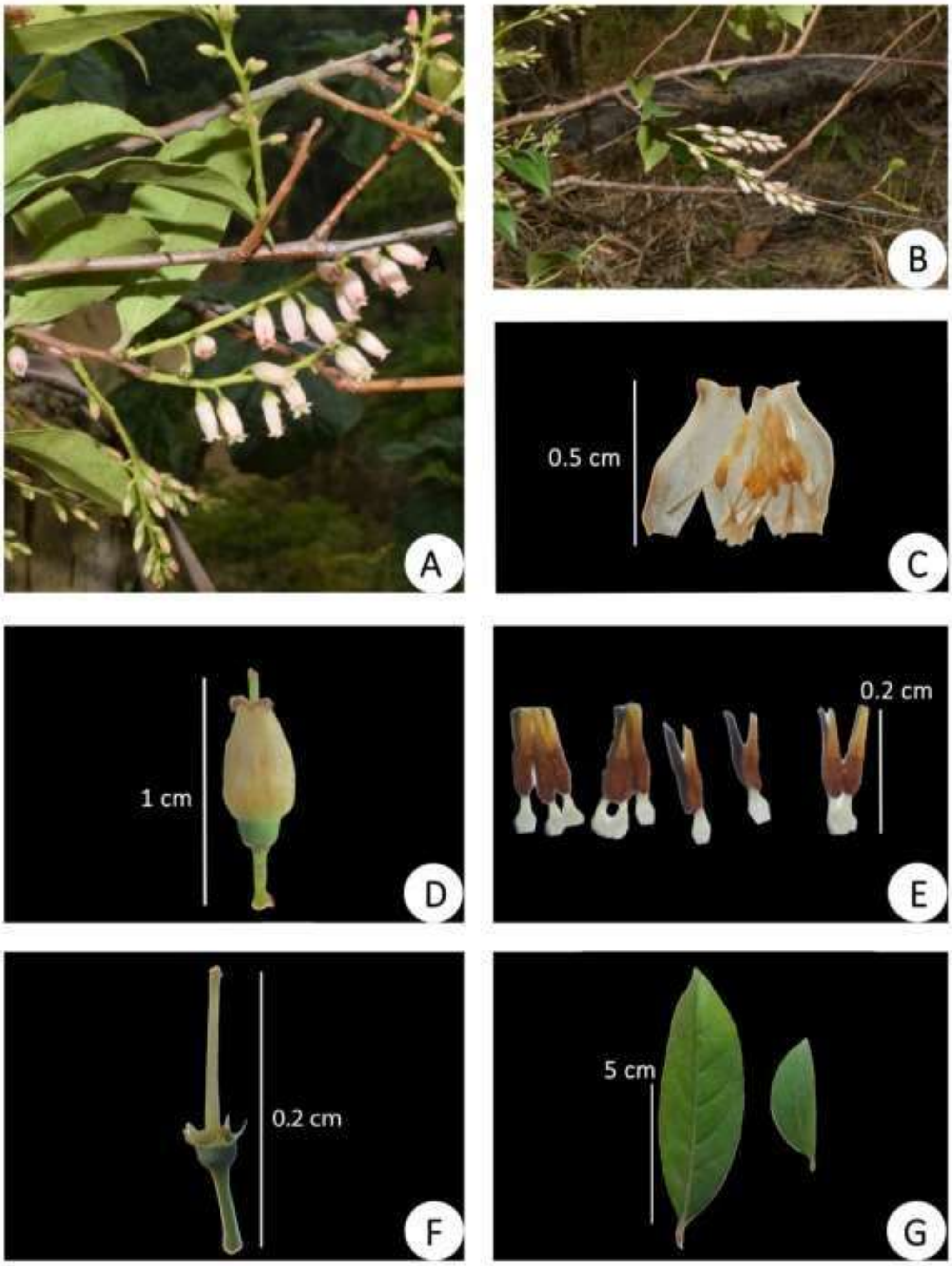

Plate 9: *Vaccinium sprengelii* G. Don. A. Habit; B. Flowering twig; C. Open flower; D. Flower; E. Androecium; F. Gynoecium; G. Leaves.

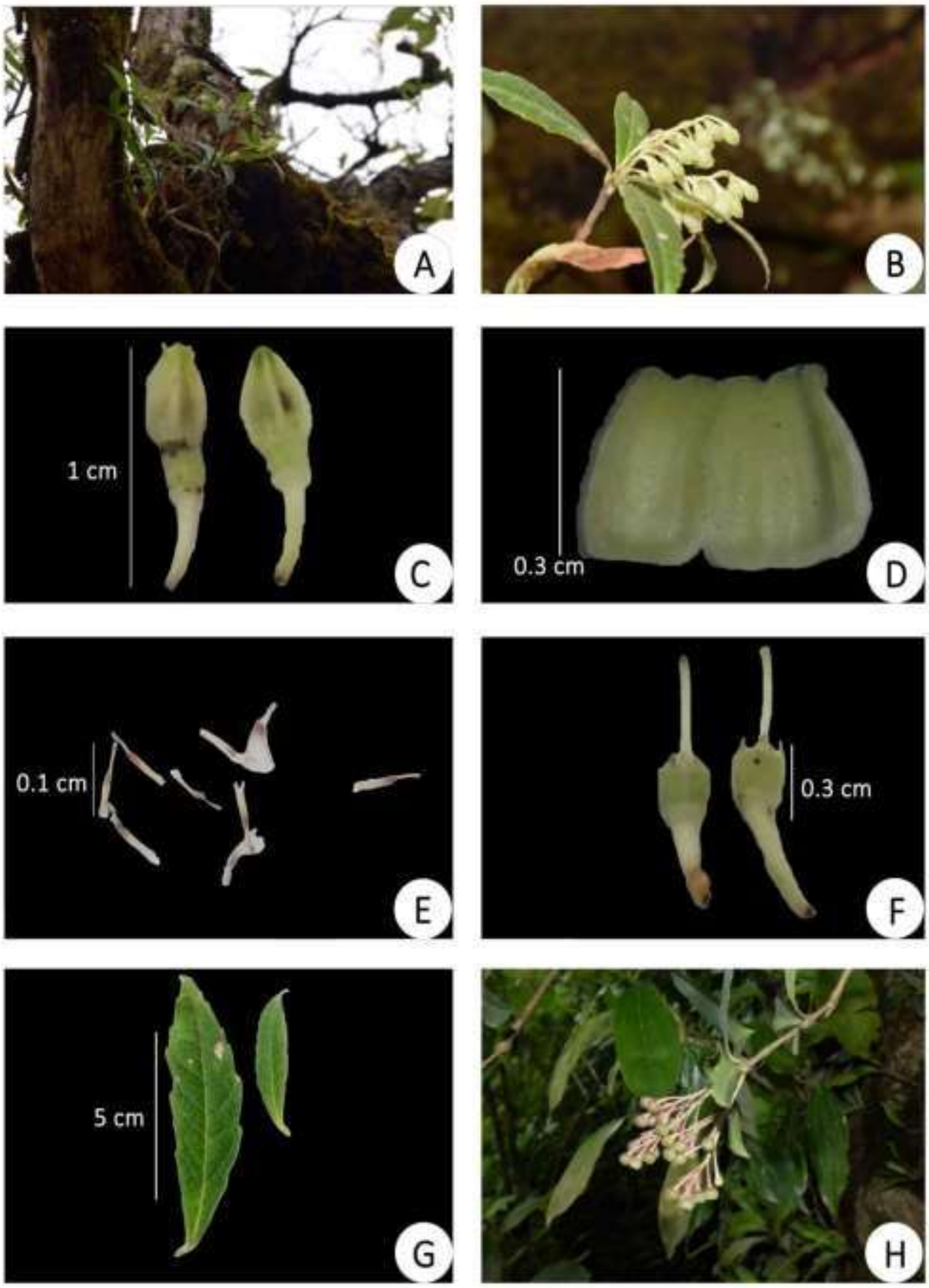

Plate 10 : *Vaccinium vacciniaceum* Sleumer A. Habit; B. Flowering twig; C. Flower;
D. Corolla; E. Androecium; F. Gynoecium; G. Leaves; H. Fruits.

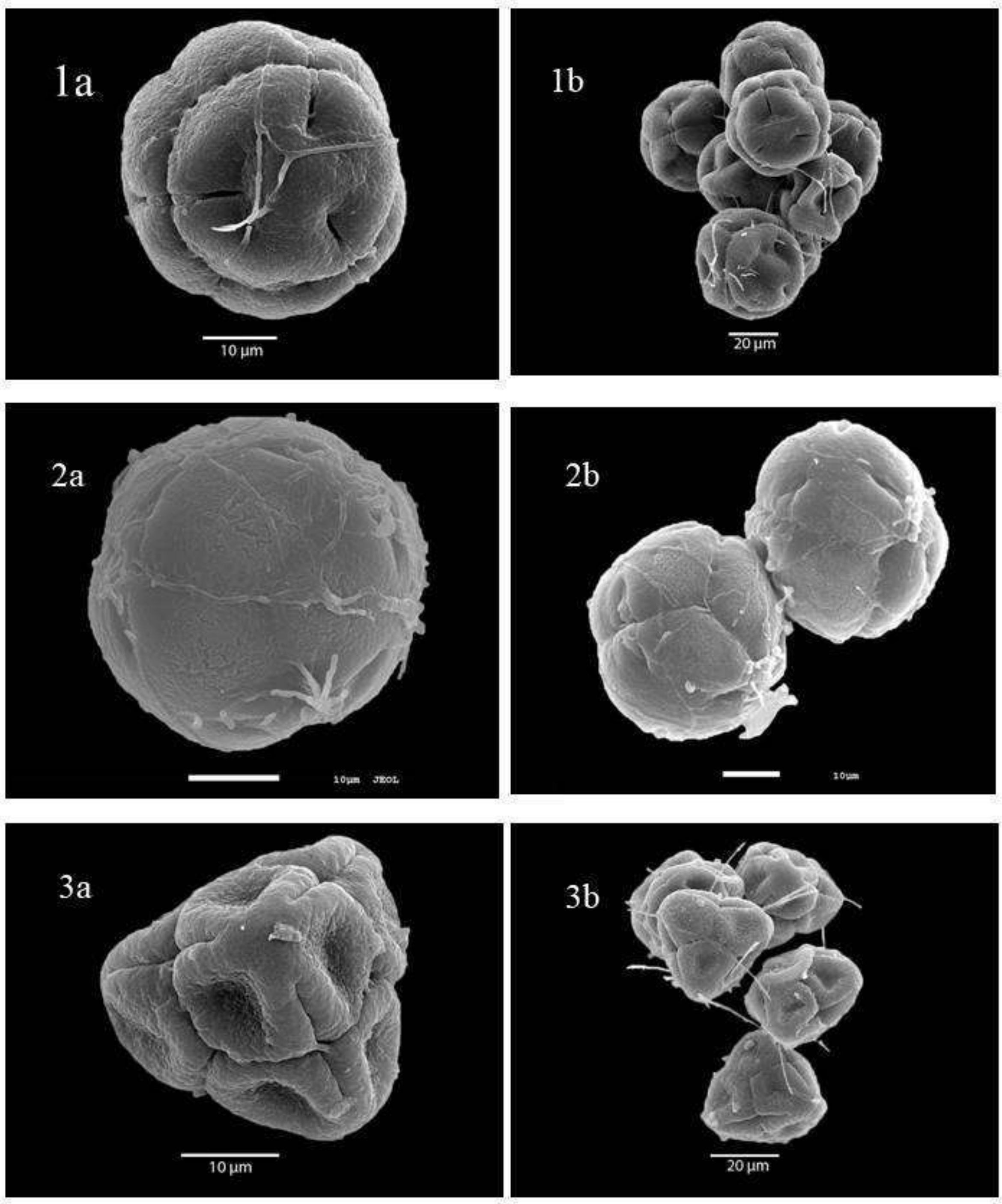

Plate 11: SEM Microphotographs of pollen: 1. *Agapetes odontocera* var. *mizoramensis*, 2. *Agapetes odontocera* var. *odontocera*, 3. *Lyonia ovalifolia*; a-single pollen, b- pollen clusters

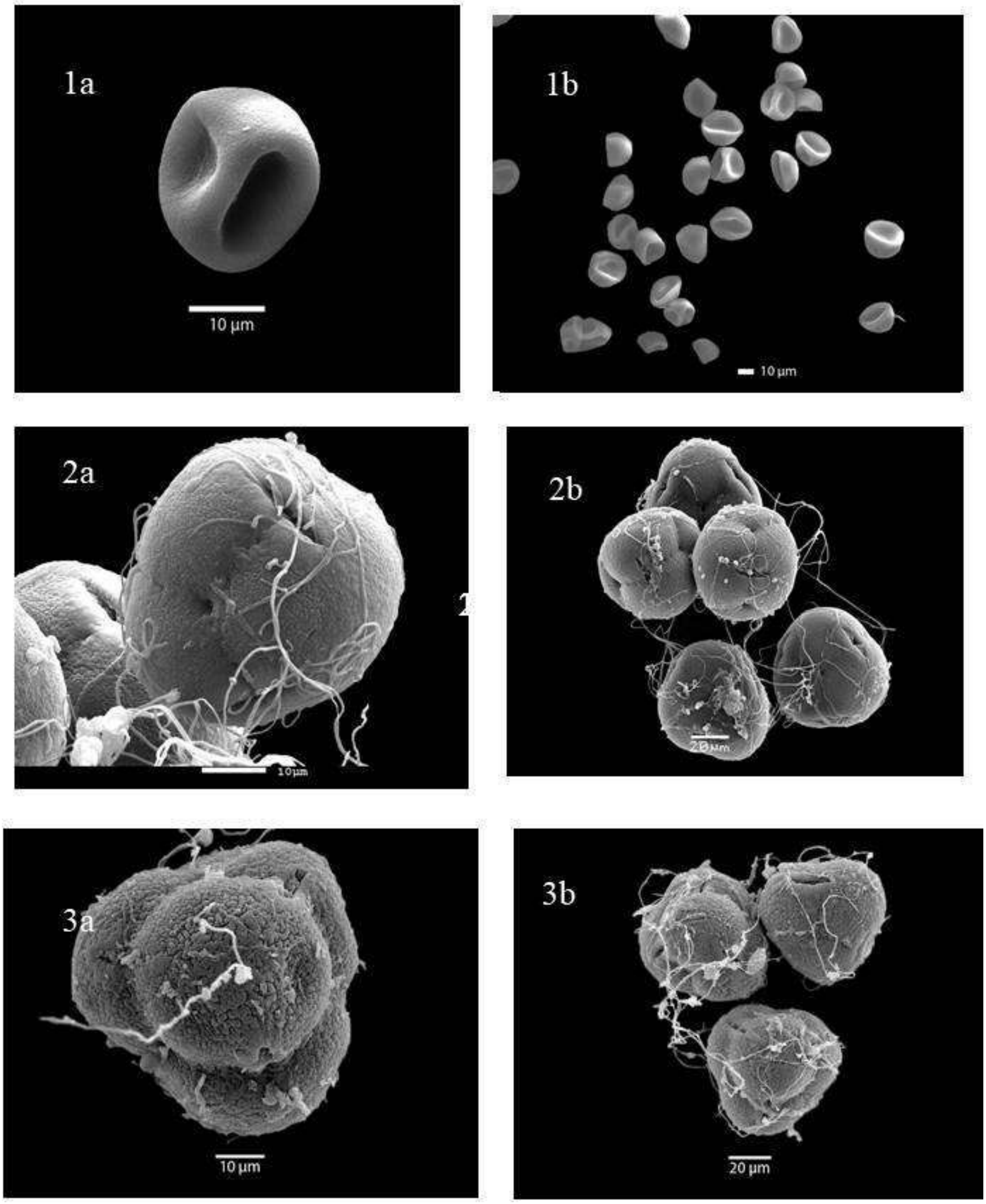

Plate 12: SEM Microphotographs of pollen: 1. *Monotropa uniflora*, 2. *Rhododendron arboreum*, 3. *Rhododendron formosum*; a-single pollen, b- pollen clusters

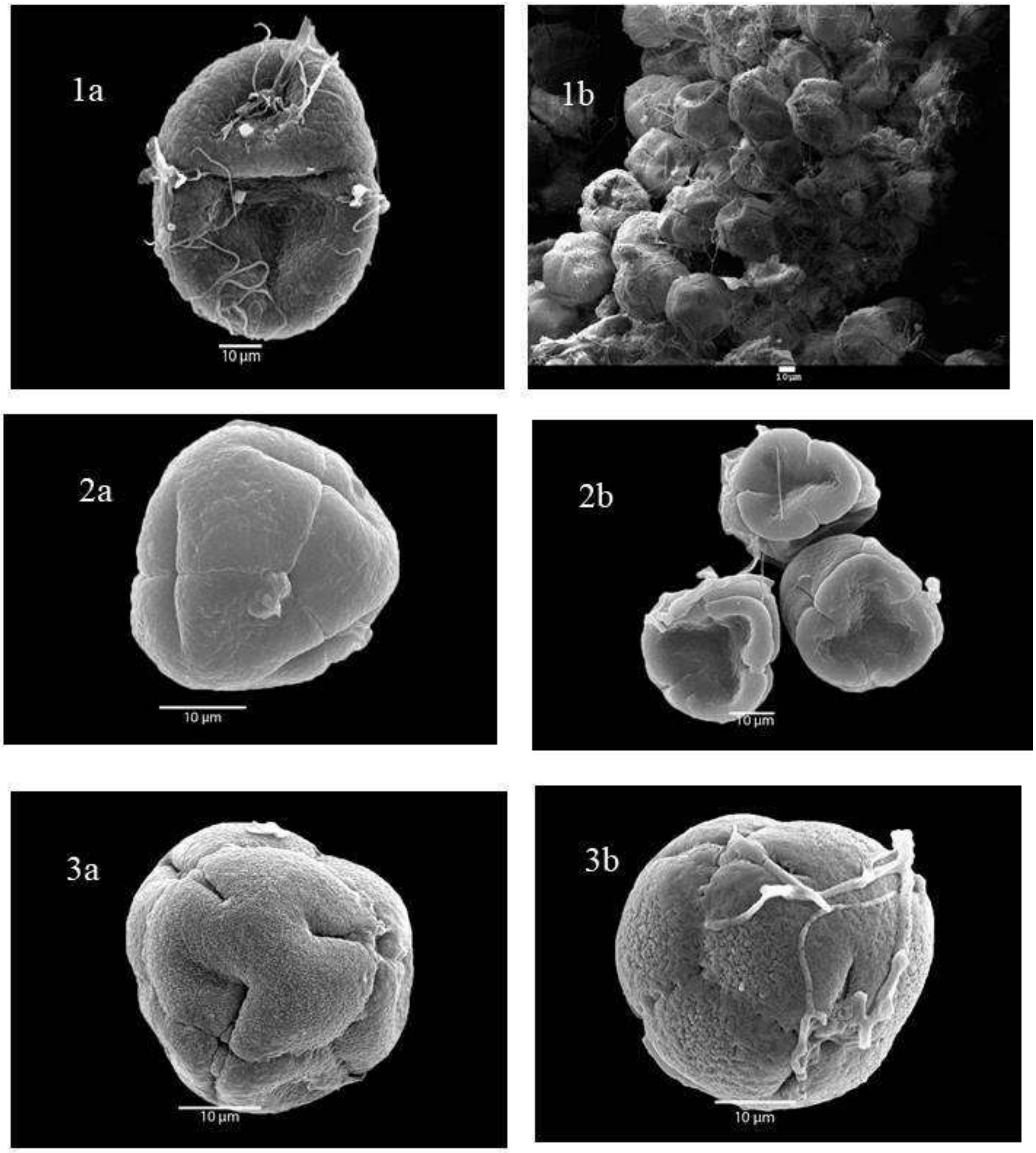

Plate 13: SEM Microphotographs of pollen: 1. *Rhododendron vietchianum* 2. *Vaccinium sprengelii*, 3. *Vaccinium vacciniaceum*; a-single pollen, b- pollen clusters

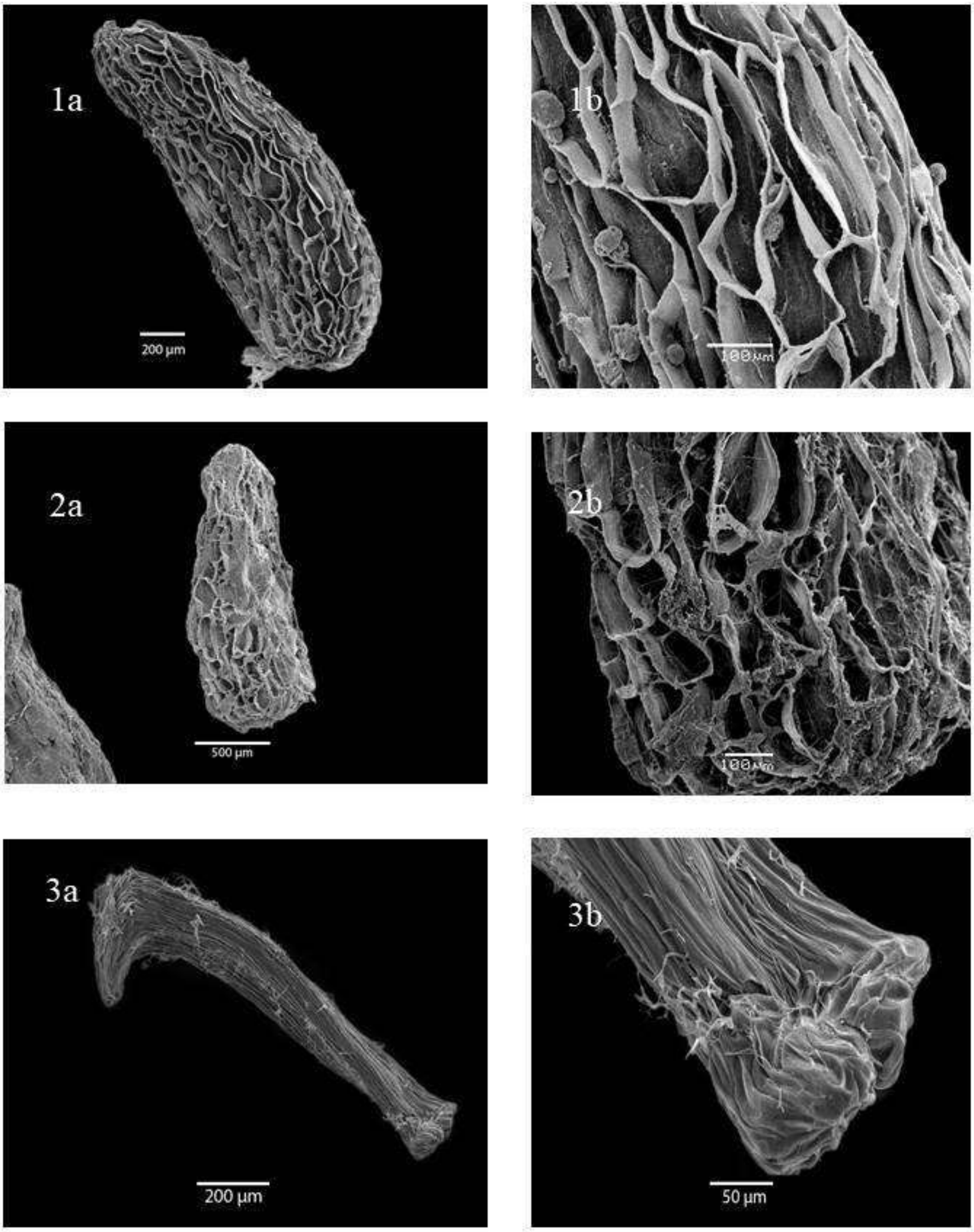

Plate 14: SEM Microphotographs of seeds: 1. *Agapetes odontocera* var. *mizoramensis,* 2. *Agapetes odontocera* var. *odontocera,* 3. *Lyonia ovalifolia*; a-outline view, b-details of seed coat

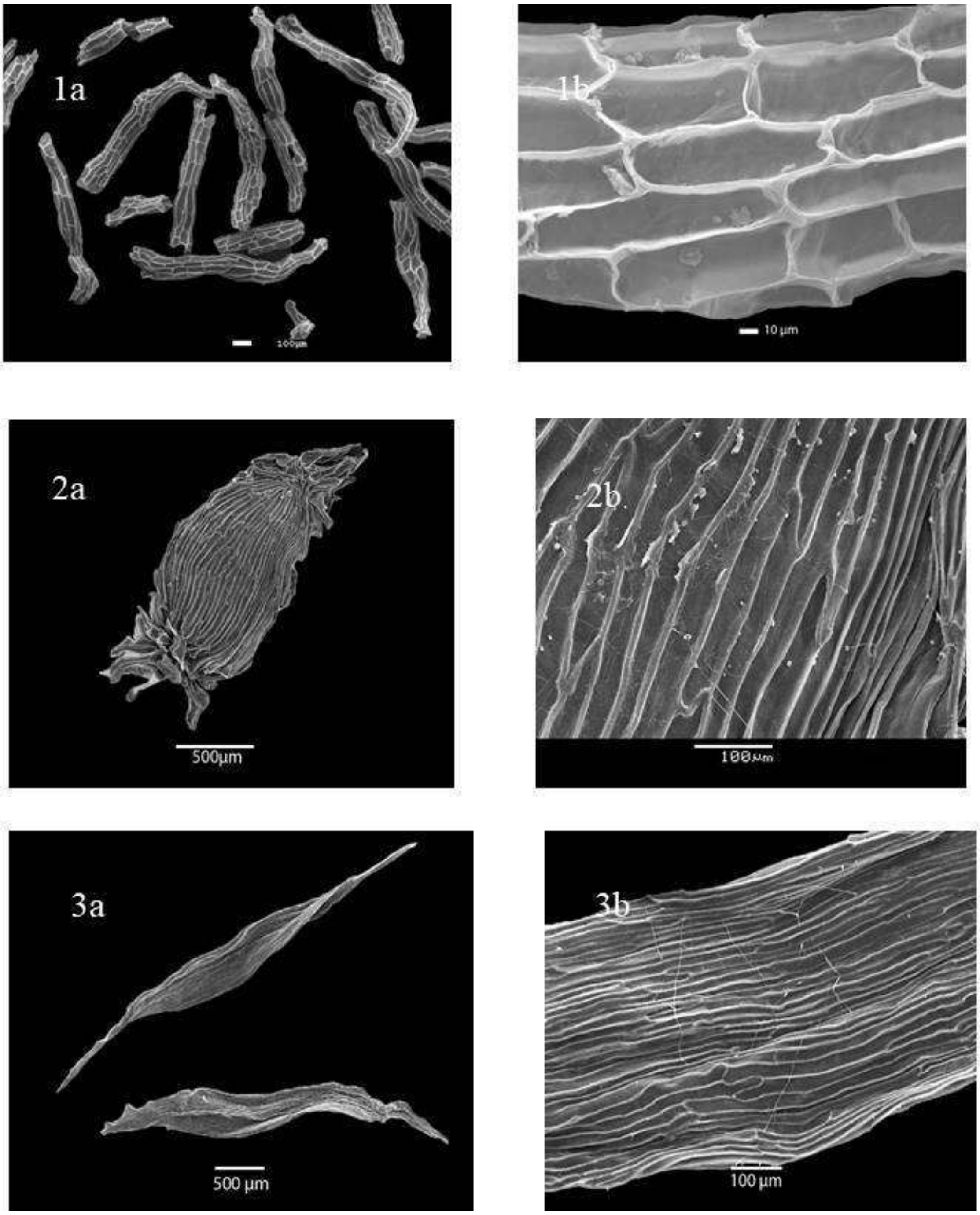

Plate 15: SEM Microphotographs of seeds: 1. *Monotropa uniflora*, 2. *Rhododendron arboreum*, 3. *Rhododendron formosum*; a-outline view, b- details of seed coat

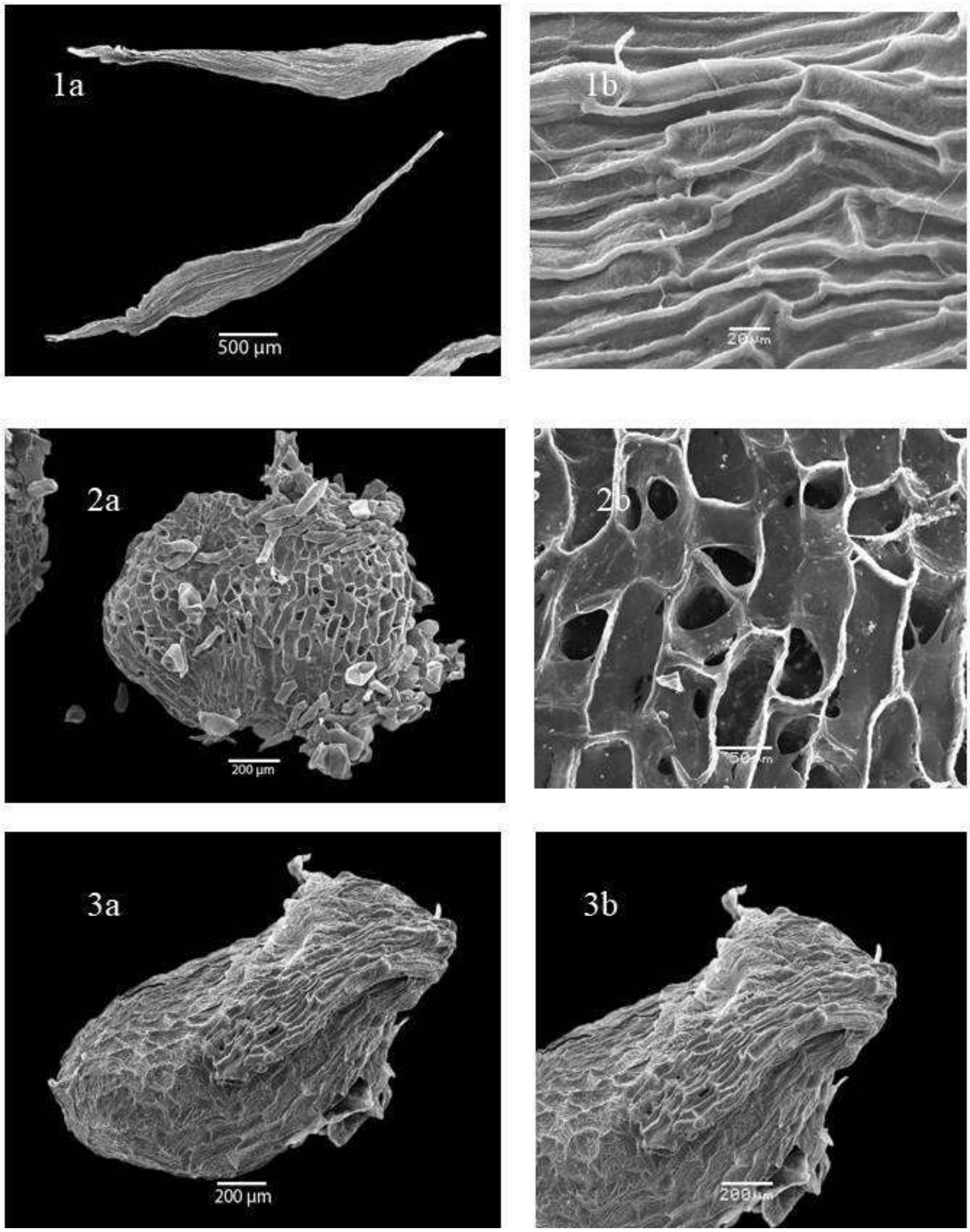

Plate 16: SEM Microphotographs of seeds: 1. *Rhododendron vietchianum*, 2. *Vaccinium sprengelii*, 3. *Vaccinium vacciniaceum*; a-outline view, b- details of seed coat

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B.Sc. (Botany)	2015	MZU	69.9	First
M.Sc. (Botany)	2017	MZU	78.5	Distinction

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Department : Botany
Title of Research : Studies on Species Diversity and Systematic Implications of Seed Coat morphology of Ericaceae in Mizoram, India
Supervisor : Dr. Khomdram Sandhyarani Devi

List of Paper Publications

1. **Tlanhlui, L**., Lalhlupuii, M., Yumkham, S. D., & Khomdram, S. D. (2023). Addition of four invasive alien plant species to state flora of Mizoram, India. *Journal of Threatened Taxa*, *15*(10), 24135-24139.
2. **Tlanhlui, L.,** Khomdram, S. D., Yumkham, S. D., Lalhlupuii, M., Khiangte, L., & Singh, S. S. (2025). *Chamaegastrodia reiekensis*: A new holomycotrophic orchid from Mizoram, Northeast India. *Webbia*, *80*(2),
3. Lalhlupuii, M., **Tlanhlui, L.,** Khomdram, S. D. & Yumkham, S. D. (2025). *Argostemma sawmlianae* (Rubiaceae, Argostemmateae), a new species from Northeast India under the Indo-Burma Hotspot. *PhytoKeys*, *266*, 317.

List of Presentations

1. Presented paper on **―The genus *Monotropa* L. (Ericaceae) in Mizoram‖** at the International Symposium on Plant Taxonomy and Ethnobotany, organised by Botanical Survey of India, Ministry of Enviroment, Forest & Climate Change, Kolkata from 13th–14th February, 2020

2. Presented paper on **Systematic implications of seed morphology in Vaccinium, Ericaceae of Mizoram'** in the National conference on Recent Advances in Plant Biology with special references to North-East India, organized by Department of Botany, School of Life Sciences, Mizoram University, Aizawl, Mizoram, India- 796004 from 20th–21st April, 2023

3. Presented paper on **'A noteworthy collection and identification of interesting plants in Mizora** with Enviroment, Forest & Climae Change Department, Government of Mizoram, during 31st October–2nd November 201

Conferences /Seminars /Workshops Attended

1. Participated in the ―Botanical Nomenclature Course‖ organised by Botanical Survey of India from 27^{th} –31^{st} January, 2020, in Shillong

2. Participated in the 12^{th} Annual Convention of Association of Biotechnology and Pharmacy (ABAP) & International Conference on Biodiversity, Enviroment and Human Health: Innovations and Emerging Trends (BEHIET 2018) organuzed at the school of Life Sciences, Mizoram University, Aizawl, Mizoram 796004 during November 12 to 14, 2018.

3. Participated in the International Conference on Chemistry & Enviroment Sustainability (ICCES–2019) organisepartment of Chemistry, Mizoram University during February 19–22, 2019.

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ABSTRACT

STUDIES ON SPECIES DIVERSITY AND SYSTEMATIC IMPLICATIONS OF SEED COAT MORPHOLOGY OF ERICACEAE IN MIZORAM, INDIA

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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MAY, 2025

STUDIES ON SPECIES DIVERSITY AND SYSTEMATIC IMPLICATIONS OF SEED COAT MORPHOLOGY OF ERICACEAE IN MIZORAM, INDIA

BY

LALTLANHLUI

Department of Botany

Supervisor

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Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Botany of Mizoram University, Aizawl.

Abstract

The family Ericaceae, commonly known as the heath or heather family, is a large and diverse group of flowering plants that holds significant ecological and botanical importance. Comprising over 120 genera and approximately 4,000–5,000 species globally (Kron et al., 2002), members of Ericaceae are predominantly distributed in temperate regions but extend into tropical montane habitats, especially in Southeast Asia and Central and South America. The family includes both woody shrubs and small trees, with some herbaceous members, characterized by sympetalous flowers, often evergreen leaves, and adaptations to nutrient-poor, acidic soils. In India, the Ericaceae family is represented by several genera such as *Rhododendron*, *Vaccinium*, *Gaultheria*, and *Agapetes*, among others. The northeastern region of India, particularly the state of Mizoram, is part of the Indo-Burma biodiversity hotspot and harbors a significant diversity of Ericaceous species due to its unique topography, climate, and floristic affinities with Southeast Asia. However, despite their ecological and ethnobotanical relevance, many Ericaceae members in this region remain poorly documented or studied.

The present study aims to provide a comprehensive account of the Ericaceae family in Mizoram, integrating taxonomic, morphological, palynological, and molecular data. It also addresses the ecological roles and conservation status of the family, with a focus on rare, endangered, and threatened (RET) species. By synthesizing multiple lines of evidence, this work seeks to contribute to a more robust understanding of the family's diversity, systematics, and significance in the region and to bridge this gap through a multidimensional approach to Ericaceae systematics and conservation.

The present study was conducted in the state of Mizoram, located in the northeastern region of India (21°56′N to 24°31′N latitude and 92°16′E to 93°26′E longitude). Mizoram is characterized by rugged terrain, with elevations ranging from 500 m to over 2,100 m above sea level, and a climate that varies from tropical to subtropical and temperate across altitudinal gradients. The region is part of the Indo-Burma biodiversity hotspot and hosts extensive forest types, including tropical semi-

evergreen, moist deciduous, sub-tropical broadleaved, and montane forests—ideal habitats for various Ericaceae species. Field surveys were carried out across key forest areas and protected regions, including Phawngpui National Park, Dampa Tiger Reserve, Lengteng Wildlife Sanctuary, and community-managed forest patches in Aizawl, Champhai, and Serchhip districts. Surveys were conducted during the flowering and fruiting seasons (March–June and September–November) from 2018 - 2022. Specimens were collected using standard floristic methods. Each collection included flowering and fruiting materials along with vegetative parts. GPS coordinates, elevation, habitat type, and phenological data were recorded in situ. Voucher specimens were processed and deposited in the Mizoram University Herbarium (MZUH), with duplicates sent to the Botanical Survey of India (BSI), Shillong. Identification was carried out using regional floras (e.g., Hooker, 1882; Chowdhery & Wadhwa, 1984; Haridasan & Rao, 1985), comparative analysis with herbarium specimens, and consultation with specialists. Nomenclature follows the World Flora Online (WFO) and Plants of the World Online (POWO). Detailed macro- and micromorphological observations were conducted on leaves, stems, flowers, fruits, and seeds. Characters such as leaf arrangement, venation, trichome types, inflorescence structure, floral morphology, and seed surface features were documented. Observations were made using a Leica S8APO stereo zoom microscope, and photographs were captured with a Nikon D7500 DSLR camera for documentation and comparative analysis.

Fresh flowers were collected and fixed in FAA (formalin-acetic acid-alcohol) and stored at 4°C. Pollen grains were acetolyzed following the modified Erdtman (1960) technique. Cleaned pollen was mounted on aluminum stubs with double-sided adhesive tape and sputter-coated with gold using a JEOL JFC-1100 ion sputter coater. SEM analysis was carried out using a JEOL JSM-6360 microscope. Pollen grain parameters including polar axis (P), equatorial diameter (E), P/E ratio, exine ornamentation, aperture type, and colpus length were measured. Quantitative palynological data were subjected to principal component analysis (PCA) and cluster analysis using RStudio (v4.1.2) to identify patterns of variation and assess taxonomic significance. Mature seeds of 9 Ericaceae taxa from Mizoram were collected during fruiting seasons and examined using Scanning Electron Microscopy (SEM). Seeds were mounted, gold-coated, and observed for features like shape, wing structure, hilum, epidermal cells, and surface sculpturing using standard terminology

Genomic DNA was extracted from fresh leaf tissues using the CTAB method (Doyle & Doyle, 1987). The nuclear ITS2 region and plastid markers *rbcL* were amplified using universal primers. PCR products were purified and sequenced commercially.. Phylogenetic trees were constructed using maximum likelihood (ML) in MEGA X,. Bootstrap values (1,000 replicates) and posterior probabilities were used to assess clade support. Sequences from related taxa were retrieved from GenBank for comparative analysis. Population surveys were conducted to assess the distribution and habitat preferences of each species. Abundance data and anthropogenic pressures were used to assign IUCN threat categories following IUCN (2022) guidelines. Ethnobotanical data were collected through structured interviews and questionnaires with local communities and traditional healers, focusing on medicinal, culinary, and cultural uses of Ericaceae members.

A total of **10 taxa (9 species, 1 variety) belonging to 5 genera** of the family *Ericaceae* were recorded from various habitats across Mizoram during the survey period (2018–2022). The morphological study of Ericaceae species in Mizoram highlights the importance of morphotaxonomy in accurate species identification and classification, particularly in underexplored regions like Northeast India. Key diagnostic traits included variations in plant habit, leaf phyllotaxy, floral structure, ovary position, and fruit type—ranging from dehiscent capsules in *Rhododendron* to berries in *Vaccinium*. Subtle features such as corolla color, stamen number, and calyx morphology were critical in distinguishing closely related taxa. All studied species exhibited morphological diversity in key vegetative and reproductive traits. Leaf types varied from coriaceous and glabrous to pubescent and rugose. Inflorescences were predominantly racemose or axillary clusters, with considerable variation in corolla shape (campanulate, tubular, urceolate) and color (red, pink, and white). Fruit types were either berries or capsules, with seeds displaying varied testa ornamentation under SEM microscopy.

9 Ericaceae taxa showed significant variation in traits like configuration, polar length (P), tetrad diameter (D), equatorial diameter (d), aperture structure, and exine sculpturing. Most genera (e.g., *Rhododendron*, *Agapetes*, *Vaccinium*) had tetrad pollen, with variable viscin thread presence and diverse sculpturing patterns (psilate, rugulate, granulate, etc. Cluster analysis using UPGMA and Euclidean distance grouped species into two major clades based on eight pollen traits. Varieties of *Agapetes odontocera* clustered together due to similar exine patterns and were closely related to *Vaccinium* spp. *Rhododendron formosum* and *R. veitchianum* also grouped together, reflecting similarities in pollen size and sculpturing. PCA results (PC1 = 61.6%, PC2 = 22.7%; total = 84.3%) confirmed these groupings. PC1 was influenced by exine and apocolpial sculpturing and viscin threads, while PC2 captured variation in aperture type, colpus margin, and size. Notably, *Monotropa uniflora* showed distinct traits due to its monad pollen and unique apertures, reinforcing its morphological divergence.The palynological diversity observed among the nine Ericaceae taxa highlights the value of pollen traits in taxonomic and phylogenetic studies. Tetrad configuration, sculpturing, and viscin thread presence were especially informative. Findings agree with prior research (Moore *et al*., 1991; Hesse *et al*., 2009; Halbritter *et al*., 2018), affirming that exine and aperture characters are useful for differentiating closely related taxa and understanding evolutionary patterns within the family.

Significant interspecific variation was observed. *Agapetes odontocera var. mizoramensis* had oblong-ellipsoid, winged seeds with reticulate surfaces, while *A. odontocera var. odontocera* had wingless, striate seeds. *Lyonia ovalifolia* produced oblong seeds with a protuberant hilum and faint reticulations. *Monotropa uniflora* had small, white seeds with distinct reticulate sculpturing and sinuous walls. *Rhododendron arboreum* had ellipsoid, winged seeds; *R. formosum* and *R. veitchianum* bore longer seeds with faint wings and undulate walls. *Vaccinium sprengelii* and *V. vacciniaceum* showed globose forms, green coloration, and varied surface textures. Cluster analysis grouped the taxa into two clusters: one with *Agapetes* and *Rhododendron* (shared ellipsoid shape and reticulation), and another with *Vaccinium*, *Lyonia*, and *Monotropa*. PCA revealed PC1 (39.1%) was influenced by seed shape and wall type, while PC2 (23.6%) reflected texture and hilum traits. *M. uniflora* was morphologically distinct. Overall, seed micromorphology proved taxonomically valuable, supporting intergeneric relationships and confirming its utility in Ericaceae systematics.

The molecular phylogenetic study of Ericaceae taxa from Mizoram employed concatenated sequences of ITS2 and *rbcL* markers to elucidate interspecies relationships. Sequence alignment and BLAST analysis were conducted via NCBI, with GenBank accession numbers assigned to all studied taxa. Using MEGA X, a Maximum Likelihood Tree (MLT) based on the K2P model and 1000 bootstrap replicates revealed well-supported clades consistent with traditional taxonomy. Rhododendron species formed a distinct monophyletic group, with *R. formosum* and *R. veitchianum* clustering closely. *Monotropa uniflora* exhibited minimal divergence, suggesting recent speciation or low variability in the markers used. *Lyonia ovalifolia* and its variety formed a robust clade, confirming taxonomic validity. Similarly, *Vaccinium* species clustered together, with *V. griffithianum* closely aligning with *Agapetes odontocera var. mizoramensis*, implying potential intergeneric affinity. These results reinforce the effectiveness of ITS2 and *rbcL* markers for resolving phylogenetic relationships in Ericaceae, echoing previous findings by Zimmer *et al.* (2002). The study demonstrates strong molecular support for traditional classifications and highlights evolutionary relationships among Mizoram's Ericaceae, offering insights into lineage diversification and guiding future taxonomic and conservation efforts.

The region's favorable climate supports species such as *Agapetes odontocera var. mizoramensis* and *Rhododendron veitchianum*, both highly localized and threatened due to limited populations and increasing anthropogenic pressures. Habitat loss from shifting cultivation, tourism, deforestation, and infrastructure development threatens these taxa, many of which remain unassessed or under-assessed by the IUCN. Endemic species *A. odontocera var. mizoramensis*, restricted to fewer than 500 individuals across two sites, highlight the urgency of conservation efforts. Ericaceae species also contribute significantly to ecological processes, including nutrient cycling and soil stabilization, particularly in disturbed or acidic soils, through specialized mycorrhizal associations. Their role as ecological indicators further underlines their importance in monitoring environmental change. Despite their ecological value, weak conservation enforcement and habitat fragmentation persist as key challenges. Conservation strategies must include habitat protection, restoration, ex situ conservation, and community-based initiatives to ensure long-term survival. Immediate, science-driven action integrating policy, research, and local stewardship is vital to preserve Mizoram's unique Ericaceae flora and maintain the region's ecological integrity.

A total of 10 taxa were documented through field surveys conducted across seven districts and fourteen villages from 2022 to 2023. Data were gathered from 60 key informants using structured interviews, and analysis was performed using quantitative indices such as Use Value (UV), Relative Frequency Citation (RFC), and Relative Importance (RI). Rhododendron *arboreum* emerged as the most culturally and medicinally significant species, while *Agapetes odontocera* var. *odontocera* had the highest usage versatility. The study found ornamental use to be the most common, followed by food, cultural, and medicinal applications. This reflects the deep-rooted traditional knowledge and ecological literacy among the Mizo people. Despite their importance, several species remain underdocumented and face threats from habitat degradation, overharvesting, and climate change. The findings highlight the urgent need for conservation strategies that integrate scientific validation, sustainable use, and community participation. Bridging ethnobotanical research with policy-making and digital documentation is essential to protect both biological and cultural diversity. This research emphasizes the value of Ericaceae as vital components of Mizoram's ecological and cultural landscape.

This study documents the diversity, ecology, and conservation needs of 10 Ericaceae taxa—nine species and one variety—across Mizoram, Northeast India. Representing five genera across three subfamilies, these taxa exhibit diverse growth forms and are predominantly restricted to montane forest ecosystems between 1200–3000 meters. Integrative taxonomic methods—including morphology, palynology, seed coat anatomy, and molecular phylogenetics using ITS2 and *rbcL* markers—enabled accurate identification and revealed evolutionary relationships. Cluster analyses confirmed morphological groupings consistent with traditional classifications. Ethnobotanical data from local informants underscored the cultural and medicinal significance of several taxa, though this traditional knowledge is rapidly eroding. Many species, particularly *Agapetes odontocera var. mizoramensis*, are endemic or Rare, Endangered, and Threatened (RET), facing threats from habitat degradation, climate change, and unsustainable practices. Conservation efforts must prioritize habitat protection, ecological monitoring, and integration of indigenous knowledge. The findings emphasize the region's ecological richness and vulnerability, highlighting the Indo-Burma biodiversity hotspot's underexplored flora. Continued research, awareness campaigns, and both in situ and ex situ conservation strategies are essential to safeguard these ecologically and culturally significant taxa, ensuring long-term preservation and sustainable use of Mizoram's Ericaceae diversity.